Martins Brook, North Reading (8/31/16)
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MASSACHUSETTS
DROUGHT RETROSPECTIVE
2016-2017

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INTRODUCTION

Drought can be characterized as a dry (moisture-deficient) condition that is a shift away from normal conditions for some prolonged period of time and that causes hydrologic imbalance and impacts to the natural and human environment. It is a period of unusually persistent dry weather that continues long enough to cause serious problems such as crop damage, water supply shortages, and habitat loss. The severity of the drought depends upon how acute the water deficit is, the duration, and the size of the affected area.

Massachusetts has suffered several major statewide droughts during the last century, of which the most significant occurred in 1929-1932; 1939-1944; 1961-1969; and 1980-1983. The nine-year drought from 1961-1969 is the most severe on record in Massachusetts. The driest year since record-keeping began in 1895 occurred during this time when the average precipitation received statewide was 29.37 inches in 1965, as compared to the average annual of 48 inches. Due to the longevity of this drought, water use restrictions were instituted, and numerous communities began utilizing emergency water supplies. Several communities' water supplies reached a critical threshold where there was less than 90 days of surface water supply available and groundwater pumping had to decrease.

More recently, Massachusetts experienced a significant drought in 2016 and 2017 which is described in this report, including the progression of the drought, drought-related impacts to various sectors, and a review of the state's response. Data for the seven drought indicators described in the 2013 Massachusetts Drought Management Plan are also presented and summarized.

Massachusetts Drought Management Task Force (DMTF), co-chaired by the Executive Office of Energy and Environmental Affairs (EEA) and Massachusetts Emergency Management Agency (MEMA), consists of officials from state and federal agencies as well as certain professional organizations that are responsible for areas likely to be affected by drought conditions. The DMTF also includes representatives of agencies such as the United States Geological Survey (USGS) and National Weather Service (NWS) that provide data for assessing the severity of drought conditions, as well as representatives of agencies that have the ability to respond to drought conditions, such as public health and safety officials. The DMTF is staffed by staff to the Massachusetts Water Resources Commission - hydrologists and water resource specialists housed at the Office of Water Resources at the Department of Conservation and Recreation (DCR).

The role of the DMTF is to facilitate communication and situational awareness, provide a comprehensive assessment of the situation, develop recommendations on drought level to the Secretary of EEA, and recommend potential responses to drought situations. Members also provide their professional judgement on current conditions, on-the-ground impacts, relative severity of drought indices, and forecast of hydrologic conditions. Therefore, the primary responsibilities of the Task Force are to gather the information necessary to assess the impact of dry conditions and to make recommendations to the Secretary of EEA, the Secretary of Public Safety and Security, and others as needed. In the event of a severe drought, the DMTF makes recommendations for declaring emergencies and for developing and implementing emergency responses.

Massachusetts Drought Management Plan

The Massachusetts Drought Management Task Force utilizes the Massachusetts Drought Management Plan (DMP) to inform its recommendations and actions. The DMP was developed by EEA and MEMA to outline a methodology for determining a drought, and to guide state activities in response to droughts and extended periods of dry weather. The plan outlines the responsibilities of various state and federal agencies, the lines of communication to be used, the general sequence of actions to be followed based on the severity of the situation, and the

Table 1. Drought level thresholds for the drought indices.
Source: Massachusetts Drought Management Plan, May 2013

Drought Level	Standardized Precipitation Index	Crop Moisture Index*	Keetch-Byram Drought Index*	Precipitation	Groundwater	Streamflow	Reservoir***
Normal	3-month > -1.5 **or** 6-month > -1.0 **or** 12-month > -1.0	0.0 to -1.0 slightly dry	< 200	1 month below normal	2 consecutive months below normal**	1 month below normal**	Reservoir levels at or near normal for the time of year
Advisory	3-month = -1.5 to -2.0 **or** 6-month = -1.0 to -1.5 **or** 12-month = -1.0 to –1.5	-1.0 to -1.9 abnormally dry	200-400	2 month cumulative below 65% of normal	3 consecutive months below normal**	At least 2 out of 3 consecutive months below normal**	Small index Reservoirs below normal
Watch	3-month < -2.0 **or** 6-month = -1.5 to -3.0 **or** 12-month = -1.5 to -2.0	-2.0 to –2.9 excessively dry	400-600	1 of the following criteria met: 3 month cum. < 65% **or** 6 month cum. < 70% **or** 12 month cum. < 70%	4-5 consecutive months below normal**	At least 4 out of 5 consecutive months below normal**	Medium index Reservoirs below normal
Warning	6-month < -3.0 **or** 12-month = -2.0 to -2.5	< -2.9 severely dry	600-800	1 of the following criteria met: 3 month cum. < 65% and 6 month cum. <65%, **or** 6 month cum. <65% and 12 month cum. <65%, **or** 3 month cum. <65% and 12 month cum. <65%	6-7 consecutive months below normal**	At least 6 out of 7 consecutive months below normal**	Large index reservoirs below normal
Emergency	12-month < -2.5	<-2.9 severely dry	600-800	Same criteria as Warning and previous month was Warning or Emergency	>8 months below normal**	>7 months below normal**	Continuation of previous month's conditions

* The Crop Moisture Index is subject to frequent change. The drought level for this indicator is determined based on the repeated or extended occurrence at a given level.

** Below normal for groundwater and streamflow are defined as being within the lowest 25th percentile of the period of record.

*** Water suppliers should be consulted to determine if below normal reservoir conditions are due to operational issues.

emergency powers available to local and state government agencies[1].

Drought Determination and Indices

The Commonwealth uses a multi-index approach to determine the severity of a given drought or extended period of dry conditions. The indices are comprised of two precipitation metrics and one metric each for streamflow, groundwater, reservoirs, Keetch-Byram Drought Index, and Crop Moisture Index.

The DMTF determines drought level based on the number of indices that have reached a given drought level. Drought levels are declared on a regional basis for each of six drought regions in Massachusetts: Northeast, Southeast, Central, Connecticut River Valley, Western, and Cape Cod and Islands[2]. A majority of the indices need to be triggered in a region in order for a drought designation for that region to be established or changed to another level. Refer to Table 1 for the drought level thresholds for the drought indices.

Although typically a majority of the indices are used to determine the drought level in any region, in order to determine an end to the drought and a return to a normal status, groundwater levels must be in the normal range and/or one of two precipitation measures must be met. This is because precipitation and groundwater levels are the two factors that have the greatest long-term impact on streamflow, water supply, reservoir levels, soil moisture and potential for forest fires. Precipitation is a key factor because it is the overall driver for improving conditions while groundwater levels are good indicators of long-term recovery to normal conditions as they respond slowly to improving conditions. Indices other than groundwater and precipitation tend to return to normal at some point during the year. For example, the Crop Moisture Index returns to normal at the end of the growing season while the Fire Danger season ends when snowfall begins.

[1] The 2013 Massachusetts Drought Management Plan (DMP) was in use at the time of the 2016-2017 drought. It should be noted that the DMP was substantially updated and revised in 2019. Revisions included changes to the drought region boundaries and methods of calculating drought indices.

[2] In the 2019 DMP, the Cape Cod and Islands drought region was split into two separate drought regions.

The Drought of 2016 - 2017

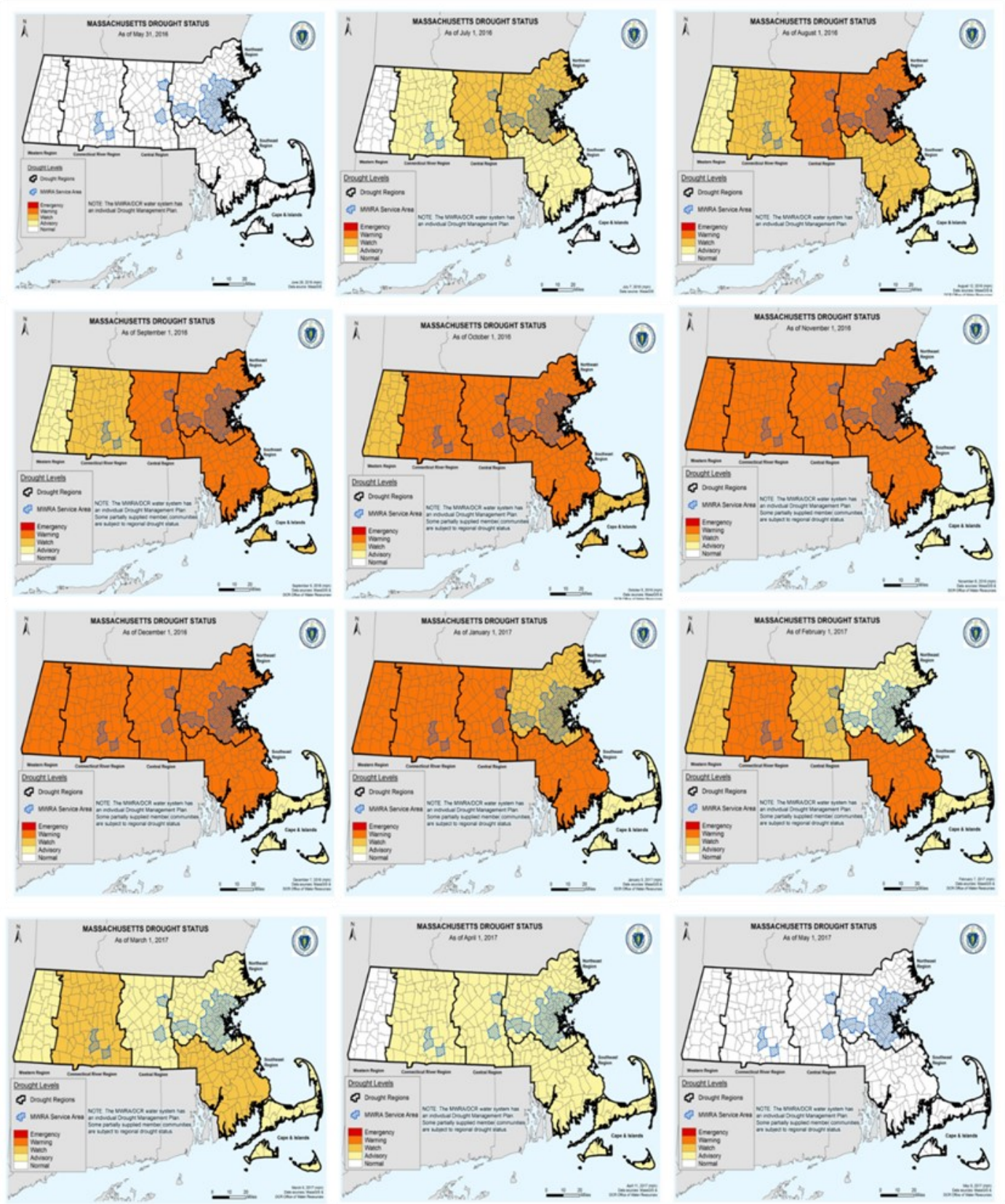


Figure 1. Series of maps displaying the drought's progression.

2016-2017 DROUGHT IN PERSPECTIVE

Onset and Summary

The 2016-2017 drought was preceded by drying conditions that began in 2015. While normal precipitation was received in most of the state in 2014, with a total of 50.10 inches, the total annual precipitation in Massachusetts during the 2015 calendar year was 15 percent below normal at 41.39 inches.

Precipitation was alternately above and below normal levels between the seasons of 2015 with the average precipitation during the winter months being 15 percent above normal while the spring months showed a deficit in precipitation of about 50 percent (Table 2) making it the fourth driest spring in Massachusetts since record-keeping began in 1895. The blizzard of January 2015 brought above normal snowfall to the region with Boston receiving more than 2 feet, its greatest amount of snowfall in 123 years[3] and a maximum of 36.0 in. being recorded in Auburn, Hudson, and Lunenburg. However, the snow-water content from the event was minimal, thus not contributing much recharge during the snowmelt season.

The second half of 2015 brought below-normal precipitation to most of Massachusetts with higher-than-average temperatures through much of this period[4]. This timeframe coincided with a strong El Niño, which often brings dry and warm conditions to the Northeast during the fall and early winter months. However, while most strong El Niños in the past have brought significant flooding rainfall during the spring, this did not happen during the following spring of 2016[5]. The persistent high pressure and jet stream passing north of New England also inhibited any tropical systems from moving towards or into the area.

Warm and dry conditions continued through September 2016 with a prolonged period of unseasonably dry and hot conditions throughout the summer which was the fifth warmest and top driest on record for Boston. Precipitation received from November 2016 through February 2017 was not sufficient to substantially ease the drought. According to the NWS, it took until April- May 2017 to see a notable improvement in rainfall.

Table 2. Average precipitation and departure from normal during the seasons of 2015 .

Season	Average precipitation (inches)	Deviation from normal
Winter 2015	12.63	+ 15 %
Spring 2015	6.35	- 50 %
Summer 2015	12.67	+ 4 %
Fall 2015	10.53	-18 %

An analysis of statewide precipitation ranks for the water year[6] of October 2015 through September 2016 by the National Centers for Environmental Information (NCEI) determined that the 2016 water year was the thirteenth driest on record, and the second warmest on record for MA overall.

Table 3. 2016 water year precipitation, departure from normal, and ranking with respect to driest water years on record. Numbers from NCEI.

Location	2016 Water Year Precipitation (Inches)	Rainfall Departure (Inches)	Ranking Driest Water Year on Record (Preliminary)	Earliest Year of Record
Boston MA	29.73”	-14.04”	7th Driest	1872
Amherst MA	33.78”	-12.24”	At least 9th Driest	1902
Lawrence MA	29.46”	-22.15”	At least 6th Driest	1893
Hingham MA	36.22”	-16.01”	4th Driest	1960

[3]Massey and Verdi, 2015

[4]For Boston, the months of August, September, November and December in 2015 all ranked as one of the top ten warmest on record.

[5]Interestingly, the only other spring on record that had a strong El Niño with no flooding in MA was during the spring of 1966, in the midst of the 1960s drought, the state’s drought of record.

[6]Water year is defined as the 12-month period starting October 1, through September 30 of the following year.

Table 3 shows some water-year specifics for a few long-term weather stations.

If just streamflow and groundwater records are considered, the 2016-2017 drought was the worst to affect the state since the drought of 1961-1969. Although the drought from 1961-1969 is still considered to be the worst on record, multiple locations across the state saw groundwater and streamflow levels reaching record low levels in 2016.

Drought Indices

Due to dry conditions that were beginning to trigger various drought indices outlined in the DMP (Table 4), the Drought Management Task Force was convened on July 7, 2016 [7]. Based on the hydrologic conditions in June and the recommendation of the DMTF, on July 8, 2016, the EEA Secretary declared a Drought Watch for the Central and Northeast drought regions and a Drought Advisory for the Southeast and Connecticut River Valley drought regions.

Precipitation

Precipitation is the measure of moisture that falls to the ground in the form of rain or snow. Two different precipitation indices were used during the 2016-2017 drought, as defined by the 2013 DMP: the Standardized Precipitation Index (SPI) and percent-of–normal index. The SPI calculates how many standard deviations actual precipitation amounts are from the average over 3-, 6-, and 12-month time periods. Depending on the time frame, drought levels begin to be triggered at 1 to 1.5 standard deviations below average. The percent-of-normal index calculates, over 2-, 3-, 6-, and 12-month time periods, the actual precipitation received as compared to the average historical precipitation, expressed as a percentage. Drought levels begin to be triggered when precipitation falls below 65% or 70% of normal (average) precipitation for a given time period.

Both precipitation indices are calculated using a subset of the precipitation monitoring stations located in each drought region. Observers at the stations report monthly precipitation totals either to DCR or to NWS. Refer to Figure 2 for a map of precipitation stations.

Table 4. Summary of drought indices for June 2016 conditions.

DROUGHT INDICATOR	DROUGHT REGIONS					
	Western	**CT River Valley**	**Central**	**Northeast**	**Southeast**	**Cape and Islands**
Standardized Precipitation Index (SPI)	Normal	Advisory	Advisory	Advisory	Normal	Normal
Precipitation % Below Normal	Normal	Watch	Watch	Watch	Normal	Advisory
Streamflow Months Below Normal	Advisory	Advisory	Watch	Watch	Normal	Not Applicable
Groundwater Months Below Normal	Watch	Advisory	Advisory	Advisory	Advisory	Normal
Size of Reservoir Below Normal	Normal	Normal	Watch	Watch	Watch	Normal
Crop Moisture Index	Normal	Advisory	Advisory	Advisory	Advisory	Advisory
Keetch-Byram Drought Index	Advisory	Advisory	Watch	Advisory	Advisory	Advisory

Normal | Advisory | Watch | Warning | Emergency

[7] During the 2016–2017 drought, the indices and methods outlined in the 2013 version of the Massachusetts Drought Management Plan were used

Below-normal precipitation persisted throughout most of 2016 (Table 5). The winter was a wetter period with average statewide precipitation totals of 9 percent above normal followed by precipitation 29% below normal in the spring. According to the Northeast Regional Climate Center (NRCC), the average temperature during the springtime was 47.7°F, making it the tenth warmest since record-keeping began in 1895. Exceptionally dry conditions continued through the summer months, with rainfall 41 percent below normal levels. Notably, the eastern portion of the state, including Cape Cod and the islands of Martha's Vineyard and Nantucket, averaged 5.11 in. of precipitation, which was 5.94 in. (54 percent) below normal, making this the third driest summer since record-keeping began in 1895 according to the NRCC. Persistently dry conditions continued through the autumn months, during which the most severe impacts to the precipitation indices were observed. In September 2016, the Northeast Region reached the Emergency drought level after which the most severe impacts to the precipitation indices were observed. In September 2016, the Northeast Region reached the Emergency drought level after receiving below 65% average precipitation for the three- and six-month time periods for two consecutive months.

Table 5. Average statewide precipitation by season for the years 2016-2017.

Season	Average Precipitation (inches)	Deviation from normal
Winter 2016	11.99 in.	+ 9 %
Spring 2016	8.96 in.	- 29 %
Summer 2016	7.22 in.	- 41 %
Autumn 2016	9.85 in.	- 23 %
Winter 2017	10.37 in.,	- 6 %
Spring 2017	14.52 in.	+15 %
Summer 2017	10.83 in.	- 11 %
Autumn 2017	12.18 in.	- 5 %

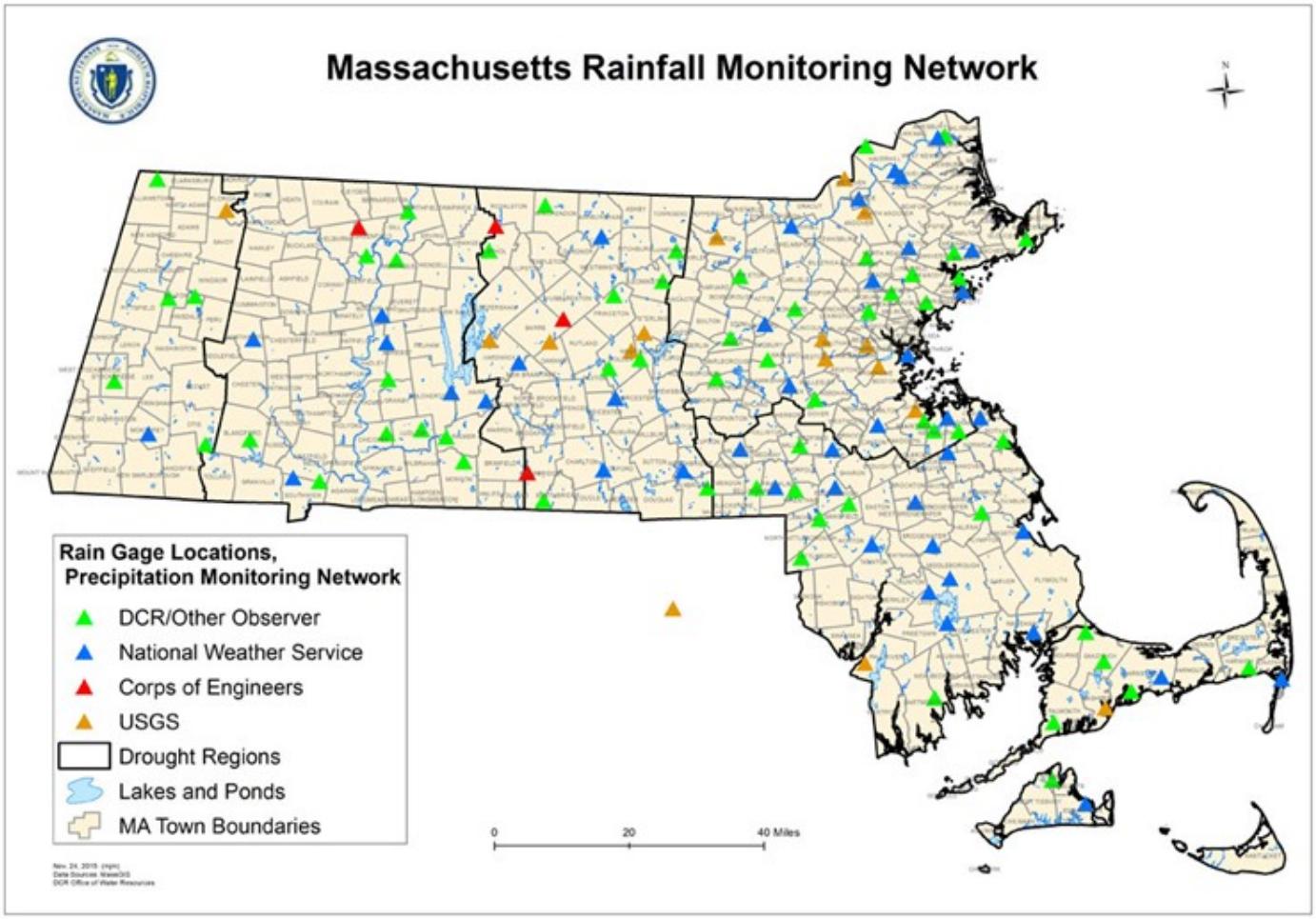


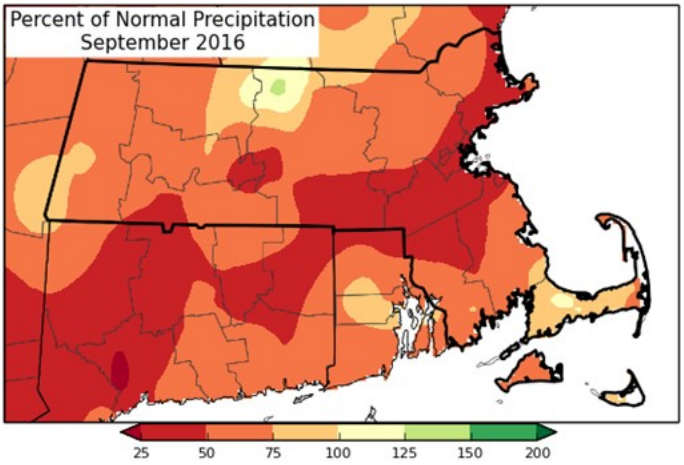
Figure 2. Map of Massachusetts statewide precipitation stations.

Table 6 displays the statewide precipitation average during the drought by year, the departure from normal, and ranking in terms of driest years. The year 2016 was the driest calendar year of the 2016-2017 drought and the 10th driest year on record, with a rainfall deficit greater than 11 inches (Data from NRCC).

Table 7 (page 8) shows the drought level for each region's precipitation indices by month from 2015 through 2017. In accordance with the methodology used at that time, the West Region did not experience below-normal precipitation throughout the duration of the declared drought, though it did have a precipitation deficit in spring 2015. Table 7 also illustrates how quickly conditions deteriorated. The indices showed rapid progression through the levels of drought. The CT River Valley, Central, and Northeast regions went from Normal to Watch in one month, skipping over the Advisory level. The Northeast and Southeast regions both went from Normal to Warning levels in just three months, and the Northeast Region went from Normal conditions to Emergency conditions in just four months. Precipitation deficits were also sustained.

The total annual precipitation in 2016 was 36.83 in. which was 11.73 in. (24 percent) below normal, making it the 10th driest year in Massachusetts since record-keeping began in 1895. Figure 3 illustrates precipitation lows in September 2016.

Figure 3. September 2016 precipitation. Source: NRCC.



Rainfall amounts began to increase in the spring months of 2017, indicating a break in drought conditions. With total springtime precipitation at 1.91 in. (15 percent) above normal, it was the thirteenth wettest spring in Massachusetts since record-keeping began in 1895, and the wettest quarter during the duration of the drought. Precipitation during the summer and autumn period was below normal with the total annual precipitation for 2017 falling 1.67 in. (3 percent) below normal. 2017 showed a recovery from drought despite the precipitation annual deficit.

Table 6. Statewide annual averages for precipitation (Jan-Dec) .

Year	Average Annual Precipitation (Inches)	Departure from Normal (Inches)	% Normal	Rank
2015	41.39	-7.17	85%	31
2016	36.83	-11.73	76%	10
2017	46.82	-1.74	96%	79

Streamflow

Hydrologic impacts of the drought and its severity were evident in data collected at many rivers throughout Massachusetts. During the drought, streamflows seldom reached normal status and were most severely impacted in the 2016 calendar year before rebounding to approximately normal status in 2017.

Streamflow drought-level decisions by the DMTF were based on the number of consecutive months that streamflow levels were below normal (defined as the lowest 25% of the period of record for the respective months). Table 8 (page 10) shows the drought levels for the streamflow index for each region by month from 2015 through 2017. The streamflow index has not historically been calculated for the Cape & Islands drought region. Each region reached at least Warning level during the 2016-2017 drought, with three of the five regions (CT River Valley, Central, and Southeast) reaching Emergency level. All regions were back to normal conditions by February 2017. Conditions were very poor in September 2016 when 15 individual streamflow gages were at period-of-record low flows.

Table 7. Monthly precipitation index drought level by region from 2015 through 2017.

2015-2017 Precipitation						
	Western	CT River Valley	Central	Northeast	Southeast	Cape & Islands
Jan-15	Normal	Normal	Normal	Normal	Normal	Normal
Feb-15	Normal	Normal	Normal	Normal	Normal	Normal
Mar-15	Advisory	Advisory	Normal	Normal	Normal	Normal
Apr-15	Watch	Advisory	Normal	Advisory	Normal	Normal
May-15	Watch	Watch	Watch	Watch	Watch	Advisory
Jun-15	Normal	Normal	Normal	Normal	Normal	Watch
Jul-15	Normal	Normal	Normal	Normal	Normal	Watch
Aug-15	Normal	Normal	Normal	Normal	Normal	Advisory
Sep-15	Normal	Normal	Normal	Normal	Normal	Watch
Oct-15	Normal	Normal	Normal	Normal	Normal	Normal
Nov-15	Normal	Normal	Advisory	Advisory	Normal	Normal
Dec-15	Normal	Normal	Normal	Normal	Normal	Normal
Jan-16	Normal	Normal	Advisory	Normal	Normal	Normal
Feb-16	Normal	Normal	Advisory	Normal	Normal	Normal
Mar-16	Normal	Normal	Normal	Normal	Normal	Normal
Apr-16	Normal	Normal	Normal	Normal	Normal	Normal
May-16	Normal	Normal	Normal	Normal	Normal	Normal
Jun-16	Normal	Watch	Watch	Watch	Normal	Advisory
Jul-16	Normal	Watch	Watch	Watch	Advisory	Advisory
Aug-16	Normal	Watch	Advisory	Warning	Watch	Watch
Sep-16	Normal	Watch	Watch	Emergency	Warning	Watch
Oct-16	Normal	Watch	Advisory	Advisory	Normal	Advisory
Nov-16	Normal	Watch	Advisory	Advisory	Advisory	Watch
Dec-16	Normal	Watch	Advisory	Advisory	Advisory	Advisory
Jan-17	Normal	Advisory	Advisory	Advisory	Normal	Normal
Feb-17	Normal	Watch	Advisory	Advisory	Advisory	Advisory
Mar-17	Normal	Watch	Advisory	Advisory	Advisory	Advisory
Apr-17	Normal	Advisory	Advisory	Normal	Normal	Normal
May-17	Normal	Normal	Normal	Normal	Normal	Normal
Jun-17	Normal	Normal	Normal	Normal	Normal	Normal
Jul-17	Normal	Normal	Normal	Normal	Normal	Normal
Aug-17	Normal	Normal	Normal	Normal	Normal	Normal
Sep-17	Normal	Normal	Normal	Normal	Advisory	Normal
Oct-17	Normal	Normal	Normal	Normal	Normal	Normal
Nov-17	Normal	Normal	Normal	Normal	Normal	Normal
Dec-17	Advisory	Advisory	Advisory	Advisory	Normal	Advisory
Jan-18	Normal	Normal	Normal	Normal	Normal	Normal

Normal	Advisory	Watch	Warning	Emergency

In October, two gages were at record lows. Streamflow impacts in terms of drought level were most severe in November 2016, when two regions were at Emergency levels, having experienced below-normal conditions for more than seven consecutive months, and two streamflow gages, at Sevenmile River near Spencer and Green River near Colrain, were at their period-of-record low-flow values (see Figures 4 & 5 for more detail). In December 2016, there was just one gage at a record low.

Table 9 (page 11) shows the results of an analysis of impacts of the 2016-2017 drought on streamflow at eight representative streamflow-gaging stations that were selected based on longevity of data at each station, as well as geographic distribution throughout the state. In 2016, the severity of the drought was apparent as the annual streamflows for all eight streamflow-gaging stations used in this analysis were well under the period-of-record average, several of the stations recorded record-low 7-day-low streamflow, and three stations set records for lowest instantaneous streamflow.

Annual streamflow at the eight representative stations during 2016 ranged from 44 percent of average at Ipswich River near Ipswich to 70 percent of average at Housatonic River near Great Barrington (Table 9).

Figure 4. November 2016 average monthly streamflow map (USGS).

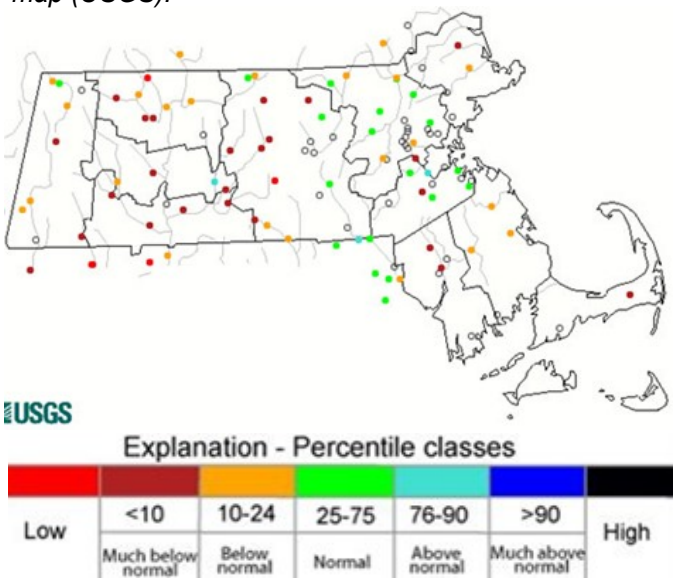


Figure 5. October and November 2016 average daily streamflow (USGS).

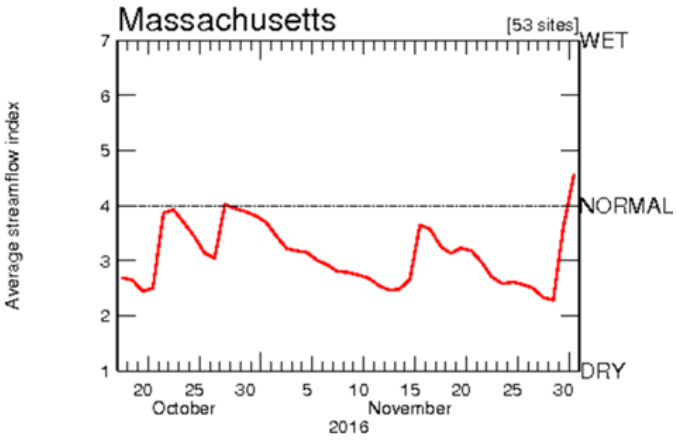
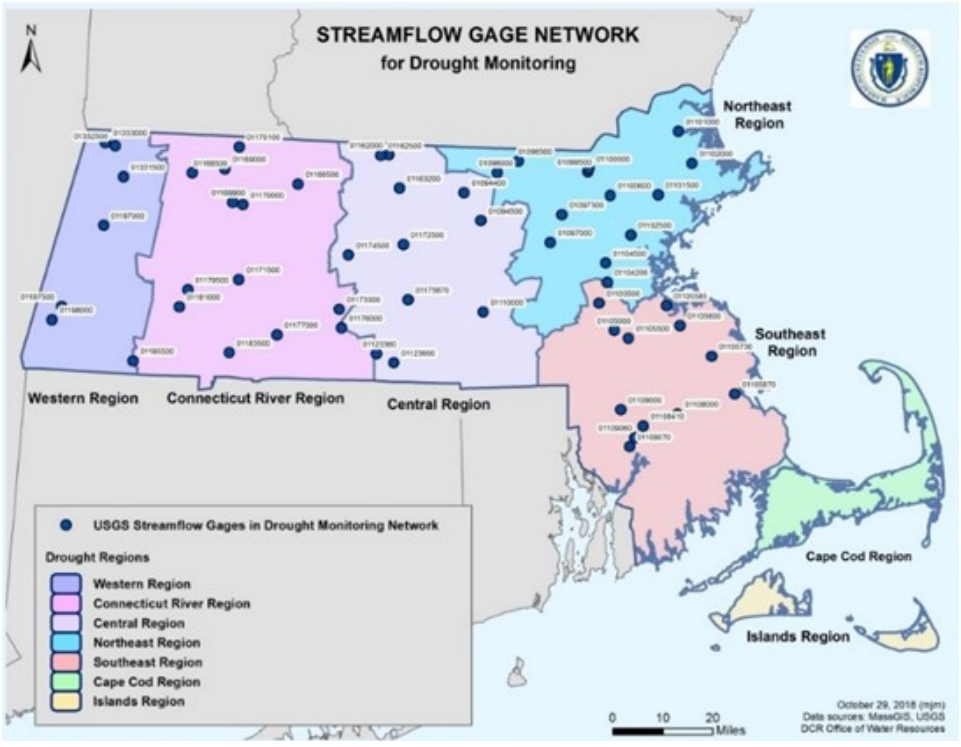


Figure 6. Map of Massachusetts statewide USGS streamflow gage network.



For most of the stations used in this study (Figure 6, page 9), the drought from 1961-1969 was the driest on record. The exception was Quaboag River at West Brimfield, when the driest year was 1930, during the 1929-1932 drought.

Table 8. Monthly streamflow index drought level by region from 2015 through 2017.

2015-2017 Streamflow					
	Western	**CT River Valley**	**Central**	**Northeast**	**Southeast**
January 2015 – April 2015	Normal				
May-15	Advisory	Advisory	Advisory	Normal	Normal
Jun-15	Normal	Normal	Normal	Normal	Normal
Jul-15	Normal	Normal	Normal	Normal	Normal
Aug-15	Normal	Normal	Normal	Normal	Normal
Sep-15	Normal	Normal	Advisory	Normal	Normal
Oct-15	Normal	Normal	Advisory	Normal	Normal
Nov-15	Normal	Normal	Advisory	Advisory	Advisory
Dec-15	Normal	Normal	Watch	Advisory	Advisory
Jan-16	Normal	Normal	Advisory	Advisory	Advisory
Feb-16	Normal	Normal	Normal	Normal	Normal
Mar-16	Normal	Normal	Normal	Normal	Normal
Apr-16	Normal	Normal	Advisory	Advisory	Normal
May-16	Advisory	Advisory	Advisory	Advisory	Advisory
Jun-16	Advisory	Advisory	Watch	Watch	Advisory
Jul-16	Watch	Watch	Watch	Watch	Watch
Aug-16	Watch	Watch	Warning	Warning	Watch
Sep-16	Watch	Warning	Warning	Warning	Warning
Oct-16	Warning	Warning	Emergency	Warning	Warning
Nov-16	Warning	Emergency	Emergency	Warning	Warning
Dec-16	Advisory	Warning	Warning	Normal	Emergency
Jan-17	Normal	Normal	Normal	Normal	Warning
Feb-17	Normal	Normal	Normal	Normal	Normal
Mar-17	Normal	Normal	Normal	Normal	Normal
Apr-17	Normal	Normal	Normal	Normal	Normal
May-17	Normal	Normal	Normal	Normal	Normal
Jun-17	Normal	Normal	Normal	Normal	Normal
Jul-17	Normal	Normal	Normal	Normal	Normal
Aug-17	Normal	Normal	Normal	Normal	Normal
Sep-17	Normal	Normal	Normal	Normal	Advisory
October 2017 – December 2017	Normal				

Normal	Advisory	Watch	Warning	Emergency

Table 9. Average annual streamflow for the period of record, annual streamflow and percent of average for the 2016 calendar year, and record low annual streamflow, year, and percent of average.

Station name	Period of record (POR) through 2017	Average annual stream-flow for POR	2016 annual stream-flow (ft^3/s)	2016 Percent of average	Lowest annual stream-flow for POR (ft^3/s)	Year	Percent of average
Squannacook River near West Groton	1950-2017	114.2	62.2	54	35.7	1965	31
Ipswich River near Ipswich	1930-2017	193.9	85.4	44	65.1	1966	34
Charles River at Dover	1938-2017	308.2	185.5	60	133.9	1966	43
Wading River at Norton	1925-2017	74.0	42.0	57	31.0	1965	42
Priest Brook near Winchendon	1916-2017	33.9	22.9	68	10.7	1965	32
Quaboag River at West Brimfield	1912-2017	252.7	134.7	53	96.9	1930	38
West Branch Westfield River at Huntington	1935-2017	196.9	132.0	67	75.5	1965	38
Housatonic River near Great Barrington	1913-2017	534.5	372.4	70	239.3	1965	45

Table 10 shows the 7-day low-streamflow values for 2016, the date on which it occurred (all in September), and the rank for the period of record. Record-low 7-day low-streamflows were experienced at four of the eight representative sites in September 2016. For example, the 7-day low-streamflow in the Quaboag River at West Brimfield was 5.33 ft^3/s on September 12, 2016, the lowest for the site's 106-year period of record. All but one site experienced a top-ten low. September 2016 was also the month when all of the lowest instantaneous streamflows for three of the eight streamflow-gaging stations occurred (Table 11). On September 6, 2016, the Quaboag River streamgage at West Brimfield recorded 5.1 ft^3/s for the first time in its 106-year history of data. The previous record low was 11.0 ft^3/s, set on October 4, 2007. Table 11 lists the lowest instantaneous streamflow and date on which it occurred for the periods before and during the 2016-2017 drought.

Table 10. The annual 7-day low streamflow during the 2016 calendar year and its rank. Red text indicates record low values.

Station name	Period of record through 2017	2016 (ft^3/s)	Date	Annual rank for period of record
Squannacook River near West Groton	1950-2017	3.89	9/18/2016	1
Ipswich River near Ipswich	1930-2017	0.25	9/22/2016	1
Charles River at Dover	1938-2017	4.52	9/28/2016	3
Wading River at Norton	1925-2017	0.24	9/27/2016	1
Priest Brook near Winchendon	1916-2017	0.56	9/18/2016	14
Quaboag River at West Brimfield	1912-2017	5.33	9/12/2016	1
West Branch Westfield River at Huntington	1935-2017	5.55	9/8/2016	9
Housatonic River near Great Barrington	1913-2017	67.6	9/8/2016	9

Table 11. Dates and lowest instantaneous streamflows for the periods of record before and during the 2016-2017 drought. Red text indicates record low values.

Station name	Period of record through 2017	Lowest instantaneous streamflow prior to 2015 (ft^3/s)	Date	Lowest instantaneous streamflow in 2015-2017 (ft^3/s)	Date
Squannacook River near West Groton	1950-2017*	2.0	9/7/1965	3.5	9/15/2016
Ipswich River near Ipswich	1930-2017	0.34	9/20/1978	0.22	9/15/2016
Charles River at Dover	1938-2017	0.50	10/24/1952	4.4	9/17/2016
Wading River at Norton	1925-2017	0.22	9/29/2014	0.12	9/26/2016
Priest Brook near Winchendon	1916-2017	0.08	9/18/1929	0.46	9/17/2016
Quaboag River at West Brimfield	1912-2017	11.0	10/4/2007	5.1	9/6/2016
West Branch Westfield River at Huntington	1935-2017	3.3	8/9/1955	4.8	9/7/2016
Housatonic River near Great Barrington	1913-2017*	1.0	10/18/1914	62.0	9/16/2016

**Lowest daily mean available only*

Groundwater

According to the USGS, impacts of the drought and its severity were evident in data collected at many groundwater monitoring wells throughout Massachusetts. During the drought many wells were well below normal, and similar to the other drought indices, groundwater was most severely impacted in the 2016 calendar year. Groundwater levels returned to normal for the entirety of 2017. Please refer to Figure 7 for a map of groundwater wells.

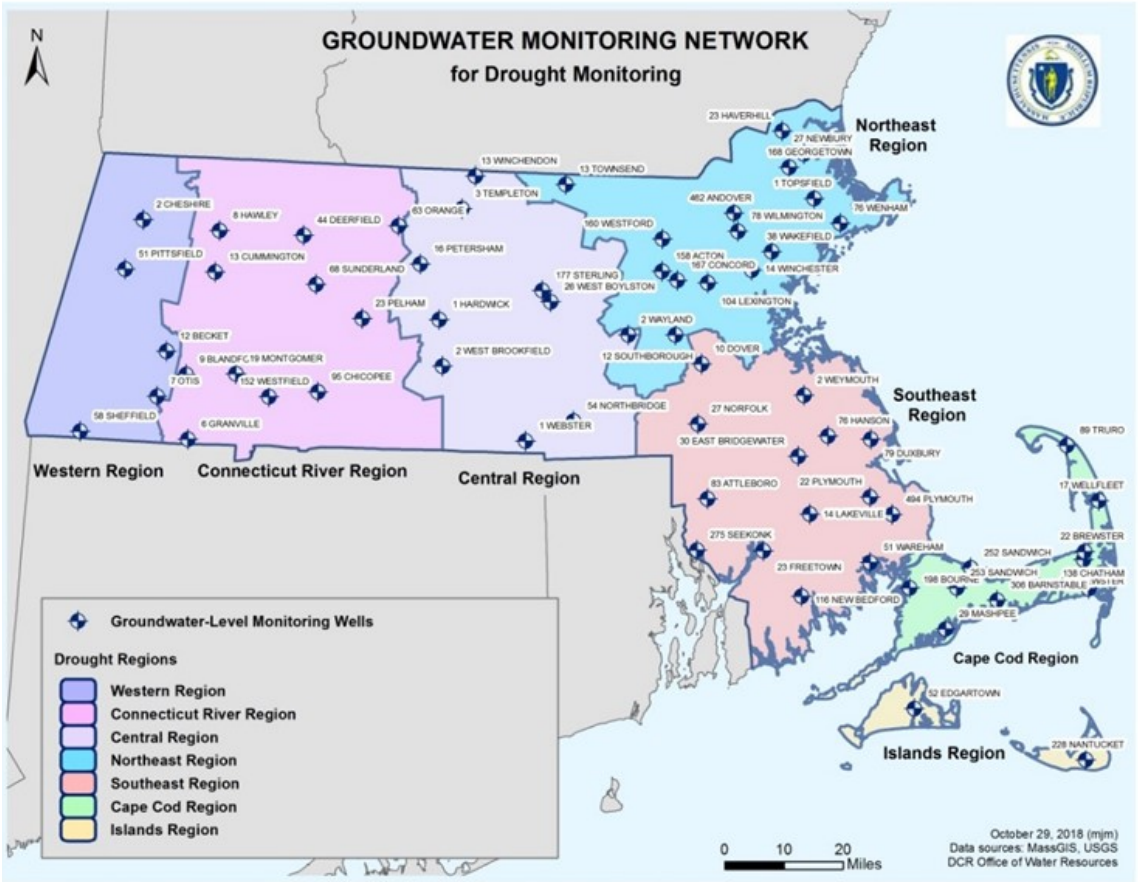


Figure 7. Map of Massachusetts statewide groundwater monitoring network.

In accordance with the 2013 DMP, groundwater drought-level decisions were based on the number of consecutive months that groundwater levels were below normal, defined as the lowest 25% of period of record for the respective months. Table 12 (page 14) shows the DMTF groundwater drought level for each region by month from 2015 through 2017. During the drought, five of six regions reached at least Warning level with four ultimately progressing to Emergency level. Groundwater levels in the Cape & Islands Region remained at Normal throughout the duration of the drought. All regions were back to normal conditions by January 2017.

In terms of individual groundwater well impacts, conditions were very poor in September 2016 when 14 individual wells were at period-of-record lows. There were 13 wells at record lows in October 2016. Groundwater impacts in terms of drought level were most severe in November 2016 when three regions reached Emergency (based on more than eight consecutive months of below-normal conditions) (Figure 8) and eight groundwater wells were at their period-of-record low values. There were six wells at record lows in December 2016, four in January 2017, three in February 2017, and two in March 2017.

Statewide impacts of the 2016-2017 drought on groundwater levels at seven representative observation wells are described in this section. The observation wells were selected based on longevity of data at each observation well, as well as geographic distribution throughout the state. The period of record for much of the Massachusetts groundwater observation well network is substantially less than that of the streamflow-gaging network. Only a limited number of groundwater observation wells have data that extend back to include the drought of 1961-1969. There was an active effort to expand the groundwater network after the drought of the 1960s.

Five of the seven observation wells included in this study have a period of record that extends back to include all or some of the 9-year drought of 1961-1969 (Table 13, page 14).

Two of those five wells, Lakeville and Pittsfield, recorded their lowest groundwater levels during the drought of 1961-1969. The West Boylston well recorded its lowest groundwater level during the 2016-2017 drought. However its period of record only goes back to 1995. Groundwater levels at the wells were at their lowest during the 2016 calendar year with two exceptions: the Edgartown well, located on Martha's Vineyard, which was at its lowest on December 26, 2015, and the Brewster well on Cape Cod which reached its lowest level on January 13, 2017. In general, except for a couple of locations, groundwater levels across the state rebounded to normal conditions by the end of the 2017 calendar year.

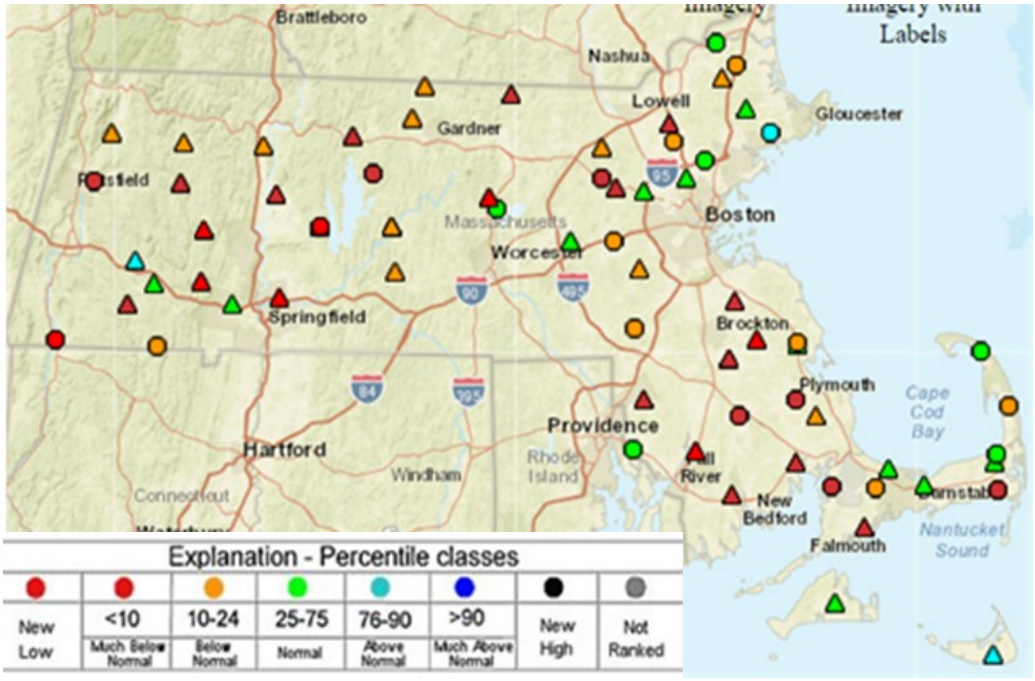


Figure 8. Groundwater conditions at the end of November 2016.

Table 12. Monthly groundwater index drought level by region from 2015 through 2017.

2015-2017 Groundwater						
	Western	CT River Valley	Central	Northeast	Southeast	Cape & Islands
January 2015-November 2015	Normal					
Dec-15	Normal	Normal	Normal	Advisory	Normal	Normal
Jan-16	Normal	Normal	Normal	Normal	Normal	Normal
Feb-16	Normal	Normal	Normal	Normal	Normal	Normal
Mar-16	Normal	Normal	Normal	Normal	Normal	Normal
Apr-16	Normal	Normal	Normal	Normal	Normal	Normal
May-16	Advisory	Normal	Normal	Normal	Normal	Normal
Jun-16	Watch	Advisory	Advisory	Advisory	Advisory	Normal
Jul-16	Watch	Watch	Watch	Watch	Advisory	Normal
Aug-16	Warning	Watch	Watch	Watch	Watch	Normal
Sep-16	Warning	Warning	Warning	Warning	Watch	Normal
Oct-16	Emergency	Warning	Warning	Warning	Warning	Normal
Nov-16	Emergency	Emergency	Emergency	Normal	Warning	Normal
Dec-16	Emergency	Emergency	Normal	Normal	Emergency	Normal
January 2017 – December 2017	Normal					

Normal | Advisory | Watch | Warning | Emergency

Table 13. Lowest groundwater level and date during 2015-2017 and before 2015. Red text indicates a record low value.

Station name	Period of record through 2017	Lowest water level for 2015-2017 (feet)	Date	Lowest water level before 2015 (feet)	Date
Edgartown, MA	1976-2017	13.37	12/26/2015	13.05	3/28/2002
Brewster, MA	1962-2017	18.54	1/13/2017	16.62	11/12/2002
Lakeville, MA	1964-2017	83.67	12/21/2016	81.41	10/26/1966
West Boylston, MA	1995-2017	**449.69**	10/20/2016	450.61	10/23/2014
Pittsfield, MA	1963-2017	1,022.06	11/25/2016	1,020.00	12/11/1964
Wilmington, MA	1951-2017	79.56	9/30/2016	78.84	10/30/1957
Winchendon, MA	1939-2017	1,196.37	11/30/2016	1,195.47	11/19/1993

Reservoirs

Water levels of 20 surface water bodies and water supply systems across the state were collected at the end of each month and added to the historical DCR reservoir database (Table 14). A reservoir level was considered below normal for the month when it reached more than one standard deviation below its average level for that month for the period of record available in the DCR reservoir database. The drought level was determined by the reservoir size (i.e., small, medium, large), which was based on service population size.

Data from October 2015 to September 2017 (Table 15, page 16) show all reservoirs were at least one standard deviation below normal at some point during that time, except for Hudson and Rockport with the latter being just 0.5% short of one standard deviation below-normal. Some reservoir levels fell more than two standard deviations below normal including those in Cambridge, Lynn, Taunton, and Worcester. The worst months for individual reservoirs were September 2016 through December 2016 with 14 of the 19 reservoirs reporting below normal levels in November 2016. As a result of the drought, Cambridge and Worcester took water from their Massachusetts Water Resources Authority (MWRA) connections. On October 11, 2016, Cambridge started sourcing 90% of its demand for water supply from MWRA[8].

The Reservoir index for the Connecticut River Valley Region remained at the Warning level in April 2017. This is because the Quabbin Reservoir, which falls in this region, is categorized as a large reservoir and according to the 2013 DMP automatically moves the region to a Warning level if the reservoir drops below normal. However, the other monitored reservoir in the Connecticut River Valley Region which is a medium-sized system, had returned to normal by this time.

Table 14. Reservoirs used for drought monitoring.

Drought Region	Water System	Size
Western	Lenox	Small
	Pittsfield	Medium
CT River Valley	Springfield	Medium
	Quabbin/MWRA	Large
Central	Rutland Muschopauge	Small
	North Brookfield	Small
	Southbridge	Medium
	Worcester	Medium
Northeast	Breakheart/Pearce	Small
	Rockport	Small
	Hudson	Medium
	North Andover	Medium
	Salem/Beverly	Medium
	Lynn	Medium
	A-1	Small
	Cambridge	Medium
Southeast	Cohasset	Small
	Milford	Medium
	Assawompsett (Taunton/ New Bedford)	Medium
Cape/Islands	Falmouth Ashumet	Small

[8]"Extreme Drought Forces Cambridge to Purchase $3.6 Million of Water," Harvard Crimson, by Sarah Wu and Phelan Yu, October 26, 2016

In accordance with the 2013 MA DMP methodology, the Quabbin was more than one standard deviation below normal starting in June 2016[9]. However, as one of two reservoirs that supply the MWRA water system, the Quabbin has its own drought management plan with drought levels that are different than those defined above in the State's 2013 DMP. In November 2016, the Quabbin went into below-normal status for the first time since 2002. According to MWRA, the 2016 watershed yield for the Quabbin was the second lowest on record, with 1965 being the lowest[10]. However, it never reached the Warning stage according to the MWRA plan, a factor taken into account by DMTF members when they determined the recommended drought level for April 2017.

The Reservoir index for the Northeast Region remained at the Watch level for April 2017. This is because Cambridge's reservoir was below normal according to the 2013 DMP. When a medium reservoir, such as Cambridge's, is below normal, it automatically moves the index to the Watch level. However, Cambridge has an interconnection with the MWRA, which it can continue to tap into during dry conditions. There are seven other monitored reservoirs in the Northeast Region, and these had all returned to normal. All other indices

Table 15. Monthly reservoir drought level by region from 2015 through 2017.

2015-2017 Reservoirs						
	Western	**CT River Valley**	**Central**	**Northeast**	**Southeast**	**Cape & Islands**
January 2015 – October 2015	Normal					
Nov-15	Normal	Normal	Watch	Normal	Normal	Normal
Dec-15	Normal	Normal	Watch	Watch	Normal	Normal
Jan-16	Normal	Normal	Normal	Normal	Normal	Normal
Feb-16	Normal	Normal	Normal	Normal	Advisory	Normal
Mar-16	Normal	Normal	Normal	Normal	Normal	Normal
Apr-16	Normal	Normal	Normal	Normal	Watch	Normal
May-16	Normal	Normal	Normal	Normal	Watch	Normal
Jun-16	Normal	Normal	Watch	Watch	Watch	Normal
Jul-16	Normal	Normal	Watch	Watch	Watch	Normal
Aug-16	Normal	Normal	Watch	Watch	Watch	Normal
Sep-16	Normal	Normal	Watch	Watch	Watch	Normal
Oct-16	Watch	Watch	Watch	Warning	Watch	Normal
Nov-16	Watch	Warning	Watch	Watch	Watch	Advisory
Dec-16	Watch	Warning	Watch	Watch	Watch	Advisory
Jan-17	Normal	Warning	Advisory	Normal	Watch	Normal
Feb-17	Normal	Warning	Normal	Watch	Normal	Normal
Mar-17	Normal	Warning	Watch	Watch	Watch	Advisory
Apr-17	Normal	Warning	Normal	Watch	Normal	Advisory
May-17	Normal	Warning	Normal	Normal	Normal	Advisory
Jun-17	Normal	Warning	Normal	Normal	Normal	Normal
Jul-17	Normal	Warning	Normal	Normal	Normal	Normal
Aug-17	Normal	Warning	Normal	Normal	Normal	Normal
Sep-17	Normal	Warning	Normal	Normal	Normal	Normal
October 2017 – December 2017	Normal					

Normal	Advisory	Watch	Warning	Emergency

[9] Based on a period of record in the DCR reservoir database of 16 years [10]MWRA staff summary January 18, 2017

were in the normal range, so the overall recommendation for the Reservoir index was Normal.

Reports of impacts to reservoirs not in the 2013 DMP monitoring network can be found in media reports. Of note were the communities of Westfield and Scituate. The Granville Reservoir in Westfield in the CT River Valley Region was taken offline for part of November 2016 and then again in December 2016 because of low water levels [11]. Reservoirs in the Southeast Region were also affected. The level in Scituate's reservoir was down to about 20% in September 2016[12]. By June 2017, all reservoirs in the State's 2013 DMP monitoring network had returned to normal levels, except for the Quabbin which did not return to normal until July 2017, according to its own plan, and September 2017, according to the 2013 DMP.

Keetch-Byram Drought Index (Forest Fire Potential)

The Keetch-Byram Drought Index (KBDI) is designed specifically for fire potential assessment (Keetch, John J; Byram, George. 1968. [Revised 1988]). The KBDI gives a longer-term indication of drought conditions related to the severity of forest fire behavior (fuel moisture), that affect potential fire spread and the resources needed to extinguish fires. The KBDI is reported weekly from 13 Massachusetts fire districts by DCR's Bureau of Forest Fire Control. The districts calculate and report KBDI values usually from 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 DCR Fire Chief, as a member of the DMTF, provides updates should any fire danger arise.

Effects of the drought on KBDI were seen during the summer of 2016, specifically in the months of June through October (Table 16). By November 2016, KBDI was back to normal, and remained normal throughout 2017 as the drought came to an end.

The worst KBDI conditions occurred in August 2016, as shown by the map in Figure 9. Conditions in the Northeast, Southeast, and Cape (excluding the Islands) reached the Warning category, with KBDI values generally exceeding 600. The remaining three regions (Central, CT River Valley, and Western) were in the Watch category, with KBDI values generally between 400 and 600.

Table 16. Monthly reservoir drought level by region from 2015 through 2017.

Keetch-Byram Drought Index						
	Western	CT River Valley	Central	Northeast	Southeast	Cape & Islands
January 2015 – February 2016	not reported					
March 2016 – May 2016	Normal					
Jun-16	Advisory	Advisory	Watch	Advisory	Advisory	Advisory
Jul-16	Advisory	Watch	Warning	Warning	Watch	Watch
Aug-16	Watch	Watch	Watch	Warning	Warning	Cape Only
Sep-16	Watch	Watch	Warning	Watch	Watch	Excl. Nantucket
Oct-16	Advisory	Advisory	Advisory	Advisory	Normal	Normal
November 2016 – May 2017	Normal					
June 2017 – December 2017	DCR numbers not available – national numbers Normal					

Normal	Advisory	Watch	Warning	Emergency

[11] Westfield Taking Reservoir Offline Again Because of Drought," Associated Press, December 26, 2016

[12] ""Drought Hits Home in Brockton Area", The Enterprise, by Benjamin Paulin and Chris Burrell, September 17, 2016.

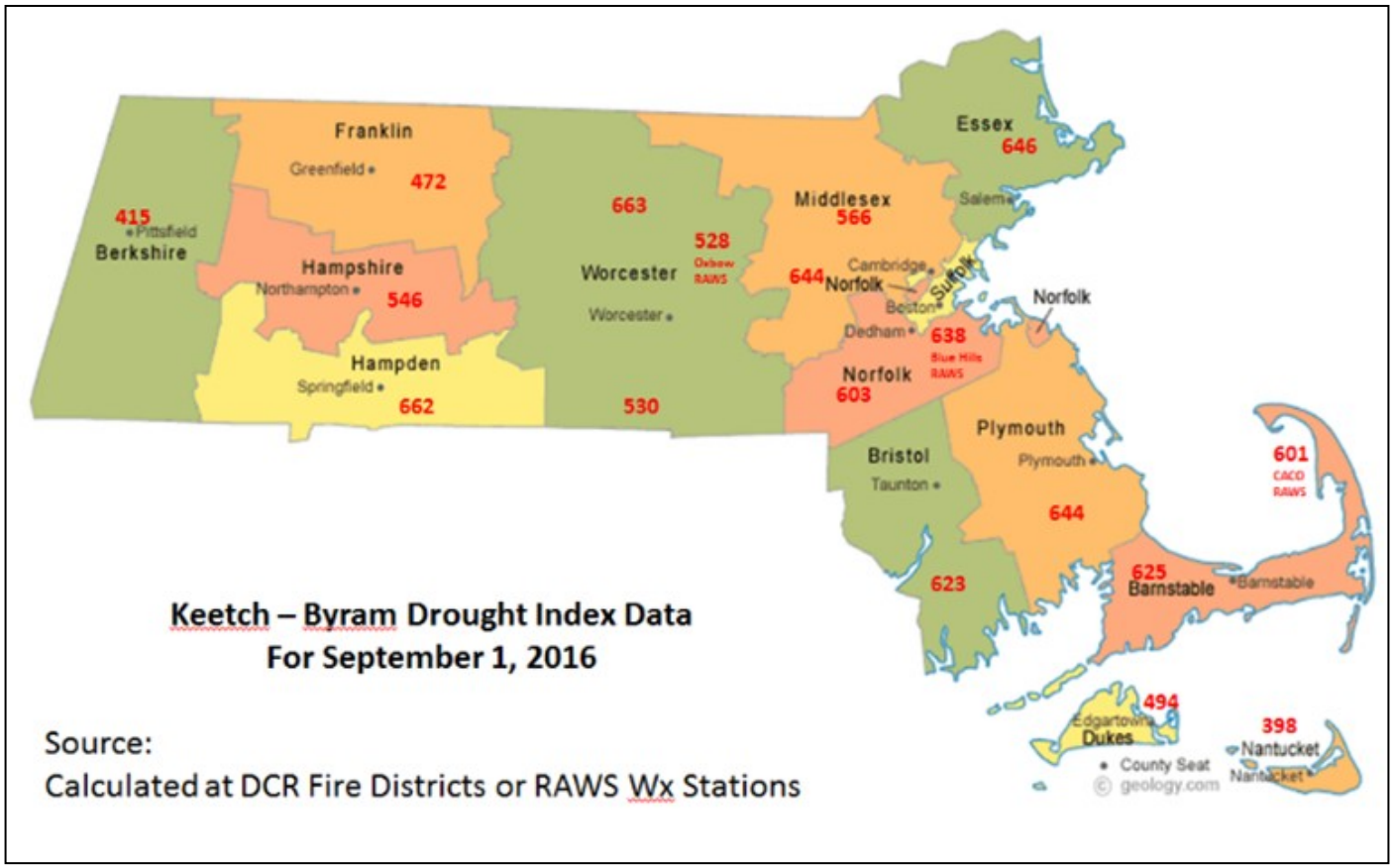


Figure 9. KBDI map for September 2016.

Crop Moisture Index

The Crop Moisture Index (CMI) reflects short-term soil moisture conditions as needed for agriculture and is applicable during the growing season. The crop moisture index was developed (Palmer, 1968) to assess short-term crop water conditions and needs across major crop-producing regions [13].

Effects of the drought on CMI were seen during the summer of 2016, specifically in the months of June through September (Figure 9, Table 17). By October 2016, CMI was back to normal as the growing season came to a close. By the time the 2017 growing season began, conditions throughout the state were returning to normal as the drought came to an end.

The worst crop moisture conditions occurred in August 2016, as shown by the map in Figure 10. Conditions in the easternmost sections of the state and the Islands reached the Severely Dry category, which corresponds to a Warning drought level. The majority of the rest of the state was in the Excessively Dry category (Watch). Only the westernmost region never advanced past Abnormally Dry for the duration of the drought (Advisory).

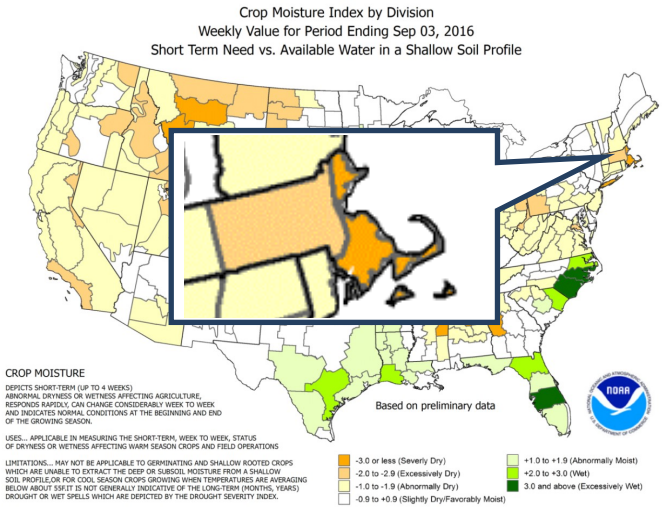


Figure 10. Crop moisture index map for August 2016.

[13] Maps are issued weekly and can be found on-line at:
http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/regional_monitoring/cmi.gif (MA DMP, 2013)

Table 17. Monthly crop moisture index level by region from 2015 -2016.

Crop Moisture Index						
	Western	CT River Valley	Central	Northeast	Southeast	Cape & Islands
January 2015 – February 2016	not reported					
March 2016 – May 2016	Normal					
Jun-16	Normal	Advisory	Advisory	Advisory	Advisory	Advisory
Jul-16	Advisory	Watch	Watch	Watch	Watch	Watch
Aug-16	Advisory	Watch	Watch	Warning	Warning	Warning
Sep-16	Normal	Advisory	Advisory	Watch	Watch	Watch
October 2016 – December 2017	Normal					

Normal | Advisory | Watch | Warning | Emergency

End of Drought

The final DMTF meeting for the 2016-2017 drought took place on May 9, 2017 when the DMTF reviewed hydrologic conditions for the month of April (Table 18) to help inform its discussion and recommendations to the Secretary of EEA. Per the 2013 DMP, determinations regarding the end of a drought focused on two key drought indicators: precipitation and groundwater levels.

On May 11, 2017, the EEA Secretary declared that all drought regions had returned to normal and that the drought had ended.

Table 19 (page 20) shows the drought level declared by region throughout the duration of the 2016-2017 drought. The months where the drought declarations were the most severe were October, November, and December 2016.

Table 18. Summary of drought indices for April 2017 conditions.

Drought Indicator	West	CT River Valley	Central	Northeast	Southeast	Cape and Islands
Standardized Precipitation Index	Normal	Advisory	Advisory	Normal	Normal	Normal[1]
Percent of Normal Precipitation	Normal	Normal	Normal	Normal	Normal	Normal
Streamflow	Normal	Normal	Normal	Normal	Normal	N/A
Groundwater	Normal	Normal	Normal	Normal	Normal	near Normal[2]
Reservoir	Normal	Warning[3]	Normal	Watch	Normal	Advisory
Crop Moisture Index	Normal	Normal	Normal	Normal	Normal	Normal
KBDI - Fire danger	Normal	Normal	Normal	Normal	Normal	Normal
March	Normal	Advisory	Advisory	Advisory	Advisory	Advisory
Recommended April	Normal	Normal	Normal	Normal	Normal	Normal

1 Note: 12-month SPI is very close to Advisory level

2 Some wells remain below normal; however, since the majority of wells in the region are not below normal, a drought level is not triggered

3 Quabbin reservoir is below normal. This is an exceptionally large reservoir which jumps the index to warning. However, the other monitored reservoir in the CT River Valley region has returned to and remains normal. It is classified medium.

Table 19. 2016-2017 drought declarations by region.

	West	CT River	Central	Northeast	Southeast	Cape & Islands
Jul-16	Normal	Advisory	Watch	Watch	Advisory	Normal
Aug-16	Advisory	Watch	Warning	Warning	Watch	Advisory
Sep-16	Advisory	Watch	Warning	Warning	Warning	Watch
Oct-16	Watch	Warning	Warning	Warning	Warning	Watch
Nov-16	Warning	Warning	Warning	Warning	Warning	Advisory
Dec-16	Warning	Warning	Warning	Warning	Warning	Advisory
Jan-17	Warning	Warning	Warning	Watch	Warning	Advisory
Feb-17	Watch	Warning	Watch	Advisory	Warning	Advisory
Mar-17	Advisory	Watch	Advisory	Advisory	Watch	Advisory
Apr-17	Normal	Advisory	Advisory	Advisory	Advisory	Advisory
May-17	Normal	Normal	Normal	Normal	Normal	Normal

SECTOR SPECIFIC DROUGHT IMPACTS

Agricultural Impacts

The 2016-2017 drought in Massachusetts had major impacts on the Commonwealth's agricultural producers, particularly in 2016 though the impacts were felt throughout the winter of 2016-2017. The Massachusetts Department of Agricultural Resources (MDAR) monitored the drought situation and worked with state and federal partners to provide as many resources as possible to help farmers mitigate the impacts of the drought.

Capturing and documenting the impacts of the drought on agriculture was challenging and relied primarily on farmers reporting losses to the UMass Extension Survey that was conducted during the summer of 2016 and anecdotal information captured by individual county committees and MDAR.

Producers were encouraged to conserve water and implement long-term water savings technologies and practices; however, agricultural water use is not subject to mandatory restrictions. Agricultural water uses include but are not limited to: water used for the production of food and fiber, for maintenance of livestock, and to meet the core functions of a business (for example, irrigation by plant nurseries as necessary to maintain stock).

In general, impacts and losses were felt in every county across the state and on all crops. Impacted farmers incurred increased costs for production and reduced revenues. Cranberry growers increased their costs from running irrigation pumps and decreased revenues from lower yields and reduced quality of berries. They were also concerned with the availability of water over the winter for use in frost protection. Due to the loss of forage as a result of the drought, livestock farmers had to purchase feed much earlier than usual, which resulted in huge cost increases.

Table 20. Economic impact of 2016 drought on Massachusetts by county.

County	% Farm Acres Affected	Estimated Crop Loss ($)
Barnstable	4.30%	15,730
Berkshire	1.30%	66,667
Bristol	18.10%	2,014,632
Dukes	0.80%	7,865
Essex	5.20%	1,031,142
Franklin	11.20%	3,332,120
Hampden	6.30%	432,960
Hampshire	3.30%	2,984,992
Middlesex	1.60%	676,277
Nantucket	8.10%	4,850
Norfolk	18.70%	477,368
Plymouth	0.90%	43,100
Worcester	24.50%	7,085,057
Massachu-setts	10.30%	18,172,759

Produce, greenhouse, and nursery growers and beekeepers experienced short-term impacts during the summer and fall months of 2016; these impacts began diminishing once the season's harvest was complete. The drought will have long-term impact on tree growers because of the loss of the year's seedlings. The overall economic impact of the drought is estimated at over $18 million. Tables 20 and 21 list the estimated monetary losses by county and by crop. Worcester County had the highest percentage of farm acres affected at 24.5%, followed by Norfolk County at 18.7%, and Bristol County at 18.1%. Worcester County also had the highest loss of $7,085,057, followed by Franklin County at $3,332,120, and Hampshire County at $2,984,992 (Table 20).

The mixed forage crops had the greatest area affected by the drought with 31,090 farm acres, followed by mixed forage pasture with 10,375 farm acres, and corn-silage with 6,289 farm acres affected (Table 21). Mixed forage crops also had the highest economic loss at $5,277,550, with potatoes reporting a $4,244,574 loss, and corn-silage at $2,344,016. Other crops exceeding $1 million dollars in lost revenue include sweet corn ($1,892,261) and squash ($1,026,293).

Water Supply Impacts

The Massachusetts Department of Environmental Protection (MassDEP) tracks the state of water supply across Massachusetts through its regional offices. The Water Management Act (WMA) which came into effect in March 1986, authorizes MassDEP to regulate the quantity of water withdrawn from both surface and groundwater supplies. The WMA consists of a few key components, including a registration program and a permit program.

WMA permits have varying requirements for non-essential outdoor water use restrictions. Non-essential uses are defined as uses not required for health or safety reasons, by regulation, for production of food or fiber, for maintenance of livestock, or to meet the core function of a business. While more recent WMA permits have escalating restriction requirements that become more stringent as streamflow hits particular low-flow values, older permits included more stringent restrictions at certain drought level triggers. Water suppliers may implement restrictions that are more stringent than MassDEP's requirements and were encouraged to do so during the summer of 2016. Figure 11 (page 22) shows outdoor water use restrictions enacted by public water suppliers as of September 28, 2016.

In Massachusetts, any Public Water System (PWS) having difficulty meeting demands, drought related or not, may request a Declaration of Water Supply Emergency ("Emergency Declaration") from MassDEP. An Emergency Declaration requires a PWS to submit a plan to remedy the emergency. Plans can include measures to purchase water from other suppliers, use emergency sources, implement aggressive conservation measures, and provide a mechanism to restrict outdoor water use for those PWS that do not have the legal authority to implement such measures. During the drought a total of five systems requested an emergency declaration -

Table 21. Economic impact of 2016 drought on Massachusetts by crop.

Crop	Farm Acres Affected	Estimated Crop Loss ($)
Blueberries	132	483,760
Cabbage	27	49,133
Cranberries	75	380,250
Corn- Grain	415	96,114
Corn- Silage	6,289	2,344,016
Corn- Sweet	1,094	1,892,261
Cucumbers	0	434
Eggplant	1	3,266
Mixed Forage	31,090	5,277,550
Mixed Forage Pasture	10,375	718,788
Peppers	38	157,139
Potatoes	3,677	4,244,574
Pumpkins	359	354,354
Squash	320	1,026,293
Strawberries	50	460,877
Tomatoes	85	683,950
TOTAL	54,027	18,172,759

Ashland, Burlington, Foxborough, Ipswich, and Plymouth (as seen in Figure 11). Water supply emergencies were also declared in 2016 by the Cherry Valley Water District (Leicester) and Natick. The causes for these emergencies varied, with several involving mechanical or operational difficulties, while others had regulatory drivers, but the drought certainly contributed to their difficulties meeting demands.

Case Studies of Community Impacts and Responses

This section details the varied responses of several PWS that experienced very low water levels in their reservoirs during the height of the drought in 2016 but did not request an Emergency Declaration.

Cambridge:

The Cambridge water supply has less than one year of supply at maximum capacity, making the system susceptible to multi-year droughts. Low rainfall in 2015 and 2016 led to the decision to reserve 500 million gallons in Hobbs Brook (Cambridge) Reservoir and supplement the city's supply with MWRA water beginning in October 2016. The lowest measured reservoir level was approximately 18% of full capacity on October 9, 2016.

The Cambridge Water Department (CWD) supplemented its supply with MWRA water from October 11 to December 12, 2016. During that time, CWD supplied approximately 45% of the city's drinking water, and MWRA supplied approximately 55%. As an MWRA member community, CWD follows MWRA's Drought Management Plan and urged conservation. No mandatory restrictions were issued. Many outreach activities were undertaken, including the following:

- The City and CWD webpages were updated with conservation information
- Social media updates were sent through Twitter and Facebook
- A bill insert was added for indoor and outdoor water conservation
- The drought was discussed at the City Council Health and Environmental Committee meeting on September 28, 2016

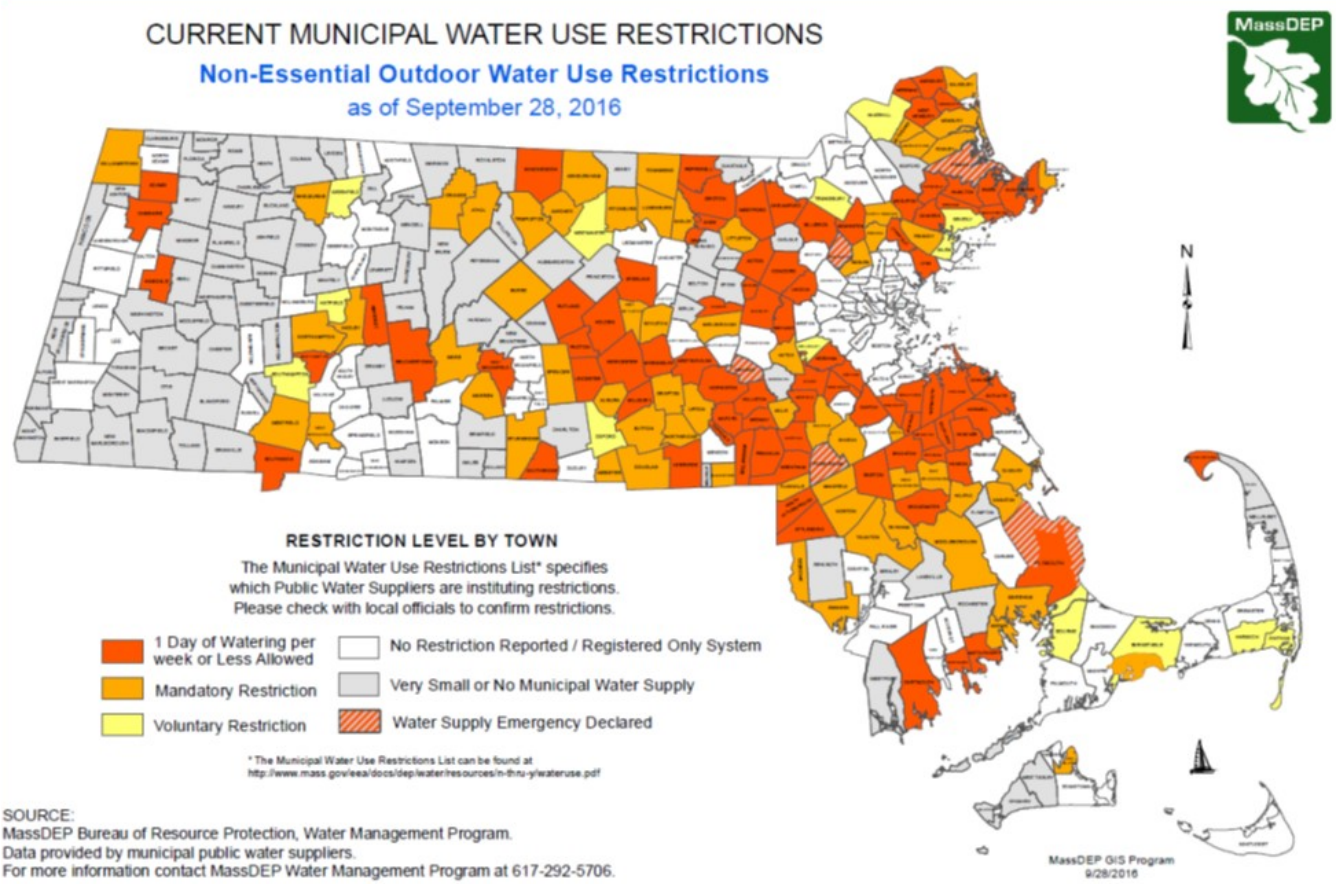


Figure 11. Map of Massachusetts statewide municipal water use restrictions in September 2016.

- Top water users and universities were engaged to better conserve water
- Individual letters were sent to all customers starting in October 2016
- A public event on 4/13/17 was held to give a presentation on the drought and water supply system
- Relevant city departments were engaged to reduce municipal usage, in particular from outdoor municipal irrigation

Scituate:

The Scituate Water Division has had a proactive history of reducing outdoor water usage. As of May 2015, no new irrigation systems can be added to the public water supply and streamflow restoration efforts were undertaken on First Herring Brook. During the summer of 2016, when the Scituate Water Division experienced extremely low reservoir levels, non-essential outdoor water use restrictions escalated from the standard one-day-per-week restriction enacted on May 1 when initial reservoir levels were 100% capacity, to hand-held watering only on July 8 at 50% reservoir capacity, to a total ban by August 5, 2016 when levels fell to below 28% capacity. The reservoir reached its lowest level of 21.4% capacity on September 26, 2016.

During the 2016 drought, the Water Division was able to reduce water usage from 1.94 million gallons per day (mgd) in July 2016 to 1.26 mgd in late August 2016, which is similar to its January 2015 water usage (1.20 mgd). To achieve this, the Town and Water Division conducted extensive public education and outreach, such as [14]:

- Weekly Drought Crisis Management Team meetings
- Water conservation postcard sent 9/2/16
- Town website posting of PSA and water conservation tips
- Soliciting town residents to submit water conservation tips
- Facebook postings & emails via town email alert list
- Conservation education in schools with North and South Rivers Watershed Association
- Video series on Scituate's water supply and conservation tips
- Enforcement of water use restriction violations
- Public posting of streets where violations occurred

Worcester:

The watershed to Worcester's water supply had a deficit of 20.25 inches of rainfall between the winter of 2015 and the spring of 2017. Conditions were severe enough that the city supplemented supplies by purchasing water from MWRA from September through December 2016, totaling approximately 824 million gallons and costing $2.9 million. The lowest level that Worcester's combined reservoir system reached was 47% full in November 2016. The city's approach to watering restrictions at each drought stage was to impose stricter restrictions on municipal water use than on that of customers. These use restrictions were published and enforced due to the support of the City Manager.

Many outreach activities were undertaken, including but not limited to the following:

- Direct calls to large water users, municipal boards, the Fire Department, and Chamber of Commerce
- Billing inserts and posters/flyers sent to customers, schools, and businesses
- Issuance of citations
- Information posted on city website and social media
- Updates given via news interviews and press conferences
- Messaging provided via signs/message boards on city streets and buses

[14] https://www.mass.gov/files/documents/2016/10/tf/2016-oct-5-dep-dmft-summary.pdf

MWRA Water System:

The Massachusetts Water Resources Authority (MWRA) is the largest regional water supplier in the state and provides drinking water to 2.5 million people in 51 communities. MWRA has a separate drought response plan with specific triggers based on Quabbin Reservoir storage levels (Figure 12). The state drought plan is regionally flexible; for example, small water systems may need water use restrictions during a short-term drought while only a long-term drought affecting the Quabbin and Wachusett reservoirs would lead to significant restrictions in MWRA's service area. MWRA has primary responsibility for communication with its service area communities and customers during a drought.

MWRA's drought planning assumes that there will be additional demand from partially supplied communities and potentially from neighboring non-user communities. This additional "pop-up" demand is built into MWRA's drought planning models and demand assumptions. During drought conditions, MWRA staff routinely communicate with MWRA partially-supplied communities about the drought and how their water supplies are coping, and assess the need for emergency water assistance.

For example, in the 2016 drought, water use was elevated in many of the partially supplied communities, with some having water use restrictions in place either due to local supply conditions or their Water Management Act Permit conditions. On August 19, 2016, MWRA approved a 30-day emergency water request for the town of Ashland, contingent on MassDEP's issuance of an emergency declaration. Ashland periodically took MWRA water through Southborough in the fall of 2016.

Worcester took MWRA water in September and October 2016. Cambridge also took water from MWRA in the fall of 2016. Burlington purchased a total of approximately 8 million gallons of water through Lexington from October 24, 2016, to November 4, 2016. During this time MWRA also received preliminary inquiries from other communities which may have needed to use emergency interconnections if dry conditions continued.

By August 2016, when much of Massachusetts was approximately five months into drought conditions, the MWRA source reservoirs, the Quabbin and the Wachusett, remained at normal levels. MWRA began to perform forecasting modeling for the Quabbin Reservoir and at the same time began to roll

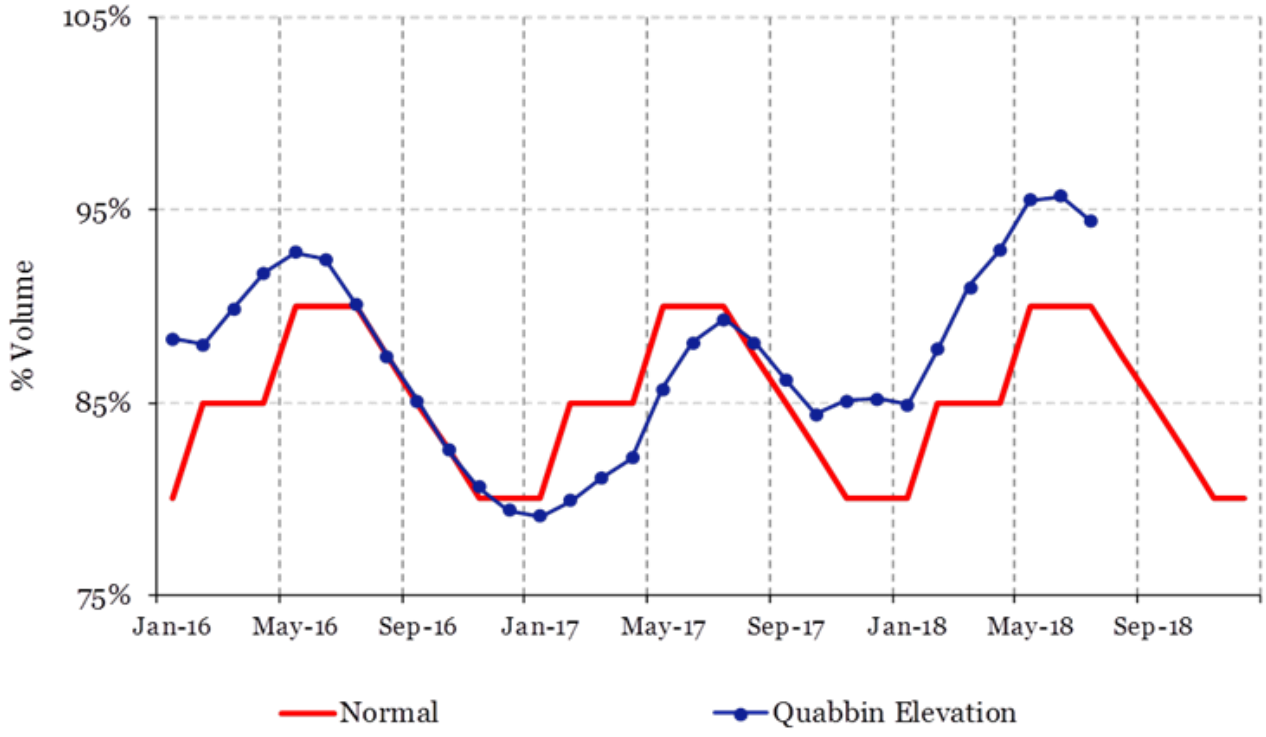


Figure 12. Quabbin Reservoir volume 2016-2018.

MWRA Drought Management Stages		
Stage	**Trigger** Range (Quabbin % Full)	**Target Water Use Reduction**
Normal Operation	80-100	0
Below Normal	65-90	Previous year's use (Voluntary)
Drought Warning	50-75	5% (Voluntary)
Drought Emergency		(Mandatory Restrictions)
Stage 1	38-60	10%
Stage 2	25-38	15%
Stage 3	Below 25%	30%

Table 22. MWRA drought management stages.

out conservation messages to MWRA communities. On November 12, 2016, the Quabbin reached the 'Below Normal' drought management stage. There are no mandatory restrictions associated with this stage (Table 22). The reservoir did not progress to the next stage of 'Drought Warning' stage, before returning to Normal status in mid-June 2017.

Private Well Impacts

During the drought, various state agencies received reports from a small number of private well owners about impacts to their wells. Four municipalities contacted MEMA to report that some private wells were running dry and to seek guidance.

To better understand the extent of the impacts across Massachusetts, in May 2017 the DCR Office of Water Resources (OWR) created a survey to gather information on the effects of the drought on private wells throughout the Commonwealth. OWR worked with the Massachusetts Department of Public Health (DPH) to distribute the online survey to all municipal health departments in Massachusetts. The survey asked for respondent name and contact information and consisted of the questions shown in Figure 13 (page 26).

Over the following month, responses were received from 87 municipalities. Representatives from forty-five municipalities (52%) reported being aware of private wells impacted by the drought, totalling an estimated 220 incidents. Ten towns reported one incident each while the Town of Tolland reported the highest number of impacts, with an estimated 20 incidents. The most commonly reported impact was low or no water, followed by the need to improve or replace a well, then by poor water quality. In total, 55 respondents (63%) felt that impacts on private wells were underreported. Of these 55 respondents, 30 had reported private well impacts and 25 reported no impacts.

The four municipalities that reported dry wells to MEMA did not respond to this survey. Given that there are over 300 municipalities in Massachusetts and at least four municipalities with dry wells did not report them via this survey, it is likely that there was an overall underreporting of drought impacts on private well water supplies.

In terms of assistance that state agencies could provide to help municipalities and private well owners manage future droughts (question 4, Figure 13), respondents could select more than one option and also provide their own written response. Of the options provided, 84% (n=73) chose educational materials for private well owners, 68% (n=59) selected resources for private well owners, and 64% (n=56) chose a centralized online system for reporting drought impacts. Written responses included requesting information on whether private wells impact public water supplies, information on municipal powers to regulate private well water use during drought, the availability of money or low-interest loans for well replacements, and a list of water testing laboratories.

1a. How many incidents are you aware of in which private wells in your city or town were impacted by the 2016 drought? Impacts can include wells going dry, cloudy/heavily silted water, or other water quality or quantity issues. *

Your answer

1b. Please describe the impacts reported above, if any.

Your answer

2. Do you think the number of known incidents is an accurate reflection of the true impacts? *

- ○ Accurate reflection
- ○ Suspected underreporting of impacts

3. Can you provide an actual or estimated total number of the private wells in your city or town? *

Your answer

4. What could state agencies provide to help municipalities and private well owners manage future droughts? Please check all that apply. *

- ☐ Educational materials for private well owners (e.g., Preparing for and managing drought conditions)
- ☐ Resources for private well owners (e.g., List of certified well drillers, list of emergency water tank providers)
- ☐ A centralized online system for reporting drought impacts to understand the extent of these impacts
- ☐ Other:

Figure 13. DCR private well survey.

Public Health Impacts

DPH provides oversight or assistance to local boards of health (BOHs) regarding drought-related issues such as recreational water quality impacts and private drinking water supply capacity. 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, and when conditions exceed limits set in the FIB standards or algae guidelines, they are posted with a notice alerting the public to the risk.

Historically, there has been a general correlation between statewide FIB sample exceedance rates and rainfall. In 2016, due to the drought, Massachusetts received the lowest amount of rainfall during any beach season since testing requirements were enacted in 2001. This coincided with average rates of FIB exceedances at marine (3.5%) and freshwater (3.0%) beaches that were below the historical averages of 4.8% and 3.9%, respectively. Rainfall rates during the 2017 beach season were more typical, as were exceedance rates at marine (4.1%) and freshwater (3.8%) beaches (Figure 14). There are no regulatory requirements for monitoring of cyanobacteria, which can form harmful algae blooms (cyanoHABs). Upon request, DPH provides technical assistance and may recommend the issuance of advisories by local, state, and federal agencies at recreational waterbodies under their jurisdiction. The factors that contribute to cyanoHABs include increases in water temperature, sunlight, and nutrients - particularly nitrogen and phosphorus. Dry conditions are generally thought to favor the formation of cyanoHABs as they increase water temperatures and decrease nutrient outflow from the waterbody.

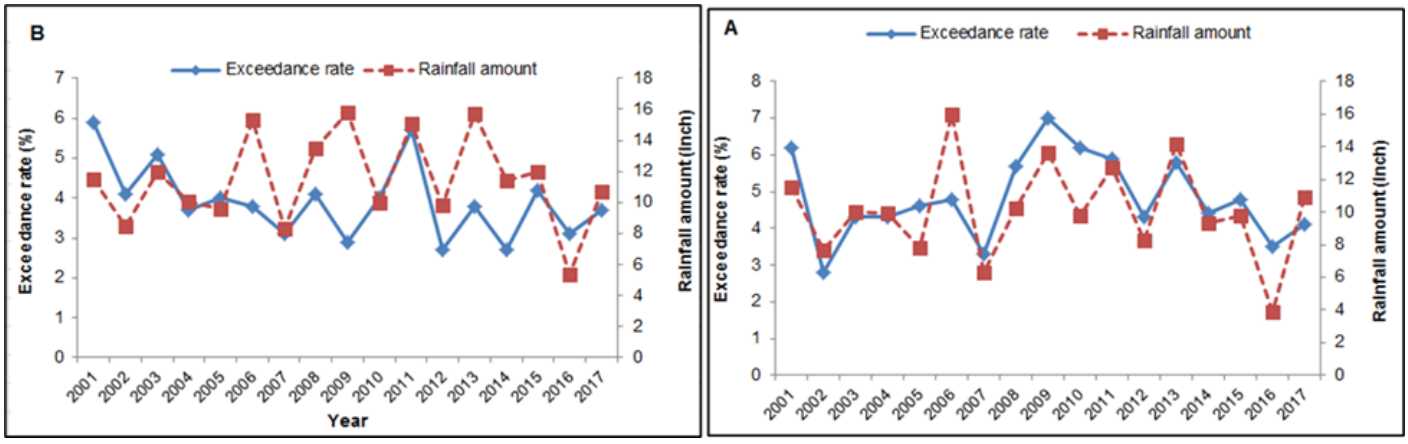


Figure 14. The historical relationship between rainfall amounts and exceedance rates at (A) marine and (B) freshwater beaches in Massachusetts from the 2001 to 2017 beach seasons.

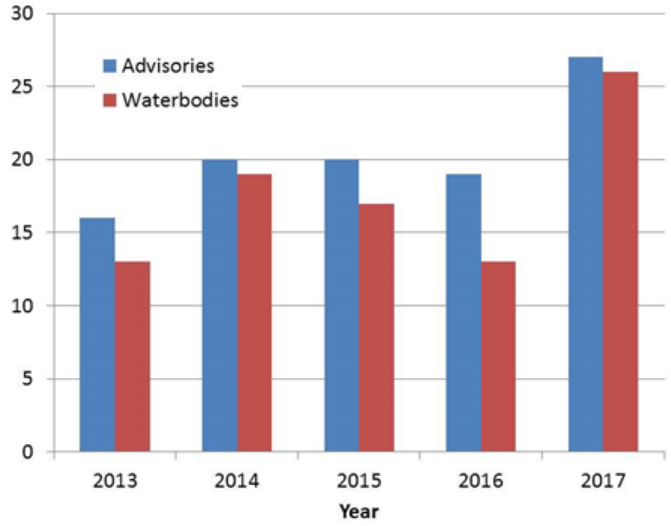


Figure 15. The number of cyanobacterial harmful algae bloom advisories and impacted waterbodies in Massachusetts from 2013 to 2017.

However, since nutrients can accumulate on land and enter the waterbody from rainfall-related runoff, it is also possible that dry conditions followed by rainfall may increase the formation of cyanoHABs. This may partly explain the increase in advisories and impacted waterbodies from 19 advisories issued for 13 waterbodies in 2016 to 27 advisories issued for 26 waterbodies in 2017 (Figure 15). The 2017 totals are also above the average number of advisories and impacted waterbodies from 2013-2017 (20 and 18, respectively). Images from two blooms in 2017 are shown in Figure 16.

Figure 16. (top) Fort Meadow Reservoir, Marlborough (credit: Kelli Calo, 2017) and (below) Lake Chauncy, Westborough (credit: Steve Baccari, 2017).

Streamflow and Habitat Impacts

The Massachusetts Division of Ecological Restoration (DER) monitors streamflow at 28 sites across Massachusetts. These data are used to better understand streamflow alteration and to document streamflow restoration projects. The monitoring sites, a majority of which are on headwater streams with watersheds smaller than 15 square miles, are located in all of the state's drought regions with the exception of Cape Cod and the Islands.

During the summer and fall of 2016, DER documented many drought-related impacts to streamflow and associated aquatic habitat. Many of the monitored rivers had critically low flows or extended periods of no flow or dry streambed conditions. While rivers are adapted to periods of low flow and drought, they are not adapted to the combined impacts of drought and anthropogenic stressors such as water withdrawals, dams, and other factors, which can exacerbate the impacts of drought.

Extended periods of low-flow and no-flow conditions can have myriad impacts on river ecosystems, including reduced aquatic habitat for fish and other organisms, increased water temperatures and reduced dissolved oxygen. As streamflow decreases or disappears, aquatic habitats can become fragmented as pools become isolated from riffle habitat. This can lead to increased predation and competition for resources as species become concentrated in the limited remaining habitat and refugia are reduced. As habitat continues to dry up, aquatic organisms such as fish and macroinvertebrates can become stranded and die. Water temperatures in rivers can increase as water levels decrease and solar radiation heats the

water column. Additionally, as groundwater levels decline during periods of drought, the volume of cold water entering the streambed as base flow can be reduced or eliminated. As temperatures rise and algae blooms occur in isolated pools, dissolved oxygen can drop to low, potentially lethal, levels.

These impacts can lead to loss of organisms as well as stress to those that survive. Organisms that are stressed may have decreased growth and recruitment. Figure 18 includes photos of drought impacts to streamflow and habitat in 2016-2017 in some of the DER-monitored rivers throughout the state. DER has documented periods of no flow and dry streambed conditions in these brooks in the past, but the conditions typically did not persist for extended periods of time. Streamflow is impacted by a variety of factors including upstream water withdrawals and impervious surfaces. The extended periods of dry streambed conditions in these brooks were likely due to declining groundwater levels from pumping and drought that resulted in a disconnection from the streambed, eliminating base flow.

In addition to the sites described below, dry streambeds were also documented in the Weir River (Hingham), First Herring Brook (Scituate), Mattapoisett River (Mattapoisett), and Parker River (Georgetown). This is certainly not an exhaustive list of all the rivers that went dry during the 2016-2017 drought, but it highlights the impact to streams that face multiple anthropogenic stressors.

Gulf Brook, Pepperell, and Martins Brook, North Reading is a Coldwater Fisheries Resource in the Nashua River watershed where streamflow is monitored both upstream and downstream of a municipal well. In 2016, portions of Gulf Brook downstream of the well were dry from at least mid-July to late October, at least 95 days. Streamflow was observed at the headwaters of the brook throughout the summer, despite dry conditions downstream near groundwater wells. In 2016, portions of Martins Brook, another brook in the Northeast Drought Region and the largest tributary to the Ipswich River, were dry from mid-July to early October, a total of 68 days (Figure 17).

Montague Brook, Belchertown is a designated Coldwater Fisheries Resource in the Connecticut River Valley Drought Region. Streamflow in the brook is impacted primarily by a water supply well and is monitored both upstream and downstream of the well. In 2016, sections of the river in the vicinity and downstream of the well were dry from mid-July to late November, for a total of 128 days (Figure 17). During precipitation events, streamflow resumed briefly, but never for more than one day. By contrast, streamflow was documented throughout the summer and fall in the areas upstream of the well, with no days of zero flow recorded during the same time period. The streamflow measured at sites both upstream and downstream of the water supply well is shown in Figure 18 (page 29).

Figure 17. (left to right) Gulf Brook, Pepperell (8/31/16), Martins Brook, North Reading (8/31/16), Montague Brook, Belchertown (9/22/16), Third Herring Brook, Norwell (8/31/16) .

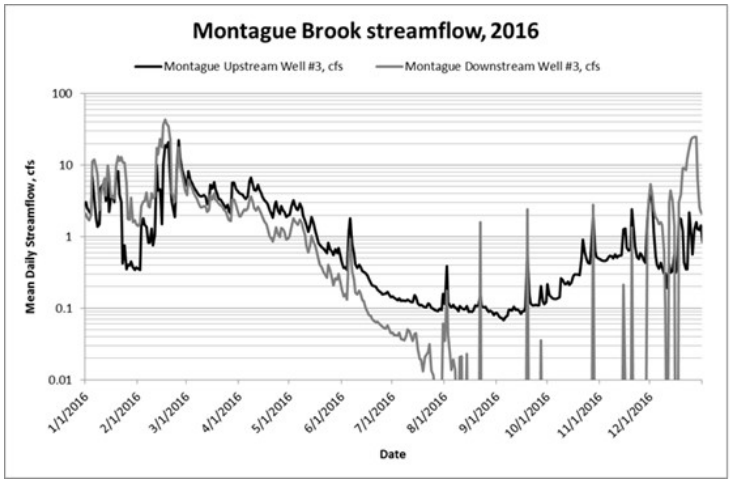


Figure 18. Daily mean streamflow at Montague Brook, Belchertown upstream and downstream of the water supply well (2016).

Third Herring Brook, Norwell is a tributary to the North River in the Southeast Drought Region where streamflow is impacted by a variety of factors including water supply wells, impervious surfaces, and the Jacobs Pond dam. In 2016, a combination of drought conditions, groundwater pumping, and lack of flow over the dam spillway in the headwaters resulted in the lack of flow as a result of which portions of the river were dry from early July to mid-October, a total of 100 days.

Freshwater Fisheries Impacts

The Massachusetts Division of Fisheries and Wildlife (DFW) monitors impacts of drought on freshwater fish and wildlife. Beginning in June 2016, field staff observed diminished streamflows statewide. Throughout July, stream levels remained very low and in particular, groundwater-dominated streams on Cape Cod were also substantially lower than normal, suggesting that the drought had progressed to the point that groundwater levels were being affected.

By early September 2016, many of the smaller streams scheduled to be surveyed by DFW had gone nearly or completely dry. Survey efforts then shifted to larger rivers that still retained adequate flow; however, even larger rivers were becoming severely low. It appeared that some fish normally occupying smaller streams were able to take refuge in larger rivers, if the smaller streams were physically connected to these rivers, and were able to handle the environmental conditions of the larger rivers (e.g., water temperature, oxygen concentrations). If small stream fish were able to survive in larger connected rivers, then they may have been able to recolonize the small streams once the drought ended and flows returned. DFW had not received an abnormal number of fish kill reports, suggesting that, to this point in the drought, most pond and lake fish assemblages were surviving. However, because of the sheer number of smaller streams and their relative inconspicuousness, it was difficult to determine the occurrence of fish kills in locations likely hardest hit by the drought; it is highly likely that a number of small streams experienced localized fish kills when they went dry. District biologists reported that many streams they observed had large areas that were completely dry, and the few scattered thunderstorms during late summer and early fall did not replenish surface flows.

The drought also impacted DFW fish hatcheries in the Connecticut River Valley. Three of these hatcheries are groundwater-fed systems and as the groundwater levels dropped, so did the volume of water available to raise trout in the hatcheries. With a further reduction in volume anticipated with the continuing drought conditions, a subset of fish that would normally have been held in the hatchery through the winter and stocked in the spring as larger individuals needed to be stocked out early to make room. As a result, fewer fish were raised overall than normal.

DFW's survey protocol is not designed to monitor the same stream or stream reach every year. Streams are typically surveyed on a 5- to 15-year rotation. Without a definitive picture of the pre-drought fish assemblage characteristics, it is not possible to know with certainty what the effects of the one-year drought have been on fish. However, there is a long-term project to monitor the changes in abundance of juvenile Atlantic Salmon in a number of streams, as well as the other fish that coexist with the salmon. These streams have been surveyed annually for at least the past decade. This too might provide only limited conclusions pertaining to the drought because fish population metrics respond to myriad conditions within and among years. Furthermore, these index streams are relatively large and occur in only a few watersheds in western Massachusetts, thus missing potentially severe negative effects of the drought in the hardest hit systems (e.g., small streams) and areas (e.g., Northeast).

Marine Fisheries Impacts

The Massachusetts Division of Marine Fisheries (DMF) manages the state's commercial and recreational saltwater fisheries and oversees other services that support the marine environment and fishing communities. During the drought, DMF staff observed that in small river systems and mid-sized rivers influenced by water supply withdrawals, juvenile river herring experienced substantial challenges during the summer and fall 2016 emigration. Alewife Brook in Essex, the Ipswich River, and the Parker River (all in the Northeast Region) all had sections that ran dry during the drought, resulting in acute impacts to aquatic life. The drought will potentially negatively impact river herring recruitment over the next few years. Throughout the state, many of the smaller coastal rivers had reduced herring counts in 2017 as compared to 2016.

DMF staff and local volunteers witnessed significant juvenile migrations in March and April 2017 in many rivers, including Herring Brook (Pembroke), Back River (Weymouth), Alewife Brook (Essex), and the Parker River (Newbury). DMF staff conducted emergency work in the Nemasket River to release juvenile river herring from Assawompsett Pond in December 2016 as low flow and a sediment berm prevented downstream passage. Local residents commented that for more than 70 years, these poor conditions for juvenile migration had only been observed once before, in the early 1960s. The Cape Cod region had widespread poor conditions in 2016 for juvenile herring emigration. The effects on populations will not be fully known until the cohorts born in 2016 are mature and return to spawn.

STATE RESPONSE TO DROUGHT CONDITIONS

As specified in the 2013 DMP, EEA communicates drought-related advice to state agencies, and EEA's press office is the primary vehicle through which information is made available to the media and the general public. EEA partners with other agencies or offices (such as MEMA or the Governor's Office) when jointly released public announcements are needed to bring attention to the situation or to communicate specific response actions. The following section describes the actions taken by MEMA and EEA during the drought of 2016-2017.

DMTF Meetings

Beginning from the declaration of the drought in July 2016, the DMTF continued to meet on a monthly basis through the duration of the drought to discuss hydrologic conditions and make recommendations to determine drought levels in each region. At each meeting, state and federal agencies that comprise the task force provided updates on conditions and any impacts caused by the drought. Following each meeting the Secretary of EEA declared the level of drought for each region based on the recommendations of the DMTF and issued a press release to notify the public.

Interagency Coordination

In August 2016, EEA pulled together an internal coordinating group with representatives from EEA, MassDEP, DCR, the Massachusetts Department of Fish and Game (DFG), and DAR

that met multiple times each week. In addition, EEA was in regular communication with MEMA and DPH to ensure sharing of up-to-date information as well as coordination of response actions.

Communication

- Governor's Press Conference: On August 18, 2016, Governor Baker and EEA Secretary Beaton held a press conference on the drought at Smolak Farms in North Andover where they urged residents to conserve water. They also appealed to Massachusetts residents to continue to frequent local farmers markets and buy local to support farmers experiencing financial difficulties as a result of the drought.

- Press Releases: Starting with the first drought declaration on July 8, 2016, EEA distributed monthly press releases announcing drought conditions across the state. As the drought progressed, these press releases provided guidance on appropriate responses, such as limits on outdoor watering, and urged the public to conserve water. The last press release, on May 11, 2017, announced that drought conditions had ended.

- Information to Municipalities: EEA and MEMA conducted a conference call with municipal officials on August 19, 2016, to provide information about the drought and updates on water supply, agricultural and public health impacts.

- Situational Awareness Statements: MEMA sent a series of Situational Awareness Statement emails (in addition to broadcasting information on social media and the MEMA webpage). These were targeted at local and state public safety officials statewide, including Emergency Management Directors, Fire Chiefs, Police Chiefs, Public Health, Departments of Public Works, Emergency Support Function partners, and the public sector.

- MEMA regularly communicated with the Fire Mobilization Committee, to ensure they were up to speed on current water supply issues. In the event of a major fire with a reduced water supply, the Fire Mobilization Tanker/Tender Task Forces would have likely been activated to support fire suppression efforts.

- MEMA received direct calls from approximately ten communities, who were experiencing drought-related emergencies and were looking for guidance and/or assistance.

Information Sharing and Tips

- EEA set up a drought website[15] with periodically updated information on hydrologic conditions and drought levels, water conservation tips for indoor and outdoor water use, information for private well users, and drought disaster assistance for businesses[16].

- MassDEP focused on individual outreach to PWS through monthly update letters sent to each supplier from July through December 2016. Each update included:

    - updated drought map
    - updated guidance for suppliers on outdoor water use restrictions appropriate for the increasing drought conditions
    - information on numerous ways to conserve water, both indoors and outdoors, which became more expansive as the drought continued
    - how to declare a drought emergency, if needed
    - additional resources available to communities
    - All letters, maps, and guidance and website links were posted on the MassDEP website.

- MassDEP Boston and regional offices provided technical assistance to individual communities on management and the use of emergency connections and emergency water supplies as needed.

Financial Assistance

- In September 2016, the Baker-Polito Administration made micro-loans available for small businesses and farmers that had been impacted by the drought. The Massachusetts Drought Emergency Loan Fund had the capacity to provide up to $1 million in micro-loans to family farms and other small businesses affected by widespread drought conditions in Massachusetts. The Drought Emergency Loan Fund was part of the Administration's coordinated response to months of abnormally dry weather across the Commonwealth.

- The agricultural sector was deeply affected by the 2016-2017 drought. Post-drought, MDAR continued to look at ways to assist farmers in adapting to climate change, including ways to mitigate the impacts from drought. In Fiscal Year 2018, MDAR received a total of $500,000 in capital funding and launched the new Agricultural Climate Resiliency & Efficiencies (ACRE) Program. The program provides reimbursement funding to agricultural operations for the implementation of practices that address the agricultural sector's vulnerability to climate change, improve economic resiliency and advance the general goals identified in the Massachusetts Local Action Food Plan. In its first year, the program awarded $500,000 in awards to 16 projects.

- The U.S. Small Business Administration (SBA) announced federal Economic Injury Disaster Loans for small businesses, small agricultural cooperatives, small businesses engaged in aquaculture, and private nonprofit organizations located in Essex, Middlesex and Worcester counties. SBA provides low-interest, long-term loans for physical and economic damage caused by a declared disaster.

CONCLUSION

The 2016-2017 drought was an event with statewide impacts and was the most significant drought in Massachusetts since the 1960s. It was characterized by a rapid decline in conditions from one month to the next, and at times in some regions, it fit the concept of a "flash drought". All drought regions were affected by the drought, with five out of six regions reaching the Warning Level (drought severity level of three out of four). Several regions reached the Emergency Level (four out of four) for the precipitation, streamflow, and groundwater indices. In many parts of the state, USGS data for streamflow and groundwater reached new record low levels for several consecutive months when compared to their period of record (which in some cases went back 100 years). The most significant impacts were felt in the agricultural and natural resources (particularly fisheries) sectors. Several communities also experienced issues with water supply.

During the 2016-2017 drought, the 2013 DMP was used and implemented, and many lessons were learned, resulting in an update to the DMP that was released in 2019. Between the lessons learned during the 2016-2017 drought and the 2019 revision of the DMP, the Commonwealth is in a stronger position to react to and manage any future droughts.

[15] https://www.mass.gov/drought-information-and-assistance

[16] http://www.mass.gov/eea/docs/eea/outdoor-indoor-water-use-tips.pdf