



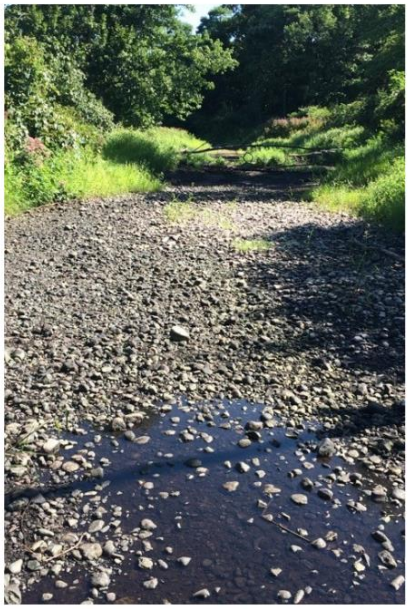


December 2023

MASSACHUSETTS
Drought Management Plan

Preparedness & Response

Massachusetts Energy and Environmental Affairs

Massachusetts Emergency Management Agency

Acknowledgements

The Executive Office of Energy and Environmental Affairs and the Massachusetts Emergency Management Agency would like to thank the staff at both their agencies, and staff at the Department of Conservation and Recreation who are staff to the Water Resources Commission and the Drought Management Task Force for their work in updating the Drought Management Plan (DMP). In addition, we are very grateful to the technical and policy staff at Department of Environmental Protection, Department of Fish and Game, Department of Agricultural Resources and Department of Public Health as well as federal agencies partners - the United States Geological Survey, National Oceanic and Atmospheric Administration-National Weather Service, and the Northeast River Forecasting Center for their key scientific insights and technical input. Lastly, we would like to acknowledge and thank the Massachusetts Drought Management Task Force members for their critical thinking, invaluable input and guidance in plan updates, and to the Massachusetts Water Resources Commission for their input and final approval of the DMP.

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Section 1: Introduction

1.1 Purpose of the Drought Management Plan

The Massachusetts Executive Office of Energy and Environmental Affairs (EEA), the Massachusetts Emergency Management Agency (MEMA), and the Drought Management Task Force (DMTF) have developed the Massachusetts Drought Management Plan (DMP) to maximize the state's ability to effectively assess, prepare for and respond to drought conditions.

Specifically, the DMP aims to minimize drought impacts to the Commonwealth by improving agency coordination; enhancing monitoring and early drought warning capabilities; and outlining preparedness, response, and recovery activities for state agencies, local communities, and other entities affected by drought. The DMP lays out an integrated, multi-agency approach to managing drought, with an emphasis on state-led preparedness and response actions as drought conditions change. Critical new and updated elements provided by the DMP include:

- Defining a clear methodology for monitoring and analyzing drought indices and establishing a consistent basis for evaluating the severity of drought conditions;
- Assessing the impacts on various sectors, including the environment;
- Outlining a drought communications plan;
- Establishing membership and responsibilities of the DMTF;
- Identifying and assigning drought management roles and responsibilities and providing response guidance and actions for each drought level;
- Providing guidance to communities on drought preparedness and response actions at the local level; and
- Summarizing the emergency powers available to government agencies to respond to drought situations.

The DMP is reviewed and approved by the Massachusetts Water Resources Commission (WRC) and is a Hazard Annex under the Massachusetts Comprehensive Emergency Management Plan (CEMP).

1.2 Scope and Applicability

The DMP represents a systematic and scientific approach to drought analysis, assessment of impacts, and coordination of actions. The assessment of conditions is statewide, and determinations on the severity level of drought are made for each of seven drought regions across the state (see Figure 1 in Section 3.2 below). Drought declarations may also be made on other spatial delineations such as counties or watersheds. Coordination and drought mitigation actions outlined in the DMP are applicable to state agencies; local government; agricultural, industrial, commercial and institutional water users; regional planning agencies and other statewide stakeholder groups; and all residents of the Commonwealth.

The DMP documents how the state determines when a drought begins and establishes the drought levels. It also specifies the responsibilities of state agencies in response to drought, including the lines

of communication to be used, the general sequence of actions to be followed at the state and local levels based on the severity of the drought condition, and the emergency powers available to local and state government agencies and the Governor. The DMP also offers guidance on critical drought preparedness actions at the state and local levels.

The state agencies and departments that are assigned responsibilities within this DMP will develop and maintain the necessary protocols, standard operating procedures, and any mutual-aid agreements to successfully accomplish assigned tasks. This DMP is designed to supplement and support existing local comprehensive emergency management plans and, therefore, builds upon established capabilities at the local level.

Nothing contained in this DMP should be construed to limit the powers of local government to adopt and enforce local emergency bylaws or ordinances as necessary to protect the public welfare, safety, and health.

1.3 Background

1.3.1 Massachusetts' Climate - Past, Present and Future

Massachusetts is located on the eastern edge of the North American continent. This, coupled with its northerly latitude, exposes the state to both the moderating and moistening influence of the Atlantic Ocean, and the effects of hot and cold air masses from the interior of the continent. Its climate is characterized by cold, snowy winters and warm summers. The polar jet stream is often located near the state, giving it highly variable weather patterns, wide-ranging daily and annual temperatures, and generally abundant precipitation throughout the year.[1]

Massachusetts' annual precipitation is variable from year to year. Average annual precipitation is 48 inches per year, ranging from 30 to 61 inches in the driest and wettest years, respectively. Precipitation is generally spread fairly evenly across the months, with approximately 3- to 4-inch average amounts for each month of the year. The driest conditions in recorded history were observed in the early 1900s and again in the 1960s, with wetter conditions occurring since the 1970s. The driest five-year period was 1962-1966.

According to Runkle et. al. (2017)[1], annual precipitation in Massachusetts has been increasing in recent decades and is expected to rise further as a result of climate change. However, most of this precipitation will fall during extreme precipitation events that are projected to more than double by the end of the 21st century. As a result, coastal and inland flooding risks will substantially increase by 2050. Large storms add significantly to monthly and annual precipitation totals, but unlike a similar amount of precipitation falling in multiple, smaller storms, they do not translate to significant groundwater replenishment or steady streamflows. This dynamic is further exacerbated in developed areas with impervious cover, which also reduces groundwater recharge and contributes to fast and increased runoff leading to flashy streams with scouring. Additionally, increased evaporation from

[1] Runkle, J., K. Kunkel, R. Frankson, D. Easterling, A.T. DeGaetano, B. Stewart, and W. Sweet, 2017: Massachusetts State Climate Summary. NOAA Technical Report NESDIS 149-MA, 4 pp.

warmer temperatures, alterations in the timing and magnitude of streamflow following reductions in snowpack, as well as changes in the amount, timing, and type of precipitation, may intensify naturally occurring droughts. These changes in climate are projected to lead to an increased frequency and severity in droughts as already being observed (see Section 1.3.2, History of Drought in Massachusetts). In addition, droughts have historically developed over multiple months and lasted for months to multiple years. More recently, 'rapid intensification droughts' have been observed where the onset and/or intensification of a drought occurs within a matter of weeks (see next section).

1.3.2 Drought and Its Impacts

Drought can be characterized as an abnormally dry (moisture-deficient) condition that is a shift away from average conditions for some prolonged period of time. Abnormally dry conditions may be due to a combination of precipitation deficit and increased evapotranspiration from heat stress. In recent years, many states across the country, including Massachusetts have been experiencing rapid onset and/or rapid intensification of drought conditions, commonly termed as 'rapid intensification droughts'. These periods are characterized by unusually high temperatures, decreased precipitation, high winds, and rapid change in drought levels by two levels that can last for at least two to four weeks. They can occur either at the onset of a drought, or during a drought.

Depending on a drought's severity and duration drought can affect a wide range of natural and anthropogenic systems, and these impacts can last well beyond the drought. Examples of impacts to natural systems include diminished quantity and quality of streamflow, groundwater, and surface water, which in turn affect aquatic life and habitat; increased fire danger; decline in the health of forests and other vegetation leading to increased vulnerability to storm damage and uprooting, resulting in increased erosion and reduced bank stability; and indirect impacts to forests from insects, whose predators are vulnerable to drought.

Examples of impacts to anthropogenic systems include diminished water supply quantity and quality; reduced water supply, which may lead to diminished pressure for firefighting, increased stress on the agricultural industry, which may need to secure additional water supplies and potentially alter operations and incur crop loss; increased fire risk for people and infrastructure especially those living near forests.

1.3.3 History of Drought in Massachusetts

Massachusetts is a relatively water-rich state. However, it has suffered several major statewide droughts. Appendix H uses four different information sources to summarize the history of droughts in Massachusetts since 1879. The most severe, state-wide droughts occurred in 1879-1883, 1908-1912, 1929-1932, 1939-1944, 1961-1969, 1980-1983, and 2016-2017. Several less-severe droughts occurred in 1999, 2001, 2002, 2007, 2008, 2010, 2014, 2019, 2020-2021, 2022 and 2023 The nine-year drought from 1961-1969 is considered the drought of record. The longevity and severity of this drought forced public water suppliers to implement water-use restrictions, and numerous communities utilized emergency water supplies. Thirty-seven communities had emergency declarations for water supply,

ten communities had water supply in a critical condition with either restricted pumping or less than 90 days' worth of supply, and the Quabbin Reservoir, the state's largest, dropped to 45% of its capacity (Wandle, 1991[2]).

The 2016-2017 drought was the most significant drought in Massachusetts since the 1960's. Rainfall in 2016 was 37 inches, in comparison to the low 30s during the 1960s. In addition, in many parts of the state, U.S. Geological Survey data for streamflow and groundwater reached new record low levels for several consecutive months; 15 gages and 41 wells showed period of record lows in September 2016.

Drought is historically a slowly developing − and often long-lasting − event with cumulative impacts. However, the most recent 2016-2017 drought as well as the 2020-2021 and the 2022 droughts were characterized by some periods of rapid intensification in conditions from one month to the next particularly in the Southeast and Northeast Regions, fitting the recently introduced concept of a "flash drought"[3] or rapid intensification drought, which can rapidly change local conditions, increase evapotranspiration and lower soil moisture.

1.3.4 History of the Drought Management Plan (DMP)

The DMP was initially developed in the early 2000s in response to a period of precipitation deficiency from April 1999 to March 2000. State and federal agencies met in August 1999 as an ad-hoc DMTF to assess drought conditions and develop recommendations to the Secretary of Environmental Affairs on the level of drought and to the agencies on drought responses. The group continued to meet to develop a DMP with standard procedures to help facilitate responses to current and future situations. The DMP was developed in 2001 as a working document, and the methods outlined in the DMP have been applied several times since then. In 2013, the DMP underwent minor updates and was formally adopted by the DMTF and approved by the WRC.

During the 2016-2017 drought, the 2013 DMP was used and implemented, and many lessons were learned, resulting in an update in 2019which included substantial changes. In revising the DMP, the DMTF and state agencies conducted an in-depth review of all the indices, including how they are monitored, analyzed and applied; reexamined the boundaries of the drought regions; reviewed and researched effective preparedness and response actions; and undertook a broader review of communication pathways. This resulted in an adjustment to the boundaries of some drought regions; an introduction of a new 'Islands' region; the removal of 'percent of normal' precipitation as an index; a change to the look-back periods for the Standard Precipitation Index; a change in nomenclature of the 'reservoir' index to 'lakes and impoundments'; a change in methodology for calculating the indices and for calculating the thresholds for drought levels; the introduction of new and substantially updated actions for local and state government; and updated communication actions. Details about

[2] Wandle, S.W. Jr. 1991. Massachusetts chapter of the U.S. Geological Survey's National Water Summary 1988-1989 – Hydrologic Event and Floods and Droughts. Water Supply Paper 2375. https://pubs.usgs.gov/wsp/2375/report.pdf

[3] Otkin et. al., 2018. https://journals.ametsoc.org/doi/pdf/10.1175/BAMS-D-17-0149.1

the analyses conducted and changes made to the indices are provided in Appendix C. The 2019 DMP was also formally adopted by the DMTF and approved by the WRC.

This 2023 update to the DMP further refines the 2019 version and includes an update to the evapotranspiration index that since 2001 has relied on a National Oceanic and Atmospheric Administration (NOAA) product, the Crop Moisture Index (CMI). CMI estimates the deficit between precipitation retained in soil and the potential evapotranspiration needs of crops. NOAA produces a national map of CMI values on a weekly basis. Massachusetts is divided into three districts and CMI values are provided for each. However, there are several limitations to this index - the national maps use only three data points for Massachusetts; the CMI was developed and calibrated for the grain-producing regions of the central United States and may not be accurate for Massachusetts at the regional scale for all drought regions. In addition, in recent droughts the CMI has been very unresponsive. Therefore, the CMI has been replaced with the Evaporative Demand Drought Index (EDDI). The 2023 update also includes the addition of the streamflow index to the Cape Cod Drought Region, as adopted by the DMTF in 2021, and other minor updates and formatting changes.

Section 2: Authority and Coordination

2.1 EEA and MEMA

EEA, in conjunction with MEMA, is responsible for overall coordination of this DMP. Working together during a drought, EEA and MEMA will provide overall support and situational awareness to state and local entities and will coordinate the state response to areas of the Commonwealth impacted by drought. Specifically, EEA is responsible for coordination among all environmental agencies and carries out its tasks with the assistance of WRC staff housed at the Department of Conservation and Recreation. EEA coordinates closely with the Governor's office, plans and implements communication with the public, and leads and oversees drought response across the state. MEMA is responsible for coordinating any additional resources necessary to support drought response efforts across the Commonwealth, including additional federal, state, local, voluntary, and private resources.

Together, EEA and MEMA:

- Convene the DMTF, including establishing its agendas and facilitating its meetings;
- Collect and disseminate data on the status of the drought;
- Prepare DMTF meeting summaries;
- Coordinate communication among government agencies;
- Communicate DMTF's recommendations on the level of drought for each region;
- Coordinate federal assistance, as needed;
- Advise on and communicate with the general public; and
- Forward recommendations to the appropriate entities.

2.2 Drought Management Task Force (DMTF)

2.2.1 Composition

The DMTF consists of representatives of state and federal agencies − such as environmental agencies, public health officials, and public safety officials − that provide data related to assessing drought and weather conditions and have the ability to assess impacts to various resources and water users and respond to drought conditions. The DMTF also includes professional organizations that have responsibility for areas likely to be affected by drought conditions.

The DMTF is housed at EEA and is co-chaired by the Director of Water Policy at EEA or designee and the Director of MEMA or a designee. All DMTF-related activities and matters are directed and managed by the Director of Water Policy. The Department of Conservation and Recreation's Office of Water Resources, staff to the WRC, provides technical and planning support to the DMTF.

The DMTF has representatives from the following agencies and organizations:

- Executive Office of Energy and Environmental Affairs (co-chair)
- Massachusetts Emergency Management Agency (co-chair)
- Department of Agricultural Resources
- Department of Conservation and Recreation – Office of Water Resources, Fire Chief, Forestry and Infrastructure
- Department of Environmental Protection – Water Management Program and Wetlands Program
- Department of Fire Services (within the Executive Office of Public Safety and Security)
- Department of Fish and Game
- Department of Public Health
- Department of Public Utilities
- Farm Services Agency, U.S. Department of Agriculture
- Massachusetts Association of Health Boards
- Massachusetts Rivers Alliance
- Massachusetts Water Resources Authority
- Massachusetts Water Works Association
- National Weather Service
- Northeast River Forecast Center, National Weather Service
- U.S. Army Corps of Engineers
- Unites States Geological Survey
- Water Supply Citizens Advisory Committee

Appendix B provides a contact list for DMTF members.

2.2.2 Purpose and Responsibilities

The DMTF provides a comprehensive assessment of the drought situation based on an analysis of the drought indices, near-term forecast of precipitation and temperature, other information about

specific impacts as available, and best professional judgement. The DMTF recommends drought levels for each region of the Commonwealth to the Secretary of EEA; facilitates communication and situational awareness through EEA with the Governor's Office, the Secretary of Public Safety and Security, or others as needed; and uses the DMP to identify recommendations on potential response actions to minimize impacts to public health, safety, the environment, and agriculture. In the event of a severe drought, the DMTF makes recommendations for declaring emergencies and for developing and implementing emergency responses.

Additional DMTF responsibilities include:

- Developing and updating the DMP;
- Identifying and providing general oversight of drought response actions;
- Identifying drought management trends, issues and gaps; and
- Documenting and sharing lessons from drought events.

Implementation of the DMTF-recommended response actions is the responsibility of the appropriate agency or entity based on its jurisdiction or expertise. MEMA and EEA will forward recommendations through the appropriate chain(s) of command and follow up with the responsible agencies to ensure the successful implementation of DMP and DMTF recommendations.

The DMTF is not intended to infringe upon the statutory or other obligations of its member agencies or of others who are responsible for responding to any particular situation, but rather to ensure there is a coordinated response by state and federal agencies to drought situations.

Table 1. Responsibilities of State and Federal Agencies

Agency	Responsibilities
Department of Agricultural Resources	▪ Monitor and report on crop moisture status and agricultural impacts from drought, in coordination with UMass Extension and farmer groups ▪ Communicate with USDA for federal assistance, as appropriate ▪ Communicate with agricultural community about available aid and provide technical assistance
Department of Conservation and Recreation	Office of Water Resources ▪ Manage the state's network of precipitation observation stations and a precipitation database ▪ Coordinate, collect, and analyze data to deliver reports on drought indices ▪ Assist in DMTF meeting preparation and follow up Fire Danger ▪ Monitor and report on level of fire danger in each drought region ▪ Manage state fire suppression resources ▪ Coordinate with local, state, federal agencies, and other states to mobilize resources, as needed Engineering and Dam Safety ▪ Assess conditions and report on Charles and Mystic flood control dams ▪ Report on other critical DCR infrastructure

Agency	Responsibilities
	Forestry ▪ Assess conditions of forests and state tree planting efforts ▪ Report on any impacts from the drought
Department of Environmental Protection	▪ Collate and provide list of communities with voluntary and mandatory water bans (as reported) and declared water emergencies ▪ Review petitions from public water systems to declare a state of water emergency and declare such emergencies with applicable requirements for communities facing public health or safety threats due to drought impacts to their water supply systems ▪ Provide information on public water supplies, drinking water quality, water pressure or public health concerns associated with drinking water supplies ▪ Ensure that any public water supply with a public health order notify its customers and its local Board of Health ▪ Provide information on any wetland resource impacts
Department of Fire Services	▪ Provide guidance and support on pre-planning, risk assessment and Fire Code requirements relating to water supplies for fire-fighting purposes
Department of Fish and Game	▪ Monitor and report on impacts to coastal and inland ecosystems, flora, and fauna
Department of Public Health	▪ Summarize any public health issues related to drought such as impacts to private wells, beaches, lakes and ponds, etc. ▪ Coordinate with local Boards of Health
Department of Public Utilities	▪ Summarize impacts to private water companies and other public utility issues
Massachusetts Water Resources Authority	▪ Provide status of water levels in the Quabbin, Wachusett and other emergency or back-up reservoirs that the MWRA manages ▪ Provide status on overall system water use and trends
National Weather Service	▪ Provide summary of precipitation data, historical comparisons, and forecasts of weather and riverine conditions
United States Geological Survey	▪ Provide summary of groundwater, streamflow and surface water conditions

2.3 Drought Management Mission Group

To effectively coordinate and execute response actions by state agencies and other entities, an interagency Drought Management Mission Group will be formed to monitor drought impacts and prioritize response actions at all levels of government. This coordinating body comprises staff assigned by agency commissioners or directors from MEMA, MassDEP, DCR, DAR, DPH, and other agencies as needed and is formed when a drought reaches Level 2-Significant Drought, or as needed. The EEA Director of Water Policy (or designee) and Director of MEMA (or designee) will lead the Mission Group. The Mission Group will meet on a periodic basis with greater frequency than the DMTF and update the DMTF on response actions through agency representatives on the DMTF.

2.4 State and Federal Support Agencies

Many state and federal agencies serve on the DMTF providing data, analyses, impact reports, expert advice, and recommendations on drought determinations and response actions. These agencies have roles and responsibilities under the DMP, as described in Section 6 and summarized in Table 1.

Section 3: Drought Assessment and Determination

3.1 Drought Levels

Level 0 - Normal
Level 1 - Mild Drought
Level 2 - Significant Drought
Level 3 - Critical Drought
Level 4 - Emergency Drought

For the purposes of the DMP, conditions are classified into five levels: a normal condition and four drought severity levels. These levels are based on six drought indices, observed impacts to various resources and forecasts, as described in detail in Sections 3.3 to 3.4. The condition levels are: 'Level 0-Normal' (i.e., No Drought), 'Level 1-Mild Drought' (formerly Advisory), 'Level 2-Significant Drought' (formerly Watch), 'Level 3-Critical Drought' (formerly Warning), and 'Level 4-Emergency Drought' (formerly Emergency). These levels were selected to provide distinction between different levels of drought severity and for adequate warning of worsening drought conditions.

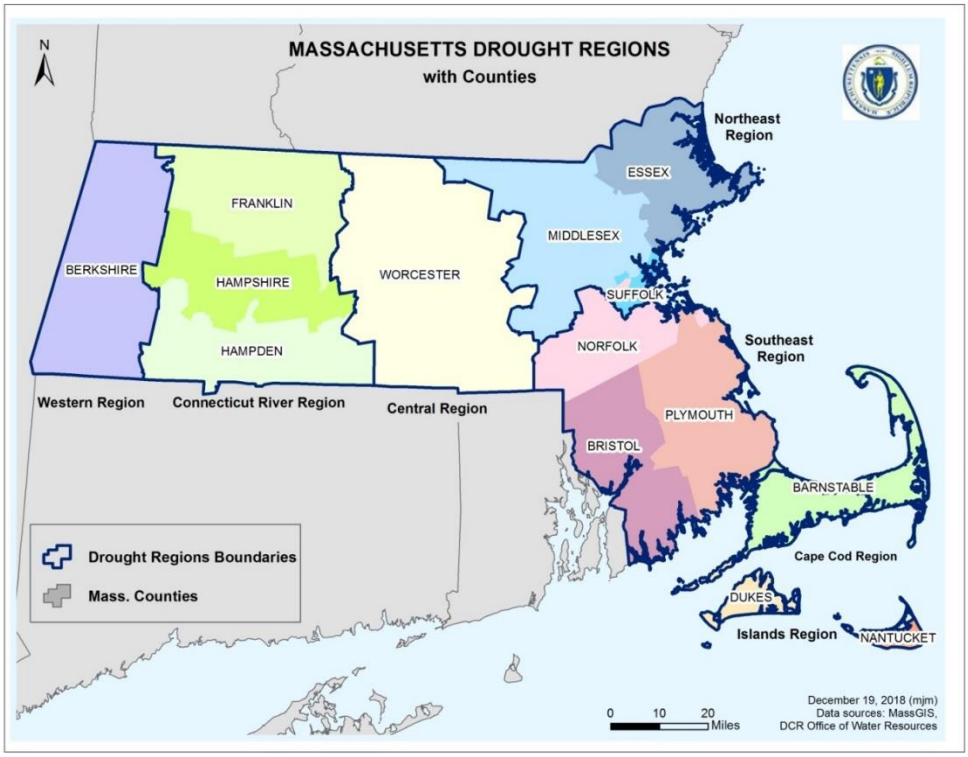
3.2 Drought Regions

Regions across the Commonwealth differ in precipitation patterns, topography, land use, population density, and other factors that affect drought propensity and intensity. The DMP delineates seven Drought Regions to allow flexibility and customization of drought declarations and response actions for different areas within the Commonwealth. The Drought Regions represent broad geographic areas, originally based on precipitation patterns, which have been refined along their boundaries to align with county boundaries. County alignment facilitates more streamlined communication and response when droughts occur. Table 2 shows the counties corresponding to each of the seven regions. Figure 1 shows drought regions and counties on a map. For maps and a list of towns by drought region, go to Appendix D.

Table 2. Counties within Each Drought Region

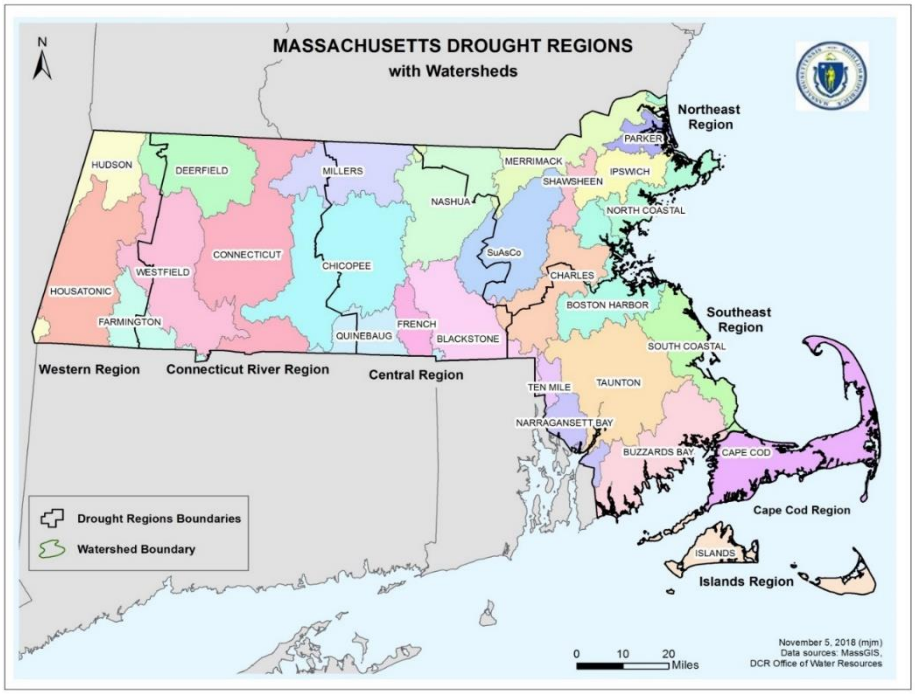
Drought Region	County(ies)
Western	Berkshire
Connecticut River Valley	Franklin, Hampshire, and Hampden
Central	Worcester
Northeast	Essex, Middlesex, and Suffolk (plus town of Brookline)
Southeast	Bristol, Plymouth, and Norfolk (minus town of Brookline)
Cape Cod	Barnstable
Islands	Nantucket and Dukes (includes Elizabeth Islands)

Figure 1: Massachusetts Drought Regions with Counties



During a drought, these regions may be adjusted based on the particular conditions of the drought. For example, drought analyses may be performed and declarations made on an individual county or watershed basis. This may be particularly useful if drier conditions exist within a watershed or county but not in the entire region(s) in which it is located. Figure 2 shows a map with the major watersheds delineated.

Figure 2: Massachusetts Drought Regions with Watersheds



3.3 Critical Information Requirements

Collecting pertinent data and monitoring trends in the data are vital to assessing the severity of drought conditions, assessing impacts to public health and the natural environment, and making timely, accurate decisions. Some data are compiled year-round by DCR's Office of Water Resources (OWR) staff into a monthly Hydrologic Conditions Report. This report summarizes the condition of water resources across the Commonwealth, including the calculation of six drought indices: Precipitation, Groundwater, Streamflow, Lakes and Impoundments, Evapotranspiration, and Fire Danger; these indices are further described in Section 3.4. The report also includes weather forecasts.

When persistently dry conditions occur, various agencies provide additional data to assist the DMTF in determining if a drought is imminent or occurring. Table 3 details the data reported to the DMTF to assist with making a drought determination, and the agencies or organizations responsible for collecting and reporting the data to the DMTF.

3.4 Drought Indices

Six Drought Indices are used as the primary drivers of drought determinations, supplemented by the other considerations described in Table 3. The six indices are: 1) Precipitation, 2) Streamflow, 3) Groundwater, 4) Lakes and Impoundments, 5) Fire Danger, and 6) Evapotranspiration. This section describes the calculation of the six drought indices. First, background is provided on the methods (subsection 3.4.1) and then the calculations are detailed for each index in subsections 3.4.2 through 3.4.7.

Table 3. Critical Information and Agencies or Organizations Responsible for Reporting

Information	Agency or Organization
Groundwater levels, streamflow, and levels of lakes and impoundments	Department of Conservation and Recreation (DCR): Office of Water Resources (OWR) United States Geological Survey (USGS) NWS: Northeast River Forecast Center (NERFC) United States Army Corps of Engineers (USACE) Massachusetts Rivers Alliance (MRA)
Precipitation and temperature	DCR OWR National Weather Service (NWS)
Forecast and weather information	NWS USGS
List of communities with reported voluntary and mandatory water bans and declared water emergencies	Department of Environmental Protection (MassDEP) Department of Public Utilities (DPU)
Other drinking water quality, water pressure or public health concerns associated with drinking water supplies	MassDEP Department of Public Health (DPH) Massachusetts Water Works Association (MWWA)

Information	Agency or Organization
Quabbin and Wachusett reservoir levels and status of MWRA communities' water supplies	DCR Massachusetts Water Resources Authority (MWRA)
Fire danger levels, forest fire conditions	DCR Bureau of Forest Fire Control and Forestry Department of Fire Services State Fire Marshal
Soil, crop, livestock and other agricultural conditions and impacts	Department of Agricultural Resources (DAR) United States Department of Agriculture (USDA) Farm Services Agency (FSA)
Public utility impacts	DPU
Public health impacts	DPH Massachusetts Association of Health Boards (MAHB)
Ecosystems, forests, flora, and fauna impacts	Department of Fish and Game (DFG), DCR (as applicable), MRA
Other	As reported through the Drought Impact Reporter or other sources

3.4.1 Methods for Calculating Indices

The following describes the methods for calculating all indices. For a given index, measurements at multiple sites within a region are analyzed wherever available. For each site, the percentile of that month's measured value is calculated based on all other values for that month at that site over the period of record[4]. A percentile is a value on a scale of 0-100 that indicates the percent of a dataset that is equal to or below the value[5]. For example, a monthly average streamflow value at the 30th percentile is equal to or greater than 30 percent of the monthly average streamflow values for that site for that month during all the years in the period of record. Characterizing how unusual a given condition is at a given site in this manner follows methods of the USGS[6] and the U.S. Drought Monitor[7] and allows for useful comparisons among sites with different hydrologic characteristics. For a site to be included in the analysis, the site must have a period of record of at least ten years.

Conditions are then characterized at a regional scale by the median of all the individual sites' percentiles within that region. This median percentile is categorized as one of five index severity levels, based on the ranges shown in Table 4. The severity level for any index may be different from the overall regional drought level, which is a comprehensive assessment of all six indices. For example, if the median percentile value across the individual sites is 25, then the region is categorized as Severity Level 1 for that index. If the median percentile is above 30, that index is classified as not

[4] The POR is the time period over which data have been measured and made available for a dataset. For example, a stream gage that has measurements from January 1970 to December 2016 would have a 47-year period of record.
[5] https://waterwatch.usgs.gov/ptile.html
[6] https://pubs.usgs.gov/twri/twri4a3/pdf/twri4a3-new.pdf
[7] http://droughtmonitor.unl.edu/AboutUSDM/DroughtClassification.aspx

exhibiting drought conditions (i.e., Level 0). A summary table of index severity levels and corresponding values for all drought indices is presented in Appendix C.

Table 4. Index Severity Levels and Associated Percentile Ranges

Index Severity Level	Percentile Ranges
0	>30
1	≤30 and >20
2	≤20 and >10
3	≤10 and >2
4	≤2

3.4.2 Precipitation

Precipitation deficit is a primary driver of dry conditions. A deficit may be an early signal of drying conditions, while a surplus during a drought may indicate the start of drought recovery.

For the calculation of this index, monthly precipitation totals are compiled from monitoring stations in DCR's Precipitation Program, the National Weather Service, and the Community Collaborative Rain, Hail and Snow Network. A map of these stations is provided in Figure 3. The values used for the Precipitation Index are the calculated Standardized Precipitation Index (SPI) values. The SPI is a widely used index that was developed to reflect the probability of a given precipitation depth occurring at a precipitation station over a given time period. SPI can be calculated for different time periods or "look-back" periods to monitor conditions on a variety of time scales. For a short-term drought signal, for example, the three-month SPI is calculated as the cumulative precipitation over the three most recent months compared to the cumulative precipitation for those same three months of the year over the period of record. The SPI values can be interpreted as the number of standard deviations by which the observed value deviates from the long-term mean. SPI values correspond to specific percentiles, the ranges of which are shown in Table 5.

Figure 3: Massachusetts Monitoring Network for Precipitation

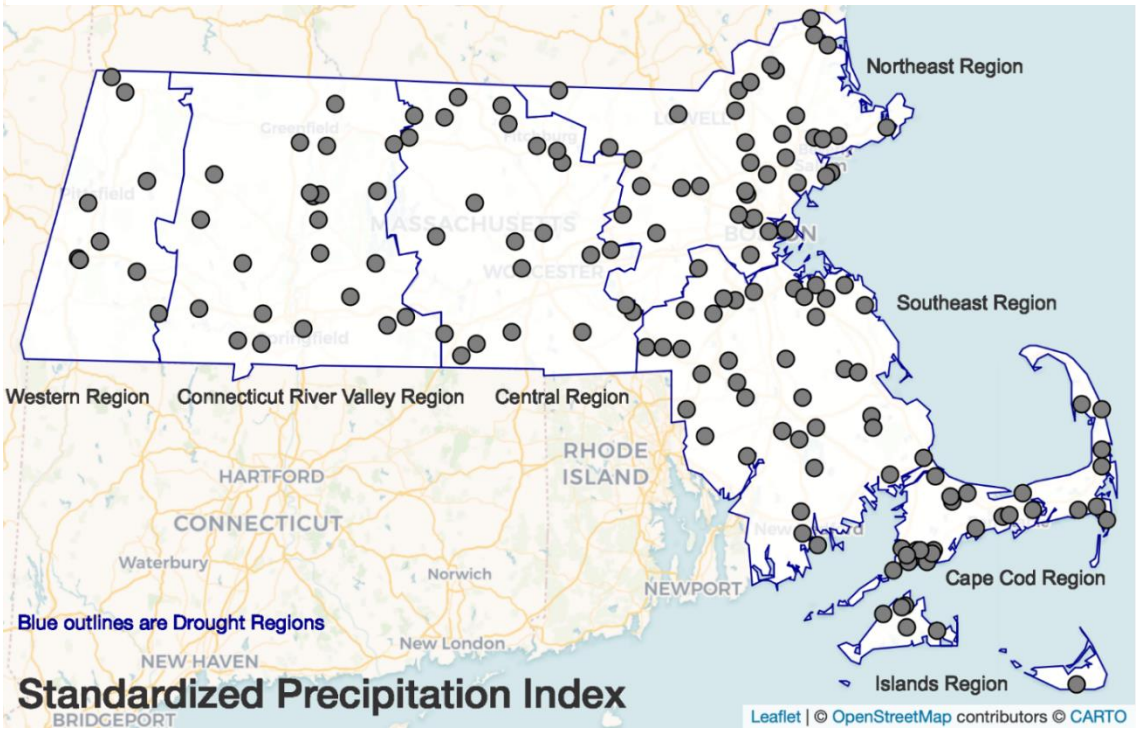


Table 5. SPI Values Corresponding to Percentile Ranges

Index Severity Level	Percentile Ranges	SPI Values
0	>30	> -0.52
1	≤30 and >20	≤ -0.52 and > -0.84
2	≤20 and >10	≤ -0.84 and > -1.28
3	≤10 and >2	≤ -1.28 and > -2.05
4	≤2	≤ -2.05

The following calculation steps are performed each month:

1) For each station,
   a) Sum the precipitation (rain plus melted snow) over the month;
   b) Calculate the SPI value based on the period of record including the current month for the following look-back periods: 1, 2, 3, 6, 9, 12, 24, and 36 months; and
   c) Calculate the percentile value from the SPI value.

2) For each drought region,
   a) Calculate the median of the individual stations' SPI percentile for each look-back period;
   b) Determine the Index Severity Level of each look-back period based on the percentile ranges in Table 5.

Weekly calculations are also performed for monitoring hydrologic conditions year-round and for drought meetings that occur more often than monthly, in particular, during periods of rapid change. The weekly values are based on the previous 30 days of precipitation from the date of analysis.

A summary table with all look-back periods and their corresponding severity levels is presented to the DMTF. The full set of look-back periods will provide a sense of the change in conditions over time. Based on discussion, the DMTF will then select the most relevant look-back period(s) and determine the overall severity level for the index. For example,

i) During normal conditions, a shorter look-back period may be selected to highlight the potential onset of a drought due to recent, short-term deficits.
ii) During a long-term drought, a longer look-back period may be selected because a short recent period of average precipitation may not be sufficient to end drought conditions and the previous deficits are still affecting conditions.

The 1-month look-back period is intended to provide information about current conditions but it is not intended to drive the severity level of the index because one isolated month of low precipitation does not constitute a drought. Similarly, one month of normal precipitation in not likely to end a drought and recovery in the longer look-back periods would likely be necessary. An analysis of the

36-month look-back period suggested that time periods beyond the 24-month time frame do not provide additional drought signals at the Drought Region scale (see Appendix C). However, based on recent research showing multi-year impact of precipitation in some wells (Weider and Boutt 2010, Boutt 2016, Boutt 2017)[8] the 36-month look-back period is retained until further research is conducted and experience is acquired.

For purposes of communication with the public, but not for determining drought status, the "percent of normal" precipitation metric will also be calculated and reported, as it is a commonly understood concept by the public. The "percent of normal" value is calculated by averaging monthly precipitation depth across all stations in a region; the next step is dividing that value by the average of all other monthly average precipitation depths for that same month of the year over the period of record and multiplying by 100. For example, for the month of April, all April monthly precipitation values in the period of record are averaged, and the current precipitation value is translated into a percent of that average value.

3.4.3 Evapotranspiration

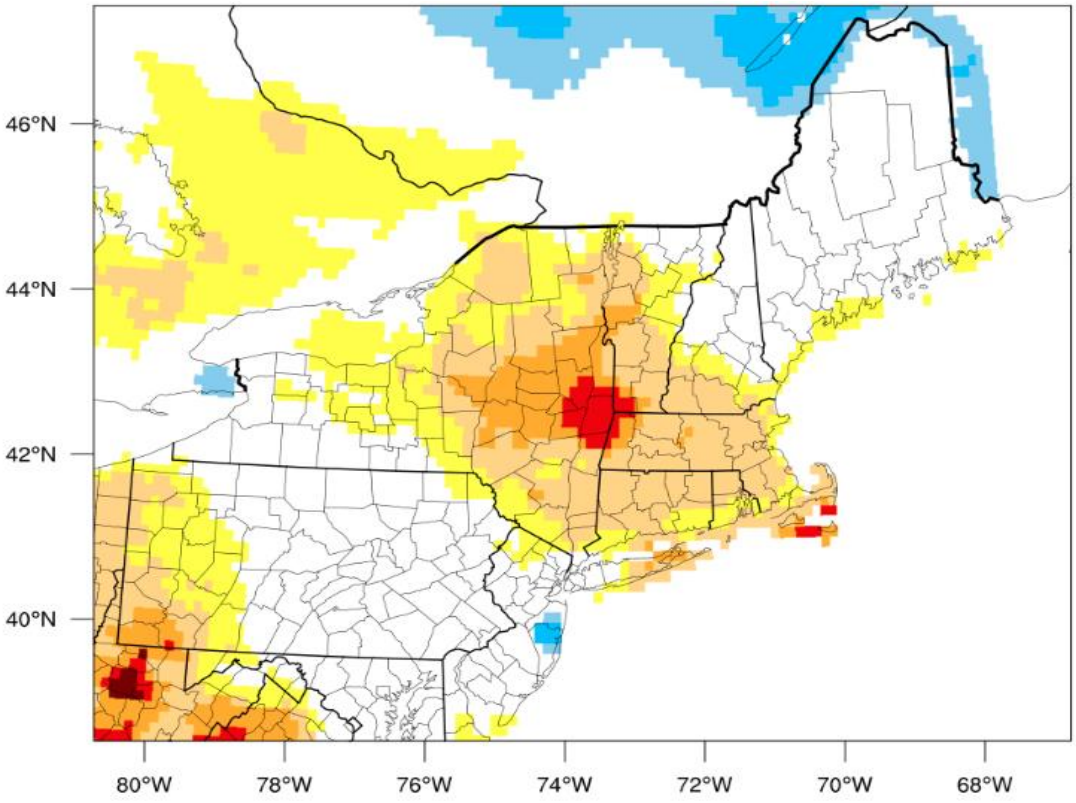
The Evapotranspiration Index (ET) is intended to help consider the effects of evaporation and transpiration as contributors or causes of drought and drought impacts. Evapotranspiration, especially during the growing season, can affect how much precipitation remains in the environment to recharge groundwater, surface water, and soil moisture. In other words, evapotranspiration is a second independent driver of dry conditions during the growing season, along with precipitation deficits. High evapotranspiration can exacerbate precipitation deficits to accelerate the onset of a drought, increase the impacts of drought, or prolong recovery from drought as precipitation begins to normalize. This index in combination with the precipitation index is especially important as a potential early warning of drought onset or intensification during the growing season. It can also provide a sense of the stress on vegetation and the agricultural sector.

NOAA's Evaporative Demand Drought Index (EDDI) is used for the DMP ET index. EDDI examines how anomalous the atmospheric evaporative demand is at a specific location, based on temperature, humidity, solar radiation, and wind. It has been dubbed the index that shows "the thirst of the atmosphere". Values are provided as percentiles relative to the period of 1979-2015. It is available at multiple time scales but the 2-month look back period was selected as most applicable to provide early warning for drought onset and intensification. This aligns with the shorter SPI time scale considered for drought onset. Spatially, it is available continuously for the entire state, as it is a grid

[8] Weider, Kaitlyn & Boutt, David. (2010). Heterogeneous Water Table Response to Climate Revealed by 60 Years of Ground Water Data. Geophysical Research Letters - 37. DOI:10.1029/2010GL045561.
Boutt, David. (2016). Assessing Hydrogeologic Controls on Dynamic Groundwater Storage Using Long-Term Instrumental Records of Water Table Levels: Assessing Hydrogeologic Controls on Dynamic Groundwater Storage. Hydrological Processes- 31. DOI:10.1002/hyp.11119.
Boutt, David. (2017). Extreme Precipitation Events and Subsurface Water Storage Dynamics of Glaciated Landscapes. GSA Annual Meeting in Seattle, Washington, USA – 2017. DOI:10.1130/abs/2017AM-307912.

product. Temporally, it is available daily with a five-day time lag, therefore, it is available for both weekly and monthly calculations.

Figure 4: An Example of the Complete and Continuous Spatial Coverage of EDDI for Massachusetts



The following calculation steps are performed from April through November:

1) For each drought region,
    a) Calculate the median of the individual grid percentiles; and
    b) Determine the severity level based on the percentile ranges in Table 4.

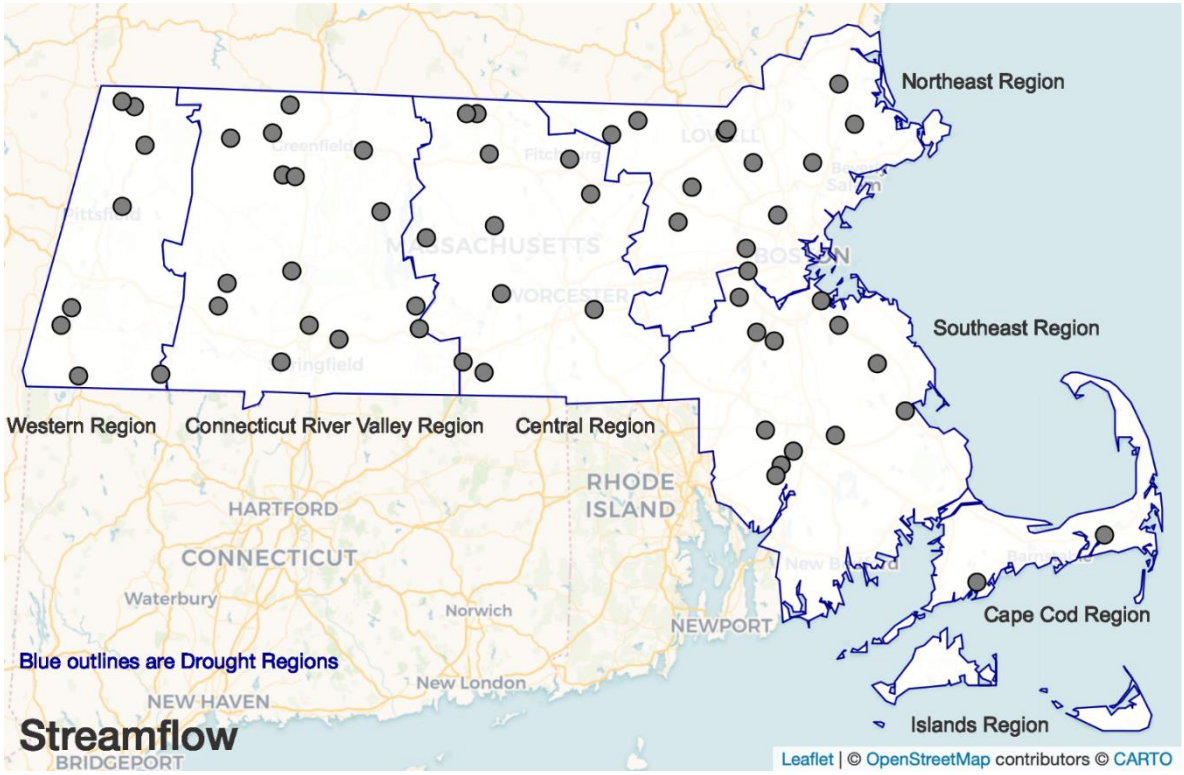
Each region's calculated severity level is presented as a summary table to the DMTF. Any areas within a region that are at a higher level than the region are qualitatively noted. These calculations are performed weekly, using the most recent 8-week EDDI map, and monthly, using the two-month EDDI map.

3.4.4 Streamflow

Streamflow can be affected quickly by precipitation deficits, and this index is intended to provide an early signal of environmental impacts, such as impacts to streams, riparian buffer areas, river front areas, wetlands, and other habitats. The Streamflow Index responds faster to deficits in precipitation during the growing season, when a significant amount of the precipitation returns to the atmosphere via evapotranspiration and a smaller proportion makes it to the streams. Streamflow data are acquired from the Massachusetts USGS website at https://ma.water.usgs.gov/. A map of the streamgages used in the calculation of this index is provided in Figure 4. Historically, the streamflow index had not been calculated for the Cape Cod and Islands regions. However, there are now two

gages on Cape Cod with over 30 years of data that can serve as an early warning of dryness even in a groundwater-dominated system. These gages were added to the network in May 2021 as approved by the DMTF.

Figure 5: Massachusetts Monitoring Network for Streamflow



The following calculation steps are performed each month:

1) For each gage,
   a) Calculate the median of daily flows for the month; and
   b) Calculate the percentile of this median flow based on the median flows for the same month of the year over the streamgage's period of record.
2) For each drought region,
   a) Calculate the median of the individual streamgage percentiles; and
   b) Determine the severity level based on the percentile ranges in Table 4.

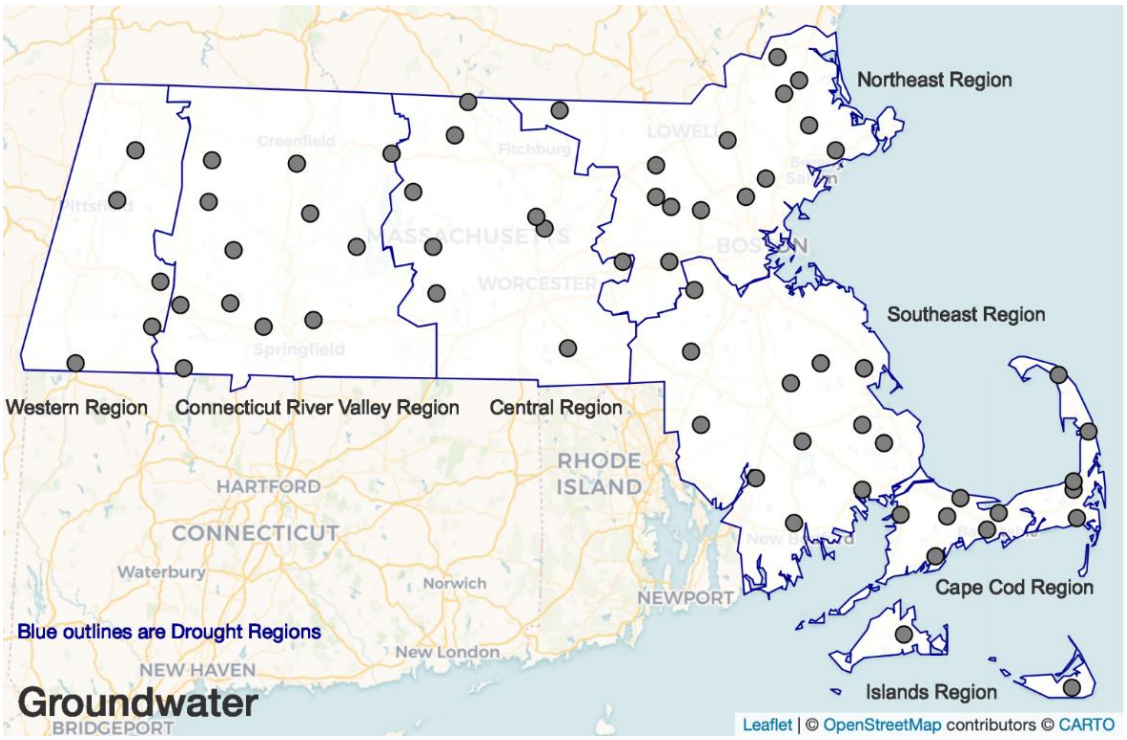
Weekly calculations are also performed for monitoring hydrologic conditions year-round and for drought meetings that occur more often than monthly, particularly during periods of rapid change. The weekly values are based on the previous 30 days of streamflow from the date of analysis.

In addition to each region's calculated severity level, a summary table is presented to the DMTF detailing the number of streamgages in each region at the various severity levels and noting instances of new record low flows.

3.4.5 Groundwater

The Groundwater Index is intended to show a general overview of the water level in aquifers. Because of recharge lag time and a storage component, this index generally shows drought impacts later than other indices and takes longer to recover. Groundwater data from wells in the USGS Climate Response Network are used for this index and are acquired from the Massachusetts USGS website at https://ma.water.usgs.gov/. A map of the wells used in the calculation of this index is provided in Figure 6.

Figure 6: Massachusetts Monitoring Network for Groundwater



The following calculation steps are performed each month:

a) For each well, calculate the percentile of the water-level measurement for the month[9] based on values for the same month of the year over the well's period of record. To align monthly, manually measured wells with continuously, automatically measured wells, use the following data points: for manually measured wells, use the one available value; if multiple measurements exist due to maintenance or other reasons, use the one closest to the 24th of the month, except in December, when manual wells are measured early, use the one closest to the 19th of the month;

b) for continuously measured wells, use the daily average water level for the 24th day of the month, except in December, when manual wells are measured early, use the 19th of the month.

2) For each drought region,

a) Calculate the median of the individual well percentiles; and

b) Determine the severity level based on the percentile ranges in Table 4.

[9] Wells are measured either periodically (manually, once per month, and generally the last week of the month) or continually (real-time equipment measure data at 15-minute or hourly intervals).

Weekly calculations are also performed for monitoring hydrologic conditions year-round and for drought meetings that occur more often than monthly, in particular, during periods of rapid change. The weekly values are based on the last day that groundwater values are available from real-time sites (i.e., the day before the date of analysis) and for the manual sites, the nearest values available within 7-days of the date of analysis.

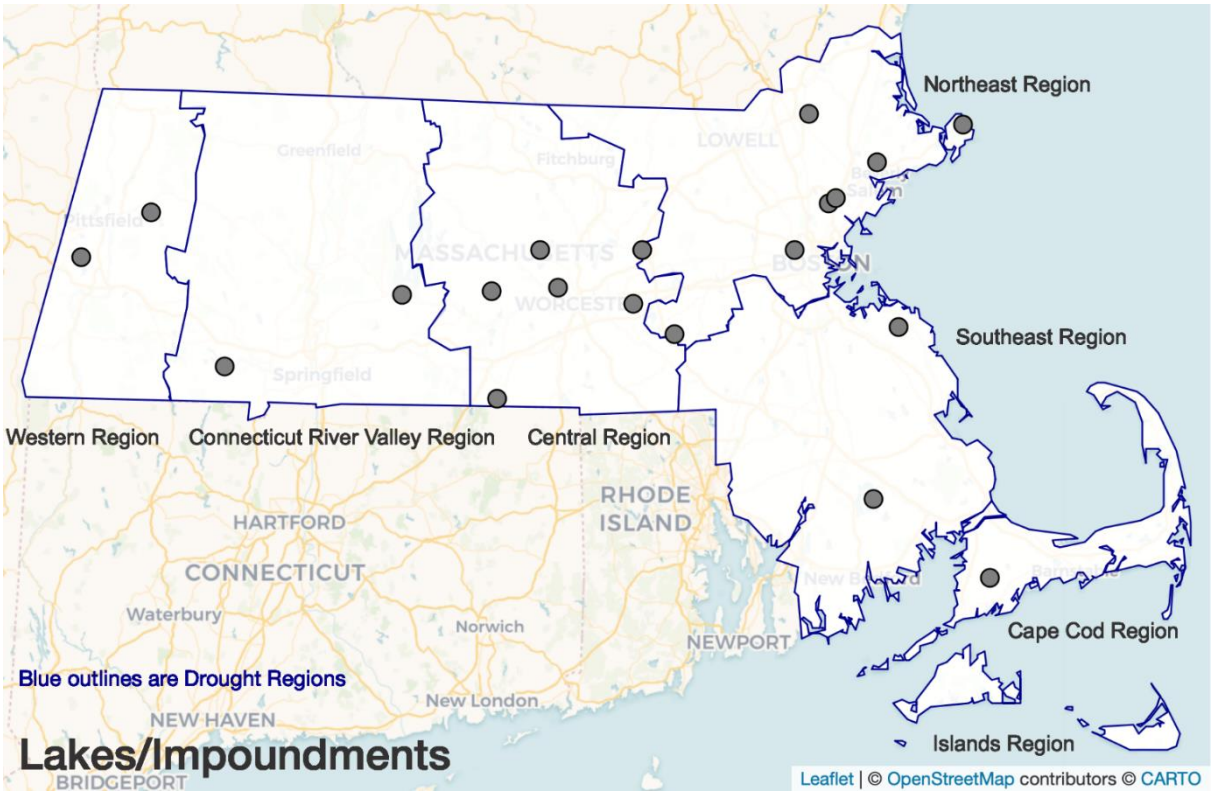
In addition to each region's calculated severity level, a summary table is presented to the DMTF detailing the number of wells in each region at the various severity levels, including the number of wells at new record lows.

3.4.6 Lakes and Impoundments

The Lakes and Impoundments Index characterizes the condition of surface water storage across lakes, ponds, water supply reservoirs, flood control reservoirs and other human-made impoundments. It is not intended to be a measure of water supply adequacy and, therefore, is not adjusted to reflect drought thresholds in individual public water system drought management plans. Because of its storage component, this index may show drought impacts later than other indices. Alternatively, some reservoir systems may show drought impacts concurrent with other indices given the shallow nature of their impoundments.

Water elevation data for this index are acquired from public water suppliers via personal communication, from online USGS data, and from direct measurements. A map of the lakes and impoundments used in the calculation of this Index is provided in Figure 7.

Figure 7: Massachusetts Monitoring Network for Lakes and Impoundments



The following calculation steps are performed each month:

1) For each lake or impoundment, calculate the percentile of the measurement for the month based on measurements for that same month of the year over the water body's period of record. To align monthly reported reservoirs with continuously, automatically reported reservoirs, use the following data points:
   a) For monthly reported reservoirs, use the one reported value or, if there are multiple values reported, use the latest in the month,
   b) For continuously reported reservoirs, use the 7 a.m. reading on the last day of the month. This time corresponds to the time the precipitation gages are read in the state's Precipitation program.
2) For each drought region,
   a) Calculate the median of the individual percentiles; and
   b) Determine the severity level based on the percentile ranges in Table 4.

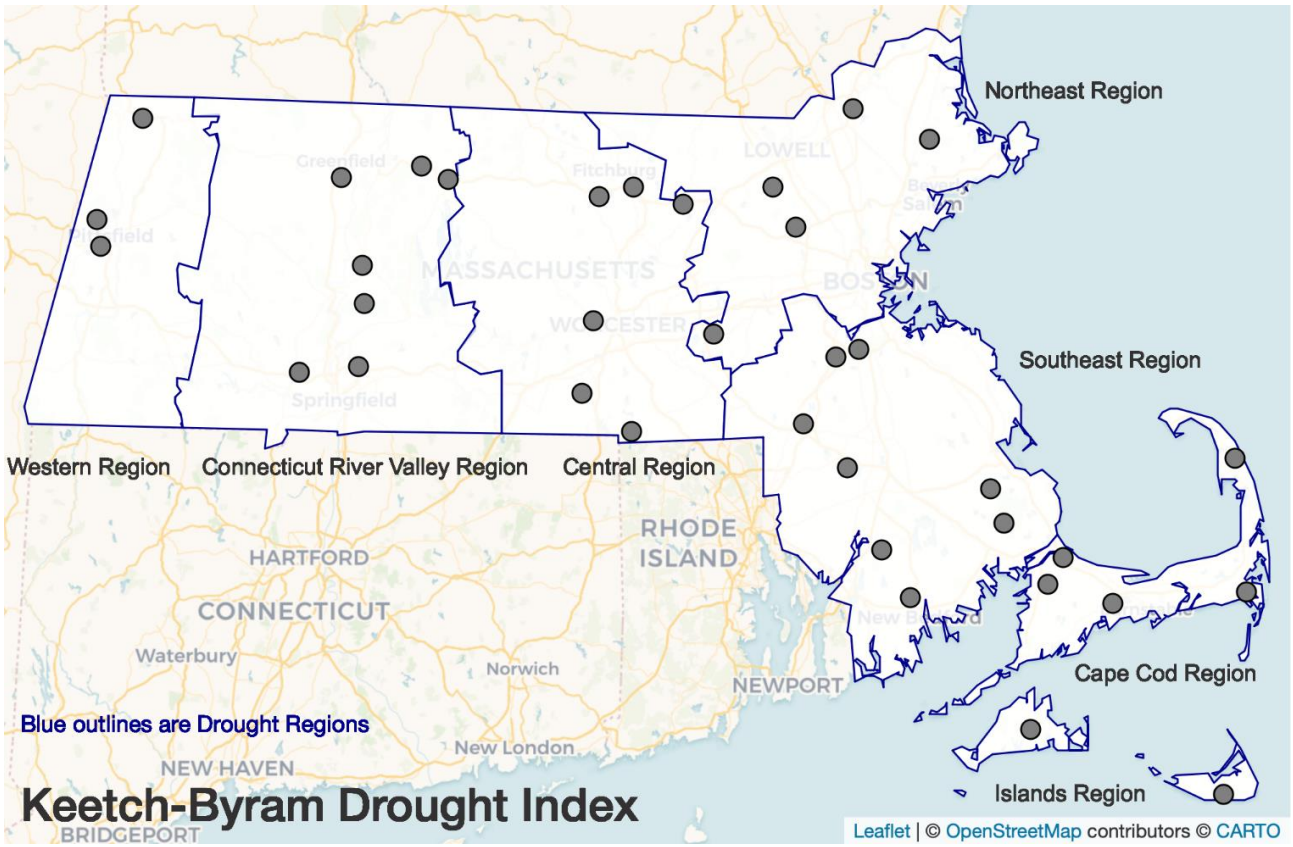
If an outlier in a location's data is noticed, the responsible entity for that location will be contacted to determine whether the location should be included in that month's assessment. For example, a reservoir may be drawn down for maintenance purposes, or a water supply system may be operated differently from historical practice. In either case, the measurement is not comparable to measurements in the period of record and would be excluded. These data are collected monthly and therefore calculations are only performed monthly (i.e., no weekly calculations).

In addition to each region's calculated severity level, a summary table is presented to the DMTF detailing the number of lakes and impoundments in each region at the various severity levels.

3.4.7 Fire Danger – Keetch-Byram Drought Index

The values used for the Fire Danger Index are those from the Keetch-Byram Drought Index (KBDI). KBDI is a drought index for fire potential assessment and relates to the flammability of organic material in the ground. It attempts to measure the amount of precipitation necessary to return the top eight inches of soil to full "field capacity," that is, the total moisture the soil can retain once excess has drained. Each of the 14 Fire Districts of the Massachusetts Bureau of Forest Fire Control and Forestry calculates and reports KBDI values, usually March 1 through November 30. During the cooler, wetter months of December through February, KBDI is not calculated because fire danger is low. However, the Fire Chief, as a member of the DMTF, provides updates should any fire danger arise.

Figure 8: Massachusetts Monitoring Network for KBDI



At least one Massachusetts Fire District is in each of the seven Drought Regions. A map of the Fire Districts overlaid with the Drought Regions is provided in Figure 8.

The approach for this index differs from the approach used for other indices because historical data for KBDI are not available; therefore, calculating the percentile value of a KBDI for its period of record is not feasible. Instead, the Fire Danger Index is determined using the following steps:

For each district, the latest available weekly KBDI value is used.

1) For each region,
   a) If there is more than one fire district, select the highest value (i.e., higher fire danger); and
   b) Translate KBDI values to index severity levels using Table 6.

Table 6. Fire Danger Index - Severity Levels and Corresponding KBDI Values

Index Severity Level	KBDI Range
0	<200
1	200 to <400
2	400 to <600
3	600 to <700
4	700 to <800

3.4.8 Additional Information

In addition to the drought indices, other relevant information is presented to the DMTF by task force members as described below. The DMTF relies upon this additional information for a comprehensive characterization of drought conditions and impacts and weighs it in their discussions and drought determinations.

3.4.8.1 Forecasts

The NWS presents the following information and forecasts:

- Recent weather and any large-scale climatic events that may be contributing to local weather patterns (e.g., El Niño, La Niña) in recent or coming months;
- Snowpack status including water equivalent of snowpack relative to historical data, and rain-on-snow or snowmelt events;
- Weather forecasts for the 7-day, 2-week, 1-month and 3-month timeframes[10];
- One- and three-month outlooks on potential drought conditions[11]; and
- Streamflow forecasts.

These data may help interpret anomalies in the drought indices and provide forecasts that can be helpful when determining drought severity for a region.

3.4.8.2 Impact Reports

Multiple agencies and organizations provide information and qualitative summaries of drought impacts on various interests, including public drinking water supplies, public health, public utilities, agriculture, aquatic ecosystems, forests, and recreation. Table 3 details each agency and organization and its reporting responsibilities. Information gathered through other sources such as members of the public and the newly developed Massachusetts Water Impact Reporter[12] may also be considered.

Section 4: Process of Determining Drought Status

This section describes the process by which state entities determine drought status. The process has two components: the DMTF reviews data, makes a drought determination and a formal recommendation to the EEA Secretary; and the EEA Secretary declares drought levels for each region.

4.1 DMTF Deliberation and Drought Recommendation

As described in Section 3 above, DCR Office of Water Resources staff routinely collect and analyze data and report on hydrologic conditions on a monthly basis to the WRC. When the analyses indicate that conditions are drying and action may be warranted by the DMTF, EEA and MEMA convene a DMTF meeting. DMTF members present the data and information described in Sections 3.3 and 3.4. An opportunity is also provided for members of the public to contribute additional information. The DMTF reviews and discusses the presented information detailed in Section 3 and deliberates on a drought level for each region[13] and/or watershed, as needed.

The DMTF may consider whether a region(s) is coming into a drought, is experiencing ongoing drought, or appears to be emerging from a drought. In each phase, different indices and information

[10] http://www.cpc.noaa.gov/products/forecasts/
[11] http://www.cpc.ncep.noaa.gov/products/Drought/
[12] http://www.mass.gov/wir
[13] The requirement from the 2013 DMP for a majority of indices to be below normal has been eliminated. As described in the following paragraph, the deliberation considers which phase of the drought is occurring, the most relevant indices to weight, and severity of those indices.

may be weighted more than others. For example, the faster-responding indices such as the Precipitation (short-term look-back periods), Streamflow, Evapotranspiration, and Fire Danger indices may be the first to signal a developing drought. During drought recovery, the Groundwater and Precipitation (long-term look-back periods) indices will likely weigh more heavily, as these can take longer to recover from drought deficits. In addition, a high ET Index level may be helpful in explaining a slower than expected recovery based only on improved precipitation. Additionally, forecast data and the forecasted status of the indicators will be considered. A smaller spatial delineation, such as a county or watershed, for a drought declaration may also be recommended. The meetings conclude once the DMTF has evaluated all available and relevant information and determined a drought-level recommendation for all regions. The DMTF provides these recommendations to the Secretary of EEA. The DMTF continues to meet at least monthly for the duration of the drought.

4.2 Drought Declaration

After due consideration of the information and recommendations provided by the DMTF – including current conditions, on-the-ground impacts, relative severity of indices, and forecasts of climatological and hydrological conditions – the Secretary of EEA declares the drought levels for each region across the Commonwealth. The start date of declared drought conditions is specified on the drought status map.

4.3 End of Drought

Determinations regarding the end of a drought focus on the precipitation and groundwater indices. These metrics will be prioritized when evaluating declarations for the end of a drought. Precipitation is a key factor because it is the overall cause of improving conditions. Depending on the severity and length of the drought, surplus precipitation is likely necessary not only for recovery of the shorter but also for the longer look-back periods. In determining the end of drought, the DMTF may discount short-term precipitation surplus and focus on longer term precipitation recovery. Additionally, the DMTF will consider the timing of precipitation events, because the same amount of precipitation can differ in its effect on drought conditions depending on the season. Precipitation occurring during the fall and spring, when the ground is not frozen and evapotranspiration is relatively low, is ideal for groundwater recharge and, therefore, should result in the quickest return to normal groundwater conditions. Groundwater levels are also good recovery indicators because they have a storage component that may require time to recharge to average levels making them, in general, among the last of the indices to respond to improving conditions.

Section 5: Drought Communication

Establishing clear lines of communication with the public, public safety partners, and decision-makers to ensure they have accurate and timely information on which to base decisions is a key component of managing and responding to droughts. Clarity and consistency of message is also critical. EEA and MEMA will serve as the primary coordinating entities for drought communications. This section of the DMP outlines the general notification and communication framework for drought management.

5.1 Communication Platforms

Primary communication among EEA, MEMA, and state agencies and departments with roles and responsibilities under the DMP is via telephone, email and other virtual platforms. As required, and at the direction of EEA, conference calls, remote/virtual meetings, and in-person meetings may be utilized. If the State's Emergency Operations Center (SEOC) is activated at MEMA (for an emergency drought that requires a coordinated state response, for example), WebEOC will be the primary information sharing platform utilized to provide situational awareness and manage resource requests amongst our partner agencies and communities. This is consistent with any activation of the SEOC.

Additionally, EEA will manage and regularly update a drought-specific website, and provide information such as:

- Drought maps and any current drought declarations
- Links to relevant data
- Frequently asked questions about the drought
- Information about community water restrictions
- Access to messaging and other outreach material
- Information for private well owners
- Tips on saving water for various sectors
- Information on disaster assistance for drought-affected sectors
- Links to agency drought-related pages
- Case studies of drought response and water conservation successes

The following direct forms of communication will also be utilized, as appropriate:

- Conference calls with municipal officials with the assistance of MEMA
- Conference calls/ webinars with local Boards of Health with the assistance of DPH
- Conference calls with water suppliers, with the assistance of DEP and MEMA
- Regular mailings (e.g., MassDEP mailings to the water supply community after DMTF meetings with updates about drought status, tips, and information on recommended practices)
- Email distribution lists managed by various state agencies
- Outreach to regional planning agencies
- Use of local reverse 911-type systems to deliver messages
- Use of Integrated Public Alert and Warning System (IPAWS) tools as needed to alert the public, coordinated through MEMA
- State agency social media platforms
- High-visibility public signage, such as on major highways
- Printed material posted or distributed at state properties

5.2 Communication with State and Local Entities

During a drought, EEA and MEMA will jointly communicate with local and state entities on hydrological conditions, drought-level transitions, potential impacts, and appropriate response actions or measures.

5.2.1 EEA and MEMA Responsibilities

Once EEA has determined that a region of the Commonwealth has entered a drought or a new drought level, the following notification steps will be taken:

- EEA will notify state agencies and partners of a drought level transition;
- As needed, MEMA will share appropriate information regarding the drought level and hydrological conditions and will coordinate with EEA to disseminate the message to local and state stakeholders;
- If the SEOC is activated, or if MEMA is coordinating state responses to manage consequences or deploy/distribute commodities, MEMA will develop and distribute SAS per established procedures;
- EEA will update its drought webpage with a drought status report;
- EEA will communicate drought-related guidance and recommendations from the DMTF to state agencies and departments; and
- EEA will provide updates to the appropriate state agencies and departments, as needed.

5.2.2 Other State Agencies' Responsibilities

To ensure that all local stakeholders are notified about drought conditions, specific state agencies will be responsible for communicating with their constituents. Table 7 lists the state agencies and departments responsible for notifying specific local and regional entities. The method of notification will be determined by the responsible agency; however, redundant means of communication are strongly encouraged.

Table 7. Notification List for State Agencies

Entity Receiving Notification	Agency Providing Notification
Public Water Suppliers	Department of Environmental Protection Department of Public Utilities
MWRA Community Water Suppliers	Massachusetts Water Resources Authority
Local Boards of Health	Department of Public Health
Foresters	Department of Conservation and Recreation
Farmers	Department Agricultural Resources
Other Large Water Users regulated by WMA Program (including industrial consumers and golf courses)	Department of Environmental Protection
Outdoor Recreational Interests	Department of Fish and Game
Local Fire Departments	Department of Fire Services DCR Bureau of Forest Fire Control and Forestry
Regional Planning Agencies, Watershed Groups and other environmental nonprofits	Executive Office of Energy and Environmental Affairs

5.3 Communicating with the Public

It is extremely important that accurate and timely information about the current status of drought conditions and the resultant impacts are communicated to the public. Consistent messaging is the key to effective communication and reaching the target audience. EEA's press office will be the primary vehicle through which information will be made available to the general public. EEA will partner with other agencies or offices (such as MEMA, DEP, DPH) when jointly released public announcements are needed to bring attention to the situation or to communicate specific response actions.

As needed, EEA will hold a press conference to alert the general public to information about a drought. Additionally, information may be shared through various print and social media outlets and direct communication avenues, including, but not limited to, the following:

- Regular press releases
- Drought-related Tweets, such as water conservation, safe fire practices, and agricultural impacts
- Social media outreach on platforms of all involved state agencies
- Signs on the highways, private digital billboards (through MassDOT's PSA program)
- Flyers and factsheets to hand out at state properties

For impacted businesses, including those in the agricultural sector, EEA will coordinate with state agencies to provide and publicize helpful web-based resources.

Receiving communications from the public is also of critical importance during a drought, to help monitor the extent of impacts. To this end, EEA will use the above communication strategies to build public awareness of the national web-based platform, the Drought Impact Reporter[14] and the Massachusetts Water Impact Reporter[15]. EEA will encourage its use by the public to document drought impacts, including but not limited to impacts to private wells, fisheries and wildlife, streams and aquatic habitats, crops and agricultural operations, industry, tourism, and recreation.

5.4 Communicating with the Media

For the media and members of the press, EEA, along with MEMA and other state agencies, will engage in targeted and coordinated communication through:

- Press releases (monthly, or as needed),
- Press conferences by the Governor, Secretary of EEA, Director of MEMA, Commissioners of various state agencies (as needed),
- Interviews, media pitching, and other communication with the press.

[14] http://droughtreporter.unl.edu/submitreport/
[15] http://mass.gov/wir

5.5 Emergency Alert and Notification

If an emergency condition exists that requires a state response, MEMA may activate the State Emergency Operations Center (SEOC) and will utilize several systems and tools, as outlined in the Commonwealth's Comprehensive Emergency Management Plan (CEMP), to notify emergency response partners. These partners come from a myriad of local, state, federal, nonprofit, and private-sector organizations. MEMA will also utilize WebEOC as a primary information sharing and situational awareness tool during response and recovery activities.

Public warnings may be issued when there is a threat to life, property, and safety. When the need to relay a public warning is present, MEMA will coordinate with EEA and all other appropriate stakeholders (e.g., DPH, Department of Fire Services, DCR Bureau of Forest Fire Control and Forestry) to develop public warning messages. MEMA may disseminate public warnings and messages via smartphone applications, the mass.gov and MEMA websites, and established social media platforms. MEMA's Communications Center, serving as the state's Primary Warning Point, will disseminate these messages via established public warning systems.

5.6 Notification of the End of Drought Conditions

Once a drought is determined to have ended, as described in Section 4.4, EEA and MEMA will engage in public outreach. Additionally, relevant agencies and organizations should communicate this information to their target audiences. This message should not only include an update on the current conditions, but should communicate the need for general conservation measures and emergency planning as part of good water resource management practice.

Section 6: Summary of Responsibilities by State Agency

This section describes in further detail the responsibilities of each state agency on the DMTF. Table 1 in Section 2.4 provides an overview of the responsibilities of state and federal agencies.

6.1 Executive Office of Energy and Environmental Affairs (EEA)

As a state cabinet-level office, EEA oversees both environmental and energy agencies, including the Departments of Conservation and Recreation, Energy Resources, Environmental Protection, Agricultural Resources, Fish and Game, and Public Utilities. EEA serves as co-chair, along with MEMA, of the DMTF, convening DMTF members and considering their technical input in making a decision about the geographical extent and severity of drought conditions. The Secretary of EEA makes the drought declarations for the state.

In general, EEA manages all coordination with the media and is the lead state agency responsible for communicating and coordinating with other state agency stakeholders and partners regarding drought response actions and activities at the state level, and for coordinating with the Governor's office as well as the federal government on technical and financial assistance. In preparation for and during a drought, EEA directs, in coordination with EEA agencies, the development of drought and

water management policies; develops the public communications strategy; and generally coordinates and directs the actions of the agencies it oversees.

6.2 Massachusetts Emergency Management Agency (MEMA)

MEMA serves as the state agency with primary responsibility for ensuring the Commonwealth's resilience to disasters. MEMA is responsible for coordinating and implementing the statewide emergency management program. The program is supported by local, state, federal, nongovernmental, and private-sector organizations that have capabilities to prevent, mitigate, prepare for, respond to, and recover from emergencies impacting the Commonwealth.

During a drought, MEMA serves as Co-Chair of the DMTF coordinating with the EEA to convene DMTF members and facilitate meetings. MEMA also serves in a supportive and coordinating role in drought planning, preparedness, response, and recovery activities as needed. This includes providing planning guidance and support, logistics and resource support, situational awareness management and dissemination, event tracking and documentation, and notification and communications coordination. In addition, MEMA provides support to local authorities as required to address community-specific requirements. These roles are defined further in the Comprehensive Emergency Management Plan.

6.3 Department of Conservation and Recreation (DCR)

DCR's **Office of Water Resources** (OWR) manages the state's Precipitation Program, a network of 140 precipitation observation stations, and a precipitation database for research and analysis. DCR uses its precipitation data to calculate a composite of precipitation conditions statewide and in each of the seven drought regions. Staff at OWR also serve as staff to the WRC and the DMTF. The office prepares a monthly report on Hydrologic Conditions in Massachusetts for the WRC and for the DMTF when it meets. The report summarizes monthly precipitation amounts and trends, streamflow conditions, groundwater and reservoir levels, drought conditions and forecasts from federal agencies, fire danger, and soil moisture via evapotranspiration.

DCR's Office of Water Resources also plays a key internal coordination role, assisting in DMTF meeting preparation and summaries and acting as a liaison between the DMTF co-chairs and the agencies responsible for data collection and analyses. Staff from the Office of Water Resources are also key authors of the DMP .

Assessment of fire risk and management of fire control resources is an ongoing activity of DCR's **Bureau of Forest Fire Control and Forestry**. Risk of fires in wild land, rural areas, and state forests and parks are linked to dry conditions, and a drought can affect the availability of water for fire suppression. The DCR State Fire Warden manages state fire suppression resources and coordinates with local, state, and federal agencies and other states on the appropriate resources, as needed. Both before and during a drought, the Bureau of Forest Fire Control and Forestry monitors and reports on the level of fire danger in each drought region.

The DCR **Offices of Engineering and Dam Safety** manage key infrastructure across the state including the operations and maintenance of many flood control structures. As part of their role on the DMTF, the offices will assess conditions and report on the Charles River and Mystic River flood control dams, as well as report on other critical DCR infrastructure.

6.4 Department of Environmental Protection (MassDEP)

MassDEP oversees various aspects of water supply, allocation, and resource protection through its Water Management Act (WMA), Drinking Water (DW), and Wetlands programs. The agency also has the authority to issue public health orders, and declare, terminate, and extend a state of water supply emergency for communities with water supply systems that are experiencing public health or safety threats, including drought conditions and contamination.

The **WMA and DW Programs** track the implementation of nonessential[16] outdoor water use restrictions imposed by public water systems (PWS) across the state. By regulation, any PWS with a registration must restrict nonessential outdoor water use by their customers when a drought is declared by the EEA Secretary. If a registrant also holds a Water Management Act permit that includes conditions requiring restrictions on nonessential outdoor water use, the conditions in the permit are controlling. In addition, any PWS that imposes mandatory outdoor water use restrictions must report this information to MassDEP. MassDEP regularly prepares maps showing the status of non-essential outdoor water use restrictions, and posts this information to the Mass.gov website. WMA program staff and DW program staff identify potential problem areas or identify specific PWS issues. During periods of low streamflow, MassDEP corresponds with WMA permit holders and all PWSs to encourage them to review their WMA permit requirements, encourage additional conservation measures, and suggest that more stringent water-use restrictions be implemented. Staff from both Programs work with PWSs to identify possible emergency situations and solutions, as necessary. This includes emergency reporting requirements; and, for all “community” systems and “Non-transient Non-community water” systems, development of an Emergency Response Plan (ERP) that includes detailed steps the PWS must implement to ensure the continuation of service in the event of a potential or actual emergency, including drought. MassDEP’s authority to declare local

[16] Nonessential Outdoor Water Use means a use that is not required: (a) for health or safety reasons, including public facilities used for cooling such as splash pads and swimming pools, and for washing of boats, engines, or marine equipment to prevent negative saltwater impacts or the transfer of invasive aquatic species; (b) by permit, license, statute or regulation; (c) for the production of food, including vegetable gardens, and fiber; (d) for the maintenance of livestock; (e) to meet the core functions (those functions essential to the commercial operations) of a business, including but not limited to: 1. plant nurseries as necessary to maintain stock; 2. golf courses as necessary to maintain greens and tees, and limited fairway watering per 310 CMR 36.07(2)(c)2.a. through c.; 3. venues used for weddings or similar special events that limit watering to hand-held hose or drip irrigation as necessary to maintain gardens, flowers and ornamental plants; 4. professional washing of exterior building surfaces, parking lots, driveways and/or sidewalks as necessary to apply surface treatments such as paint, preservatives, stucco, pavement, or cement in the course of construction, reconstruction or renovation work; (f) for irrigation of public parks before 9:00 A.M. and after 5:00 P.M., (g) for irrigation of public and private recreation fields, including those operated by schools, colleges, universities and athletic associations, before 9:00 A.M. and after 5:00 P.M., (h) for irrigation of publicly-funded shade trees and trees in the public right-of-way; or (i) to establish a new lawn as necessary to stabilize soil in response to new construction or following the repair or replacement of a Title 5 system. (https://www.mass.gov/doc/310-cmr-3600-the-water-management-act-regulations/download)

water supply emergencies is outlined in detail in Section 10.2.3 of the DMP. The regulations also require golf courses to implement restrictions in nonessential outdoor water use restrictions for the irrigation of fairways, roughs, landscaping and ornamentals.

During periods of drought, the MassDEP **Wetlands Program** reaches out to its regional staff and tracks the number of inquiries to MassDEP from external parties (local Conservation Commissions, consultants, and others) regarding perennial streams that have ceased to flow. This information is provided to the DMTF.

6.5 Department of Agricultural Resources (DAR)

Crop losses can pose severe financial constraints on farmers, aquaculturists, and other agricultural businesses. During drought conditions, DAR monitors and reports on the status of crops in each drought region.

In general, the Department encourages farmers to take advantage of agricultural grant opportunities and financial assistance programs offered by DAR, such as funding programs that help to reduce the impacts of climate change on agriculture and to enhance the economic resiliency of agricultural operations.

DAR works with the USDA and UMass Extension, along with EEA and other state agencies, to collect information and monitor drought conditions and to identify any needed resources on behalf of the agricultural community. Regular communications to farmers and the agricultural community are provided through the Department's email listserv and the Farm and Market Report to highlight any resources that may be available from state and federal agencies. These efforts are combined with encouraging the public to purchase local agricultural products even during drought conditions to help support local farms.

During a drought, DAR is responsible for working with the United States Department of Agriculture's (USDA) Massachusetts Farm Service Agency (FSA) to communicate information from farmers and the agricultural community about agricultural products and livestock that are actually or predicted to be impacted by drought.

DAR works with UMass Extension to distribute a crop loss survey to farmers so they can report directly on crop losses resulting from drought. As a result of reported crop losses, federal assistance may become available through the FSA. The USDA designates counties as primary natural disaster areas based on crop losses caused by drought. A USDA declaration makes farms in designated counties eligible for assistance from FSA, including low-interest emergency loans. In addition, FSA has a variety of assistance programs that are triggered based on the U.S. Drought Monitor and that do not require a disaster declaration.

6.6 Department of Fish and Game (DFG)

The impacts of dry conditions on fisheries and wildlife range from reduced habitat to fish kills, displacement of certain populations of animals, and increased human-wildlife interactions that include mortality or injury, population losses, and inability to find sufficient refugia. Drought can affect fish and wildlife on an individual or population level and can also affect people who rely on adequate water levels for recreation, including fishing, hunting, and boating.

The **Division of Fisheries and Wildlife** (DFW) at DFG serves as first responder to fish kills through a formal interagency Memorandum of Understanding between DFW, MassDEP, DAR, and the Office of Law Enforcement. Other responses to drought include identifying impacts to specific fisheries and wildlife populations as they are developing so that DFG and other agencies, such as local governments or MassDEP, can implement measures to reduce the impacts to these resources. In some cases, population impacts may require regulatory changes to hunting seasons, permits, bag limits, species listing, or site-specific habitat management actions, or the regulatory review of projects that might impact the habitat of state-listed rare species. From a recreational standpoint, drought can severely impact the use of natural resources by hundreds of thousands of people in Massachusetts. For example, boat ramps can become unusable as lake water levels drop and streams or rivers that are fished or boated can become too low for recreation. MassWildlife has the capability to inform the recreational public regarding drought conditions through a variety of social media outlets.

DFG's **Division of Ecological Restoration** (DER) monitors streamflow at sites across Massachusetts to better understand streamflow alteration and document and implement streamflow restoration projects. The majority of sites are located on headwater streams with watersheds smaller than 15 square miles. During dry periods and droughts, DER increases the frequency of data collection, coordinates with project partners on updates on local streamflow conditions and impacts, and provides updates and photos at DMTF meetings. DER also coordinates with partners to adjust streamflow releases based on existing drought management/streamflow release plans.

DFG's **Division of Marine Fisheries** (DMF) is responsible for managing diadromous or sea-run fish populations in coastal waters of Massachusetts. This role includes monitoring spring runs of river herring, American shad, rainbow smelt and American eel. The migrations of these sea-run fish depend on adequate flows to allow spring spawning migrations and the emigration of juvenile fish later in the summer and fall. Drought and low outflow in many watersheds is a significant concern for the recruitment of juvenile river herring to marine waters. DMF staff are active in managing fishway operations and maintenance and stream channel maintenance, tasks that are challenged by low flows and directly related to the success of juvenile river herring. DMF staff conduct water level and flow monitoring in specific cases related to fishway designs, and also coordinate with MassDEP on the permitting of water withdrawals and registrations when diadromous fish impacts are a concern.

6.7 Department of Public Health (DPH)

Dry conditions can affect the availability and the quality of water. DPH provides oversight or assistance to local boards of health (BOHs) by transmitting drought-related information and responding to drought-related issues, such as impacts on private wells and recreational water quality impacts. DPH beach regulations require regular water quality monitoring for fecal indicator bacteria (FIB) and public notification of unsafe conditions. On occasion, freshwater waterbodies (with or without beaches) are monitored for harmful algae. When beaches and waterbodies exceed FIB standards or algae guidelines, they are posted with a notice alerting the public to possible risk. BOHs and DCR are required to report the water quality monitoring data to DPH on an annual basis. During a drought, DPH can also communicate with local BOHs on impacts to private well users and disseminate information and resources to affected communities and/or users.

6.8 Department of Public Utilities (DPU)

The DPU oversees investor-owned water utilities, or every person, partnership, association or corporation, other than a municipal corporation, and other than a landlord supplying a tenant, engaged in the distribution and sale of water in the Commonwealth through its pipes or mains. This excludes municipally owned water systems, water and fire districts, and homeowner associations that provide water service. DPU oversees water companies seeking to alleviate the effects of a long-term drought or frequently occurring droughts by purchasing or taking by eminent domain waters or lands for collecting, storing, holding, purifying, and preserving water within its franchise territory. Also, DPU is able to grant a water company the authority to acquire and hold real estate beyond amounts limited by the company's charter or special laws if DPU finds that such additional real estate is necessary or convenient for the company to carry out the purposes of its organization and the acquisition and holding will not be contrary to the public interest.

6.9 Massachusetts Water Resources Authority (MWRA)

The MWRA is the largest regional water supplier in the Commonwealth and withdraws water from two large source reservoirs - Quabbin and Wachusett, which are owned and managed by the Commonwealth and several smaller emergency reservoirs throughout the Metro Boston and MetroWest areas. MWRA provides drinking water supply to 2.5 million consumers across 53 communities - mostly in Metro Boston and MetroWest areas,

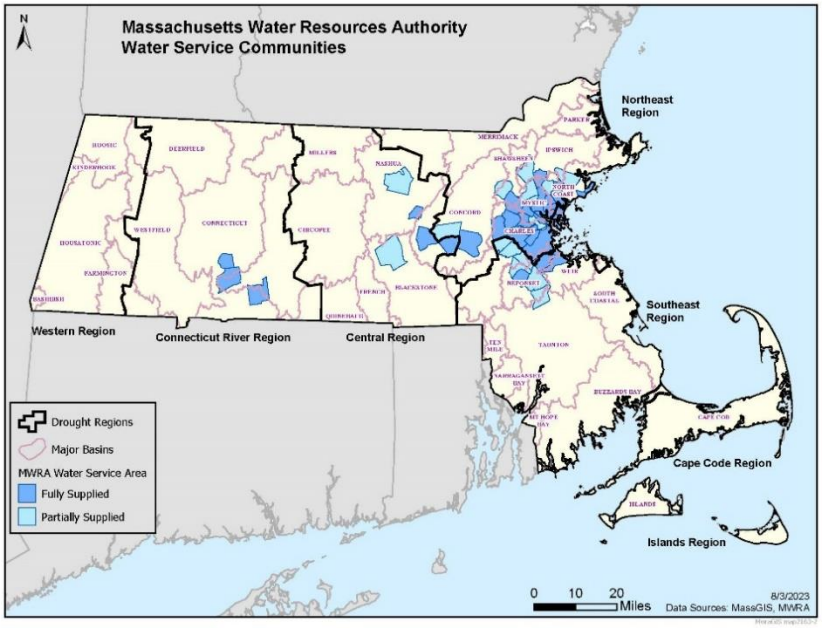


Figure 9: Massachusetts Water Resources Authority water service communities

some of which are only partially-served or have emergency connections. MWRA also supplies three Chicopee Valley communities.

During periods of drought, MWRA may provide water to its emergency connection communities and additional water to its partially-served communities along with some adjacent communities through emergency connections should their local sources become stressed. MWRA also communicates with local water departments in MWRA communities on drought and demand management, as well as public drought messaging on MWRA media such as www.mwra.com and the annual Consumer Confidence Report.

Section 7: Drought Preparedness and Response Actions of State Agencies

This section describes the roles and responsibilities of state agencies in preparing for a drought and responding to drought conditions at various levels of intensity.

7.1 State Agency Drought Preparedness Actions

Actions taken before a drought begins ensure that state agencies are positioned to respond effectively when drought conditions emerge. Some actions taken in preparation for a drought, such as development of policies or the implementation of water conservation measures, can help to delay or minimize the impacts of drought. Preparedness actions by state agencies include routine data gathering and analysis; establishing lines of communication among local, state, and federal agencies; developing a public communications and outreach plan; developing policies that will help lessen the effects of drought; and providing technical and financial assistance in implementing sound water conservation and management practices. Table 8 outlines key drought preparedness actions of state agencies.

Table 8: State Preparedness Actions

Action Category	Actions	Responsible Agencies
Data Gathering, Analysis, and Reporting	• Collect data for calculating six drought indices. • Analyze hydrologic conditions and produce monthly report disseminated through the Water Resources Commission. • Assess monitoring networks for data gaps and data quality. Address identified data needs. • Pursue opportunities, as feasible, to automate field data collection to support more timely and more frequent assessment of hydrologic conditions.	DCR

Action Category	Actions	Responsible Agencies
	• Track the public water suppliers (PWS) that have reported implementation of voluntary and mandatory water-use restrictions. • Oversee the PWS requirement to have Emergency Response Plans, which includes identification of alternative drinking water supply sources that can be activated in an emergency. • Monitor the statewide progress of PWSs in meeting the performance standards for residential consumption (65 Residential Gallons per Capita per Day-rgpcd) and unaccounted-for water (10%) through review of Annual Statistical Reports.	MassDEP
Coordination	• Convene meeting of the DMTF at least annually, or more often if needed, to assess drought preparedness. Establish lines of communication among members of the DMTF and update contact information for effective coordination when a drought is in effect.	EEA, MEMA
Water Conservation	• Implement the standards and recommendations of the *Massachusetts Water Conservation Standards* at state facilities. • Widely publicize the Massachusetts drought management nonessential outdoor water-use restrictions. • Work with PWS with performance standards in their Water Management Act permits to achieve compliance. • Coordinate with farmers and growers in the agricultural community to ensure water savings programs are well-publicized and incentivized	All agencies MassDEP DAR
Communication and Public Outreach	• Develop a communications strategy to inform the public and communities about drought conditions, raise public awareness about the importance of using water wisely, and actions for reducing water use. This strategy may include the following: ○ Create websites for public outreach and drought impact reporting, including: 1) Up-to-date drought information and links; 2) water conservation tips and resources; and 3) a portal for reporting drought impacts. ○ Establish lines of communication with traditional media outlets, including newspapers, television, and radio outlets. ○ Develop templates and a schedule for using a variety of social media platforms to communicate with the public about drought. ○ Develop educational leaflet for private well owners on drought response with actions such as checking well water levels and conserving water.	EEA, MEMA, DCR, MassDEP, DPH
	• Develop a wildland fire prevention education program.	DCR

Action Category	Actions	Responsible Agencies
	• Disseminate the *Massachusetts Water Conservation Standards* to all public water suppliers and communities; provide online resources and information to accelerate adoption of water conservation practices across all sectors and the general public.	EEA, DCR, MassDEP
Technical Assistance	• Assist Boards of Health in developing requirements to register private wells and in developing mechanisms to track private wells and communicate with private well owners.	DPH, MassDEP
	• Assist the agricultural sector (including nurseries) on methods to improve water efficiency and reduce water use, including implementing the standards and recommendations of Chapter 8 (Agricultural Water Use) of the *Massachusetts Water Conservation Standards*.	DAR
	• Assist public water suppliers in developing drought preparedness and response plans and water conservation programs.	MassDEP, DCR
	• Review adequacy and status of intermunicipal agreements and emergency preparedness plans, including the development of emergency connections with neighboring or regional systems such as the MWRA, and provide guidance. • Encourage public water supply (PWS) participation in the voluntary Massachusetts Water/Wastewater Agency Response Network (MAWARN), which allows public water and wastewater systems to receive rapid mutual aid and assistance from other public systems to restore services damaged by natural or human-caused incidents.	MassDEP, MEMA
	• Work with regional planning agencies to assist municipal government bodies with developing tools to minimize water use through land-use planning.	EEA, DCR
	• Assist high water-use industries on measures to reduce water use, including implementing the standards and recommendations of Chapter 7 (Industrial, Commercial, and Institutional Water Use) of the *Massachusetts Water Conservation Standards*.	EEA (through Office of Technical Assistance)
	• Inform PWS, golf facilities, and others with Water Management Act permits of their water conservation related permit requirements. Where possible, assist golf facilities on methods of reducing water use.	MassDEP
	• Assist state facilities in implementing the standards and recommendations of the *Massachusetts Water Conservation Standards*, particularly in Chapters 5 (Residential/Indoor Water Use), 6 (Public Sector Water Use), Chapter 7 (Industrial, Commercial, and Institutional Water use) and 9 (Outdoor Water Use).	DCR, DCAMM

Action Category	Actions	Responsible Agencies
Financial Assistance	• Compile and maintain directory of state and federal programs for drought funding assistance.	EEA, MEMA, DAR
	• Identify and develop funding sources to assist communities, public water suppliers, and the private sector in implementing water conservation measures.	EEA
	• Identify incentives to encourage use of non-potable supplies where appropriate.	EEA, MassDEP
Policy and Regulatory	• Review the *Massachusetts Water Conservation Standards* every five years. Update as needed.	EEA, DCR
	• Review the *Massachusetts Drought Management Plan: Preparedness and Response* after each significant drought or every five years and update as needed.	DMTF
	• Work with the Massachusetts Board of State Examiners of Plumbers and Gas Fitters to improve efficiency standards in the state Plumbing Code.	EEA, DCR
	• Develop recommendations for legislation to implement statewide outdoor water-use controls during drought.	EEA
	• Evaluate barriers to and opportunities for reuse of graywater and reclaimed water. Review regulations and update, if needed.	EEA, MassDEP

7.2 State Agency Drought Response Actions

When drought conditions begin to emerge, EEA convenes the DMTF. State agencies continue many of the actions taken to prepare for a drought at a more intense level or on a more frequent basis. Data gathering, analysis, and reporting continue, with an emphasis on determining the extent and severity of drought conditions in each drought region. State agencies also intensify their coordination, communication, and technical and financial assistance actions in response to each drought level. This section outlines key actions of state agencies in response to each level of drought.

7.2.1 State Guidance on Nonessential[17] Outdoor Water Use Restrictions

The actions in Table 9 below apply to all outdoor water users and represent one of the most effective ways to minimize the impacts of drought on water supply and the environment. They will also be applied to state entities as outlined in Tables 10a through d.

[17] Essential uses are defined by MassDEP as uses required: a) for health or safety reasons; b) by regulation; c) for the production of food and fiber; d) for the maintenance of livestock; or e) to meet the core functions of a business. Nonessential uses are those *other than* essential uses and are defined in footnote #20.

Table 9: State Guidance on Nonessential Outdoor Water-Use Restrictions at Various Drought Levels

State Drought Condition (by Region)	Nonessential Outdoor Water-Use Restrictions
Level 1 (Mild Drought)	1 day per week watering, after 5 p.m. or before 9 a.m. (to minimize evaporative losses)
Level 2 (Significant Drought)	Limit outdoor watering to hand-held hoses or watering cans, to be used only after 5 p.m. or before 9 a.m.
Level 3 (Critical Drought)	Ban on all nonessential outdoor water use
Level 4 (Emergency Drought)	Ban on all nonessential outdoor water use

7.2.2 Level 1- Mild Drought

At Drought Level 1, the emphasis is on conservation through education, communication, and planning. The objective is to take action under the precautionary assumption that conditions may deteriorate further. Key response actions that should be undertaken are captured in Table 10a.

Table 10a: State Agency Drought Response Actions during a Level 1 Mild Drought

Action Category	Response Actions	Responsible Agencies
LEVEL 1, MILD DROUGHT		
Data gathering, analysis, and reporting	• Review data and calculate six drought indices; report on the severity of conditions for each index. • Prepare and distribute monthly summary of hydrologic conditions (Current Water Conditions in Massachusetts) to Water Resources Commission and DMTF. • Monitor Drought Impact Reporter for public reporting of drought impacts (e.g., to agriculture, private water supplies, fisheries, wildlife, and the environment).	DCR
	• Gather information and report on the status of drinking water supplies.	MassDEP
	• Gather information and report on impacts to agriculture.	DAR
	• Gather information and report on impacts to fisheries and wildlife.	DFG
Coordination	• Convene monthly meetings of DMTF. Members report on affected resources and user groups.	EEA, MEMA
	• Assess conditions to determine drought level in each drought region. Recommend regional drought-level declarations to EEA Secretary.	DMTF

Action Category	Response Actions	Responsible Agencies
Water Conservation	• Continue to implement the standards and recommendations of the *Massachusetts Water Conservation Standards* at state facilities. • Implement the Massachusetts drought management nonessential outdoor water-use restrictions (see Table 9). • Apply the drought management nonessential outdoor water-use restrictions (Table 9, level 1) to all state entities and publicize them for all Commonwealth users. • Work with local governments to support implementation of Level 1 nonessential outdoor watering restrictions, if not already in place. • Advise self-supplied users, including private well users, to follow Level 1 nonessential outdoor water-use restrictions.	All agencies
Communication and Public Outreach	• Prepare memorandum on status of situation for Governor's Office, EEA Secretary, Secretary of Public Safety and Security, and other agencies, as needed. • Implement communications strategy to inform the public about drought conditions, raise awareness about the importance of using water wisely, and strategies for reducing water use. • In coordination with the Governor's Press Office, issue statewide news release and targeted news releases in impacted geographic regions.	EEA
	• Provide updates, as needed, to the state drought status website.	DCR
	• Communicate drought status and recommended actions to stakeholders, including municipalities, water suppliers, agricultural interests, Boards of Health, nonprofit organizations, and wildland fire officials.	All agencies
Technical Assistance	• Host (in coordination with regional planning agencies) regional drought education workshops to guide community drought response efforts.	EEA
	• Continue assistance to communities on implementing the *Massachusetts Water Conservation Standards* and statewide guidance on nonessential outdoor water-use restrictions during a drought (see Table 9).	MassDEP, DCR
Financial Assistance	• Develop recommendations for special legislation and/or state funding to address drought. • Review and confirm potential new options for federal financial assistance for drought.	MEMA, EEA, DAR
Policy and Regulatory	• Issue reminders to water suppliers with permits under the Water Management Act, and approvals under the Interbasin Transfer Act to adhere to regulatory conditions related to drought.	MassDEP, WRC

7.2.3 Level 2- Significant Drought

At Drought Level 2, conditions are becoming significantly dry. Emphasis continues to be on conservation, and more stringent watering restrictions may be imposed by water service providers. Table 10b outlines key actions that should be undertaken.

Table 10b: State Agency Drought Response Actions during a Level 2 Significant Drought

Action Category	Response Actions	Responsible Agencies
LEVEL 2, SIGNIFICANT DROUGHT		
Data gathering, analysis, and reporting	• Continue data gathering, analysis, and reporting activities of Level 1. • Assess vulnerability of water supplies and environmental resources.	All agencies
Coordination	• Continue coordination activities of Level 1.	All agencies
	• Host conference call with all municipalities, water suppliers, local BOHs to provide consistent information about the drought and mitigating actions.	MEMA
	• Contact local Boards of Health to assess public health threats and impacts to private wells and take actions as needed.	DPH
	• Initiate contact and coordination with federal agencies.	EEA, DAR
Communication and Public Outreach	• Continue communication and outreach activities of Level 1.	All agencies
	• Provide content and issue press releases to advise the public of watering restrictions, encourage conservation, and provide updates on local water supply status specific to the community.	EEA, MassDEP
	• Utilize mass notification systems, social media platforms, state websites, and MassDOT billboards to advise the public of current conditions and general conservation measures.	MEMA and EEA
Water Conservation	• Continue water conservation activities of Level 1, including applying Level 2 nonessential outdoor water use restrictions (Table 9, level 2). • Work with local governments to support implementation of Level 2 nonessential outdoor watering restrictions. Advise self-supplied users, including private well users, to follow Level 2 nonessential water-use restrictions.	All agencies
Technical Assistance	• Continue technical assistance activities of Level 1.	All agencies
	• Offer technical assistance to communities on managing systems, including use of emergency connections to systems like the MWRA, and emergency supplies. • Conduct outreach to help ensure that PWSs know how to request a declaration of water supply emergency.	MassDEP, MEMA
	• Offer technical assistance to the agricultural community on water conservation measures.	DAR

Action Category	Response Actions	Responsible Agencies
	• Offer assistance to Boards of Health on addressing private well impacts and obtaining emergency water supplies.	DPH, MEMA
Financial Assistance	• Begin process to utilize federal assistance options.	MEMA, EEA, DAR
Policy and Regulatory	• Continue policy and regulatory activities of Level 1.	MassDEP

7.2.4 Level 3- Critical Drought

At Drought Level 3, many sectors, community functions, and environmental resources are facing critical strain. At this stage, there is an increased reliance on mandatory conservation measures to augment voluntary measures. Coordination efforts are expanded to include neighboring states, and preparations begin for emergency conditions. Table 10c outlines key state actions that should be undertaken.

Table 10c: State Agency Drought Response Actions during a Level 3 Critical Drought

Action Category	Response Actions	Responsible Agencies
LEVEL 3, CRITICAL DROUGHT		
Data gathering, analysis, and reporting	• Continue data gathering, analysis, and reporting activities of Levels 1 and 2.	All agencies
	• Review information on availability and use of emergency sources of water.	DMTF
Coordination	• Continue coordination activities of Levels 1 and 2.	All agencies
	• Initiate contact and planning with New England states and New York regarding drought coordination and response.	MEMA, EEA
	• Communicate and coordinate with the Governor's Office on drought conditions and agency response and responsibilities on a weekly basis.	EEA
Communication and Public Outreach	• Continue communication and public outreach activities of Levels 1 and 2.	All agencies
	• Prepare/Draft Governor's Proclamation of a State of Emergency.	MEMA, EEA
	• Connect with local Boards of Health on the drought and to assess any local impacts to private wells.	DPH

Action Category	Response Actions	Responsible Agencies
Water Conservation	• Continue water conservation activities of Levels 1 and 2, including applying the next level of nonessential outdoor water use restrictions (Table 9, level 3). • Advise local governments to implement Level 3 watering restrictions, including bans on all nonessential outdoor uses[17]. • Work with self-supplied users, including private well users, to follow Level 3 nonessential outdoor water-use restrictions. • Advise public water systems and self-supplied water users to minimize and/or eliminate nonessential flushing of water lines. • Work with the public sector and the Industrial-Commercial-Institutional sectors to reduce overall water use. • Explore the need to reduce essential water use in target areas.	All agencies
Technical Assistance	• Continue technical assistance activities of Levels 1 and 2.	All agencies
	• As requested, provide assistance to communities seeking alternative or temporary water supplies information about water vendors and supplies on state contract for procurement of water, establishment and operation of Commodity Points of Distribution for distribution of bottled water; prepare for emergency response where risk of water supply loss exists.	MassDEP, MEMA
Financial Assistance	• Coordinate with federal government agencies to request federal assistance.	MEMA, EEA, DAR
Policy and Regulatory	• Continue policy and regulatory activities of Level 1 and 2.	MassDEP
	• The Department of Fire Services and DCR may declare open burning bans in wildfire-susceptible areas of the Commonwealth.	DFS, DCR

7.2.5 Level 4- Emergency Drought

At the Emergency Drought Level 4, the state may face failure of local or regional drinking water supplies, impairment or loss of supply for firefighting, major agricultural and business losses, and impairment or loss of critical natural resources. In this situation, the objective becomes to implement emergency response actions to protect public health and safety and critical environmental resources, and to minimize losses and damages resulting from drought. Key state actions that should be undertaken in an Emergency Drought are described in Table 10d. Specific emergency authorities and powers are further described in Section 10.

Table 10d: State Agency Drought Response Actions during a Level 4 Emergency Drought

Action Category	Response Actions	Responsible Agencies
LEVEL 4, EMERGENCY DROUGHT		
Data gathering, analysis, and reporting	• Continue data gathering, analysis, and reporting activities of Levels 1, 2, and 3.	All agencies
	• Provide a minimum of bi-weekly reports of drought conditions to EEA. Significant changes in drought conditions will be reported weekly.	DMTF
Coordination	• Continue coordination activities of Levels 1, 2, and 3.	All agencies
	• Update the Governor's Office on drought conditions and agency responses on a weekly basis.	EEA
	• As needed, confer with state agency partners and local authorities from impacted/threatened communities to determine what precautionary or protective measures need to be implemented to protect the health and safety of the general public. • As warranted, activate Regional Emergency Operations Centers (REOC) and/or the State Emergency Operations Center (SEOC) to coordinate state operations in support of affected communities and mobilize needed resources. • As needed, utilize WebEOC to provide continuous situational awareness. • As needed, issue emergency notification to local and state agencies and non-governmental organizations. • As needed, issue public warnings in accordance with the state's Alert and Warning Annex.	MEMA
Communication and Public Outreach	• Continue communication and public outreach activities of Levels 1, 2, and 3.	All agencies
	• Finalize Governor's Proclamation of a State of Emergency to use state emergency authorities and powers to restrict water uses and implement measures to provide emergency water supplies.	MEMA, EEA
	• Issue weekly press releases targeted to drought emergency areas and encourage local media outlets to publicize updates.	Governor's Office
	• Inform all local Boards of Health within the drought emergency area of the drought emergency status.	DPH
	• Inform all public water suppliers within the drought emergency area of the drought emergency status.	MassDEP

Action Category	Response Actions	Responsible Agencies
Water Conservation	• Continue water conservation activities of Levels 1, 2, and 3, including applying the next level of Nonessential Outdoor Water Use Restrictions (Table 10, level 4). • All agencies and institutions will implement drought water conservation and contingency plans with the goal of reducing water usage by at least 15% and on a continued graduated basis as conditions worsen. • All self-supplied users, including private well users, implement mandatory nonessential water use restrictions. • All public water systems and self-supplied water users eliminate nonessential flushing of water lines. • Implement reductions of essential water use to the extent feasible.	All agencies
Technical Assistance	• Continue technical assistance activities of Levels 1, 2, and 3. • Work with communities to establish and enable emergency water supply connections to neighboring communities and regional systems such as the MWRA.	All agencies
Financial Assistance	• Work to secure state/federal emergency funding and/or legislation.	EEA, MEMA, DAR, MassDEP
Policy and Regulatory	• Continue policy and regulatory activities of Levels 1, 2, and 3.	MassDEP
	• For the duration of the declared drought emergency, the Department of Fire Services shall be authorized to declare open burning bans in wildfire-susceptible areas of the Commonwealth.	DFS, DCR
	• For the duration of the declared drought emergency, the Department of Transportation shall be authorized to grant temporary overweight/overwidth/registration/license exemptions to carriers transporting essential emergency relief supplies into and through the Commonwealth in order to support the disaster response and recovery.	MassDOT

Section 8: Drought Preparedness and Response Actions – Guidance for Communities

8.1 Community Drought Preparedness Actions

Everyone has a role in preparing for and responding to a drought. This section identifies key actions that can be taken at the local level before a drought (to prepare) and during a drought (to respond), along with resources to implement key actions.

The primary audience for this section is municipalities and/or public water systems. A secondary audience includes partners that can support and assist with implementation, including environmental groups, concerned citizens, and local boards such as the planning board, conservation commission, and town select board or city council. At the local and regional level, water suppliers will remain responsible for ensuring that water supplies are adequate to maintain public health and safety. Local governments and water suppliers should monitor their situation closely to ensure that mitigation measures undertaken are sufficient to prevent the loss or failure of water supplies. In the event that loss of supply occurs or is forecast, water suppliers should follow the steps in their Emergency Response and Contingency Plan as required by MassDEP. Depending on circumstances, it may be necessary to impose comprehensive and closely monitored watering restrictions, allocate water on a per capita basis, or seek use of alternative water supplies.

Planning is the key word. One of the most important actions a community can take to prepare for a drought is to develop a local drought plan to guide actions before, during, and after a drought. A critical companion to the local drought plan is a Water Conservation Program, which will help conserve water at all times, but especially during a drought. The Water Conservation Program should be developed before the local drought plan because it will inform the plan. Each of these requires significant effort to develop and establish. When the next drought is experienced, appropriate tools and programs will be in place to respond without delay and minimize impacts and disruptions to municipal services, businesses, and residents.

Below is a brief introduction to important components of a Water Conservation Program and a Drought Management Plan, along with resources for additional guidance.

8.1.1 Develop a Water Conservation Program

Establishing a year-round Water Conservation Program should be thought of as part of drought management planning. Water conservation is one of the most important tools for both preparing for and responding to a drought. Year-round water conservation, including public education and communication, will help reduce baseline demand. This reduction may lead to greater water supply reserves, creating greater resilience during droughts. A Water Conservation Program also establishes channels of communication with the public, which can be used during a drought.

The *Massachusetts Water Conservation Standards* (MA WCS, updated in 2018) provide a broad overview of key water conservation actions for the many types of water users in the state. Highlighted below are five of the most important actions municipalities and water suppliers should include in a Water Conservation Program to support drought preparedness and response.

1. Collect, Manage, and Analyze Water Usage Data

An important first step in determining where water conservation efforts and resources should be directed is collecting and analyzing water usage data. Although the specific analyses might vary by community depending on such factors as the level of technology used for metering and customer base composition, the goal should be to use water use data to identify and prioritize community-

specific water conservation needs. Even basic analyses can help explain overall and seasonal water use patterns, such as long-term consumption trends, percent of water used by each sector (i.e. single-family residential, multi-family, commercial, irrigation, municipal), determining the top 10% of water users and total water used by the top the 10%, and summer/winter water use ratios. Detailed guidance on collecting/analyzing water usage data is included in the data analysis workbook located at https://www.mass.gov/doc/collecting-managing-and-analyzing-water-usage-data.

2. Implement an Outdoor Water Use Program

Note: Please work with your local planning board and other appropriate local authorities to review the options and ideas presented here and in Chapter 9 and Appendices B, E, H, I, and J of the MA WCS.

Authority: The first step of an outdoor water use program should be to establish legal authority to limit nonessential outdoor water use. Nonessential outdoor watering is defined by MassDEP as uses not required by regulation, for health or safety reasons, for production of food and fiber, for maintenance of livestock, or to meet the core functions of a business (for example, irrigation by plant nurseries as necessary to maintain stock). Whether through a bylaw, ordinance or other mechanism, establishing authority can take time, so it is important to complete this step prior to the start of a drought. See MassDEP's Model Outdoor Water Use By-Law/Ordinance at https://www.mass.gov/service-details/model-water-use-restriction-bylawordinance-update.

Irrigation System Efficiency: The outdoor water use program should address the use and efficiency of irrigation systems if applicable to a community. A key factor in improving efficiency is proper design, installation and auditing by professionals holding the appropriate certifications (by nationally recognized certification programs, such as EPA WaterSense-labeled certification programs). In addition, some municipalities have chosen not to allow the installation of new irrigation systems. See MA WCS Chapter 9 and Appendix I for more information.

Land Use Planning: The outdoor water use program should support land use planning and landscaping that minimizes water use and mimics the natural hydrological cycle. Urbanization and impervious surfaces reduce the capacity of the land to infiltrate water. Therefore, reducing effective imperviousness of land and employing low impact development techniques in all new development and redevelopment, preserving natural vegetation, and using native plants all help in increasing recharge and minimizing the impacts of droughts. There are bylaws, ordinances, policies or regulations that can encourage or require development and landscaping that minimize site alterations and preserve or restore healthy soils and plant communities appropriate to the Massachusetts climate. Please work with your local planning board and other appropriate local authorities to review the options and ideas presented in Chapter 9 and Appendices B and H of the MA WCS. For additional guidance on incorporating water conservation into land use planning, visit https://www.mass.gov/guides/planners-conservation-commissions-land-use-boards.

3. Implement an Indoor Water Use Program

The scope of an indoor program will be specific to circumstances in each community but focusing on high-efficiency plumbing products and appliances is likely to achieve significant water and energy

savings. Toilets, showers, and faucets alone make up 62% of indoor use. The Environmental Protection Agency's WaterSense program labels products and services using rigorous water efficiency, performance, and testing requirements. Addressing indoor water leaks can also lead to significant water savings. Therefore, notifying water users of possible leaks and/or higher than expected use should also be incorporated into the indoor water use program. See Chapter 5 and Appendices A, C, D, and E of the MA WCS for more information on how to encourage greater indoor efficiencies by end users. Additional guidance for indoor water conservation can be found at https://www.mass.gov/guides/indoor-water-conservation.

4. Implement a Water Loss Control Program

System efficiency is always important, but especially so during a drought. A water loss control program ensures that water entering a distribution system is efficiently delivered to each point of use. Water loss control measures typically fall into two categories: 1) accounting for the water distributed in the system with accurate and comprehensive metering and record-keeping, and 2) managing the infrastructure to prevent the physical loss of water. Developing a Water Loss Control Program takes time, and system managers must continually evaluate measures of their effectiveness and make adjustments as needed. Therefore, it is important to establish such a program before the onset of a drought. See Chapters 2 and 3 of the MA WCS for more information.

5. Enhance Revenue Resilience and Provide Incentives for Water Efficiency through Effective Water Rates

Developing an effective price signal can be challenging but is worthwhile, because the price of water is an important driver of water conservation behavior. More discretionary uses of water (such as lawn watering and car washing) are the most responsive to price signals. A variety of water rate structures exist that encourage conservation and efficient use year-round as well as additional conservation during drought. Additionally, best practices in billing can encourage conservation. Protecting stability of revenue streams is critical when price signals and other policies are effective at driving down demand. Rate strategies should be employed that ensure sufficient revenue in the face of both short and long-term anticipated reductions in demand. Many rate strategies are able to achieve revenue stability and water conservation goals at the same time. See the MA Water Conservation Toolkit guidance on water pricing for more information on these rates and strategies and links to additional resources (https://www.mass.gov/guides/water-pricing).

8.1.2 Develop a Local Public Water Supply Drought Management Plan

A local public water supply drought management plan will strengthen a community's ability to provide enough water during a drought. A DMP will outline key actions to be taken in preparation for and during a drought and identify who is responsible for coordinating and implementing the actions. Multiple levels of drought should be defined in the DMP to reflect increasingly severe conditions. Each drought level can then be assigned escalating levels of actions that are appropriate to each drought level. The following summary of planning steps was adapted from the American Water Works Association's 2011 *Drought Preparedness and Response Manual of Water Supply Practices*

M60. It gives a snapshot of the process, but those developing a plan should review the full M60 manual and other available guidance referenced in this section for explanations and details.

1. Form a drought response team and establish coordination and communication strategies

This step involves forming a team and establishing priority objectives and a schedule for completing the plan. The team should outline coordination and communication plans within and between municipal departments, with the community, and among all relevant partner agencies and organizations.

Team Members: M60 notes that every department of the utility will be involved in developing and implementing the plan. In smaller systems, this may mean only one or two people do all the work. In medium to large systems, the team members will likely include multiple departments (such as the General Manager, Administration, Billing, Customer Service, legal staff, etc.). In addition, other municipal departments should generally also be included, such as Finance, Public Works, Fire, Health and Human Services, Emergency Management, Board of Health, Parks and Recreation, Conservation Commission, and Planning.

Schedule: M60 includes a detailed plan development schedule that can be used to set completion dates for each plan element. It also notes that plan development typically takes three to six months of dedicated effort.

Coordination and Communication: M60 emphasizes that a good plan is contingent upon internal and external coordination and communication and highlights items for the team to consider, such as:

1. Establish a community advisory committee.
2. If the water supplier is a city or town, include coordination actions with departments such as parks, fire, and the office of emergency services.
3. Identify external partners, such as state agencies and local watershed groups, and include coordination and communication with them.
4. Establish a public communication program.

2. Forecast Supply in Relation to Demand

The goal of this step is to develop a reasonable estimate of how much water will be available under various shortage conditions, including multi-year droughts. This step involves supply and demand data collection and analyses, looking ahead to any projected changes in supply or demand, and conducting analyses to help identify and quantify potential supply shortfalls under various scenarios of drought and supply interruptions. M60 notes that projections based on historical data may not be sufficiently protective and suggests adding an uncertainty factor. For example, planning for the drought of record may no longer be sufficient, given the possibility of back-to-back drought periods that do not allow time to replenish regular and emergency supplies.

3. Assess Options for Balancing Supply and Demand

This step focuses on two general types of drought mitigation options: reducing customer demand and augmenting supply. It involves identifying a range of demand reduction and supply augmentation options to address shortage scenarios.

Demand Reduction: Ideally, a demand reduction program during a drought will draw on tools, programs, and experience developed through an existing year-round Water Conservation Program, which is described above in section 8.1.1. Demand reduction actions during a drought should be intensified as drought levels increase as part of a Staged Drought Response Program (see step 5). Numerous demand reduction examples are provided in M60 and the *Massachusetts Water Conservation Standards* ranging from conservation pricing to setting emergency rationing allocations. Here we highlight 11 actions that represent a range of options for inclusion in a Staged Demand Reduction Program. Some of these actions represent good practices for water conservation every day and could be part of the year-round Water Conservation Program. However, at a minimum, an appropriate combination of these actions should be implemented under drought conditions to address projected shortfalls. A community's choice of appropriate actions should always be guided by an assessment of their water use data to guide the most effective actions.

1. Adopt and implement the state's nonessential outdoor water use restrictions as outlined in Table 10 or a more updated version developed by EEA. Where appropriate and in response to local supply conditions, local governments may impose restrictions more stringent than these.
2. Communicate need for and importance of drought response actions (e.g., to ensure adequate water for fire protection, drinking water, and natural habitats). Evaluate and utilize all appropriate means of communication.
3. Limit or prohibit: installation of new sod, seeding, and/or landscaping; watering during or within 48 hours after measurable rainfall; washing of hard surfaces (sidewalks, patios, driveways, siding); personal vehicle or boat washing; operation of non-recirculating fountains; filling of swimming pools, hot tubs, and backyard informal rinks.
4. Promote or offer loans or rebates for removal of high-water-use plants and sod, and replacement with less water-intensive vegetation.
5. Provide incentives for installing efficient irrigation technologies.
6. Provide assistance with installation of water-efficient fixtures and appliances, and leak repair.
7. Implement or increase incentives for indoor and/or outdoor water audits.
8. Implement drought surcharge or seasonal water rates.
9. Establish water-use reduction targets for all water users.
10. Identify top water users and conduct targeted outreach to help curb their use.
11. Enforce water-use restrictions with increasingly stringent penalties.

Supply Augmentation: M60 classifies methods of supply augmentation into three groups:

1. Your Sources: increase existing supplies, draw from reserve supplies, or develop new supplies for redundancy and/or to serve as a backup during drought;
2. Efficiency: increase supplier water use efficiency through a water loss control program; and
3. Other Sources: cooperate with other agencies (water purchases, transfers, and interconnections to supplement local supplies and/or provide for emergency connections).

Examples within each group are provided in M60, along with the guidance that even minimal supply augmentation programs, while they may be difficult and time consuming to establish, have been helpful in water-shortage situations.

4. Establish Triggering Levels

This step identifies the specific conditions that will trigger each of the local drought stages. First, the number of drought levels must be chosen. DMPs often have three to five drought stages that reflect the severity of conditions and associated actions. The number of drought stages will depend on a number of factors, such as the number of times different actions or different levels of actions are desired in response to worsening conditions. However, there should not be so many drought stages that they change too frequently for actions to be adjusted by municipal staff and the public. Once the number of stages is decided, setting triggers for each would include:

1. Identifying indicators for drought conditions (e.g., precipitation, groundwater depths, reservoir levels, streamflow);
2. Determining values for each indicator that define increasing levels of drought; and
3. Establishing a monitoring plan for the indicators including potentially increasing frequency of monitoring during a drought.

In addition to reviewing M60, please follow Massachusetts-specific guidance for Public Water Suppliers presented in Appendix I.

5. Develop a Staged Drought Response

In this step, each drought stage is assigned response actions. Specifically, the plan should establish water savings goals for each drought stage tied to the anticipated supply shortfalls, and identify actions that will achieve those savings. Information from Steps 3 and 4 will inform the actions and the levels of the actions that are necessary for each drought stage. The example in Table 12 shows how coordination, demand reduction, supply augmentation, and communication actions could be organized in an overall staged response matrix in your plan. A complete drought response matrix would include additional actions for each category.

6. Adopt the Plan

The adoption of the plan should formalize all plan elements and cooperative arrangements. This step includes engaging the community, preparing a revenue management program, formalizing cooperative agreements, and reviewing and finalizing the plan.

Engage the Community: M60 emphasizes that involvement of customers is critical to create a program that the community understands, contributes to, and supports. Opportunities to engage should include presenting a draft plan at several community forums and making the plan available for public review.

Prepare a Revenue Management Program: Reduction in water use can result in a revenue shortfall if your rates and budget do not have a mechanism to minimize or avoid such shortfall. Therefore, it is important to include financial planning as part of developing your drought plan. M60 describes several ways of balancing costs and revenues, including modifying water rates, adding a water shortage surcharge, and tapping financial reserves (such as those in a general or water revenue fund or a water shortage emergency account). M60 Table 6-2 shows an example budget worksheet projecting the financial effects of four stages of a drought program and discusses options for keeping the budget balanced.

Formalize Cooperative Agreements: This step includes adopting any draft ordinances or interagency/inter-municipal agreements that are part of your plan. Confirming agreements can take time, so it is best done in advance to enable rapid response during an emergency.

Review and Finalize Plan: M60 strongly recommends that the plan be subjected to a formal public review process to help minimize future objections when mandatory provisions are needed. This should include several public meetings following sufficient public notice.

7. Implement the Plan

At this point, all staffing needs, budget, and funding considerations should be resolved. M60 provides several helpful checklists that outline categories of resources needed for implementation (such as office space, staff levels and budget, and customer assistance) and provides an example of specific drought implementation program needs for a community of 75,000 people.

Once the plan is adopted, it should be periodically reviewed to ensure that it meets its objectives. In addition, review should be completed if significant changes occur (e.g., in demand, supply, operations) or results during a drought are not satisfactory.

8.2 Community Drought Response Actions

Local authorities that may be involved in drought management include municipal governments, water suppliers, local public safety, local and regional health authorities, local planning boards and conservation commissions, Tribal Councils, and other regional agencies with responsibilities for water. During a drought, the general roles and responsibilities of local authorities may include the following:

- Gathering available drought information for the community and identifying information gaps
- Identifying vulnerable aquatic ecosystems
- Implementing the local drought plan (Section 8.1.2), and the water conservation program (Section 8.1.1)
- Managing community water supplies
- Providing timely information to the public about water supplies, low stream flows, projected flow levels without water conservation efforts, public health risks, and drought conditions
- Communicating with the appropriate state agencies in the coordination of drought response
- Coordinating with local water agencies/suppliers to ensure local systems can provide water sufficiently to meet public health and safety needs
- Establishing MOUs or emergency contracts for potable drinking water, as needed.
- Imposing water restrictions and other measures early so that serious deficits, pressure problems, environmental impacts, or water quality issues are avoided to the greatest extent possible.

Table 11: Example Staged Drought Response Matrix*

		STATE DROUGHT LEVEL and DESCRIPTION			
	ACTIONS	Level 1: MILD DROUGHT	Level 2: SIGNIFICANT DROUGHT	Level 3: CRITICAL DROUGHT	Level 4: EMERGENCY DROUGHT
	Reservoir Trigger(s)	Fill in if using local reservoir triggers for staged drought response			
ACTION CATEGORY	Groundwater Trigger(s)	Fill in if using local groundwater triggers for staged drought response			
Coordination	Drought Management Team (DMT)	Convene Monthly DMT Meetings	Biweekly or weekly DMT Meetings	Weekly or Daily DMT Meetings	Daily DMT Meetings
Demand Management	Nonessential Outdoor Watering	1 day per week watering, before 9 am and after 5 pm.	Hand-held watering only, before 9 am and after 5pm	No nonessential outdoor water use	No nonessential outdoor water use
	New sod, seeding, and landscaping	Follow best management practices for efficient watering.	Installation of new sod, seeding, and landscaping is discouraged	Installation of new sod, seeding, and landscaping is strongly discouraged.	Installation of new sod, seeding, and landscaping is prohibited.
	Water Savings Goal	reduce use by __%	reduce use by __%	reduce use by __%	reduce use by __%
Water Supply Augmentation	Interconnections/Backup and Emergency Supplies	Review/test backup supplies	Prepare for/ possible activation of backup supplies	Possible activation of backup supplies	Activate backup supplies
Communication	Website/Press/Social Media	Update website and social media with latest information on drought status and restrictions/tips	Weekly Tweets on Water Conservation	Press Events and Weekly or Daily Social Media Updates	Daily Communication using all tools

**A complete drought response matrix would include additional actions for each category*

8.2.1 Local or Regional Water Agencies/Suppliers

- In conjunction with MassDEP and DPU, manage systems to ensure that they can provide water sufficiently to meet public health and safety needs.
- Systems (like the Massachusetts Water Resources Authority (MWRA) water supply system), which serve areas outside their watersheds, may assess their water supply conditions and initiate their own plan based on the capacities of their system, in addition to the regional indices.
- Implement up-to-date emergency response plans.

- Educate the public and elected officials on the need to impose water restrictions and other measures early so that serious deficits, pressure problems, environmental damage, or water quality issues are avoided to the greatest extent possible.
- During dry conditions, coordinate with local government to request mandatory or voluntary reductions in water use and/or declare a local water emergency (either under local bylaw or through petition to the MassDEP) based on the status of local water supplies.

8.2.2 Local Public Health and Safety Agencies

- Coordinate with other members of local government to provide timely information to the public about water supplies, public health risks, water conservation efforts, and drought.
- Communicate with self-supplied households on the status of their water systems and provide technical assistance as needed.
- Communicate with the appropriate state agencies in the coordination of drought response.
- Provide technical assistance as needed.
- Coordinate with local water agencies/suppliers to ensure local systems can provide water sufficiently to meet public health and safety needs.
- Establish MOUs or emergency contracts for potable drinking water, as needed.

Section 9: Post-Drought Actions

Following the end of a drought, emphasis should shift to maintaining the resources affected and to applying the lessons learned to improve long-term water sustainability. Tasks include the following:

- The DMTF recommends an end to existing drought recommendations and notes return to Normal Conditions, Level 0.
- The state continues to monitor hydrological conditions and maintains the long-term monitoring network.
- Water suppliers should restore operations and ensure that drought-driven system improvements and modifications are in compliance with relevant standards and regulations.
- State and federal data and information providers may review the effectiveness of systems to monitor and characterize stream flows, reservoir levels, and groundwater levels during the drought and implement any identified improvements.
- The Drought Management Mission Group, the DMTF, and other involved parties should hold an After Action Review to assess the equity, efficiency, and effectiveness of communications, information, actions, and monitoring that were undertaken. Lessons learned should be documented. This might result in recommended improvements to:
    - Local Drought Management Plans
    - Functions of the Drought Management Mission Group and the DMTF
    - The DMP
    - Other state policies, guidelines, and fact sheets
    - Amendments to state legislation and municipal bylaws
- All entities revisit water conservation strategies and reduction targets.
- All entities work to continuously improve water-use efficiency.

Section 10: Drought and Emergency Declarations: Legal Authorities and Powers

The following section discusses the local, state, and federal authorities and powers related to drought situations. This section provides a general summary of the laws applicable to drought issues. However, the appropriate legal staff should be consulted in advance of the use of any of these powers by a state agency or municipal government.

10.1 Local Government

Municipal governments are critically important to managing drought, assessing the impact of drought conditions, and using their authority to respond to the impacts.

- Municipalities are authorized to adopt and implement bylaws or ordinances in appropriate circumstances such as during a drought.
- Municipalities may regulate through such bylaws or ordinances the use of water from public or private water systems, including voluntary or mandatory water-use restrictions.
- When determined by MassDEP that an emergency exists in the case of a drought or disaster, a municipality may, following appropriate notice, regulate or otherwise restrain the use of water on public or private property (regardless of whether the supply source is public or private) pursuant to G.L. c. 40, § 41A, even in the absence of an established bylaw or ordinance. Additionally, once a state of water emergency is declared and MassDEP has approved a plan to address the emergency, the operator of the public water system may take by eminent domain the right to use any land for the time necessary to use water on the land for addressing the emergency. M.G.L. c. 21G, § 16. (See section 10.2.3 for more detail.)
- Municipalities, particularly those that experience chronic water shortages, are encouraged to promulgate bylaws or ordinances to address necessary rules for responding to an actual or threatened drought condition. A model water-use restriction bylaw is provided in Appendix G of the DMP.

In the event of a declared emergency, a municipality may, generally, raise, appropriate, and expend money for the purposes of maintaining, distributing, and providing at reasonable rates a sufficient supply of the common necessities of life, which include water.

10.2 State Government

The Commonwealth has several established authorities related to responding to drought conditions. The legislature has placed the primary statutory-based drought management authorities at the disposal of the Governor and the MassDEP.

10.2.1 Governor-Declared State of Emergency

Chapter 639 of the Acts of 1950, as amended by Chapter 425 of the Acts of 1958, (the “Civil Defense Act” or “CDA”) allows the Governor to proclaim a state of emergency to address certain conditions in all or in any part of the Commonwealth. When it may be reasonably anticipated that the health, safety, or property of the citizens will be endangered, the Governor may declare the existence of such an emergency situation due to a shortage of water resulting from an absence of rainfall or from the

occurrence of a disaster or catastrophe of natural causes. CDA, Section 5. A proclamation of such a state of emergency provides the Governor with expansive power, authority, and discretion to address and resolve the declared emergency.

During a state emergency, section 5(a) of the CDA authorizes the Governor to employ every agency and the members of every department to protect the lives and property of the citizens and to enforce the law. Under section 5(b) of the CDA, the Governor may, in the event of a disaster or shortage that makes such action necessary for the protection of the public, take possession of land and many types of personal property. The owner of any such property taken, however, is entitled to reasonable compensation for its value. Section 7 of the CDA allows the Governor "to exercise any and all authority over persons and property, necessary or expedient for meeting the state of emergency," including for example, policing, protecting or preserving all property, public or private. The Governor also has and can exercise authority over the "maintenance, extension or interconnection of services of public utility or public-service companies, including public utility services owned or operated by the commonwealth or any political subdivision thereof." This broad authority should provide the Governor the power to take necessary steps, such as restraining the use of water on private property, to address an actual or threatened drought.

In addressing threatened disaster such as a water shortage, pursuant to section 4 of the CDA, the Governor has the authority to cooperate with federal authorities and other states, propose a comprehensive plan and program, conduct studies and surveys, ascertain the capabilities of the Commonwealth, and delegate any such administrative authority provided to him under the Civil Defense Act. Finally, pursuant to Section 8 of the CDA, the Governor may exercise, any power conferred under the CDA, either under an actual proclamation of a state of emergency or in reasonable anticipation of such a proclamation, by issuing executive orders or promulgating regulations.

10.2.2 Massachusetts Emergency Management Agency

MEMA is responsible for direction and control of all state emergency operations as outlined in Chapter 639, Acts of 1950. The Massachusetts Comprehensive Emergency Management Plan (CEMP) is the framework for managing preparedness, response, recovery and mitigation actions at all levels of government in the Commonwealth. Utilizing the CEMP, MEMA coordinates state, federal, and private resources with regard to planning, response and recovery activities.

In the event a declaration of a state of emergency is warranted as a result of drought conditions, the CEMP is the framework for response and recovery actions. Executive Order 144 (issued in 1978 to facilitate planning for, and operations during disasters and emergencies) requires state agencies to designate liaison officers to MEMA for the purposes of coordinating resources, training, and operations. MEMA is authorized to deploy the resources which their organizations can provide to local governments during emergencies or disasters. A list of the agencies and their responsibilities is available in the CEMP.

10.2.3 Department of Environmental Protection

MassDEP's authority for addressing water supply shortage emergencies is derived from the Water Management Act, M.G.L. c. 21G, §§ 15-17, and from M.G.L. c. 111, § 160, related to ensuring the provision of safe drinking water.

Any operator of a public water system, such as a municipality, water company or other public agency, may petition MassDEP to declare a state of water emergency (M.G.L. c. 21G, § 15). In declaring such a state, MassDEP must find that "there exists or impends a water supply shortage of a dimension which endangers the public health, safety or welfare." MassDEP must limit the applicability of the state of water emergency to the petitioning municipality or to the area served by the petitioning public water supplier, whichever the case.

In declaring a state of water emergency, MassDEP may require the operator of the public water system to submit a plan, which must be approved by MassDEP, designed to address and resolve the emergency. This plan may include provisions for shutting off water on public or private property, and MassDEP may further require the following: (1) an approved water resources management plan; (2) a leak detection program; (3) a program for auditing water use; (4) a program for overall system rehabilitation; (5) conservation programs for public and private buildings; (6) bans or restrictions on certain water uses; (7) a moratorium on the issuance of building permits; (8) a plan for establishing priority for distribution of water among competing uses; and, (9) drought management or contingency plans.

Once a state of water emergency is declared and MassDEP has approved a plan to address the emergency, the operator of the public water system may take by eminent domain the right to use any land for the time necessary to use water on the land for addressing the emergency (M.G.L. c. 21G, § 16). In the case of a water emergency affecting the MWRA system, DCR, rather than MWRA, has such eminent domain authority. This eminent domain authority is narrower than that which the Governor may exercise following a declaration of a state of emergency under the Massachusetts Civil Defense Act (Chapter 639 of the Acts of 1950). Further, any such taking by eminent domain must be authorized by MassDEP and, except in the case of a private water company, the municipality in which the proposed taking will occur. Water companies must give notice to the affected municipality. During a state of water emergency, MassDEP may issue orders, applicable within or outside the affected area of the water emergency, to: (1) establish priorities for the distribution of any water or quantity of water use; (2) permit any person engaged in the operation of a water supply system to reduce or increase by a specified amount or to cease the distribution of that water; to distribute a specified amount of water to certain users as specified by the department; or to share any water with other water supply systems; (3) direct any person to reduce, by a specified volume, the withdrawal or use of any water; or to cease the withdrawal or use of any water; (4) require the implementation of specific water conservation measures; and, (5) mandate the denial, for the duration of the state of water emergency, of all applications for withdrawal permits within the areas of the Commonwealth to which the state of water emergency applies.

MassDEP is also granted broad powers to protect the public health through the oversight of water supplies as provided in M.G.L. c. 111, § 160. This section gives the Department the ability to "…make rules and regulations and issue such orders as in its opinion may be necessary to prevent the pollution and to secure the sanitary protection of all such waters used as sources of water supply and to ensure the delivery of a fit and pure water supply to all consumers." Violation of orders, rules or regulations made pursuant to this statute are punishable by either fines of up to $25,000 per day for each day a violation occurs or by imprisonment for not more than one year, or both; or by a civil penalty up to $25,000 per day for each day a violation occurs.

10.2.4 Massachusetts Water Resources Authority

The MWRA, which serves the water needs of many municipalities in the metropolitan Boston area, is generally authorized to develop programs, procedures and regulations for water conservation, leak detection and repair - M.G.L. c. 92 App., § 1-8(m) (1998). Such programs and regulations may also provide for "water use limitations in the time of drought or other emergency." With respect to water emergencies, MWRA and its communities have the power to provide connection and supply to adjoining communities under an order from MassDEP with appropriate compensation to MWRA - Section 8 (d). This is parallel to MassDEP's powers under c. 21G, but does not go beyond them. Further, in an emergency situation, MWRA is authorized to incur expenses in excess of those shown in its annual budget - M.G.L. c. 92 App., § 1-8(b) (1998).

The MWRA has developed a drought management plan for its system that is tailored to the capacity of its system. The MWRA has daily on-line tracking of its system, including reservoir levels and system demand, as well as sophisticated modeling ability to predict the ability of the MWRA system to meet short- and long-term demands. See the MWRA drought management plan for more details.

MWRA is charged with promoting water conservation, protecting the adequacy of a pure water supply and improving environmental quality under M.G.L. c. 92 § 8(e) and has general authority to promote leak detection and water conservation through its regulations, charges and other programs under Section 8(m). Section 8(m) specifically includes water use limitations in time of drought or other emergency.

10.2.5 Department of Public Health

The Department of Public Health (DPH) has broad authority over matters affecting public health and is mandated to "take cognizance of the interests of life, health, comfort and convenience among the citizens of the commonwealth" - M.G.L. c.111 § 5. DPH is specifically mandated to "conduct sanitary investigations and investigations as to the causes of disease…" - M.G.L. c. 111 § 5. With regard to water quality, MassDEP is required to report to DPH any violations of MassDEP regulations relating to drinking water quality standards and, based upon that report or upon its own investigation, DPH may order the appropriate party to cease violating the water quality standards and take whatever steps are necessary to purify the water. If any such order of DPH conflicts with any order of MassDEP, the order of DPH takes precedence - M.G.L. c. 111 § 160B. MassDEP regulations require MassDEP to

report to DPH all violations of MassDEP drinking water regulations and to consult with DPH with regard to enforcement actions taken to obtain compliance with MassDEP drinking water regulations 310 CMR 22.03(4).

In addition, pursuant to M.G.L. c. 111 §127A, DPH has promulgated State Sanitary Code Chapter II, entitled Minimum Standards of Fitness for Human Habitation, which requires all owners of residential dwellings to provide a potable water supply - 105 CMR 410.180. Local boards of health have primary authority to enforce the sanitary code requirements, but DPH may enforce these regulations if the local board of health fails to act.

10.2.6 Department of Public Utilities

The DPU's authority for addressing water supply emergencies is derived from M.G.L. c. 25, § 4B. Upon declaration of a state of emergency by the governor, the governor may authorize the chair of the DPU to take such action that the chair may consider necessary to assure public safety and welfare through the priority restoration or continuing availability of gas, electric, and water utility services. Under such authority, the chair may issue operational and management directives and order expenditures or other measures by any investor-owned utility that the chair considers necessary to respond to the state of emergency. Any orders issued by the chair shall expire within 30 business days unless ratified by the commission prior to the 30-day expiration; provided, however, that said ratification by the commission shall prescribe an end date for each order. Failure of any investor-owned utility to carry out an order by the chair authorized under this section shall be subject to investigation and a penalty of up to $1,000,000 per violation, with any such penalty levied to be returned to ratepayers through distribution rates.

Section 11: DMP Update and Maintenance

The DMP is considered a living document and may be updated and revised by EEA based on experiences, in particular after a significant drought, or every five years. Substantive changes may be made based on the approval of the DMTF, in consultation with MEMA, and with final approval of the WRC. Notices of substantive change will be distributed by EEA. Minor administrative updates may be made directly by staff between substantive review and approval processes.

The DMP will be posted with the Massachusetts Comprehensive Emergency Management Plan on the MEMA website and will help inform updates to the State Hazard Mitigation and Climate Adaptation Plan. The DMP will also be posted on the EEA website. If interested parties are unable to obtain the document from these websites, requests must be coordinated through EEA or MEMA.

Appendix A: Abbreviations

BOH	Board of Health
CDA	Civil Defense Act (Massachusetts; Acts of 1950, chapter 639)
CEMP	Comprehensive Emergency Management Plan
CMI	Crop Moisture Index
DAR	Department of Agricultural Resources (Massachusetts)
DCAMM	Division of Capital Asset Management and Maintenance (Massachusetts)
DCR	Department of Conservation and Recreation (Massachusetts)
DER	Division of Ecological Restoration
DFG	Department of Fish and Game (Massachusetts)
DFW	Division of Fisheries and Wildlife (Massachusetts)
DMP	Drought Management Plan (Massachusetts)
DMT	Drought Management Team
DMTF	Drought Management Task Force (Massachusetts)
DPH	Department of Public Health (Massachusetts)
DPU	Department of Public Utilities (Massachusetts)
DW	Drinking Water
EEA	Executive Office of Energy and Environmental Affairs (Massachusetts)
ERP	Emergency Response Plan
FIB	Fecal Indicator Bacteria
FSA	Farm Services Agency (USDA)
HHAN	Health and Homeland Alerting Network
ICS	Incident Command System
KBDI	Keetch-Byram Drought Index
MAESF	Massachusetts Emergency Support Function
MAHB	Massachusetts Association of Health Boards
MassDEP	Massachusetts Department of Environmental Protection
MassDOT	Massachusetts Department of Transportation
MA WCS	Massachusetts Water Conservation Standards
MAWARN	Massachusetts Water/Wastewater Agency Response Network

MEMA	Massachusetts Emergency Management Agency
MWRA	Massachusetts Water Resources Authority
MWWA	Massachusetts Water Works Association
NASA	National Aeronautics and Space Administration
NLDAS	North American Land Data Assimilation System
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
OWR	Office of Water Resources (Massachusetts Department of Conservation and Recreation)
POR	Period of Record
PSA	Public Service Announcement
PWS	Public Water Supplier
REOC	Regional Emergency Operations Centers
rgpcd	residential gallons per capita per day
SAS	Situational Awareness Statement
SEOC	State Emergency Operations Center (Massachusetts)
SPI	Standardized Precipitation Index
UMass Extension	University of Massachusetts, Amherst, partner in the national Cooperative Extension System
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USDM	U.S. Drought Monitor
USGS	United States Geological Survey
VMS	Variable Messages Signs
WCS	Water Conservation Standards (Massachusetts)
WebEOC	A web-based crisis management system supporting operations in an Emergency Operations Center
WMA	Water Management Act (Massachusetts General Laws, Chapter 21G)
WRC	Water Resources Commission (Massachusetts)

Appendix B: Drought Management Task Force Contact List[18]

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Appendix C: Additional Information about Drought Indices

This appendix outlines the 2017-2019 and the 2021-2022 processes of reexamining and revising the drought indices as part of the two DMP updates (in 2019 and 2023), and the resulting changes to the indices.

C.1 2017-2019 Revision Process and Resulting Changes

The DMP was created in 2001 and updated in 2013. The 2016-2017[19] drought was the most significant drought in recent history, and it was the first time a Warning level drought was reached since the creation of the Massachusetts DMP in 2001. During this drought, the DMTF, staff, and stakeholders identified several aspects of the 2013 DMP that needed further updates.

In the fall of 2017, an inter-agency technical workgroup was formed to address changes desired for the Drought Indices. DCR Office of Water Resources (OWR) staff served as technical leads for the group, which included the U.S. Geological Survey (USGS), the National Weather Service (NWS), EEA, and other EEA agency staff. The group met 10 times between December 2016 and April 2018. Staff briefed the DMTF and stakeholders on two occasions: they presented on the goals for the revision and results from preliminary analyses using the revised methods in July of 2017 and presented additional results and responses to comments in March 2018. Listening sessions were held with water suppliers (January 2017), Massachusetts River Alliance members (February 2017), and agricultural stakeholders (April 2017). Comments and input were received at meetings and through letters, email, and personal communication.

Revision of the Indices

Goals for revising the drought indices were to:

- Provide earlier warning of drought onset (e.g., in the 2013 DMP, multiple indices required two to three months to signal a Level 1 drought),
- Provide more accurate reflection of drought severity (e.g., in the 2013 DMP, the streamflow index was based on a count of months below the 25th percentile but did not consider whether those flows were 10th percentile or even record low flows),
- Include longer look-back periods for the precipitation index, to capture the cumulative effect of dry periods over multiple years, and
- Review regions and regional boundaries (e.g., make the Islands into their own drought region separate from Cape Cod, given the differences in impacts seen during the 2016-2017 drought).

[19] The 2016-2017 timeframe designation for this drought is based on when there were official drought declarations by the Secretary of EEA. There were, however, portions of the state that experienced dry conditions in 2015, and the U.S. Drought Monitor placed part or all of the state in level 1 drought status during different portions of 2015.

Index Selection

The indices revision started with a review of the indices used in the 2013 DMP and potential addition or elimination of indices. Of the seven original indices, there were two precipitation indices – standardized precipitation index (SPI) and percent of normal. This meant that the same data was used twice, calculated in two different ways. This resulted in applying more weight to precipitation than other indices. In the revised DMP, the SPI is retained as the single precipitation index. Percent of normal was dropped as a determining index, but will still be calculated and used as a tool to assist with communicating to the public. The DMTF felt that the public is accustomed to hearing about precipitation as a percent of normal.

The ***SPI*** was selected as the official index because it standardizes the measure of precipitation to a normal distribution allowing for a more intuitive sense of the deviation from average conditions and a simple translation to frequency. For example, precipitation in 1965 was the lowest annual precipitation year in the drought of record, which lasted from 1961 to 1969. Precipitation that year was "71% of normal," which does not convey the severity of the value; however, the SPI for that year was -2.06, which is equivalent to a 2-percentile event, which conveys the rarity and severity of the event. The translation to frequency is not only intuitively meaningful, but it aligns with the approach for other indices, as discussed below.

The 2019 revision of the DMP identified the ***Crop Moisture Index*** (CMI) as an index that needed replacement by another product that would more accurately capture the effect of temperature on evapotranspiration, which is especially relevant during the growing season with respect to water availability. Two limitations to the CMI were identified. First, the national maps use only three data points for Massachusetts. Also, the CMI was developed for the grain-producing regions of the central United States[20,21] which may not accurately reflect conditions in Massachusetts.

Initial research into possible sources of evapotranspiration data showed that although multiple sources are available[22], many are similar to CMI in that they use national datasets and models with little or no data from Massachusetts. A few promising indices were identified including the Standardized Precipitation Evapotranspiration Index (SPeI), which may be calculated at precipitation stations where temperature data are also available. Some other promising products are from the National Aeronautics and Space Administration (NASA) which combine satellite data with land-based data and modeling such as NASA's GRACE products[23] and North-American Land Data Assimilation System (NLDAS)[24]. A full analysis and testing of these various products are needed to determine which would be most appropriate for Massachusetts and could replace the CMI. Until further research and testing is completed on alternatives, the CMI is retained as the evapotranspiration index.

[20] http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/cdus/palmer_drought/wpdanote.shtml
[21] http://www.droughtmanagement.info/crop-moisture-index-cmi/
[22] https://www.drought.gov/drought/data-maps-tools/soil-moisture
[23] https://nasagrace.unl.edu/About.aspx
[24] https://ldas.gsfc.nasa.gov/nldas

The remaining indices – streamflow, reservoirs, groundwater, and fire danger – were retained from the 2013 DMP. "Reservoirs" was renamed to Lakes and Impoundments to more accurately reflect that the index's intent is to represent surface storage across multiple types of water bodies. As such, it is not meant to be an indicator of water supply capacity or sufficiency. The new name also more accurately reflects that the types of water bodies monitored for this index include both natural and human-made surface water bodies.

Method Development

The second part of the revision included looking at the methods used to calculate the indices and determine drought levels. Staff consulted with authors of the U.S. Drought Monitor (USDM) to learn about their methods. The USDM uses the frequency of occurrence of an event relative to all historical measured events expressed as percentiles to gage the severity of a measurement at individual stations and to gage the severity of overall drought. The interpretation is that less frequent events suggest more severe conditions that are farther from the usual "operating" conditions for the environment and infrastructure. As such, this approach allows for a more intuitive interpretation. The USGS also uses a frequency of occurrence approach to provide a sense of severity for streamflow and groundwater-level measurements relative to all historical measurements at a given station.

The USDM assigns percentile ranges to each drought level. For the 2019 DMP update, drought thresholds were adopted that use approximately the same values as the USDM, which split into four drought categories instead of the USDM's five. See the comparison table in Exhibit 1. The USDM and the Massachusetts DMP also use the respective percentile ranges in Exhibit 1 for categorizing the severity of individual drought indices. Although the USDM percentile thresholds are generally adopted in the current DMP, the USDM drought determinations are not themselves relied upon in lieu of this DMP because the USDM is a national-level product that does not consider all the locally available data, notably Massachusetts' extensive groundwater network, lakes and impoundments data, and local KBDI values.

In addition to allowing for a more intuitive interpretation, the frequency approach is robust against non-normal data distributions and outliers[25]. The values in the data set are ranked and assigned a specified percentile that reflects the percentage of the data points that lie below that value. The frequency approach does not use the actual values to make a calculation like taking the mean of values does. As a result, very high and very low values do not disproportionately impact the result. This is exemplified by considering daily streamflow values at a station gage. Streamflow data are not normally distributed because they contain infrequent but high values that occur during high precipitation events. As a result, the average can be skewed high and may not represent the "normal" or typical conditions. The typical condition is better approximated by the median or middle value of all measured values, also called the 50th percentile value. The 2013 DMP based the streamflow index on monthly averages of daily measurements at a gage. In light of the considerations described here,

[25] For example, the median (50th percentile) and interquartile range (the 75th and 25th quantiles) measure the central tendency and spread like the mean and standard deviation, respectively, but are robust against non-normal data and outliers.

the 2019 DMP uses the median of daily streamflow values to represent conditions for the month at a gage.

Exhibit 1. Comparison of Percentile Ranges for the Massachusetts DMP and the USDM

USDM Names	Recurrence	Percentile Ranges	MA DMP Levels	MA Percentile Ranges	MA DMP Names
D0: Abnormally Dry	once per 3 to 5 years	21 to 30	1	>20 and ≤30%	Mild Drought
D1: Moderate	once per 5 to 10 years	11 to 20	2	>10 and ≤20%	Significant Drought
D2: Severe Drought	once per 10 to 20 years	6 to 10	3	>2 and ≤10%	Critical Drought
D3: Extreme Drought	once per 20 to 50 years	3 to 5			
D4: Exceptional Drought	once per 50 to 100 years	0 to 2	4	≤2%	Emergency

The frequency of occurrence – or percentile – approach also allows for comparison of data across stations and even across indices. For example, the 25th percentile precipitation event in Boston and in Worcester may represent different values, but in the context of their respective historical records, the severity or "unusualness" of the event is the same. Similarly, a 25th percentile value at a precipitation station and a 25th percentile value at a groundwater well reflect comparable levels of rarity and severity.

Given these advantages, the current DMP applies the percentile approach to individual Indices, where possible (Precipitation, Streamflow, Groundwater, and Lakes and Impoundments), providing consistency and comparability across indices. In the 2013 DMP, the method for several of the indices set percentile or standard deviation thresholds that served simply to characterize conditions as "normal" or "below normal", but did not distinguish based on the degree to which a measurement was below normal. The 2019 DMP transitions to directly using percentiles to categorize the index severity level, allowing for a more complete understanding of the severity of conditions. Additionally, the 2013 DMP relied on a count of months "below normal" to signal the start and severity of droughts (e.g., streamflow must be below normal for 2 months before signaling level 1 severity). The 2019 DMP eliminates duration thresholds, allowing for a more direct representation of a given month's conditions and an earlier signaling of drought.

Exhibit 2 shows the index severity levels and the corresponding values for each index. Historical data are not available for the Fire Danger[26] and Evapotranspiration indices. Therefore, these two indices were not conducive to the percentile approach. The only change to these indices for the 2019 DMP is the creation of new thresholds that split apart Severity Levels 3 and 4. In the 2013 DMP, there was no distinction in value between these two drought severity levels for these two indices. The Chief Fire Warden for DCR was consulted for the new threshold for the Fire Danger Index. NOAA's NWS Climate Prediction Center's CMI explanation page was used to establish the new threshold for the CMI[27].

Exhibit 2. Table of Indices Values Corresponding to Index Severity Levels

Index Severity Level	Standardized Precipitation Index	Streamflow	Lakes and Impoundments	Groundwater	Keetch-Byram Drought Index	Crop Moisture Index
0	>30th percentile				< 200	> -1.0
1	≤30 and >20				200-400	≤-1.0 and > -2.0
2	≤20 and >10				400-600	≤-2.0 and < -3.0
3	≤10 and >2				600-700	≤ -3.0 and > -4.0
4	≤2				700-800	≤-4.0

Indices Testing

The third part of the revision was testing the new approach. The method was tested for individual indices on two drought regions – the Northeast and Southeast – and for overall drought determination in the Northeast Region.

Three indices (Precipitation, Streamflow, and Groundwater) were calculated monthly for each region using the proposed 2019 DMP methods. The period of record for these calculations started from the time when at least three stations had data available within a region and went through December 2016. The performance of these newly calculated indices was compared to the performance of the previous indices (DMP 2013) and assessed in the context of known droughts.

The percentile or frequency of occurrence approach, described above, was applied to individual stations for each of the three indices. Two options were tested for assigning a regional value for each index based on these individual station percentiles - using the 25th percentile and the 50th percentile of the individual station percentiles within the region[28].

[26] The indices workgroup considered the U.S. Forest Service's Wildland Fire Assessment System as a source of historical and ongoing KBDI values. However, that system relies on one station from the State which is spatially interpolated with stations in neighboring states. Due to this lack of spatial resolution, this source of data was not pursued.

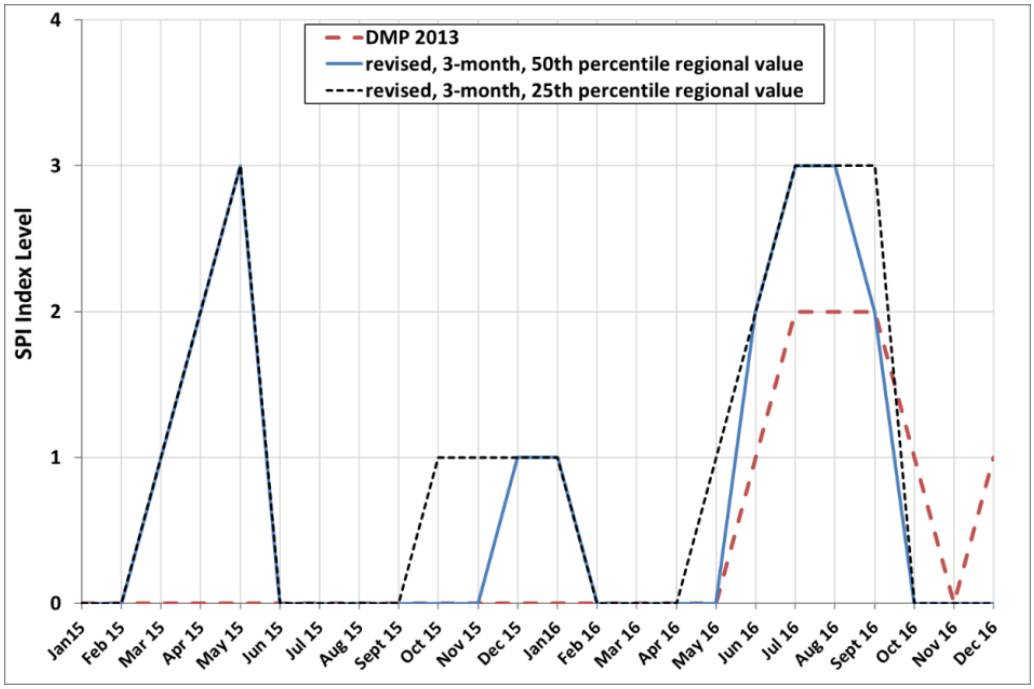
[27] http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/cdus/palmer_drought/wpdanote.shtml

[28] Note that in the case of the SPI precipitation index, the 2013 DMP method used an average of station values for calculating a regional value. For streamflow and groundwater, the 2013 DMP methods required that the majority of

Exhibits 3 to 5 below show the Index Severity Levels for the Northeast Drought Region during part of the 2016-2017 drought based on: the 2013 DMP methods; the revised methods using the 25th percentile of station percentiles as the regional value; and the revised methods using the 50th percentile of station percentiles as the regional value. The SPI for the revised methods in these exhibits reflects the highest severity level of all look-back periods. While the most recent drought is shown in the exhibits, other drought periods were examined including 1960s, 1980-1981, 2001-2002, 2010, and 2006-2007.

In general, the testing revealed that the revised indices provide an earlier signal of a drought onset and show severity more in line with observed conditions. Without a time delay built-in to the indices, the severity is not delayed or dampened as with the 2013 DMP method. This results in a more timely and accurate reflection of on-the-ground conditions. For example, the Streamflow Index signaling earlier and at higher levels for the 2016-2017 drought reflects the numerous 10th percentile and record low flows experienced during this time period. In comparing the 25th and 50th percentile as representative regional values, the 25th percentile signals earlier and at higher levels compared to the 50th percentile. See Exhibits 4 and 5.

Exhibit 3. SPI Index Severity Levels for the Northeast Drought Region, 2015-2016



stations in a region had to be below normal (i.e., less than 25th percentile) to count the month as below normal, and furthermore, required specific counts of months below normal before a severity level was reached.

Exhibit 4. Streamflow Index Severity Levels for the Northeast Drought Region, 2015-2016

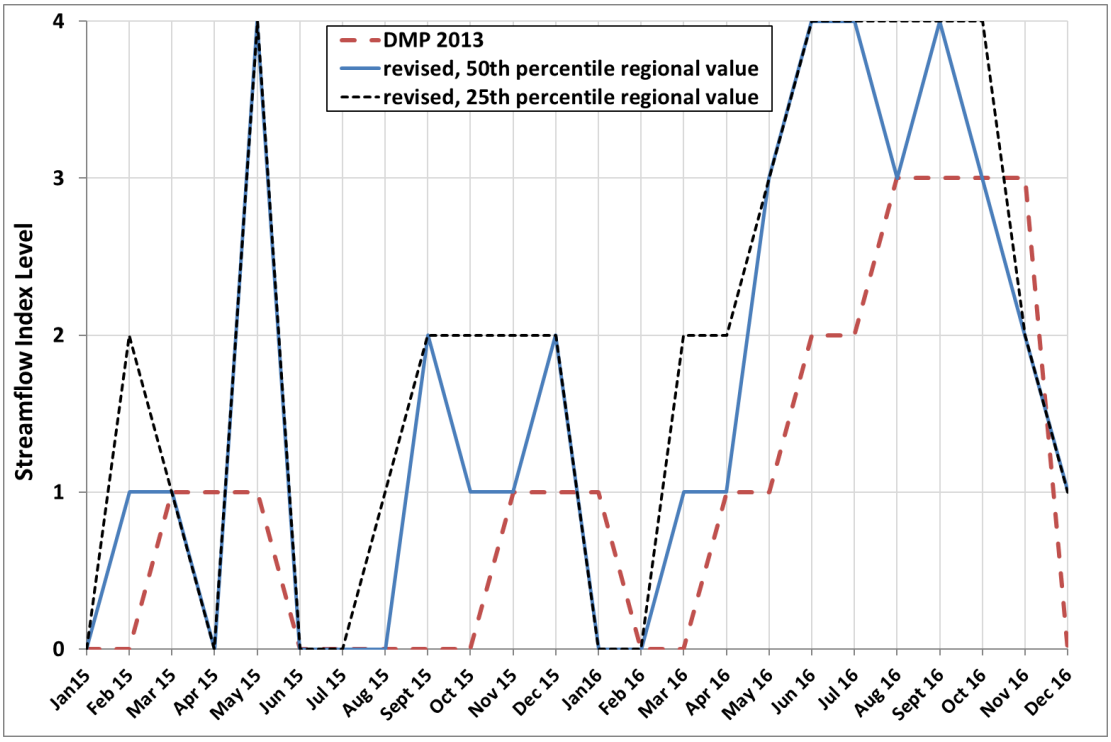
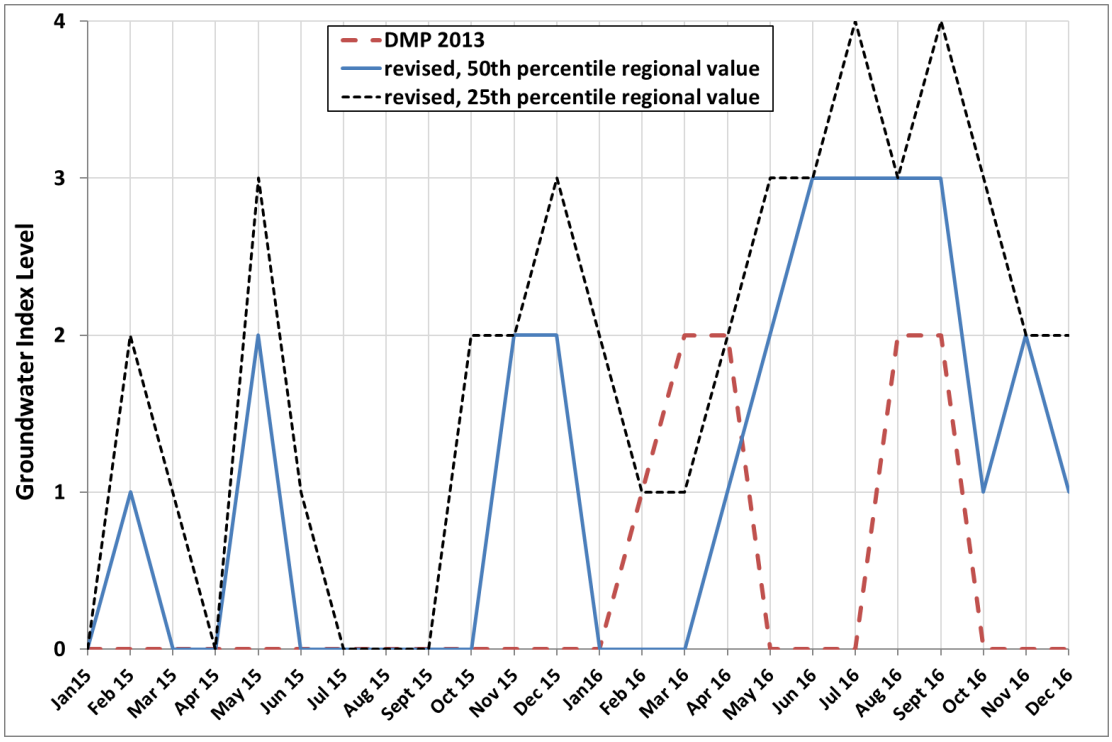


Exhibit 5. Groundwater Index Severity Levels for the Northeast Drought Region, 2015-2016



In addition to graphical analyses, the frequency of each severity level was calculated for the period of record for each method and compared to the target frequencies as shown in Exhibit 6. The exhibit shows the target percentiles that define each severity level and the corresponding percent of months over the period of record that would statistically be expected at each severity level. The revised methods with the 50th percentile as the regional value show the closest alignment with the target percentiles; therefore, the technical workgroup selected that approach to assigning a regional value based on individual station values. There is a significant improvement especially for the Groundwater Index when compared to the 2013 DMP method.

Exhibit 6. Percent of Months at Each Index Severity Level for the Northeast Region[29]

SPI	Target Percentile Range	Percent of Months over Period of Record (1900-2016)			
Index Severity Level		Target	2013 DMP	Revised method with 50th percentile as regional value, 3-month look-back	Revised method with 25th percentile as regional value, 3-month look-back
0	>30%	70	76	69	61
1	>20 and ≤30%	10	14	13	12
2	>10 and ≤20%	10	9	12	15
3	>2 and ≤10%	8	1	5	9
4	≤2%	2	<1	1	2

STREAMFLOW	Target Percentile Range	Percent of Months over Period of Record (1931-2016)			
Index Severity Level		Target	2013 DMP	Revised method with 50th percentile as regional value	Revised method with 25th percentile as regional value
0	>30%	70	79	70	61
1	>20 and ≤30%	10	11	10	12
2	>10 and ≤20%	10	5	11	13
3	>2 and ≤10%	8	4	8	11
4	≤2%	2	2	1	3

[29] Although Exhibit 6 shows only one look-back period for the SPI, the other look-back periods showed similar results.

GROUNDWATER	Target Percentile Range	Percent of Months over Period of Record (1957-2016)			
Index Severity Level		Target	2013 DMP	Revised method with 50th percentile as regional value	Revised method with 25th percentile as regional value
0	>30%	70	91	73	58
1	>20 and ≤30%	10	3	9	13
2	>10 and ≤20%	10	3	10	14
3	>2 and ≤10%	8	1	7	11
4	≤2%	2	2	1	4

Although we only present examples from the Northeast Region, the same patterns and results were seen for the Southeast Region.

SPI Look-Back Periods

The look-back periods used for the SPI were also evaluated. The 3-, 6-, and 12-month time periods were included in the 2013 DMP. For the revised DMP, the 2-, 9-, 24-, and 36-month look-back periods were added to provide a more refined assessment of shorter-term deficits and to capture the cumulative effect of dry periods over multiple years. An analysis of the 36-month look-back period suggested that time periods beyond the 24-month time frame do not provide additional drought signals at the Drought Region scale. However, based on recent research by Boutt showing a multi-year impact of precipitation in some wells (Weider and Boutt 2010, Boutt 2016, Boutt 2017[30]), the technical group suggested that the 36-month look-back period be retained until further research is conducted and experience is acquired.

The 2013 DMP based the SPI Index Level on the lowest percentile from among the look-back periods. This approach was tested for the 2019 DMP while also including the additional look-back periods. Exhibit 7 shows that always using the lowest percentile look-back period to drive the index would signal dry conditions more frequently than our target percentile range with the new method. The individual look-back periods, on the other hand, result in frequencies closely aligned with our target percentile ranges. Although Exhibit 7 shows only three look-back periods, the other look-back periods showed similar results. Instead of always using the driest look-back period to establish the index

[30] Weider, Kaitlyn & Boutt, David. (2010). Heterogeneous Water Table Response to Climate Revealed by 60 Years of Ground Water Data. Geophysical Research Letters - 37. DOI:10.1029/2010GL045561.

Boutt, David. (2016). Assessing Hydrogeologic Controls on Dynamic Groundwater Storage Using Long-Term Instrumental Records of Water Table Levels: Assessing Hydrogeologic Controls on Dynamic Groundwater Storage. Hydrological Processes- 31. DOI:10.1002/hyp.11119.

Boutt, David. (2017). Extreme Precipitation Events and Subsurface Water Storage Dynamics of Glaciated Landscapes. GSA Annual Meeting in Seattle, Washington, USA – 2017. DOI:10.1130/abs/2017AM-307912.

severity level, all look-back periods will be presented as a table to the DMTF under the 2019 DMP. This will provide a sense of the severity at various time scales and the progression or changes in dry conditions through time. The DMTF will use this broad range of data to select the most relevant look-back period to drive the Precipitation Index severity level.

Exhibit 7. Comparison of Different Look-Back Periods for SPI Applying 2019 DMP Methods to the Northeast Drought Region

SPI Index Severity Level	Target Percentile Range	Percent of Months over Period Of Record				
		Target	Worst of Look-Backs	3 month	6 month	12 month
0	>30%	70	37	69	70	72
1	>20 and ≤30%	10	17	13	11	10
2	>10 and ≤20%	10	24	12	12	10
3	>2 and ≤10%	8	17	5	7	7
4	≤2%	2	5	1	1	1

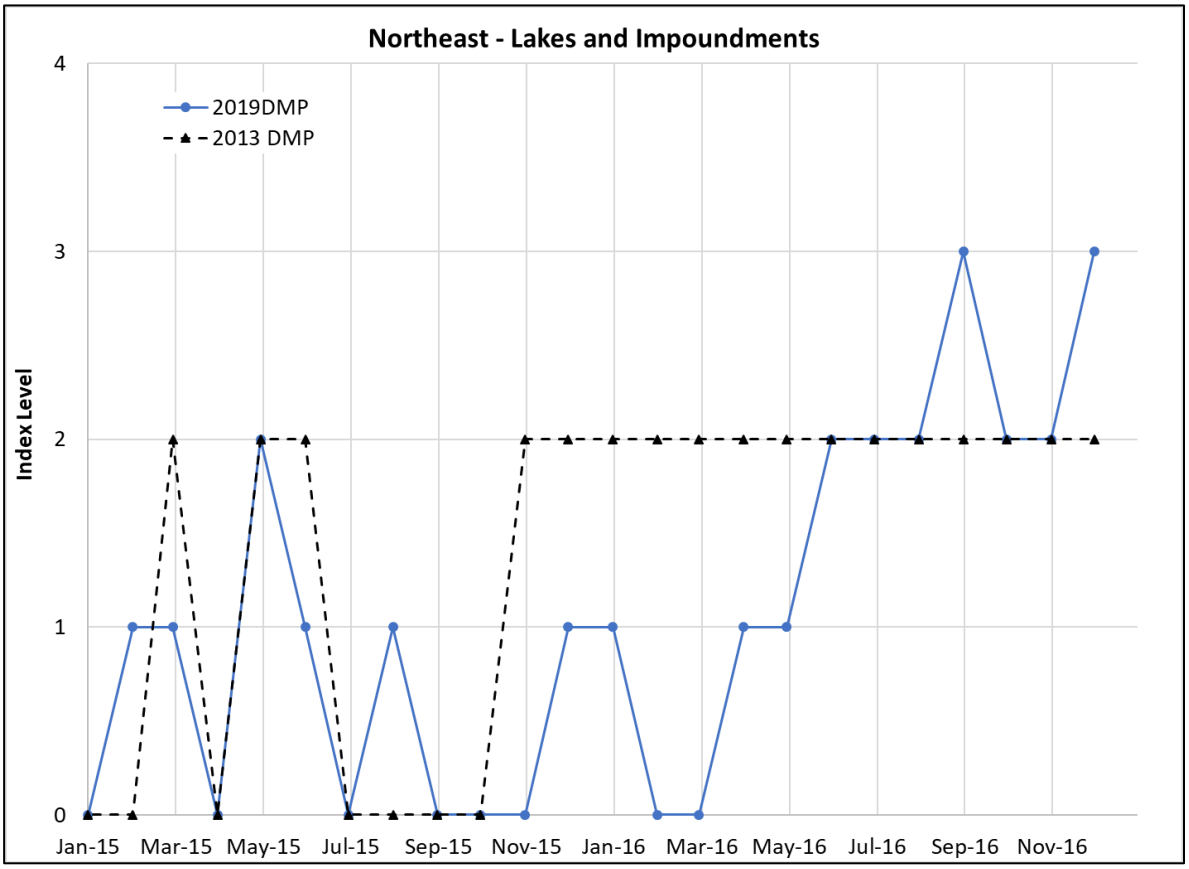
Lakes and Impoundments

The revised method with the 50th percentile for regional representation was tested for the Lakes and Impoundments index for the Northeast and Southeast regions.

Exhibit 8 shows the comparison between the revised method (2019 DMP) and the 2013 DMP method. For this index, there is not a consistent pattern between the two methods as with the previous three indices described above.

The 2013 DMP categorized severity for a region based on any single lake or impoundment that was "below normal" (i.e., more than one standard deviation below average). That is, it was based on the worst of all water bodies resulting in an earlier drought signal than the revised methods which uses the median of the individual water bodies' percentiles. In addition, the 2013 DMP categorized severity based on the size of the water body. For example, in the Northeast region where there are only small and medium water bodies, it would result in a maximum possible index severity level of only 1 or 2, respectively, and preclude the region from ever going into level 3 (large water bodies) and level 4 (sustained status of level 3) even if water levels in the reservoirs decrease significantly. With the revised method all severity levels are possible in all regions because water body size is not a factor in the calculations. The revised method uses the individual water bodies' percentiles to gauge the status of the reservoir compared to its own historical levels and data. The regional value is then calculated based on the median of all individual sites. These changes align this index with the methods and interpretation of the other indices.

Exhibit 8. Lakes and Impoundments Index for the Northeast Region for the 2013 DMP method and the revised method using the 50th percentile for a regional value (2019 DMP)



Overall Drought Determinations Testing

After the indices were evaluated individually, the method for establishing the regional value based on the station percentiles was established, and the process for selecting the SPI look-back period was revised, the technical group conducted a mock DMTF meeting to gage the effect of the new methods on potential drought determinations. Three indices – precipitation, streamflow and groundwater – calculated by the new methods were presented to the group one month at a time for two time periods (September 2001 to April 2002 and June 2010 to January 2011) for the Northeast region, without the group knowing which months' data were being presented. These periods included non-drought conditions and drought conditions up to level 3 (using the new method). In addition to the three indices, other relevant and available historical data from past hydrologic conditions reports were presented. It should be noted that this mock exercise did not include all the data the DMTF usually has available at a meeting, nor did participants have the benefit of lengthy deliberations for each month that is typical at a DMTF meeting, since conditions for many months were assessed in one meeting. Despite these limitations, staff still found the exercise helpful in evaluating the new method.

During the mock meeting, the group first made drought-level determinations for each month. These were then compared to drought-level determinations for the same time period that were made historically by the DMTF using the 2013 DMP and by the USDM and after considering documented impacts and experiences by technical staff during those drought years. As the revisions intended, droughts, in general, were called slightly earlier and with slightly higher severity compared to the historical determinations based on the 2013 DMP. In addition, based on drought impacts reported at the time and on staff who had been present during those droughts, it was confirmed that these changes were appropriate relative to the conditions that were experienced. Each time period is discussed in more detail below.

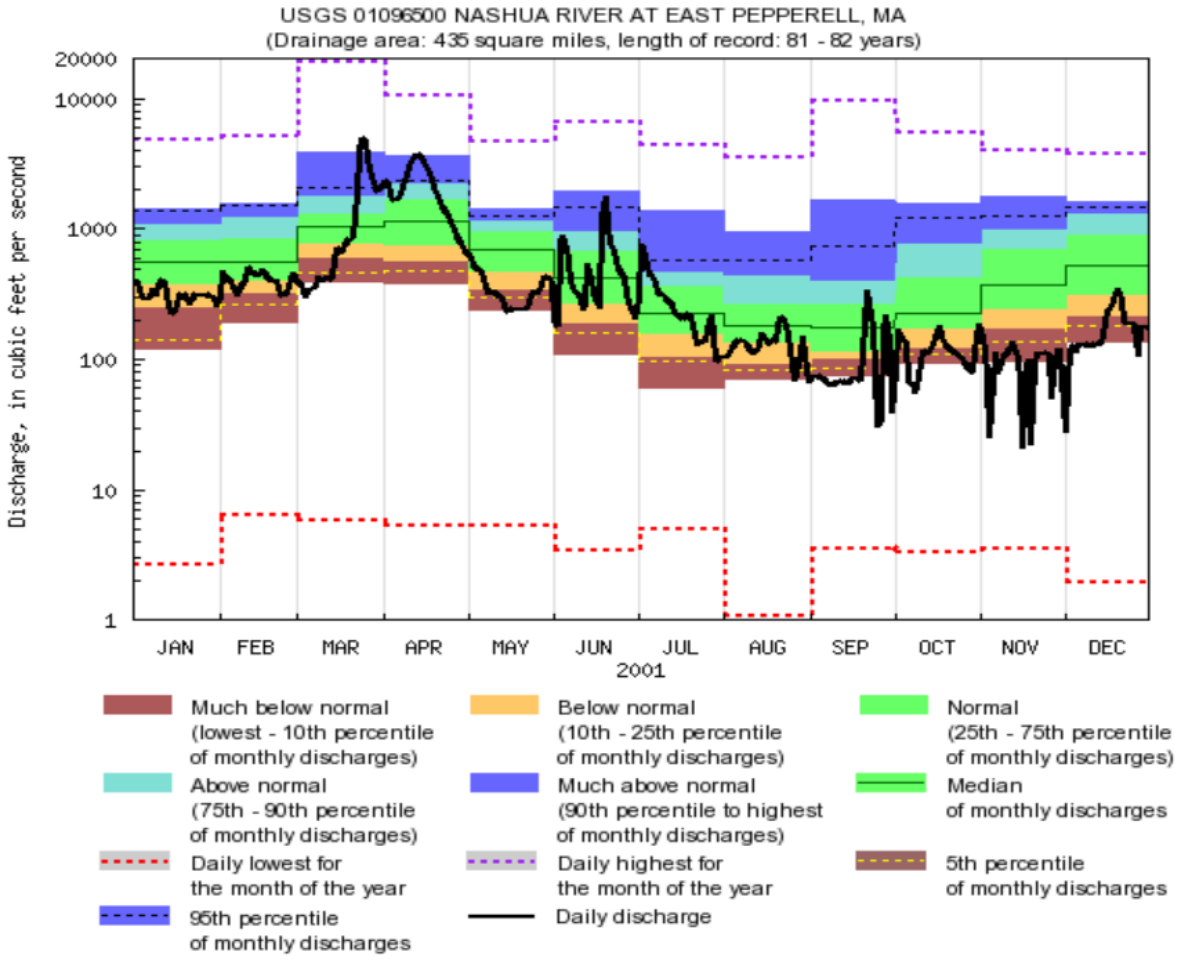
During the 2010-2011 drought exercise, the technical group called a level 1 drought for June 2010. Upon comparison, this was one month before the historical state determination, but the same timing as the USDM that made its determination of level 0, abnormally dry conditions (Note that the USDM level 0 corresponds to the new state level 1). In addition to the indices, the technical group had considered on-the-ground impacts that had been reported, including increased fires especially in the Northeast Region, mandatory and voluntary water restrictions, and a forecast that projected normal rainfall but normal to above-normal temperatures. In July, all three methods escalated their respective drought levels by one category and maintained that category for August 2010. The revised method resulting in an escalation to a level 2 drought (one higher than the DMP 2013 and equivalent to the comparable USDM drought level) was deemed appropriate based on a severity level 3 streamflow index, the escalation of other impacts including the need for water tankers for fire suppression due to supplies drying up, difficulty extinguishing fires because of the deep drying of soils, and additional water supply restrictions. In addition, the National Weather Service reported the warmest spring and summer to-date at the time with an early start to the growing season followed by a particularly dry June and August explaining some of the observed impacts and their severity. Finally, the Massachusetts Water Resources Authority reported inquiries from public water suppliers about establishing new connections.

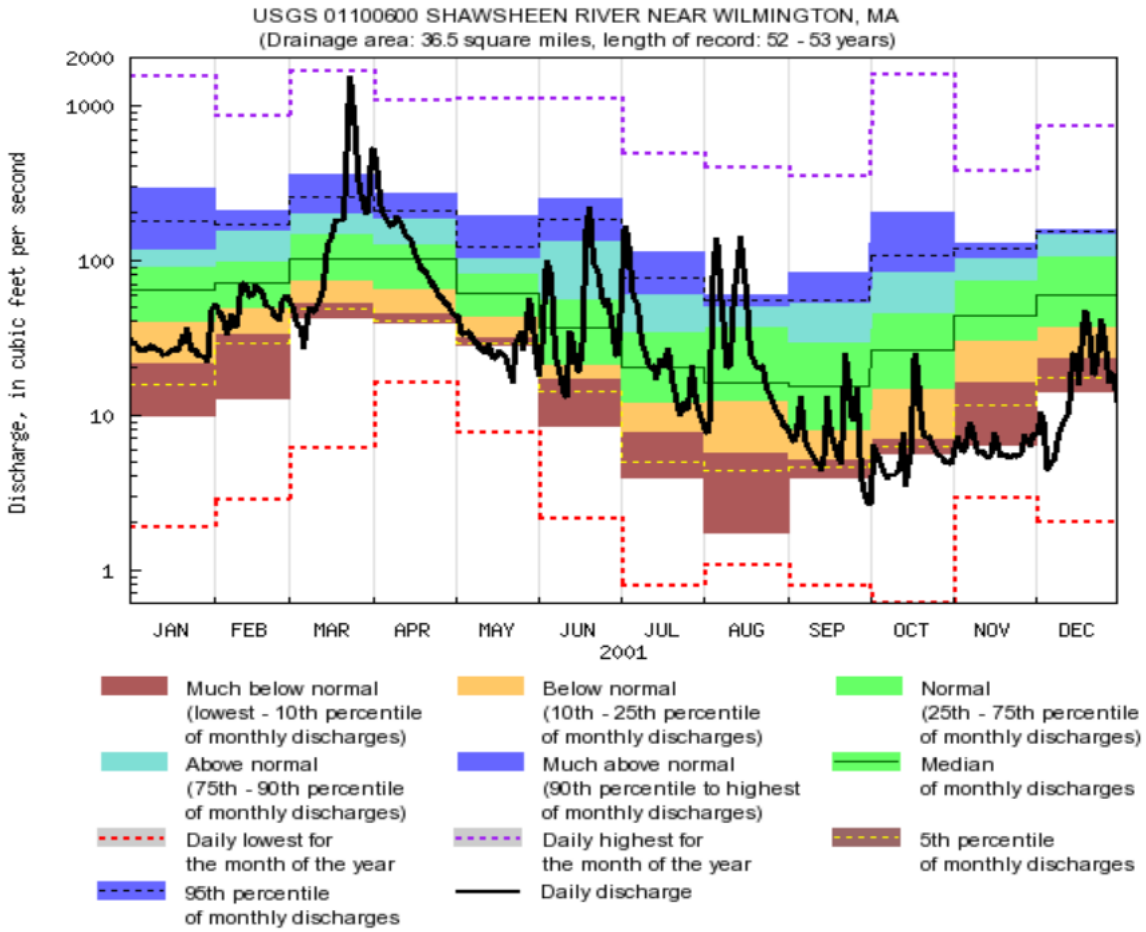
In September 2010, the USDM dropped two categories to normal/no drought level, while both the 2013 DMP and revised methods continued at the previous levels. Given that all three indices being considered showed some level of severity (including level 3 for SPI, level 2 for streamflow, and level 1 for groundwater), the technical group determined that maintaining the previous drought level was a better reflection of conditions than USDM's two-level drop to non-drought conditions. In October 2010, the new method resulted in a one-category decline to the same level 1 drought that was maintained by the historical determinations. Both returned to normal in November 2010 and onward.

During the 2001-2002 drought exercise, the technical group called a level 1 drought two months prior to the historical state determinations but at the same time as the USDM. The historical method reached a maximum of a level 2 drought, while the new method reached a maximum of a level 3 drought in line with the USDM. The technical group called a level 3 drought beginning in November

2001, four months prior to the equivalent USDM drought level. At the time, both SPI and streamflow index were at level 4 and groundwater was at level 3. National Weather Service staff commented that conditions were more severe earlier than indicated by the USDM and that the new methods would have served well to signal the escalation earlier. Historical records bear this out and show new record-low streamflow across the Northeast Drought Region during this period including the Ipswich River at Middleton, Ipswich River at Ipswich, Shawsheen River at Wilmington, Nashoba Brook near Acton, Nashua River at East Pepperell, Squannacook River near West Groton, Merrimack River below Concord River, Charles River at Wellesley, Sudbury River at Saxonville, and Parker River at Byfield. Two examples are shown in Exhibit 9.

Exhibit 9. Streamflow at USGS Gaging Locations in 2001





C.2 Revisions from 2019-2022

2021 Adding Streamflow Index to the Cape Cod Region

In May 2021, pursuant to discussions at DMTF meetings, the Interagency Technical Committee was provided information about adding two streamflow gages located in the Cape Cod Region as part of the streamflow monitoring network. The rationale for this proposal as well as responses from the committee are summarized below.

Background

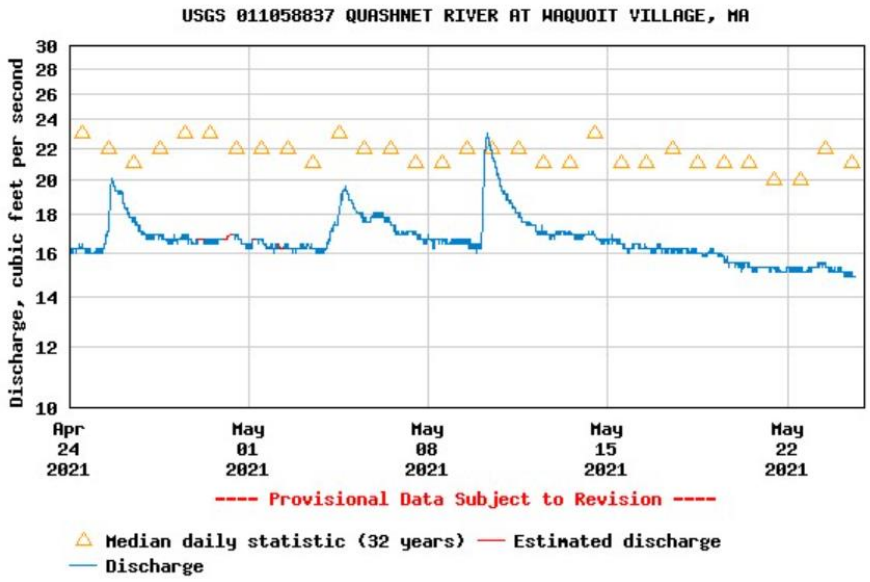
There has been a focus on using all available information for drought analysis and the need for more data points for drought monitoring and management. Historically, the streamflow index has not been calculated for the Cape Cod and Islands Regions because streams in these regions are largely groundwater-dominated. There are, however, two gages on Cape Cod that could provide useful information for drought monitoring. OWR staff proposed to start to use these two data points to provide a streamflow index for Cape Cod. The U.S. Drought Monitor also refers to these gages and uses the data in drought determinations.

Analysis

The following considerations were made when evaluating this proposal:

1. Both gages have over 30 years of data; and
2. Streamflow can serve as a relative early warning of dryness even in a groundwater-dominated system – as the groundwater decreases, streamflow is affected as streams turn into losing streams (losing water to groundwater rather than gaining from it when groundwater is high).

As part of the discussion on this proposal the Interagency Technical Committee acknowledged that both gages do a good job filling the streamflow gap on Cape Cod. They agreed that because of their location and their over 30 years of record, these gages are valid to be used to assess drought on Cape Cod. Streams in this region are groundwater-dominated (meaning that most of the streamflow is baseflow) but they will still reflect streamflow conditions and respond to precipitation events as shown in the graphs. And because Cape Cod is a groundwater-dominated system, groundwater should still weigh more heavily. The consensus was that the streamflow index should be added for the Cape Cod Region.



2020-2022 Revision of the Evapotranspiration Index

To find a replacement for the evapotranspiration (ET) index, i.e., the Crop Moisture Index, which was found to be unresponsive to most droughts, OWR staff undertook an in-depth study to analyze other alternatives. The goal for the ET index is to accurately capture the effect of temperature on evapotranspiration, which is especially relevant during the growing season with respect to water availability. With assistance from the Northeast Regional Climate Center at Cornell University, OWR and EEA staff evaluated various data products for the ET index that are based on soil moisture, evapotranspiration or evaporative demand.

The six data products considered were Climate Prediction Center soil moisture (CPCSM), Evaporative Stress Index (ESI), Gravity Recovery and Climate Experiment (GRACE), National Water Model version 2 (NWMv2), Standardized Precipitation and Evapotranspiration Index (SPEI), and Evaporative Demand Drought Index (EDDI). The evaluation criteria for each index included 1) spatial coverage for the entire state with at least one data point per drought region, 2) data availability of sufficient length to evaluate the index's performance against previous droughts, 3) reference period of sufficient length such that calculated percentiles are not biased to only recent decades, 4) multiple options for look-back period or soil depth, 5) product updated frequently enough to provide data for weekly updates, and 6) timely availability of data for weekly updates. The six data products and their review with respect to meeting the ET Index evaluation criteria are summarized in Exhibit 10 below.

After an initial screening of the products, the CPCSM data were eliminated because they are not of high enough resolution to provide a unique value for each drought region. Concerns were also noted for the ESI, due to its short reference period from 2000-2020, and for the EDDI, due to the 5-day lag in being able to access data. However, all data products in Exhibit 10 other than CPCSM were evaluated.

The process was similar to the 2019 revision of the other indices. First, how frequently each proposed index fell within the target percentile categories was evaluated. The results of this first step are further described below and shown in Exhibit 11. Next, a timeline of precipitation and streamflow indices for past drought events were plotted along with the ET data being evaluated to check for the ET data's ability to produce an early signal of the onset or intensification of a drought due to above-normal temperatures (Exhibit 12). Drought levels as indicated by the US Drought Monitor (USDM) were also included in the graphs starting with 2001 when the USDM was established. The USDM drought levels are shown because USDM methods have remained more consistent over time and are close to the 2019 Massachusetts drought methods. Since the USDM has five drought levels and Massachusetts has four drought levels, the USDM levels were converted to Massachusetts levels based on the matching percentile categories, similar to the 2019 methods (levels 3 and 4 of the USDM combine to form a single level 3 in the Massachusetts 2019 DMP). The indices are available for various soil depths or look-back periods. The most appropriate soil depths or look-back periods available for each index were selected prior to comparison with other indices.

Exhibit 10. Characteristics of each Evapotranspiration Index product evaluated

ET Product	Spatial Resolution (average miles between points)	Product Availability for evaluating index	Reference Period for percentile calculations	Lookbacks Calculated or Soil Depths Available	Update Frequency	Timely Availability (Days past observation)
CPCSM[31]	No (50 - 68 mi)	2008-present	1932-2000	Daily, Monthly	Daily, Monthly	1-day (daily), 5-day (month)
ESI[32]	Yes (5 - 7 mi)	2002-present	2000-present	4-Week, 12-Week	Weekly	3+ day lag
GRACE[33]	Yes (6 – 8.5 mi)	2002-present	1948-2014	surface (2cm), root zone (100cm)	Weekly	2+ days lag
NWMv2[34]	Yes (1.2 mi)	2001-2020	1979- 2018	0-10 cm, 10-40 cm, 40-100 cm, 100-200 cm	Daily	Current
SPEIv2[35]	Yes, at least 1 station per drought region	Varies by station like precipitation	Varies by station like precipitation	1-Month to 12-Months	Weekly	1-day
EDDI[36]	Yes (6 - 8.5 mi)	1980-present	1979-2015	1-Week to 12-Months	Daily	5-day lag

[31] https://www.cpc.ncep.noaa.gov/products/Soilmst_Monitoring/US/Soilmst/Soilmst.shtml
[32] https://www.drought.gov/data-maps-tools/evaporative-stress-index-esi
[33] https://nasagrace.unl.edu/
[34] https://water.noaa.gov/about/nwm
[35] https://spei.csic.es/home.html
[36] https://psl.noaa.gov/eddi/

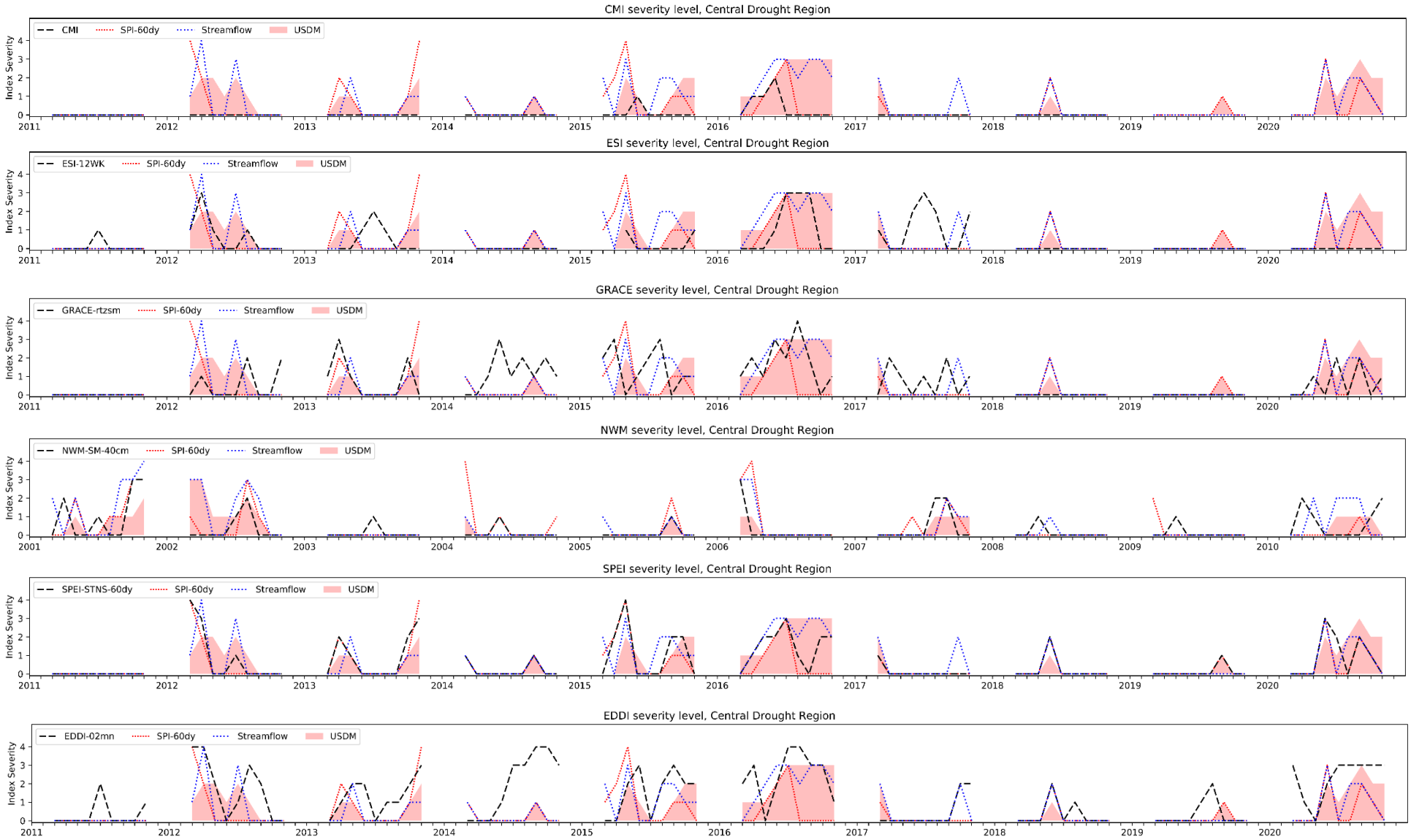
The initial analysis included a check on the frequency with which the target percentile categories were achieved. Exhibit 11 summarizes for each data product, over that product's available period of record, the percent of the time each index severity level would have been triggered. For reference, the same calculations are shown for CMI. The cells that have been greyed out indicate percentiles that are outside the expected percentage of +/-10%. Further examination of the data, however, indicates that all products are closer to the expected percentages than the CMI. Relative to each other, there were smaller differences between the products and, therefore, all five indices were carried forward for the time series analysis across past droughts.

Exhibit 11. Target Severity Levels (grey shading indicates that the values are more than +/-10% from the expected values)

Index Severity Level	0	1	2	3	4
Expected Percentage	70	10	10	8	2
+/-10%	63-77	9-11	9-11	7.2-8.8	1.8-2.2
CMI	96	3	1	0	0
ESI-04wk	71	11	7	6.1	4.8
GRACE-rtzsm-100cm	67	11	12	10.3	0.4
NWM-SM-40cm	74	13	8	5.5	0
SPEI-02mn	73	10	8	7.9	1.5
EDDI-02mn	67	11	12	7.2	3.2

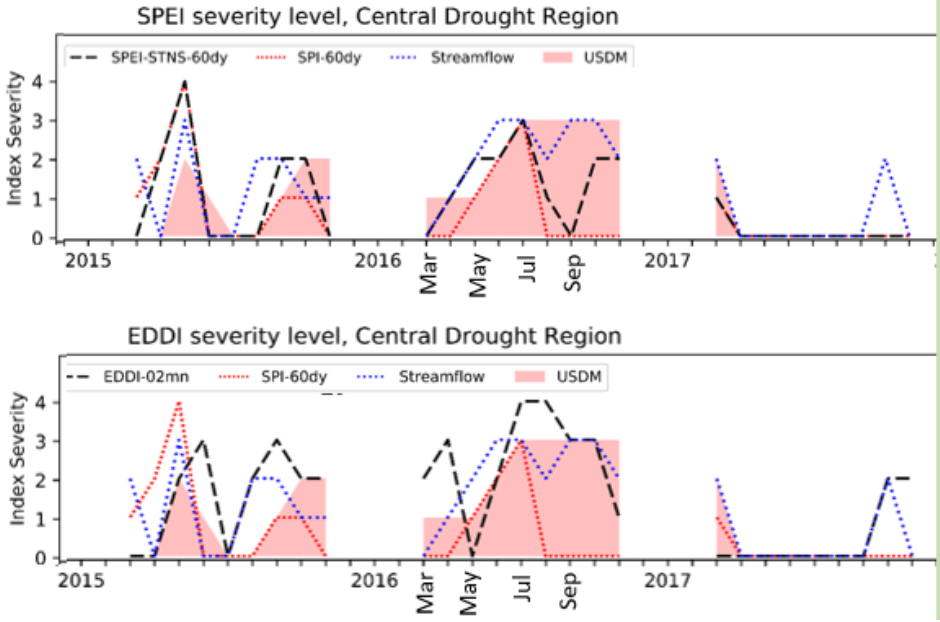
For the time series analysis, performance of each product was compared to every other product by looking at how each product performed during a drought along with some of the other drought indices such as the 60-day standardized precipitation index (SPI), and the streamflow index. In addition, the USDM drought levels were used as a surrogate for what the state drought call would have been during that time (the new MA DMP index methodology established in 2019 is similar to the USDM methodology) to provide context. Exhibit 12 shows the time series for each index for 2011 through 2020 for the Central Region. This time period is shown because it encompasses the two recent droughts that included significant temperature components which prompted a re-evaluation of the ET index. The Central Region was chosen as the example region for detailed evaluation. The 2001 through 2010 time period and all other regions were also evaluated but are not included here for brevity.

Exhibit 12. Time series of potential ET products from 2011-2020 in the Central Regio



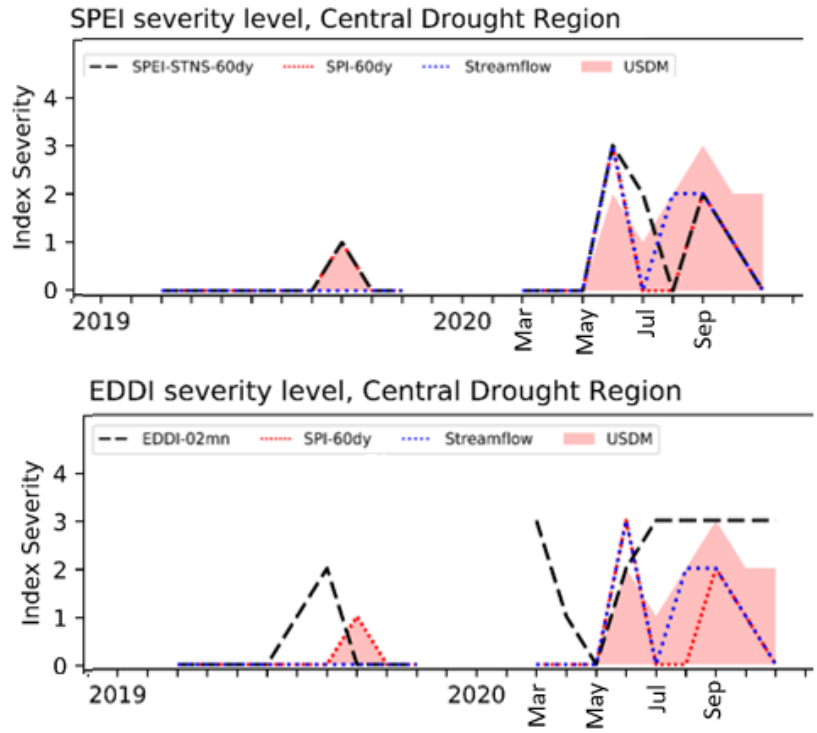
To provide further context and to be able to better characterize the behavior of the ET products during the two recent droughts, percentiles for the monthly temperatures were calculated for both droughts (Exhibit 13). High monthly temperatures can cause an elevated ET index and could cause an

Exhibit 13. Time series for the 2016 and 2020 droughts for the SPEI and EDDI. Table of monthly average temperature as percentile events relative to all other months in the period of record. [Months lower than the 30th percentile are highlighted in white.]



2016 Average Temperature	
Month	Percentile over POR
Mar	11th
Apr	67th
May	51st
Jun	47th
Jul	23rd
Aug	7th
Sep	15th
Oct	47th
Nov	23rd
Annual	*12th*

Percentiles are for the 129 years between 1892 and 2021. Lower percentiles=warmer months/year



2020 Average Temperature	
Month	Percentile over POR
Mar	12th
Apr	85th
May	63rd
Jun	15th
Jul	2th
Aug	7th
Sep	28th
Oct	43th
Nov	2th
Annual	*4th*

record high summer

elevated streamflow index even if the precipitation index is not yet elevated. At other times, the ET index may not show elevated levels but the SPI may be elevated resulting in an elevated streamflow index severity level and/or USDM drought level. In the latter case, a low ET index is appropriate and the dryness is attributed to the precipitation deficit.

Comparison of Products and Conclusions

The ESI time series in Exhibit 12 shows the most false negatives (no signal when there is drought) and false positives (a signal when there is no drought). This index was eliminated based on performance. GRACE and NWM had similar characteristics to ESI when compared with SPEI and EDDI; therefore SPEI and EDDI were retained for further examination. SPEI performed favorably in multiple comparisons with EDDI for drought onset but missed some critical high ET periods such as in August 2016 and onward and during the record high ET from June through August of 2020 (Exhibit 13). One explanation could be that the SPEI calculation includes precipitation and is therefore moderated by the increase in precipitation as shown by lowering of the precipitation index to level 0 in August 2016 and July 2020. However, the drought remained elevated in the 2016 period and intensified in the 2020 period due to record high temperatures and the resulting ET. EDDI was the best product to characterize ET during these periods. *Therefore, EDDI was selected as the preferred drought index for ET. An additional benefit of EDDI is that forecasts are provided for the 2-week and 4-week time periods[37]. While this is a recently developed product, such forecasts may prove useful for projecting quick and severe onset and intensification of droughts such as the 2016 and 2020 droughts.*

In addition to helping select EDDI as the ET index, these analyses showed the importance of temperature and ET in droughts. Two clear examples are August 2016 and July 2020 when the precipitation index was at level 0 but the streamflow index and drought levels continued to elevate due to high ET index levels. For drought onset, the 2016 drought started with high ET levels in March and April along with an elevated streamflow index and drought levels. This occurred despite the precipitation index not elevating until May. Therefore, it was ET rather than precipitation that drove the streamflow impacts and drought onset. These examples show that the ET index could provide an early warning of drought onset.

Lastly, the appropriate months of the year for which to calculate the ET index were evaluated. Exhibit 14 shows the monthly average potential evapotranspiration (PET)[38] in two Massachusetts cities. Monthly average precipitation for these two cities ranges from 3.2 to 4.9 inches. *Given that PET is significant (i.e., one third or more of precipitation) in the months of March through October, this time period was selected for drought monitoring.* For November through February, even a significant PET anomaly (i.e., 10th percentile) would only result in a negligible ET in absolute terms (i.e., in inches).

[37] https://www.drought.gov/forecasts

[38] PET is maximum theoretical ET based on weather conditions and a reference vegetation. Since EDDI estimates maximum ET, we used historical PET as calculated by the reference to assess the appropriate seasons for use in drought monitoring.

Exhibit 14. Monthly average potential evapotranspiration for a grass-covered surface in inches in Boston and Worcester, MA based on the years 1981-2010. Data was provided by the Northeast Regional Climate Center at http://www.nrcc.cornell.edu/wxstation/pet/pet.html

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Boston, MA	0.4	0.6	1.2	2.0	3.1	3.6	4.0	3.5	2.3	1.4	0.6	0.4
Worcester, MA	0.3	0.5	1.1	2.0	3.2	3.6	4.0	3.5	2.3	1.3	0.6	0.3

C.3 Continued Work

Review of Monitoring Networks

The precipitation stations will be reviewed for timeliness and consistency of reporting, spatial representation within a region, sufficient representation of variability within a region, and other factors. If needed, the stations selected to represent each region may be modified.

In collaboration with USGS, the Commonwealth is reviewing the streamflow and groundwater monitoring networks. Characteristics of gages and wells will be compiled; these may include degree of human influence, timing of response to dry conditions, aquifer type for wells, stream order for gages, and other factors. Each network will be reviewed to assess the degree to which it provides representation of desired characteristics in each region. Based on the gaps, redundancies, or other issues, the networks may be revised.

For the lakes and impoundments network, work is underway to include additional monitoring locations. State staff is contacting managers of such water bodies to request monthly reporting and compile historical data for calculating percentiles. Methods to facilitate reporting, for example, by creating an electronic reporting mechanism, are also being considered. In addition, state staff is creating a database of reservoirs and their basic characteristics to facilitate the interpretation of outliers such as management protocols that may substantially alter levels in ways unrelated to drought conditions. In addition, efforts are also underway to improve the lakes and impoundments index by evaluating existing data and alternative index calculation methods for different types of lakes and impoundments. Currently, the index uses both regulated and natural water bodies. In addition, data are reported in percentiles and as “percent full”. Both of these factors necessitate best professional judgement in determining regional index severity levels. The planned improvements would allow for evaluating all included water bodies on the same scale and allow for better calculation of regional index severity levels.

USGS is developing and testing methods to project future streamflow and groundwater levels based on historical data, current conditions, and projected weather. Once operational, these projections will greatly enhance information available to the DMTF for decision-making especially for initiating

early actions at drought onset or intensification. Once the analyses are completed, their publicly available location will be referenced.

Effects of Climate Change

Multiple comments were received about the effects of climate change on the period of record (POR) used for calculating percentiles. The POR is a reference period from which the frequency and therefore severity of a drought is calculated. It assumes that patterns are not changing and that the 10th percentile drought conditions will be similar conditions with similar impacts in the future. However, with climate change, more frequent and more intense droughts are projected. If these newer data are included in the POR, then it will skew the reference period and the more frequent but equally severe droughts will be calculated as less severe than if the POR is cut off at some point in time. Creating a cut off point for the POR will preserve historical data with fewer climate change effects as the reference or baseline period against which drought frequency and severity is measured. For example, if the POR were established as all historical data up to 1990, then future droughts would be evaluated in context of all events within that POR. If there is no cut off, then as droughts become more common in the POR, drought previously calculated as a 20th percentile event may be calculated as a 35th percentile event and classified as a "normal" condition. However, both droughts will have the same impact on people, infrastructure, and the environment. Therefore, staff will continue to evaluate this issue.

Changing Impact of Droughts

The 2016-2017 and 2020-2021 droughts showed precipitation totals near or above the 1960's drought but streamflow and groundwater impacts more severe than that of the 1960's drought. Both droughts included a rapid intensification drought element where both fast onset and intensification of droughts were observed relative to historical drought behavior. This is a new phenomenon experienced by many states and NOAA and other researchers have started to describe and study it to help define 'rapid intensification drought' and improve its characterization. The role of high temperatures resulting in high ET in rapid intensification drought has been acknowledged. Forecasts of ET are underway such as the forecasting of EDDI referenced above.

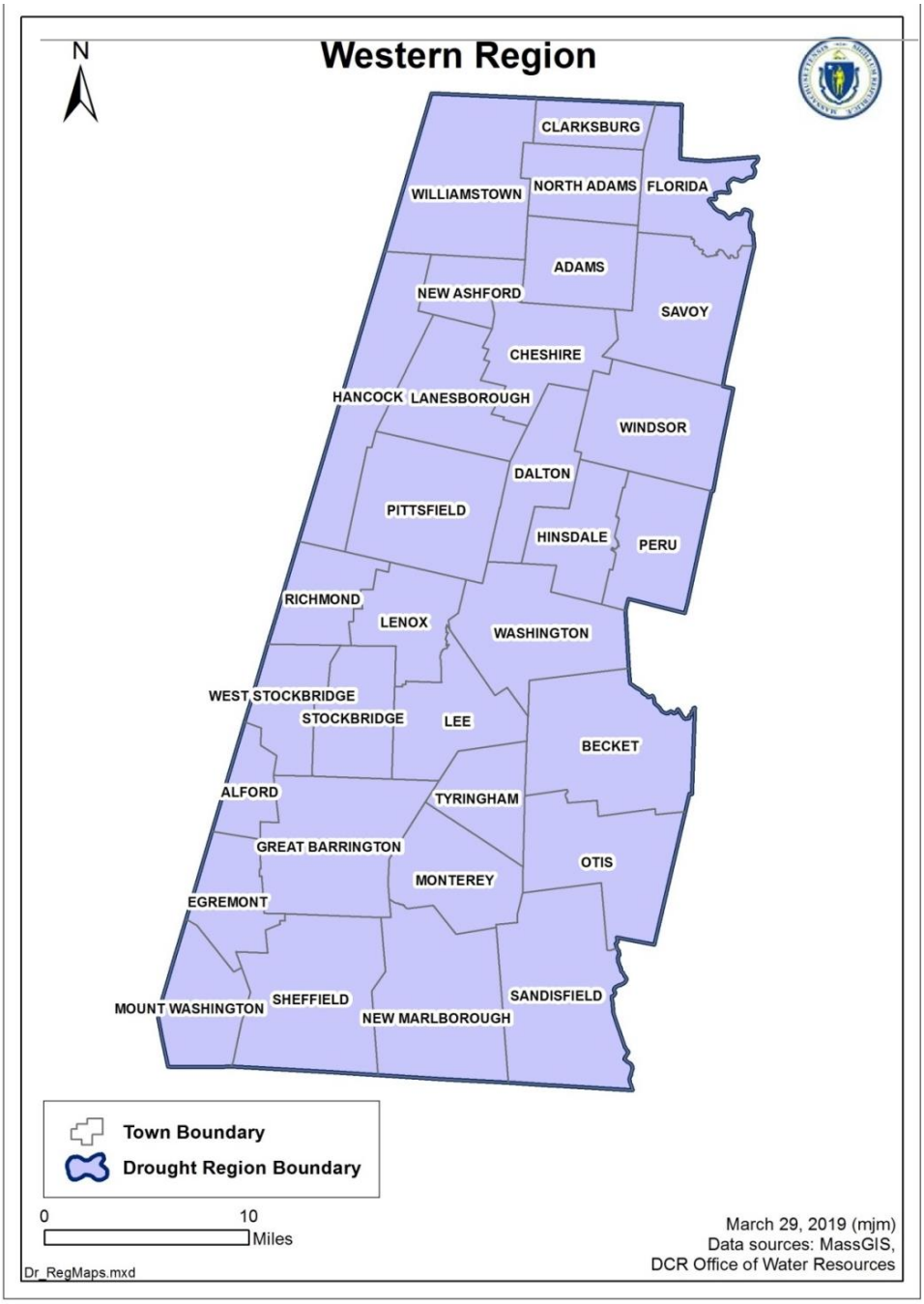
In collaboration with USGS, staff will explore the factors contributing to the severity of impacts other than temperature and resulting ET (e.g., land use change, increased water use) to better understand the changing dynamic between precipitation and drought impacts.

Appendix D: Maps of Massachusetts Drought Regions with List of Cities and Towns by Drought Region

Western Region

(Berkshire County)

Adams
Alford
Becket
Cheshire
Clarksburg
Dalton
Egremont
Florida
Great Barrington
Hancock
Hinsdale
Lanesborough
Lee
Lenox
Monterey
Mt. Washington
New Ashford
New Marlborough
North Adams
Otis
Peru
Pittsfield
Richmond
Sandisfield
Savoy
Sheffield
Stockbridge
Tyringham
Washington
West Stockbridge
Williamstown
Windsor



Connecticut River Valley Region

(Franklin, Hampden, and Hampshire counties)

Cities and Towns in the Connecticut River Valley Region

Agawam
Amherst
Ashfield
Belchertown
Bernardston
Blandford
Brimfield
Buckland
Charlemont
Chester
Chesterfield
Chicopee
Colrain
Conway
Cummington
Deerfield
East Longmeadow
Easthampton
Erving
Gill
Goshen
Granby
Granville
Greenfield
Hadley
Hampden
Hatfield
Hawley
Heath
Holland
Holyoke
Huntington
Leverett
Leyden
Longmeadow
Ludlow
Middlefield
Monroe
Monson
Montague
Montgomery
New Salem
Northampton
Northfield
Orange
Palmer
Pelham
Plainfield
Rowe
Russell
Shelburne
Shutesbury
South Hadley
Southampton
Southwick
Springfield
Sunderland
Tolland
Wales
Ware
Warwick
Wendell
West Springfield
Westfield
Westhampton
Whately
Wilbraham
Williamsburg
Worthington

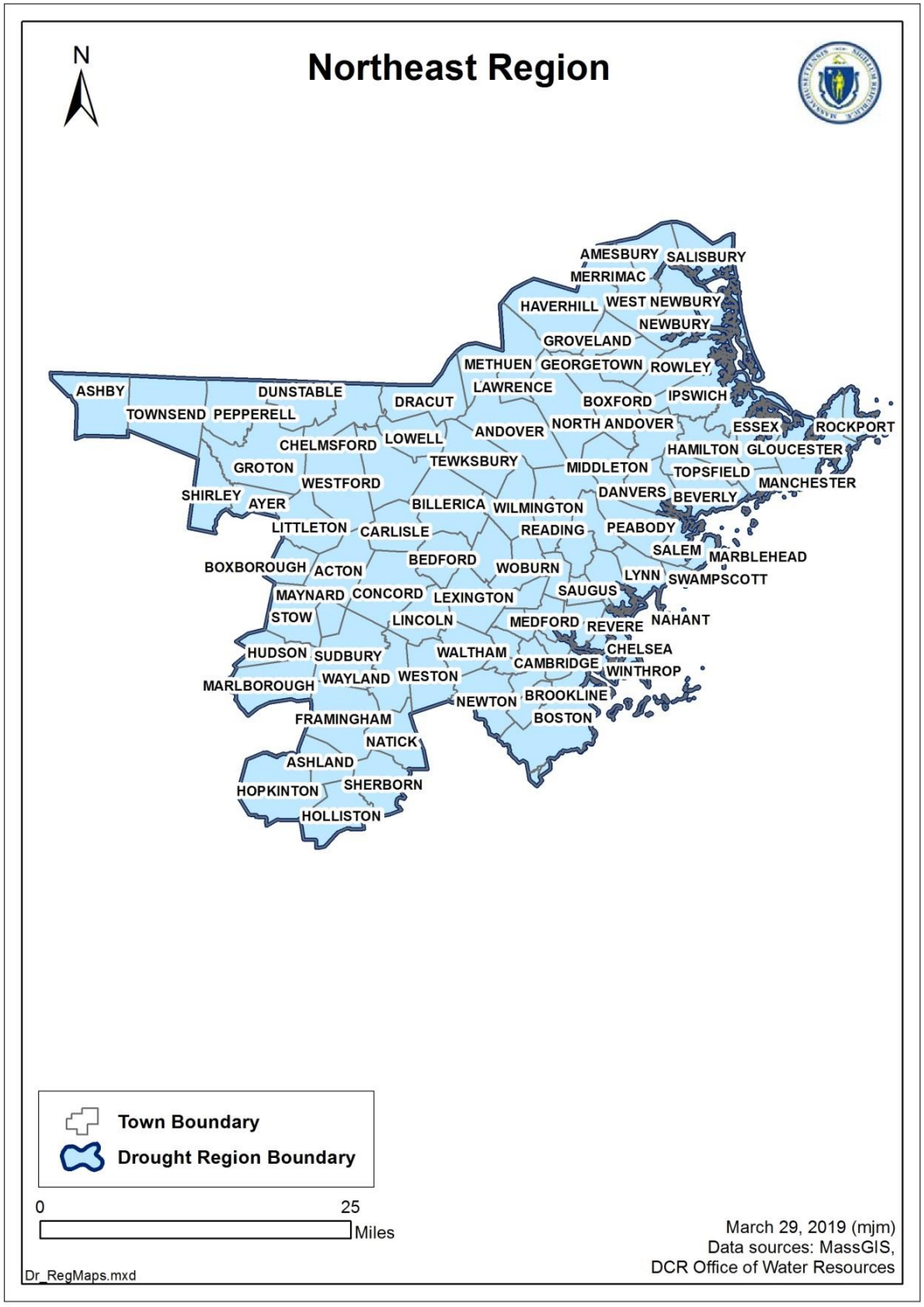
Central Region
(Worcester County)

Cities and Towns in the Central Region

Ashburnham
Athol
Auburn
Barre
Berlin
Blackstone
Bolton
Boylston
Brookfield
Charlton
Clinton
Douglas
Dudley
East Brookfield
Fitchburg
Gardner
Grafton
Hardwick
Harvard
Holden
Hopedale
Hubbardston
Lancaster
Leicester
Leominster
Lunenburg
Mendon
Milford
Millbury
Millville
New Braintree
North Brookfield
Northborough
Northbridge
Oakham
Oxford
Paxton
Petersham
Phillipston
Princeton
Royalston
Rutland
Shrewsbury
Southborough
Southbridge
Spencer
Sterling
Sturbridge
Sutton
Templeton
Upton
Uxbridge
Warren
Webster
West Boylston
West Brookfield
Westborough
Westminster
Winchendon
Worcester

Northeast Region

(Essex, Middlesex, and Suffolk Counties, plus Brookline)

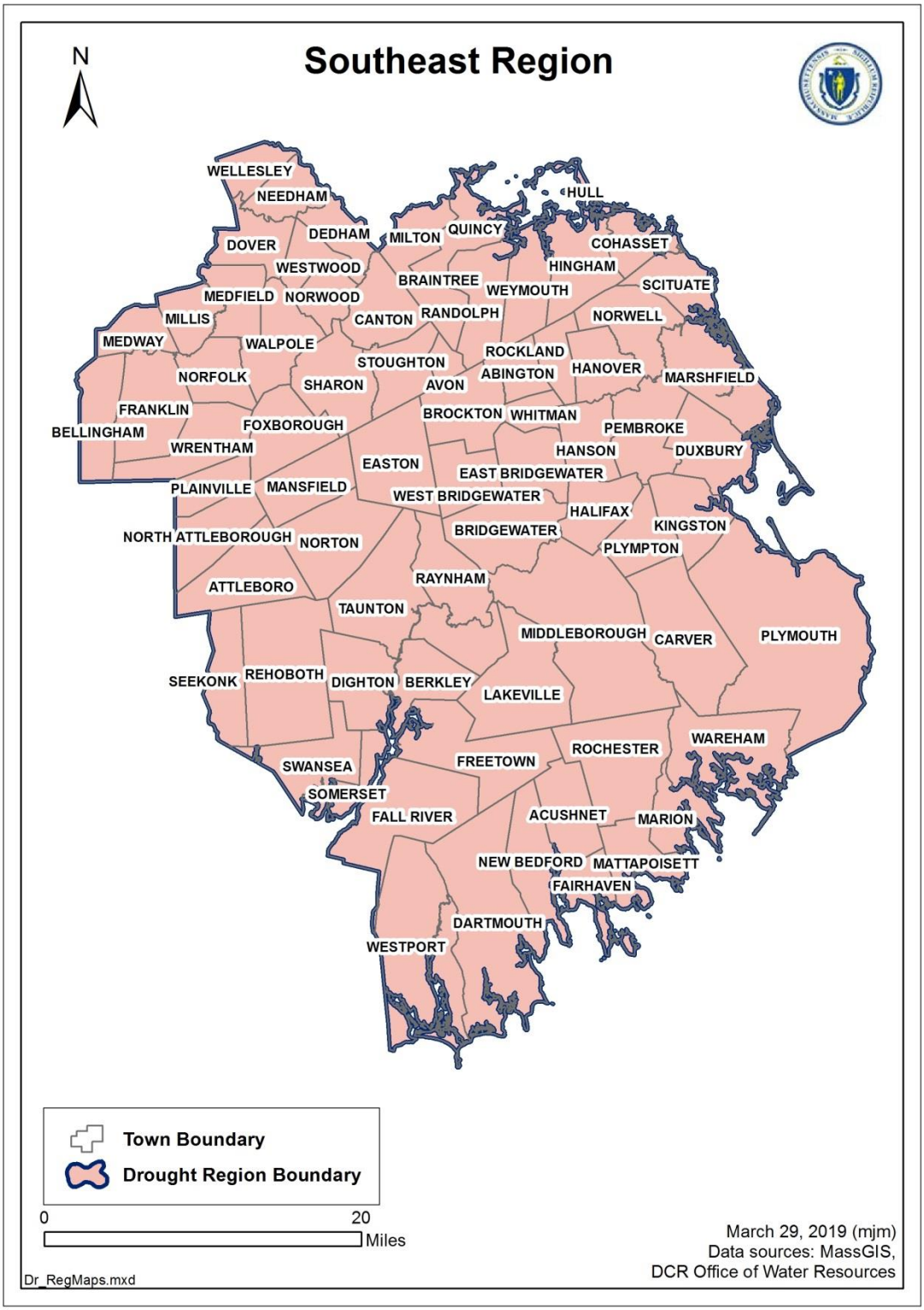


Cities and Towns in the Northeast Region

Acton
Amesbury
Andover
Arlington
Ashby
Ashland
Ayer
Bedford
Belmont
Beverly
Billerica
Boston
Boxborough
Boxford
Brookline
Burlington
Cambridge
Carlisle
Chelmsford
Chelsea
Concord
Danvers
Dracut
Dunstable
Essex
Everett
Framingham
Georgetown
Gloucester
Groton
Groveland
Hamilton
Haverhill
Holliston
Hopkinton
Hudson
Ipswich
Lawrence
Lexington
Lincoln
Littleton
Lowell
Lynn
Lynnfield
Malden
Manchester by the sea
Marblehead
Marlborough
Maynard
Medford
Melrose
Merrimac
Methuen
Middleton
Nahant
Natick
Newbury
Newburyport
Newton
North Andover
North Reading
Peabody
Pepperell
Reading
Revere
Rockport
Rowley
Salem
Salisbury
Saugus
Sherborn
Shirley
Somerville
Stoneham
Stow
Sudbury
Swampscott
Tewksbury
Topsfield
Townsend
Tyngsborough
Wakefield
Waltham
Watertown
Wayland
Wenham
West Newbury
Westford
Weston
Wilmington
Winchester
Winthrop
Woburn

Southeast Region

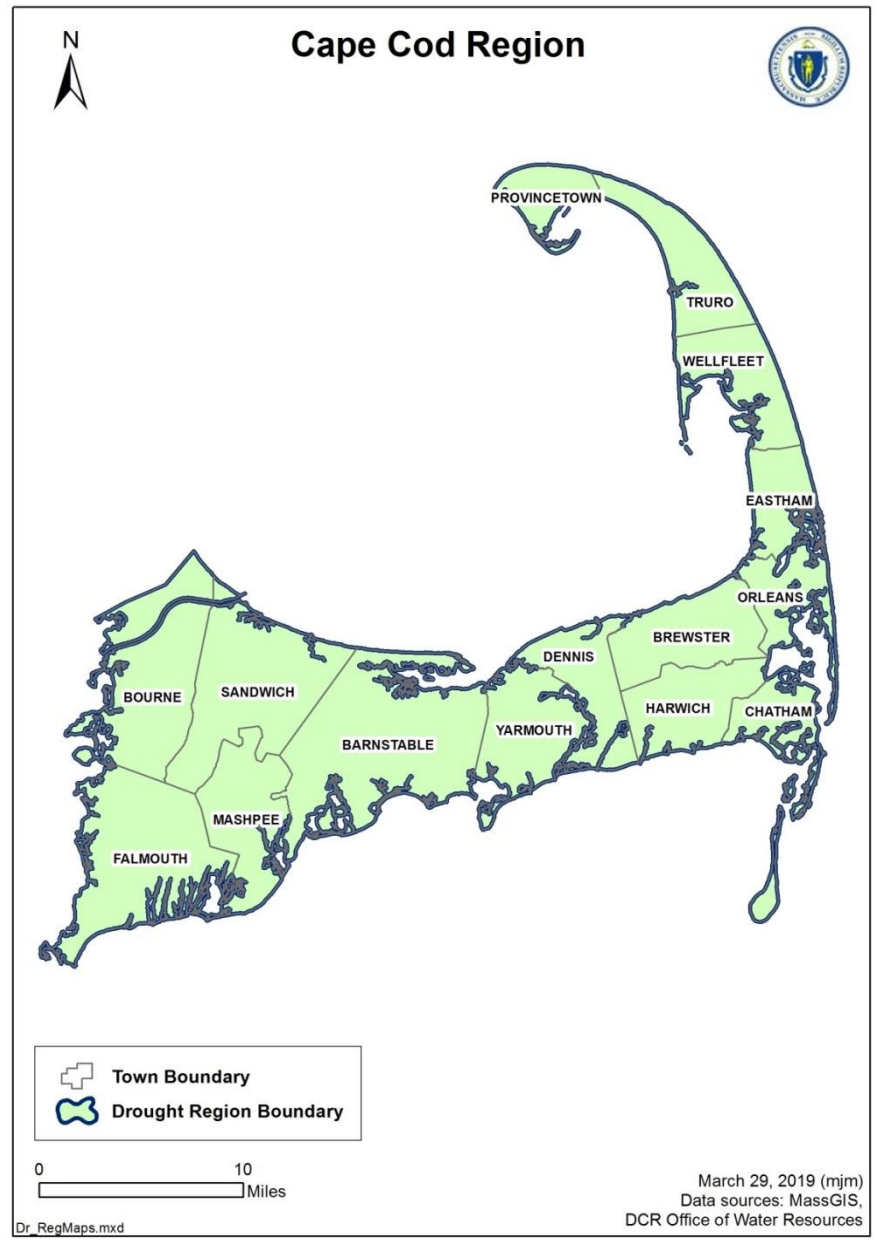
(Norfolk (minus Brookline), Bristol, and Plymouth Counties)



Cities and Towns in the Southeast Region

Abington
Acushnet
Attleboro
Avon
Bellingham
Berkley
Braintree
Bridgewater
Brockton
Canton
Carver
Cohasset
Dartmouth
Dedham*
Dighton
Dover
Duxbury
East Bridgewater
Easton
Fairhaven
Fall River
Foxborough
Franklin
Freetown
Halifax
Hanover
Hanson
Hingham
Holbrook
Hull
Kingston
Lakeville
Mansfield
Marion
Marshfield
Mattapoisett
Medfield
Medway
Middleborough
Millis
Milton
Needham
New Bedford
Norfolk
North Attleborough
Norton
Norwell
Norwood
Pembroke
Plainville
Plymouth
Plympton
Quincy
Randolph
Raynham
Rehoboth
Rochester
Rockland
Scituate
Seekonk
Sharon
Somerset
Stoughton
Swansea
Taunton
Walpole
Wareham
Wellesley
West Bridgewater
Westport
Westwood
Weymouth
Whitman
Wrentham

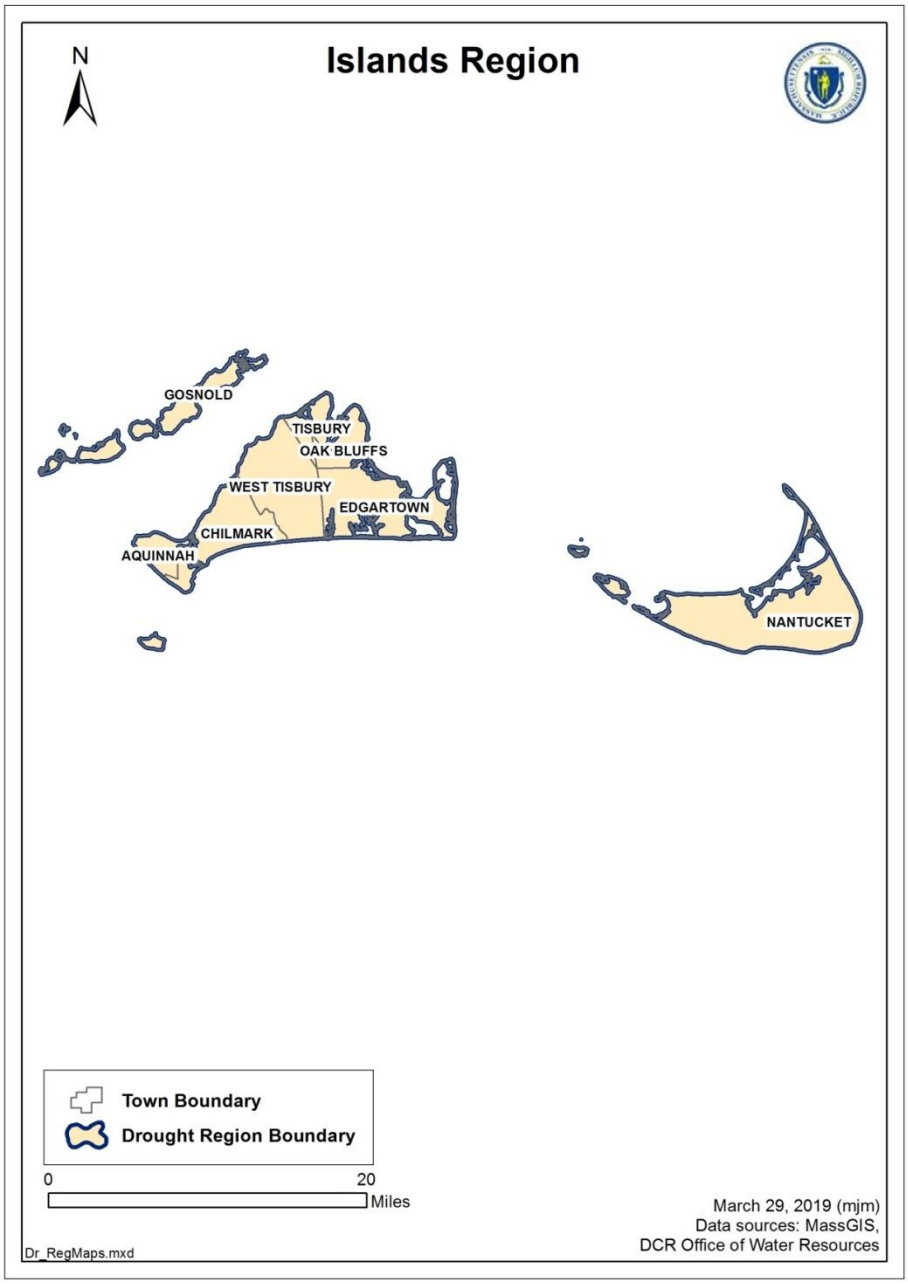
Cape Cod Region
(Barnstable County)



Barnstable
Bourne
Brewster
Chatham
Dennis
Eastham
Falmouth
Harwich
Mashpee
Orleans
Provincetown
Sandwich
Truro
Wellfleet
Yarmouth

Islands Region

(Dukes & Nantucket Counties)



Aquinnah
Chilmark
Edgartown
Gosnold
Nantucket
Oak Bluffs
Tisbury
West Tisbury

Appendix E: Private Wells - FAQ Regarding Private Well Problems Experienced during Droughts

Declining groundwater elevations during droughts can cause problems with both the yield and water quality of private wells. Determining possible remedies for these problems can be difficult and in some instances the remedy implemented may not provide a guaranteed fix to the problem. This Appendix discusses the various types of problems encountered and possible remedies.

To state the obvious, if your well is experiencing reduced yield during a drought, you should take steps to conserve your water use. See the "Tips for Saving Water" section of the following Drought Outreach and Response web page for ways to conserve water use: https://www.mass.gov/info-details/drought-outreach-and-response

What type of well do I have?

The most common types of wells in Massachusetts include bedrock wells, wells consisting of a well screen and well casing that is installed in a sand or sand and gravel aquifer, and shallow dug wells that are installed in the sediments above the underlying bedrock. The types of problems that may be encountered during a drought, and the possible remedies that can be implemented may be somewhat different for each of these well types.

Bedrock well: A bedrock well typically consists of a 6-inch diameter well boring that is drilled into the bedrock beneath the overlying loose sediments. A 6-inch diameter steel well casing is typically set within the upper section of the bedrock and runs from the bedrock to the ground surface. The 6-inch diameter steel well casing typically sticks up from the ground surface. Bedrock wells are typically hundreds of feet to approximately 1,000 feet deep.

Sand and gravel well: A sand and gravel well typically consists of a well screen that extends through the lower section of the well and a riser pipe (consisting of steel or PVC pipe) extends vertically from the top of the well screen to the ground surface. Sand and gravel wells are typically tens of feet to approximately 200 feet deep.

Dug well: Dug wells are commonly 3- or 4-foot diameter wells constructed by excavation and are usually not much deeper than 15 feet below land surface. Older dug wells are typically lined with fieldstone, and more recent construction utilizes inter-locking concrete tile[39].

Where can I obtain a copy of my well completion report?

Having a copy of your well completion report can be very useful when considering possible solutions to problems with your well yield. Massachusetts regulations have required the submittal of well completion reports by Massachusetts Certified Well Drillers to both the local board of health and the

[39] https://www.des.nh.gov/sites/g/files/ehbemt341/files/documents/2020-01/dwgb-1-16.pdf

Commonwealth since sometime in the 1960s. All of the legible reports that have been submitted to the Commonwealth are available through the EEA data portal at https://eeaonline.eea.state.ma.us/portal/#!/home. To obtain a list of available well logs for your municipality scroll down to "See All Data Search Categories" then click on "Well Drilling". That will open the "Search for Well Drilling" page. Choose your city or town from the dropdown menu and click on "Domestic" in the "Well Type" data field.

Unfortunately, not all well completion reports have been submitted to the Commonwealth as is required by the regulations, so it is possible that you may not find your well record in that database. If you can't find it there, you may want to contact your local board of health to ask if they have a copy of that report.

Typical Problems Encountered:

Why am I not getting any water, or enough water, from my well?

Well yield problems encountered during a drought may have been caused by multiple issues. It's important to try to determine the cause of the problem in order to determine the best possible solutions. Contacting a MassDEP Certified Well Driller or a well pump installer may be your best option for diagnosing the problem. Some common problems and symptoms associated with decreased well yield caused by drought conditions include the following:

- The groundwater elevation has dropped too low and sufficient water is not available.
- The decline in groundwater elevation has caused the shallower water bearing fractures in the bedrock well to run dry, resulting in water from the remaining water bearing fractures to enter the well at higher velocities than normal. Those higher entrance velocities may result in more sediment being drawn into the well and the well's pump.
- Similarly, if the shallower depths of a well screen in a sand and gravel aquifer go dry or there is any decline in the groundwater elevation in a dug well, the remaining vertical saturated thickness of the well screen or the dug well will also experience higher entrance velocities when the well pump is running.
- Regardless of the well type, if the drop in water elevation results in more silt and/or sand entering the well this may result in cloudy or colored water and/or noticeable sand particles in the water delivered to the water fixtures in your home. This situation may eventually result in the clogging of plumbing fixtures and/or your sediment filter (if you have a filter). This may result in reduced flow rates from your plumbing fixtures and, in some instances could clog any existing sediment filters.
- Air bubbles appear in water drawn from non-aerated faucets. This may be a sign that when your well pump turns on, it is unable to fill your water pressure tank before the drawdown in the well results in air being sucked into the pump's intake. This problem can result in the pump

remaining on for longer periods of time because it is unable to pump enough water into the pressure tank to reach the pump's cutoff pressure for the controlling solenoid switch.

Why does my water taste bad?

In addition to well yield problems, some people encounter water quality problems during a drought. A very common problem is increased concentrations of naturally occurring iron and manganese. Under normal precipitation conditions, the water being drawn from your well is typically coming from certain portions of the groundwater aquifer and, with certain exceptions, that water tends to have higher concentrations of dissolved oxygen due to the oxygen that is brought into the aquifer from the percolation of water through the overlying sediment from precipitation. During a drought, as the groundwater elevation declines, water is probably being drawn from further distances toward your well and it probably has lower dissolved oxygen content and is of an older average age. All of these issues can contribute to higher concentrations of iron and manganese, in addition to higher concentrations of other naturally occurring contaminants that you may not taste, such as arsenic.

Possible Remedies:

I've discovered that my well pump is not running dry but that I have a large increase in sediment in my water, what should I do?

If you already have a whole house sediment filter, you may need to increase the frequency of filter cartridge replacements. You may also need to consider either replacing your filter with a larger filter that can retain a greater volume of sediment or install additional sediment filters in parallel with your existing sediment filter. Larger filters or additional filters in parallel will allow for longer periods of time between filter replacements and increase the flow rates from your plumbing fixtures.

There may also be an increase in the proportion of silt and/or very fine sand particles that is in the sediment entering your well. This may result in sediment bypassing a filter with a larger micron size rating that had previously worked well prior to the drought. The smaller the micron size rating, the smaller the particles that the filter cartridge can remove. You may need to consider replacing your filter cartridge with one that has a smaller micron rating.

If you don't have a sediment filter because you didn't previously have a sediment problem, you may wish to consider having one installed.

I've discovered that the water level in my well has dropped too low, what should I do?

This situation is one in which it is extremely helpful to have a copy of the original well completion report, especially for bedrock wells. In addition, the depth of the pump setting or the pump's intake setting is also extremely useful information. The options vary somewhat depending upon your well type.

For all well types, one option to consider is whether or not the well pump or well pump intake may be lowered to a deeper depth. There are potential downsides to this option, including the possibility that the water may include more sediment than it did at its previous higher setting. There are also limitations as to how far the water level in a well can drop before a suction lift pump (i.e. hydraulic lift or jet pump) is no longer able to lift the water out of the well. Lowering the elevation of a submersible pump will also reduce, to some extent, the flow rate of that pump, assuming that the drawdown water level in the well drops below the elevation that it dropped to at the previous pump setting.

Another option is to deepen the existing well or install a deeper replacement well. The following discussions concern deepening your existing well:

My well is a dug well: You may want to consider replacing your dug well with a conventional bedrock aquifer well or a conventional sand and gravel well (if you are located in an area where a sand and gravel well option is feasible). Deepening an existing dug well is only possible if the bottom of the well is not currently at, or very close to, the elevation of the top of bedrock. In addition, if there is additional depth from the bottom of the dug well to the bedrock surface, if that material consists of too many fine particles such as silt or clay, it may not result in a significant increase in well yield.

My well is a conventional vertical well installed in a sand or sand and gravel aquifer: Sand and gravel aquifer wells are typically not as deep as bedrock aquifer wells. Due to the shallower depths and the lower drilling cost per vertical foot, a replacement well may not cost more than attempting to deepen an existing well. The options should be discussed with your well driller.

My well is a bedrock well: Unlike sand and gravel aquifers, there are a tremendous amount of unknowns involved in drilling a bedrock well. Assuming that the existing water bearing fractures have not gone dry, at a minimum, deepening an existing well will allow for a lower pump or pump intake setting and the added well depth will allow for more storage of water in the added length of open borehole. This may allow the drought-reduced well yield to slowly fill the well during off-peak water use periods so that more water is available during peak use periods. In the best case scenario, the deepened well will have encountered additional water bearing fractures that are below the previous elevation of the bottom of the well. If you are fortunate enough to encounter additional water bearing fractures, they will replace some, or perhaps all, of your lost well yield.

I have a bedrock well, should I hydrofrack it to increase my well yield?

Hydraulic fracturing (a.k.a. hydrofracking) of bedrock drinking water wells is done by injecting pressurized water into the bedrock fractures to clean out and open existing fractures. Unlike the hydrofracking methods used in the oil and natural gas industry, the hydrofracking methods used on drinking water wells don't include the injection of chemical additives. Although hydraulic fracturing (a.k.a. hydrofracking) of a bedrock well is often beneficial for increasing well yield under normal groundwater elevation conditions, if the water level in the bedrock aquifer surrounding your well has

dropped to, or below, the elevation of the lowest water bearing fracture in your well, your chances of increasing your well yield during a drought may be quite low. There may be a very short-term increased well yield related to the volume of water that is injected into your well during the hydrofracking process.

Are there any short-term solutions to having a dry well?

You could consider purchasing or renting a holding tank and have it filled by a bulk water hauler. If you choose to have that water temporarily connected to the plumbing of your home you should check with your local plumbing inspector to find out what local permitting requirements may exist in your municipality. If you connect to the potable water plumbing of your home you should only use water of drinking water quality. Even if the source of the water is of drinking water quality, you should consider using bottled water for drinking, food preparation, and cooking purposes to avoid the risk of ingesting any pathogens that may be present in the water or the holding tank or the temporary hoses or plumbing with which the water comes into contact. The Massachusetts Emergency Management Agency (MEMA) provides a list of bottled and bulk water providers at the following web site: https://www.mass.gov/doc/drought-resources-private-sector-water-suppliers/download

Should I have a tanker truck load of water injected into my well?

This option is not recommended. In most instances, the majority of water injected into the well will flow out of the well screen or bedrock well fractures and most of it will probably not be available for pumping back out of the well. If you have deep bedrock well where the lowest 200 feet or more of the well have no water bearing fractures, then you may obtain some marginal benefit from filling that section of the borehole with injected water, depending upon the depth of your pump or your pump intake. The typical bedrock well boring is approximately 6 inches in diameter. Every vertical foot of 6-inch diameter borehole contains approximately 1.5 gallons of storage. Therefore, every 100 vertical feet of borehole would possibly hold 150 gallons of water (assuming it's not leaking out of the well through dry fractures).

If you choose to use this option, you should only use water of drinking water quality. If the water source is not of drinking water quality, or the tanker and/or piping and pumps used to inject water into your well are not disinfected prior to use, you run a risk of introducing pathogen contamination into your well. You should consider using bottled water for drinking, food preparation, and cooking purposes after injecting water into your well, until you are able to disinfect your well and household plumbing after the drought has ended.

Additional considerations for drilling deeper at coastal or near coastal properties:

Extending the depth of an existing well or drilling a deeper replacement well in a coastal environment will increase the chance that the well may extend below the elevation of the base of the freshwater aquifer. The nature of the typical interface between fresh groundwater and saline groundwater is that

it slopes inland from the coastline such that the further from the coast, the thicker the vertical thickness of the freshwater aquifer and the deeper the depth to the transition to brackish and saline water. This needs to be taken into consideration when drilling a deeper well in a coastal setting. A well driller that has done extensive work in your municipality may have a sense as to how deep a well may be drilled at your property before running a significant risk of encountering brackish or saline water. An additional problem during a drought is that the thickness of the saturated fresh water aquifer will tend to become smaller and the depth to the transition into brackish or saline water will decrease which increases the chance of encountering brackish or saline water. To reduce your chances of pumping brackish or saline water from your well during drought conditions, you should consider taking steps to reduce your water consumption until the drought has ended.

My water tastes bad should I install a water treatment system?

If your water has a metallic taste and/or, if you are experiencing orange, brown, or black staining of sink basins, bathtubs, and toilet bowls, or staining of laundry, it may be the result of increased concentrations of naturally occurring iron and manganese. If so, you may wish to consider having your water tested by a MassDEP Certified Laboratory for iron and manganese. If the manganese concentration is no greater than 0.3 milligrams per liter (mg/L), then it is within the public drinking water limit. There is no health-based upper concentration limit for iron.

If your well is a bedrock well and is located in an area that is known to have increased risk of containing high concentrations of arsenic, you may wish to also have your water tested for arsenic. If the arsenic concentration is no greater than 0.010 mg/L, then it is within the public drinking water limits.

As long as you don’t exceed public drinking water limits, then you will have to do your own cost benefit analysis, based upon your personal preferences, to determine whether you want to install a treatment system to reduce the iron and manganese concentrations to avoid the taste and staining problems for what may be a relatively short-term problem that ends when the drought ends.

If your laboratory analytical results exceed either the manganese (and/or arsenic) public drinking water limits then you should more strongly consider installing treatment to remove those contaminants that exceed the limits. The younger the members of your household (including fetuses), the more strongly you should consider installing a water treatment system. Alternatively, using bottled water for drinking, food preparation, and cooking purposes may be a less costly option for a short-term water quality problem.

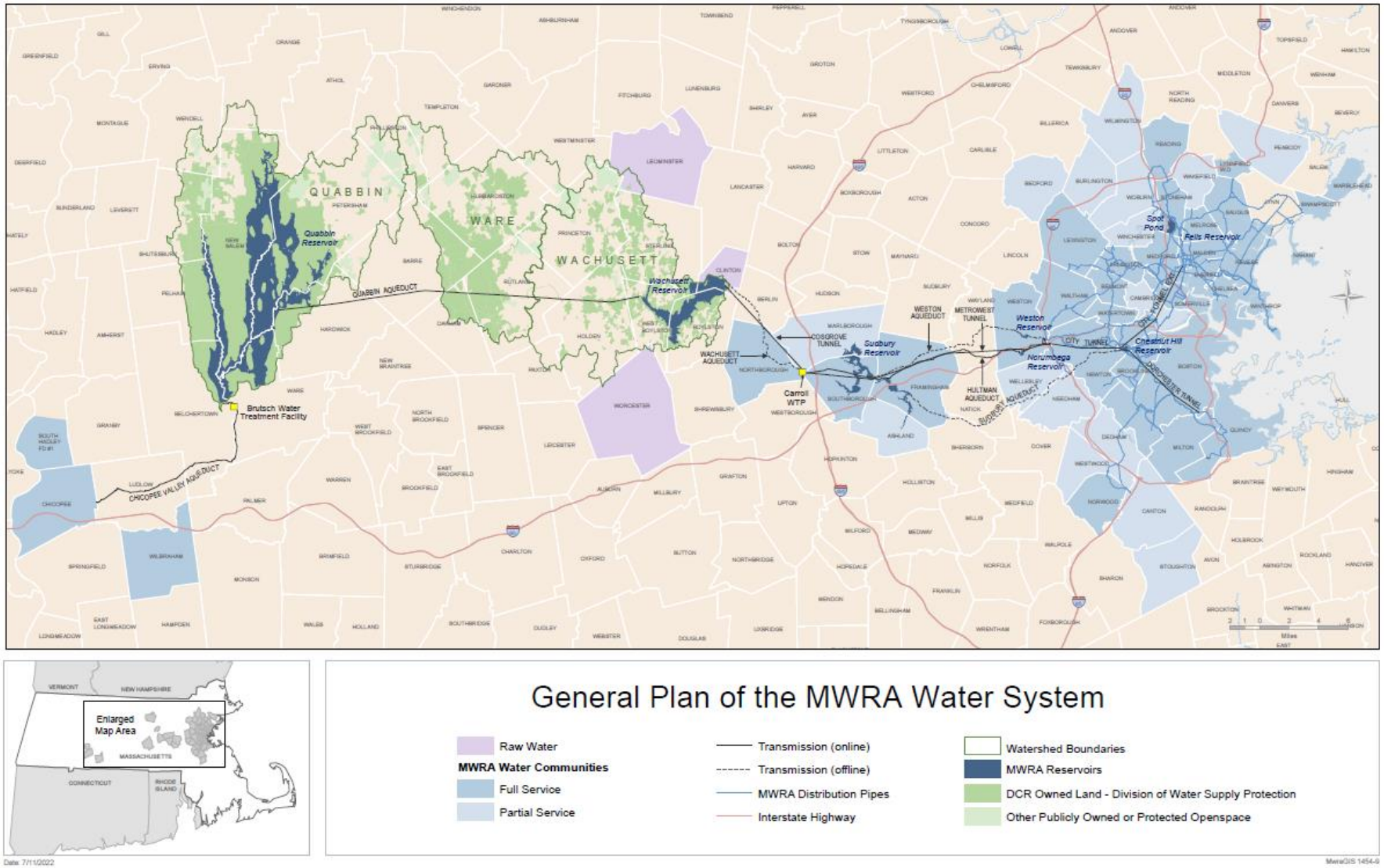
MassDEP always recommends collecting a second round of water samples for laboratory analyses to confirm any contaminant results that exceed a health-based public drinking water limit before you finalize your decision regarding the need for a water treatment system.

I connected a temporary water tank to the plumbing system in my home, or I had my well hydrofracked, or I had bulk water injected into my well. Now that the drought has ended, what should I do?

You should disinfect your well and plumbing system. Running bulk water through your household plumbing or injecting your well with bulk water or hydrofracking fluids has potentially introduced microbial contamination into your well and/or household plumbing. These microbial contaminants could include human pathogens or bacteria that may metabolize iron and manganese in the ground-water, causing incrustation of the well screen or clogging of the pore space or water bearing fractures in the aquifer.

See the well disinfection section starting on page 68 of MassDEP's Private Wells Guidelines. These guidelines are available at: https://www.mass.gov/service-details/private-well-guidelines.

Appendix F: MWRA Water Supply Communities – Fully and Partially Served



List of MWRA Water Supply Communities- Fully and Partially Supplied

Fully Supplied (metro Boston/MetroWest)

1 Arlington
2 Belmont
3 Boston
4 Brookline
5 Chelsea
6 Everett
7 Framingham
8 Lexington
9 Lynnfield Water District
10 Malden
11 Marblehead
12 Medford
13 Melrose
14 Milton
15 Nahant
16 Newton
17 Norwood
18 Quincy
19 Reading
20 Revere
21 Saugus
22 Somerville
23 Southborough
24 Stoneham
25 Swampscott
26 Waltham
27 Watertown
28 Weston
29 Winthrop

Partially Supplied (metro)

1 Ashland
2 Bedford*
3 Burlington
4 Canton
5 Dedham (D-W Water District)
6 Marlborough *
7 Needham
8 Northborough *
9 Peabody
10 Stoughton
11 Wakefield
12 Wellesley
13 Westwood (D-W Water District)
14 Wilmington
15 Winchester
16 Woburn
17 Cambridge (occasionally)
18 Lynn (G.E. Plant only)

Fully Supplied CVA System

1 Chicopee
2 South Hadley FD #1
3 Wilbraham

Raw Water

1 Clinton
2 Leominster (only in emergency)
3 Worcester (occasionally)

Miscellaneous Non-Community Users

1 Hanscom Air Base (via Lexington and Bedford)
2 Westover AFB (via Chicopee)
3 Deer Island WWTP (NTNC PWS)

29 fully supplied (metro Boston/MetroWest)
18 partially supplied (metro)
3 fully supplied CVA
3 raw water
3 Misc Non-Community

Total Community count is 53
Excluding from the count Hanscom, Westover, Westborough SH and Deer Island

* - Northborough and Marlborough are currently fully supplied; Bedford has taken its local source off line for PFAS and is also currently fully supplied

Metro Boston and MetroWest Communities Served by the Carroll Water Treatment Plant
Chicopee Valley Aqueduct Communities served by the Brutsch Treatment Facility
Westborough SH no longer served by MWRA

Appendix G: MassDEP Model Water Use Restriction Bylaw/Ordinance

DEP STRONGLY ADVISES YOU TO CONSULT WITH YOUR TOWN OR CITY COUNSEL TO ENSURE ADOPTION OF AN APPROPRIATE, ENFORCEABLE AND LEGALLY VALID BY-LAW THAT WILL MEET YOUR MUNICIPAL AND/OR DISTRICT NEEDS.

The terms "town" and "bylaw" used throughout this document are intended also to refer to cities and ordinances, respectively. References to Boards of Water Commissioners throughout this model bylaw should be edited by particular cities and towns or water districts or boards to accurately describe the municipal department or water district or board having authority and responsibility for the operation and maintenance of the public water supply.

2018 DEP MODEL OUTDOOR WATER USE BY-LAW/ORDINANCE
Includes optional language for specific restrictions during drought, regulating private wells and/or inground irrigation systems

Section 1: Authority
This By-law is adopted by the Town [or Water District][40] under its police powers pursuant to the Home Rule Amendment of the Massachusetts Constitution, Article LXXXIX, to protect public health and welfare and pursuant to its powers under M.G.L. c. 40, §§ 21 *et. seq*. and implements the Town's authority to regulate water use pursuant to M.G.L. c. 41, § 69B. This by-law also implements the Town's [or Water District's] authority under M.G.L. c. 40, § 41A, conditioned upon a declaration of water supply emergency issued by the Department of Environmental Protection under G.L. c. 21G, §§ 15-17. This by-law is also intended to implement other water conservation requirements of M.G.L. c. 21G, the "Massachusetts Water Management Act" and its regulations promulgated at 310 CMR 36.00.

Section 2: Purpose
The purpose of this by-law is to protect, preserve and maintain the public health, safety, welfare and the environment whenever there is in force a "State of Water Supply Conservation", a "State of Drought" or a "State of Water Supply Emergency" by ensuring an adequate supply of water for drinking and fire protection and to protect the quality and quantity of water in local aquatic habitats such as ponds, rivers and wetlands. This purpose will be accomplished by providing for the imposition and enforcement of any duly implemented restrictions, requirements, provisions or conditions on water use imposed by the Town [or Water District] in accordance with this by-law and/or by the Department of Environmental Protection under its state law authorities.

Section 3: Applicability
All Town [or Water District] residents that are customers of the public water supply system (and private well users[33]) shall be subject to this by-law. This by-law shall be in effect year round.

[40] If the public water supplier in the city or town is an independently authorized entity having its own legislative authority, that authority should be cited in this section rather than the municipal statutory authorities. See also, M.G.L. c 40N "Model Water and Sewer Reorganization Act". The citation to M.G.L. c. 40, § 41A ("Restraint of Use of Water During Emergency") should, however, be retained for both municipal authorities and districts. Both municipal entities and independent entities will be referred herein as "the Town or Water District".

Section 4: Definitions

Agriculture, shall mean farming in all its branches as defined at M.G.L. c. 128, § 1A.[41]

Automatic irrigation system, including sprinklers, shall mean any system for watering vegetation other than a hand-held hose or a bucket.

Nonessential outdoor water use shall mean those uses that are not required:

1. for health or safety reasons;
2. by regulation;
3. for the production of food and fiber;
4. for the maintenance of livestock; or
5. to meet the core functions of a business.

Nonessential outdoor water uses that are subject to mandatory restrictions include:

- irrigation of lawns via sprinklers or automatic irrigation systems;
- washing of vehicles, except in a commercial car wash or as necessary for operator safety or to prevent damage and/or maintain performance of agricultural or construction vehicles or equipment; and
- washing of exterior building surfaces, parking lots, driveways or sidewalks, except as necessary to apply paint, preservatives, stucco, pavement or cement.

Exceptions to nonessential outdoor water uses are:

- irrigation of lawns, gardens, flowers and ornamental plants by means of a hand-held hose controlled by a nozzle or a drip-irrigation system; and
- irrigation with harvested and stored stormwater runoff.

The following outdoor water uses are subject to review and approval by The Town [or Water District], through its Board of Water Commissioners [or Selectmen or Water District Commissioners] or their designee:

- irrigation of public parks and recreation fields outside the hours of 9 AM to 5 PM;
- irrigation to establish replanted or resodded lawn or plantings during the months of May and September;
- irrigation of newly planted lawns (seeded or sodded) in the current calendar year for homes or businesses newly constructed in the previous twelve months; and
- filling of privately owned outdoor pools.

Person shall mean any individual, corporation, trust, partnership, association, agency or authority, or other entity and any officer, employee, group or agent of such persons.

State of Drought shall mean a Drought Advisory, Watch, Warning or Emergency declared by the Secretary of Energy and Environmental Affairs in consultation with the Massachusetts Drought Management Task Force.

[41] This statutory definition includes cultivation of the soil, dairying and the production, cultivation, growing and harvesting of agricultural, aquacultural, floricultural or horticultural commodities as well as forest harvesting, raising livestock inclusive of bees and fur-bearing animals and forestry, lumbering, preparation for market, delivery to storage or market or to carriers to market incidental to an agricultural operation.

State of Water Supply Emergency shall mean a State of Water Supply Emergency declared by the Department of Environmental Protection under M.G.L. c. 21G, §§ 15-17.

State of Water Supply Conservation shall mean a State of Water Supply Conservation declared by the Town [or Water District] pursuant to Section 5 of this by-law.

Water Customers shall mean all persons using the public water supply irrespective of that person's responsibility for payment for use of the water.

Water Users shall mean all persons using the public water supply or using privately-owned wells within the Town [or Water District] boundaries.[42]

Section 5: Declaration of a State of Water Supply Conservation

The Town [or Water District], through its Board of Water Commissioners [or Selectmen or Water District Commissioners] or their designee authorized to act as such:

a) may declare a State of Water Supply Conservation upon a determination that conservation measures are appropriate to ensure an adequate supply of water for drinking and fire protection, to protect the quality and quantity of water in local aquatic habitats such as ponds, rivers and wetlands; and
b) shall declare a State of Water Supply Conservation as necessary to ensure compliance with the Water Management Act.

Upon notification to the public that a State of Water Supply Conservation has been declared, no water customer [water user] shall violate any provision, restriction, requirement or condition of the declaration. The Water Commissioners may designate the [Water Department Superintendent, Town Manager, DPW Director] to declare a State of Water Supply Conservation at any time that conditions warrant. Public notice of a State of Water Conservation shall be given under Section 9 of this by-law before it may be enforced. The applicable restrictions, conditions or requirements shall be included in the public notice.

Section 6: State of Drought[43]

Upon notification to the public that a State of Drought has been declared, no water customer [water user] shall violate any provision, restriction, requirement or condition of the Town's [Water District's] water use

[42] This model by-law has been drafted to provide the option for a Town or Water District to capture the use of privately-owned wells for nonessential outdoor water use. If you do not intend to include privately-owned wells, strike the "water users" definition and replace the term "water users" with "water customers" wherever applicable.

If you intend to include privately-owned wells during times of drought only, include the definitions of both "water customers" and "water users", and use the terms as applicable. If you intend to include both water supply system customers and private well users at all times, strike the "water customers" definition and use the term "water users" throughout.

[43] Section 6: State of Drought has been included in this model by-law to provide the option:

a) to capture the use of privately-owned wells specifically during times of drought when recharge to municipal water sources may be impacted by private well withdrawals, and/or
b) to provide the option of instituting more stringent restrictions during times of drought for water customers and private well users through inclusion of additional restrictions in the required Public Notice of a State of Drought.

If you do not intend to institute specific restrictions during times of drought, strike the State of Drought Definition, State of Drought section, and references to "State of Drought" wherever applicable.

restrictions. Public notice of a State of Drought shall be given under Section 9 of this by-law before it may be enforced. The applicable restrictions, conditions or requirements shall be included in the public notice.

Section 7: Declaration of a State of Water Supply Emergency

Upon notification to the public that a declaration of a State of Water Supply Emergency has been issued by the Department of Environmental Protection, no person shall violate any provision, restriction, requirement, condition of any order approved or issued by the Department for the purpose of bringing about an end to the State of Water Supply Emergency. Public notice of a State of Water Supply Emergency shall be given under Section 9 of this by-law before it may be enforced. The applicable restrictions, conditions or requirements shall be included in the public notice.

Section 8: Restricted Water Uses[44]

A declaration of a State of Water Supply Conservation, State of Drought or State of Water Supply Emergency shall include one or more of the following restrictions, conditions, or requirements limiting nonessential outdoor water use by water customers (water users) as necessary to control the volume of water pumped each day, except as provided as acceptable in Section 4. The applicable restrictions, conditions or requirements shall be included in the public notice required under Section 9.

a) Nonessential outdoor water use days: Nonessential outdoor water use is permitted only on the days per week specified in the State of Water Supply Conservation, State of Drought or a State of Water Supply Emergency and public notice thereof. During a State of Water Supply Conservation, nonessential outdoor water use is restricted as necessary to ensure compliance with the Water Management Act, or for a Town or Water District without a Water Management Act permit, to two days or fewer per week.
b) Nonessential outdoor water use hours: Nonessential outdoor water use is permitted only during the hourly periods specified in the State of Water Supply Conservation, State of Drought or State of Water Supply Emergency and public notice thereof. At a minimum, nonessential outdoor water use is prohibited during the hours from 9AM to 5PM.
c) Nonessential outdoor water use method restriction: Nonessential outdoor water use is restricted to a bucket or hand-held hose controlled by a nozzle.
d) Nonessential outdoor water use ban: Nonessential outdoor water use is prohibited at all times.
e) Automatic irrigation systems, including sprinklers: The use of automatic irrigation systems is prohibited.

Section 9: Public Notification and Notification of DEP

a) Public Notification of a State of Water Supply Conservation or a State of Drought – Notice to the public of all provisions, including all restrictions, requirements and conditions imposed by the Town [Water District] as part of a State of Water Supply Conservation or a State of Drought shall be made as soon as possible, but no later than 48 hours following the declaration of a State Water Supply Conservation or State of Drought by publication in a newspaper of general circulation within the Town and by signage on major roadways or intersections. Notification may also include email, web sites, public service announcements on local media, reverse 911 calls or other such means reasonably calculated to reach and inform all water customers [water users].

[44] Many Water Management permits include specific language restricting outdoor water uses. Each town, city or district should consult their Water Management permit to ensure consistency with permit requirements.

b) Public Notification of a State of Water Supply Emergency – Notice to the public of all provisions, including all restrictions, requirements and conditions imposed by a State of Water Supply Emergency declared by the Department shall be made as soon as possible, but not later than 48 hours after the public water system receives notice of the Department's declaration of a State of Water Supply Emergency, by publication in a newspaper of general circulation with the Town and by signage on major roadways or intersections. Notification may also include email, Web sites, public service announcements on local media, reverse 911 calls or other such means reasonably calculated to reach and inform all water customers [water users] of the State of Water Supply Emergency.

c) Any restriction imposed pursuant to Section 5 or Section 6 or in the Department's State of Water Supply Emergency or Order shall not be effective until notification to the public is provided.

d) Notification of DEP: Submittal of MassDEP's form "Notification of Water Use Restriction" shall be provided to the Massachusetts Department of Environmental Protection within 14 days of the effective date of the restrictions, per MassDEP regulations (310 CMR 22.15(8)).

Section 10: Termination of a State of Water Supply Conservation; Notice
A State of Water Supply Conservation may be terminated by a majority vote of the Board of Water Commissioners or by decision of their designee upon a determination by either or both of them that the conditions requiring the State of Water Supply Conservation no longer exist, or in accordance with the Water Management Act permit conditions. Public notification of the termination of a State of Water Supply Conservation shall be given in the same manner as is required in Section 9a for notice of its imposition.

Section 11: Termination of a State of Drought; Notice
Upon notification to the Town [Water Commissioners or their designee or to the Water District] that the declaration of a State of Drought has been terminated by the Secretary of Energy and Environmental Affairs, the public will be notified of the termination in the same manner as is required in Section 9a for notice of its imposition.

Section 12: Termination of a State of Water Supply Emergency; Notice
Upon notification to the Town [to the Water Commissioners or their designee or to the Water District] that the declaration of a State of Water Supply Emergency has been terminated by the Department of Environmental Protection, the public will be notified of the termination in the same manner as is required in Section 9b for notice of its imposition.

Section 13: Penalties
The Town [or Water District] through its Water Commissioners or their designee including the water superintendent, building inspector and/or local police may enforce this by-law. Any person violating this by-law shall be liable to the Town in the amounts listed below:

1) First violation: Warning
2) Second violation: $____
3) Third violation: $____
4) Fourth and subsequent violations: $_____

Each day of violation shall constitute a separate offense. Fines shall be recovered by complaint before the District Court, or by non-criminal disposition in accordance with section 21D of chapter 40 of the general laws. For purposes of non-criminal disposition, the enforcing person shall be any police officer of the town or the water superintendent or the superintendent's designee. If a State of Water Supply Emergency has been declared the Water Commissioners may, in accordance with G.L. c. 40, § 41A, shut off the water at the meter or the curb stop.

Section 14: Severability

The invalidity of any portion or provision of this by-law shall not invalidate any other portion or provision thereof.

Section 15: Controls on In-Ground Irrigation Systems[45]

Subsection XX.1 Registration and Installation

a) All new and existing in-ground irrigation systems shall be registered with the Town's Board of Water Commissioners in such form and manner as they shall determine. A fee may be charged for this registration. Registration fees shall be set by the Board of Water Commissioners.[46] The Board may require inspection of the irrigation system.

b) All in-ground irrigation systems shall be equipped with a timing device that can be set to make the system conform to the Town's [or Water District's] nonessential outdoor water use restrictions. Whenever outdoor water use restrictions are in force, the timing device must be set to conform to the daily and hourly nonessential outdoor water use restrictions.

c) All in-ground irrigation systems shall be plumbed so that a shutoff valve is located outside the building and situated so that it may be shut off if found to be in violation of this by-law. For the purposes of this section only, Police Officers of the Town and/or Agents of the Board of Water Commissioners may enter upon any property to enforce this section.[47]

Subsection XX.2 Soil Moisture-Sensor Devices

a) All in-ground irrigation systems installed in the Town [or Water District] after the date of effect of this bylaw shall be equipped with a soil moisture-sensor device, approved by the Board of Water Commissioners, to prevent the system from starting automatically when not needed. Proof of this installation shall be provided to the Board of Water Commissioners at the time of registration.

b) Any service or repair to an existing in-ground irrigation system shall include the installation of an approved moisture-sensor device, if the same is not already installed and in good working condition.

[45] This section is intended to govern automatic irrigation systems and may be passed as part of a water use restriction bylaw or separately. It is included here for convenience.

[46] Be sure that fees charged avoid characterization as a tax under the principles of Emerson College vs. City of Boston, 391 Mass. 415, 424-426 (1984) by ensuring that they are directly related to and are used to pay for the services provided (inspection, etc.).

[47] Depending on the circumstances of a particular case, a warrant may also be required to enter onto private property.

Proof of this installation shall be provided to the Board of Water Commissioners at the time of installation.

c) The Board of Water Commissioners shall maintain a list, available to the public, of approved soil moisture-sensor devices.

Subsection XX.3 Backflow Prevention

a) All in-ground irrigation systems connected to the municipal water system in the Town [or Water District] shall be protected from backflow events by the installation of a backflow prevention device approved by the Board of Water Commissioners. Each backflow prevention device shall be registered with the Board of Water Commissioners. [A fee may be charged for this registration. Registration fees shall be set by the Board of Water Commissioners.]

b) The Board of Water Commissioners shall maintain a list, available to the public, of approved backflow prevention devices. Refer to Table 22-1 in 310 CMR 22.22 for the recommended backflow protection for irrigation systems.

c) Each backflow prevention device shall be installed in accordance with 310 CMR 22.22 and the manufacturer's instructions. Each device shall be tested upon its installation and annually thereafter. A Massachusetts Certified Backflow Device Tester shall perform all testing. Copies of results of all testing shall be filed with the Board of Water Commissioners or Water Department.

Appendix H: Massachusetts Drought History Summary

Droughts in Massachusetts Based on Instrumental Records

This table reflects only the time period of recorded history going back to the late 1800s. Newby et. al. (2014) reconstructed centennial and longer paleohydrologic changes in the Northeastern United States. They concluded that the condition of water resources historically experienced are at high water levels relative to pre-recorded history and there is a low probability of these "wet" conditions remaining at current levels in coming decades and centuries.

Date	Area affected	Recurrence interval (years)	Remarks	Reference
1879-83	–	–	Kinnison 1931 referenced these periods as two of three worst droughts on record in 1931, the third being the then current drought of 1929-1932.	Kinnison 1931
1908-12	–	–		
1929-32	Statewide	10 to >50	Water-supply sources altered in 13 communities. Multistate.	USGS 1989
1939-44	Statewide	15 to >50	More severe in eastern and extreme western Massachusetts. Multistate.	USGS 1989
1957-59	Statewide	5 to 25	Record low water levels in observation wells, northeastern Massachusetts.	USGS 1989
1961-69	Statewide	35 to >50	Water-supply shortages common. Record drought. Multistate.	USGS 1989
1980-83	Statewide	10 to 30	Most severe in Ipswich and Taunton River basins; minimal effect in Nashua River basin. Multistate.	USGS 1989
1985-88	Housatonic River Basin	25	Duration and severity as yet unknown. Streamflow showed mixed trends elsewhere.	USGS 1989
1995	–	“moderate”	Based on statewide average precipitation	DMP 2013
1998-1999	–	“worst in a decade”	Based on statewide average precipitation	DMP 2013
Dec 2001 - Jan 2003	Statewide	–	Level 2 drought was reached statewide for several months	EEA 2001-2003
Oct 2007 - Mar 2008	Connecticut River Valley, Central, Northeast, and Southeast regions	–	Level 1 drought	EEA 2007-2008
Aug 2010 - Nov 2010	Connecticut River Valley, Central and Northeast regions	–	Level 1 drought	EEA 2010
Oct 2014 - Nov 2014	Southeast and Cape & Islands regions	–	Level 1 drought	EEA 2014

Date	Area affected	Recurrence interval (years)	Remarks	Reference
Jul 2016 - Apr 2017	Statewide	–	Level 3 drought	EEA 2016-2017
Sep 2019	Connecticut River Valley	–	Level 1 drought	EEA 2019
May 2020-Nov 2020	Statewide	–	Level 2 in all regions except the Southeast, Charles basin (Northeast) and Millers (Central) basin at Level 3	EEA 2020
Feb 2021 – Oct 2021	Statewide except Islands region	–	Level 1 in all affected regions except the Southeast at Level 2	EEA 2021
Apr 2022-Jan 2022	Statewide	–	Level 2 for Western and Islands and Level 3 for Cape Cod, Northeast, Southeast, Central, and Connecticut River Valley	EEA 2022
May 2023	Western and Cape Cod regions	–	Level 1 for Western and Cape Cod regions	EEA 2023
Nov-Dec 2023	Islands region	–	Level 2 drought	EEA 2023

Notes: − means data is not available; Drought levels indicated are based on 4 drought levels.

Kinnison, H.B. 1931. The 1929-1930 Drought in New England. Journal of the New England Water Works Association, v. 45, no. 2, p. 145-163. Kinnison compared runoff for the three periods from two regulated lake basins; runoff during the 1908-12 and 1929-30 droughts was about equal to and less than the runoff during the 1879-83 drought. Later analysis indicated that the 1929-30 drought extended for two more years and thus became the 1929-32 drought.

Newby, P.E.; Shuman, B.N.; Donnelly, J.P.; Karnauskas, K.B.; Marsicek, J. 2014. Centennial-to-millennial hydrologic trends and variability along the North Atlantic Coast, USA, during the Holocene. *Geophysical Research Letters:* 4300–4307 (https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2014GL060183)

USGS (U.S. Geological Survey). 1989. Water-Supply Paper 2375: National Water Summary 1988-89--Floods and Droughts: Massachusetts (https://pubs.er.usgs.gov/publication/wsp2375). USGS 1989 determined dry periods from streamflow and precipitation records. Dry periods that exceeded a recurrence interval of 10 years were deemed droughts.

DMP 2013: Massachusetts Executive Office of Energy and Environmental Affairs and Massachusetts Emergency Management Agency. 2013. Massachusetts Drought Management Plan. The plan analyzed precipitation data as a statewide average of stations.

EEA 2001-2023. Droughts as declared by the Secretary of Energy and Environmental Affairs.

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