Massachusetts Sustainable Water Management Initiative

FRAMEWORK APPENDICES

Staff Technical Support Document

November 28, 2012

TABLE OF CONTENTS

Appendix A: Reservoir Storage Volume Methodology for Safe Yield

General Approach:
The Water Management Act (WMA, 310 CMR 36.03) states: "Safe Yield means the maximum dependable withdrawals that can be made continuously from a water source, including ground or surface water, during a period of years in which the probable driest period or period of greatest water deficiency is likely to occur; provided however, that such dependability is relative and is a function of storage and drought probability." The Sustainable Yield Estimator (SYE) is being utilized to determine the basin Safe Yield, but the SYE cannot account for reservoir storage. The method described below calculates the Safe Yield storage volume for a reservoir or reservoir system. This method will only apply to systems with surplus water at the end of a drought.

Drought conditions are defined as one calendar year in duration, consistent with the streamflow methodology for calculating major basin Safe Yield. The years prior to and following the drought are assumed to have average annual inflow to the reservoir, and the reservoir is assumed to be full at the start of the drought. During a drought, surplus water in storage (i.e. the Safe Yield storage volume described below) could be used by other water suppliers experiencing shortfalls, if infrastructure allows.

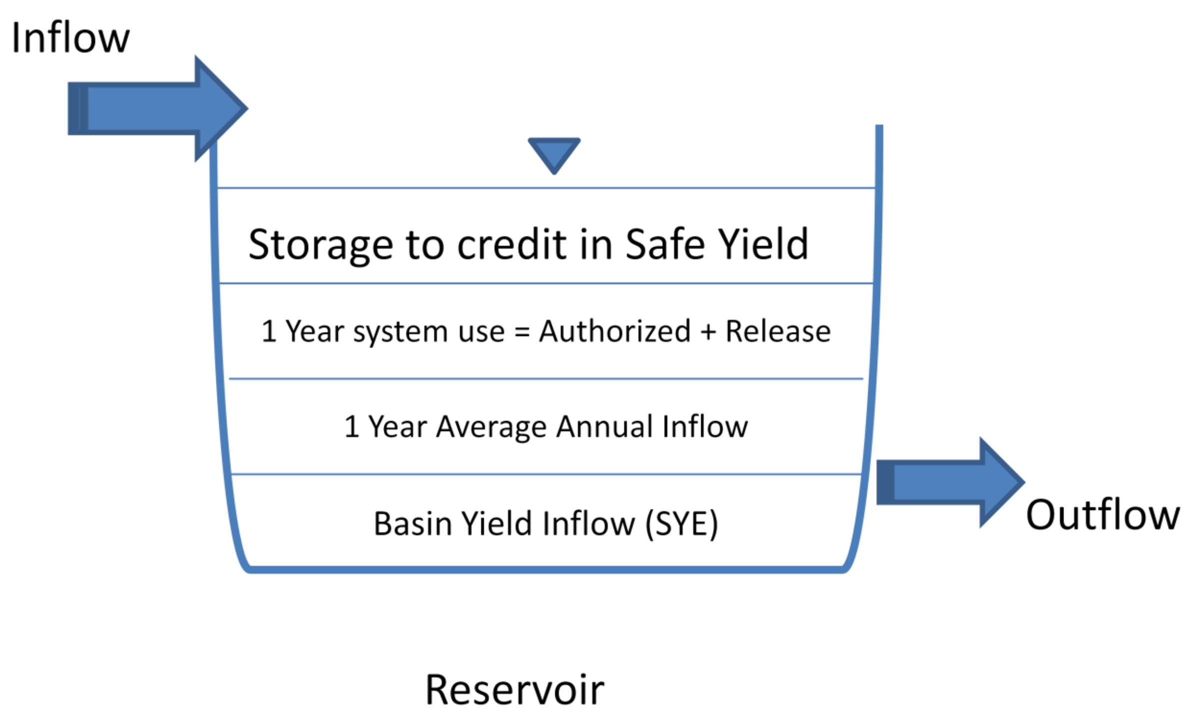
The methodology adds the water volume remaining in reservoir storage at the end of the drought to the SYE-calculated basin Safe Yield volume. This is consistent with the "function of storage and drought probability" in the WMA Safe Yield definition. The volume of water in the reservoir (or reservoir system) remaining at the end of the drought is calculated from two parameters: (1) available storage (volume above the intake structure when the reservoir is full) and; (2) the annual system use (WMA allocated volume + required release volume). The volume of water that flows into the reservoir during a drought also affects the volume of water remaining at the end of the drought, but this volume has already been counted in the major basin Safe Yield using the SYE. Therefore, to prevent double-counting it, drought year inflow is not included in the Safe Yield storage volume. However, if the reservoir storage volume is less than drought inflow or less than the annual use volume, or less than the sum of drought inflow and annual usage, then no Safe Yield storage volume is possible because under these conditions the reservoir would have little if any water available at the end of a drought.

The MWRA Quabbin and Wachusett reservoir system has significantly more storage than any other system in the state. At the end of a severe one-year drought, the MWRA system would have multiple years of usable water remaining in storage. In addition to limiting the Safe Yield storage volume to the volume remaining in storage at the end of the drought, the volume is also limited to the annual average inflow to the reservoir, as calculated with the SYE. Both the Quabbin and Wachusett reservoirs have release requirements, so the MWRA system use is the release volumes plus the WMA allocated volumes.

A lesser amount of “excess storage” volume can be added to Major Basin Safe Yield for storage above one year of water use but less than the average annual inflow volume. For systems that cannot store the drought year inflow plus one year of use, plus one year of average annual inflow, safe yield storage volume is limited to the volume above one year of WMA authorized annual use remaining in the reservoir at the end of the drought. A final cap for Safe Yield Storage volume is the reservoir Firm Yield.

The equations that follow outline how the Safe Yield storage volumes are calculated. This methodology is applied to large reservoir systems in Massachusetts for which basic data were readily available (e.g., USGS Firm Yield Studies or other sources). In the case of the MWRA reservoirs, the net inflow (ground water plus surface water inflow, minus evaporation) have been independently calculated, and are used in the analysis. For multiple reservoir systems that pump between reservoirs within a single major basin, the total storage, inflows, and withdrawal can be calculated for each reservoir and can be taken as the total for the system.

In each analysis, data for the reservoir and watershed are used. A two-question screening process determines whether or not the Safe Yield Storage Volume is possible. If the reservoir (system) passes the screening process, the analysis can proceed. Examples are given and a table of results for reservoirs screened and analyzed.



Scenario A (Maximum Safe Yield Storage Volume)

Reservoir Storage is Greater than Drought Year Inflow + Annual System Use + Average Annual Inflow

Reservoir Storage = 200,000 MG (volume between intake and spillway)
Drought year inflow = 50,000 MG
Annual System Use = 90,000 MG (authorized volume + required release volume)
Average Annual Inflow = 54,750 MG / 365 days = 150 MGD

1. Is Reservoir Storage > Drought Year Inflow?
   200,000 MG > 50,000 MG
   YES, so proceed.
   (If NO, then no Safe Yield Storage Volume given.)

2. Is Reservoir Storage > Annual System Use?
   200,000 MG > 90,000 MG
   YES, so proceed.
   (If NO, then no Safe Yield Storage Volume given.)

3. Is Reservoir Storage > Drought Year Inflow + Annual System Use?
   200,000 MG > 50,000 MG + 90,000 MG
   YES, so proceed.
   (If NO, then no Safe Yield Storage Volume given.) .

4. Is Reservoir Storage > Drought Year Inflow + Annual System Use + Average Annual Inflow?
   200,000 MG > 50,000 MG + 90,000 MG + 54,750 MG
   YES, so proceed
   (If No, cannot give maximum Safe Yield Storage Volume of Annual Average Inflow)

5. Calculate Safe Yield Storage Volume = SYE calculated Average Annual Inflow at outlet = 54,750 MG = 150 MGD

Only Quabbin and Wachusett Reservoirs are eligible for the Maximum Safe Yield Storage Volumes.

Scenario B (Excess Storage Safe Yield Volume)

Reservoir Storage is Greater than Drought Year Inflow + Annual System Use
but is Less than Average Annual Inflow

Reservoir Storage = 20,000 MG
Drought Year Inflow = 5,000 MG
Annual System Use = 8,000 MG
Average Annual Inflow = 70 MGD X 365 days = 25,500 MG

1. Is Reservoir Storage > Drought Year Inflow?
   20,000 MG >5,000 MG
   YES, so proceed.
   (If NO, then no Safe Yield Storage Volume given.)

2. Is Reservoir Storage > Annual System Use?
   20,000 MG > 8,000 MG
   YES, so proceed.
   (If NO, then no Safe Yield Storage Volume given.)

3. Is Reservoir Storage > Drought Year Inflow + Annual System Use?
   20,000 MG > 5,000 MG + 8,000 MG
   YES, so proceed.
   (If NO, then no Safe Yield Storage Volume given.)

4. Is Reservoir Storage > Drought Year Inflow + Annual System Use + Average Annual Inflow?
   20,000 MG < 5,000 MG + 8,000 MG + 25,500 MG
   (No, cannot give maximum Safe Yield Storage Volume of Annual Average Inflow)

5. Safe Yield Storage Volume = Excess Reservoir Storage above Drought Year Inflow and Annual System Use:

   Safe Yield Volume = Reservoir Storage – (Drought Year Inflow + Annual System Use)
   = 20,000MG- (5,000 MG + 8,000 MG) = 7,000 MG/365 days = 19 MGD

   Excess Storage Safe Yield Volume is given for the following:

   Springfield Cobble Mountain reservoirs in Westfield Basin
   Fitchburg Reservoirs in Chicopee Basin
   Southbridge Hatchet Brook Reservoirs in Quinebaug Basin
   Winchester Reservoirs in Boston Harbor Mystic Basin
   Fall River Reservoirs in Narragansett Basin
   Lincoln Sandy Pond Reservoir in Charles Basin

Scenarios C, D, E: No Safe Yield Storage Volume

Scenario C (No Safe Yield Storage Volume)

Reservoir Storage is Less than Drought Year Inflow

Reservoir Storage = 1,000 MG
Drought Year Inflow = 2,000 MG
Annual System Use = 1,500 MG

1. Is Reservoir Storage > Drought Year Inflow?
   1,000 MG < 2,000 MG
   NO, so no Safe Yield Storage Volume given

Westborough Sandra Pond
Amherst Reservoirs
South Deerfield Reservoirs
Leominster Distributing Reservoir System
Hinsdale Belmont Reservoir
Lynn System
Scituate Tack Factory Pond
Cohasset Aaron Reservoir/Lily Pond
Greenfield Reservoirs
Westfield Montgomery Reservoir
Lee Reservoir System

Scenario D (No Safe Yield Storage Volume)

Reservoir Storage is Greater than Drought Year Inflow
But is Less than Drought Year Inflow + Annual System Use

Reservoir Storage = 5,000 MG
Drought Year Inflow = 2,000 MG
Annual System Use = 6,000 MG

1. Is Reservoir Storage > Drought Year Inflow?
   5,000 MG> 2,000 MG
   YES, so proceed.
   (If NO, then no Safe Yield Storage Volume given.)

2. Is Reservoir Storage > Annual System Use?
   5,000 MG < 6,000 MG
   NO, so no Safe Yield Storage Volume given.

Worcester System
Cambridge System
North Brookfield
Pittsfield Reservoir System
Salem-Beverly System
Hingham Accord Pond
Weymouth Great Pond
Westborough Reservoir
Danvers Reservoirs
Peabody Reservoirs
Fitchburg Nashua Reservoirs
Leominster Notown, Fall Brook
Wakefield Crystal Lake
Westfield Granville Reservoir

Scenario E (No Safe Yield Storage Volume)

Reservoir Storage is Greater than Drought Year Inflow and Is Greater than Annual System Use
But is Less than Drought Year Inflow + Annual System Use

Reservoir Storage = 7,000 MG
Drought Year Inflow = 2,000 MG
Annual System Use = 6,000 MG

1. Is Reservoir Storage > Drought Year Inflow?
   7,000 MG > 2,000 MG
   YES, so proceed.
   (If NO, then no Safe Yield Storage Volume given.)

2. Is Reservoir Storage > Annual System Use?
   7,000 MG > 6,000 MG
   YES, so proceed.
   (If NO, then no Safe Yield Storage Volume given.)

3. Is Reservoir Storage > Drought Year Inflow + Annual System Use?
   7,000 MG < 2,000 MG + 6,000 MG
   NO, so no Safe Yield Storage Volume given.)

New Bedford and Taunton Assawompset Pond Complex
North Brookfield Horse and Doane Reservoirs
Concord Nagog Pond
Fitchburg Meetinghouse and Wachusett Reservoirs

Reservoir Storage Volume Methodology

<u>Reservoir and Basin Data Needs for Analysis</u>

Determine Reservoir Storage Volume in millions of gallons (volume between intake and spillway)

Determine Which Reservoirs are Connected in Series or if Separate Analyses Needed

Determine Drought Year Inflow

Use Basin Yield for Major Basin and scale reservoir inflow to reservoir drainage area
Major Basin Yield (MGD)/Basin Area (Sq Mi) X Drainage Area to Reservoir = Basin Yield Reservoir Inflow, MGD
Multiply Reservoir Inflow X 365 days/year = Reservoir Inflow in Millions of Gallons (MG)

Calculate Annual System Use

WMA allocation of reservoir or reservoir system (registered plus permitted volumes) (MG)
<u>+ release requirement (if applicable) (MG)</u>
= Maximum Annual System Use Volume (MG)

Calculate Average Annual Inflow:

Use SYE to calculate Average Annual Inflow at a point coincident with the reservoir dam or outlet
Convert resultant flow in cfs to MGD (cfs/1.55 = MGD)

Screening Steps 1 and 2:

Step 1: Compare Reservoir Storage Volume to Drought Year Inflow

If Reservoir Storage < Drought Year Inflow	Then no Safe Yield Storage Volume
If Reservoir Storage > Drought Year Inflow	Then continue to Step 2

Step 2: Compare Reservoir Storage to Annual System Use

If Reservoir Storage < Annual System Use	Then no Safe Yield Storage Volume
If Reservoir Storage > Annual System Use	Then continue to Step 3

Analysis Steps 3 to 5:

Step 3: Compare Reservoir Storage to Drought Year Inflow + Annual System Use

If Reservoir Storage < Drought Year Inflow + Annual System Use	Then no Safe Yield Storage Volume
If Reservoir Storage > Drought Year Inflow + Annual System Use	Then continue to Step 4

Step 4: Compare Reservoir Storage to Drought Year Inflow + Annual System Use + Average Annual Inflow

If Reservoir Storage < Drought Year Inflow + Annual System Use + Average Annual Inflow
Then Calculate Excess Safe Yield Storage Volume — Continue to Step 5A
If Reservoir Storage > Drought Year Inflow + Annual System Use
Then Maximum Safe Yield Storage Volume — Continue to Step 5B

Step 5: Calculate Safe Yield Storage Volume

Step 5A: Excess Storage Safe Yield Credit = Storage above Annual Use + Drought Year Inflow
= Reservoir Storage – (Drought Year Inflow + Annual System Use)

Step 5B: Maximum Safe Yield Volume = Average Annual Inflow
Unless exceeds Reservoir Firm Yield Cap. If so, Reservoir Firm Yield is Safe Yield Storage Volume

			Reservoir and Basin Data										*Screening Steps 1 and 2*		*Analysis Steps 3 - 5*				
System Name	**Reservoir Name**	**Major Basin**	**Reservoir Storage Volume (MG)**	**Reservoir Drainage Area (mi2)**	**Basin Yield MQ90 (cfsm)**	**Drought Year Inflow DYI (MGY)**	**Ave Ann. Inflow (cfsm)**	**Ave Ann Inflow, AAI (MG)**	**Auth Withdrawal (MGD)**	**Auth Withdrawal (MGY)**	**Release Requirement (MGY)**	**Max Annual Use (MGY)**	**1. Storage > Drought Year Inflow?**	**2. Res Storage > Annual System Use?**	**Drought Year Inflow +Use (MGY)**	**3. Res Storage > DYI + Use?**	**DYI+Use+Ave Ann Inflow (MG)**	**4. Storage > DYI + Use + AAI?**	**5. Safe Yield Storage Volume (MGD)**
Weymouth	Great Pond	BH Weym Weir	1,103	2.72	0.49	314			3.63	1,325	0	1,325	Yes	No					
Hingham	Accord Pond	BH Weym Weir	219	0.95	0.50	113			3.51	1,281	0	1,281	Yes	No					
Winchester	North, Middle, South	BH Mystic	795	1.39	0.53	175	1.81	594	1.06	387	0	387	Yes	Yes	562	Yes	1,157	No	**0.6**
Worcester	Blackstone Basin Res	Blackstone	7,030	40.7	0.60	5,624			37.2	13,578	0	13,578	Yes	No					
Cambridge	Fresh Pond	Charles	1,308	1	0.58	137			4.80	1,752	0	1,752	Yes	No					
Cambridge	Hobbs & Stony Brook	Charles	2,371	24	0.58	3,278			11.36	4,146	0	4,146	No	No					
Lincoln	Flints/Sandy Pond	Charles	506	0.80	0.58	110	1.3	245	0.57	208	0	208	Yes	Yes	318	Yes	563	No	**0.5**
Milford	Echo Lake	Charles	437	1.42	0.58	194			5.32	1,942	0	1,942	Yes	No					
Fitchburg	Bickford	Chicopee	904	3.29	0.54	418	1.75	1,355	0.27	97	0	97	Yes	Yes	515	Yes	1,869	No	**1.1**
Fitchburg	Mare Meadow	Chicopee	1,751	3.10	0.54	394	1.75	1,276	0.51	188	0	188	Yes	Yes	581	Yes	1,858	No	**3.2**
MWRA	Quabbin/Ware	Chicopee	333,720	186	0.54	23,652	1.75	76,703	186.7	68,146	14,386	82,532	Yes	Yes	106,184	Yes	182,887	Yes	**209.7**
N. Brookfield	Horse and Doane	Chicopee	271	1.68	0.54	214			0.43	157	0	157	Yes	Yes	371	No			
Concord	Nagog Pond	Concord	997	1.21	0.62	175			2.52	920	0	920	Yes	Yes	1,095	No			
Marlborough	Millham	Concord	313	3.15	0.62	456							No						
Westborough	Sandra Pond	Concord	154	1.20	0.62	174			1	365	0	365	No						
Westborough	Westborough	Concord	9	0.02	0.62	3			1	365	0	365	Yes	No					
Amherst	4 Reservoirs Combined	Connecticut	292	8.00	0.71	1,338							No						
S Deerfield	Roaring Brook	Connecticut	171	4.00	0.55	519							No						
S Deerfield	Whatley	Connecticut	10	1.22	0.55	158							No						
Greenfield	2 Reservoirs Combined	Deerfield	43	57.22	0.55	670							No						
Hinsdale	Belmont	Housatonic	36	0.39	0.51	46							No						
Lee	Schoolhouse, Upper Leahy	Housatonic	476	48.3	0.51	5,801			1.13	412	0	412	No						
Pittsfield	Ashley	Housatonic	413	2.61	0.51	1.04			1.80	658	0	658	Yes	No					
Pittsfield	Cleveland	Housatonic	1,779	14.0	0.51	1,679			7.76	2,833	0	2,833	Yes	No					
Pittsfield	Farnham, Sandwash	Housatonic	737	6.5	0.51	1.04			3.22	1,174	0	1,174	Yes	No					
Pittsfield	Upper Sackett	Housatonic	165	0.9	0.51	107			0.72	262	0	262	Yes	No					
Salem Beverly	3 Reservoirs Combined	Ipswich	3,536	6.63	0.53	830			12.44	4,541	0	4,541	Yes	No					
Peabody	Suntaug Winona	Ipswich	940	0.50	0.53	63			5.9	2,154	0	2,154	Yes	No					
Danvers	Emerson, Middleton, Swan	Ipswich	1,043	6.3	0.53	780			3.72	1,358	0	1,358	Yes	No					
Andover	Haggetts Pond	Merrimack	82	2.24	0.66	349			8.51	3,106	0	3,106	No						
Fall River	Copicut, N Watuppa	Narragansett	10,338	17.87	0.65	2,721	1.43	6,030	8.22	3,000	0	3,000	Yes	Yes	5,722	Yes	11,752	No	**12.6**
Fitchburg	Fitchburg, Lovell, Scott	Nashua	1,229	6.18	0.58	844			6.19	2,259	0	2,259	Yes	No					
Fitchburg	Meetinghouse	Nashua	646	1.57	0.58	214			1.76	644	0	644	Yes	Yes	858	No			
Fitchburg	Wachusett	Nashua	390	1.52	0.58	207			1.07	389	0	389	Yes	Yes	596	No			
Leominster	Distributing System	Nashua	182	1.9	0.58	257			0.71	259	0	259	No						
Leominster	Fall Brook	Nashua	353	1.4	0.58	184			1.37	501	0	501	Yes	No					
Leominster	Notown System	Nashua	735	5.0	0.58	676			2.86	1,043	0	1,043	Yes	No					
MWRA	Wachusett *	Nashua	215,833	107	0.58	38,266	2.01	50,776	126.12	46,034	624	46,658	Yes	Yes	61,272	Yes	112,048	Yes	**138.8**
Worcester	Nashua Basin Res	Nashua	4,769	28.1	0.58	3,838			19.14	6,986	0	9,211	Yes	No					
Lynn	5 Reservoirs Combined	North Coastal	3,937	567.00	0.42	56,078							No						
Wakfield	Crystal Lake	North Coastal	170	0.87	0.46	94			0.48	175	0	175	Yes	No					
Southbridge	Cohasse	Quinebaug	371	1.85	0.58	253	1.93	843	0.32	117	0	117	Yes	Yes	370	Yes	1,212	No	**0.0**
Southbridge	Hatchet Bk system	Quinebaug	693	2.42	0.58	331	1.93	1,104	0.60	219	0	219	Yes	Yes	550	Yes	1,653	No	**0.4**
Cohasset	Lily Pond	South Coastal	537	8.55	0.565232	1,138			0.65	237	0	237	No						
Scituate	Tack Factory Pond	South Coastal	145	3.59	0.46	386			1.85	675.25	0	675.25	No						
Taunton and New Bedford	Assawompset Complex	Taunton	12,000	49.20	0.71	8,263			28.28	10,322	0	10,322	Yes	Yes	18,585	No			
Springfield	Cobble Mt./Borden Br	Westfield	23,094	37.5	0.46	4,066	2.01	17,812	37.2	13,578	0	13,578	Yes	Yes	17,644	Yes	35,455	No	**14.9**
Westfield	Granville	Westfield	661	5.26	0.46	566			3.05	1,113	0	1,113	Yes	No					
Westfield	Montgomery	Westfield	209	2.53	0.46	272			3.05	1,113	0	1,113	No						

Notes: * Excess storage from Quabbin Reservoir allocated to Wachusett because water can be transferred from Quabbin to Wachusett.

Additional information needed to complete analysis of Andover Haggetst's Pond.

Additional information needed to complete analysis of Salem-Beverly Reservoirs.

No — Indicates End of Safe Yield Storage Volume analysis. No storage volume can be added to Safe Yield; criteria are not met.

Appendix B: Safe Yield Approach for Plymouth-Carver Aquifer, Cape Cod and Islands

Tools being used for Safe Yield estimation in Massachusetts' major basins are not capable of handling hydrogeologic conditions experienced in the Plymouth Carver Aquifer (present in southeast Massachusetts), Cape Cod and the Islands of Martha's Vineyard and Nantucket. These areas consist of thick glacial sand and gravel deposits. Rivers within these geologic materials are relatively shallow and are fed by relatively steady ground water baseflow. Much of the ground water flow through the thick sand and gravel aquifers discharges directly to the ocean, rather than discharging to area rivers. There are very few large rivers and very few USGS stream gages in these areas. USGS has developed several ground water models that quantitatively represent ground water flow conditions in these areas.

EEA agency hydrogeologists from MassDEP Water Supply, Water Management Act, and DCR Office of Water Resources have met and discussed methodologies to calculate Safe Yield in the Plymouth Carver Aquifer, Cape Cod and Islands, that would be approximately equivalent to the Safe Yield approach being used in the remainder of the state. USGS report authors were also consulted for additional details for portions of some studies (written communication, USGS). Major basins where this Safe Yield approach would be used include Basin 21b: South Coastal Shore of South Coastal Basin; Basin 22: Cape Cod; Basin 23: Islands; and the eastern portion of Basin 24: Buzzards Bay.

By definition, Safe Yield in the Massachusetts Water Management Act (WMA) is:

> "the maximum dependable withdrawals that can be made continuously from a water source including ground or surface water during a period of years in which the probable driest period or period of greatest water deficiency is likely to occur; provided, however, that such dependability it relative and is a function of storage and drought probability."

The statewide Safe Yield method being used outside of the Plymouth Carver Aquifer, Cape Cod and Islands is based on a drought condition flow represented by estimated unimpacted monthly 90th percentile river flows simulated (by the USGS/DEP Sustainable Yield Estimator, SYE) for the mainstem river for each major basin. These conditions are generally representative of the severe 1965 drought in Massachusetts. The 90th percentile monthly flows are combined into an average annual value (annual Q90). At present, 55% of this annual Q90 flow has been suggested as the value for potentially allocatable water under the Water Management Act. Safe yield would be an annual cap for Water Management Act permit volumes issued in each major basin. The remainder of the drought year flow (45% of the Q90 flows) would be reserved for the environment. In addition to safe yield limitations, permitted withdrawals would also be subject to evaluation of streamflow criteria at the local level.

This document describes the agency staff's recommended methods for determining Safe Yield and potentially allocatable water for areas of the basins listed above. Figure 1 shows approximate delineations of the areas described below.

<u>Basin 21a -- South Coastal, North and South Rivers</u>

Mass Water Indicators subbasins cover the area well—daily hydrographs 1960-2004 are available, so the same safe yield methodology applied at other areas of the state was used for this area. Monthly Q90 values were determined and combined into an area-weighted annual Q90 value for the 120.60

square mile area covered by Basin 21a. The area-weighted MQ90 from MWI subbasins data is 0.54 cfsm or 0.35 MGD/sqmi. This results in a Basin Yield of 42.2 MGD. At 55% allocatable, this would equate to a safe yield of 0.19 MGD per square mile, and 23.2 MGD.

TOTAL RECOMMENDED POTENTIALLY ALLOCATABLE WATER FOR BASIN 21A: 23.2 MGD

Basin 21b—South Coastal Shore of South Coastal Basin

The USGS PCA study (Masterson, et al., SIR 2009-5063) indicates the geology is different in the north and south parts of this basin. The total area of Basin 21b is 119.8 square miles. Different safe yield methodologies are recommended for the north and south portions of Basin 21b. The division between what we consider the north and south portions of Basin 21b is based on the geology described in USGS SIR 2009-5063 (Masterson, et al.) and is roughly along the Kingston/Plymouth town boundary.

Basin 21b North portion of South Coastal Shore

The northern part of Basin 21b is 49.45 square miles in area, is more geologically similar to Basin 21a (North and South Rivers) and is drained primarily by the Jones River. The Jones River is impacted by withdrawals from Silver Lake in its headwaters. SYE was applied to the Jones River with a drainage area of 21.4 square miles (including Silver Lake). Values of monthly mean unimpacted flows estimated for the Jones River were published in the SYE report (Archfield, et al., SIR 2009-5227). These values represent base flow only (i.e., do not include surface runoff) and were generated using the regional MODFLOW ground water model. It is recognized that generally mean flow values are higher than median values, but since the SYE flows represent base flow only, they are likely very similar to a median flow value. We recommend using 25% of the mean monthly unimpacted flows estimated for the Jones River as the approximate equivalent of 55% percent of the monthly 90th percentile flows for this area.

Jones River Estimated Safe Yield (Drainage Area 21.4 Square miles)

		Potentially Allocatable cfs	**Potentially Allocatable MGD**
Month	**SYE Average Unimpacted Monthly Flow, cfs**	**25% of Average Monthly Flow, cfs**	**25% of Average Monthly Flow, MGD**
January	42.57	10.64	6.88
February	44.30	11.07	7.16
March	46.58	11.65	7.53
April	45.00	11.25	7.27
May	40.55	10.14	6.55
June	35.62	8.90	5.76
July	29.29	7.32	4.73
August	27.36	6.84	4.42
September	28.57	7.14	4.62
October	29.72	7.43	4.80
November	35.78	8.94	5.78
December	41.03	10.26	6.63
Annual Average	37.15	9.29	6.00
Average per 21.4 sqmi	1.74 cfs/sqmi	0.43 cfs/sqmi	0.28 MGD/sqmi

cfs =cubic feet per second   sqmi = square miles   MGD = million gallons per day

Expanded to the entire drainage area of what we are considering the northern portion of Basin 21b (49.45 square miles), the potentially allocatable water would be 13.8 MGD. To equate this to 55 percent of the annual Q90, a simple ratio is applied: 13.8 MGD/0.60 = X MGD/0.55. The safe yield portion at 55% of annual Q90 flow (equivalent) would be **12.6 MGD**.

In comparison, the GZA Jones River Study (2003) developed an Aquatic Habitat Safe Yield of 25.61 MGD for a 29.8 square mile drainage area of the Jones River. The agency staff team felt the value derived from SYE was more appropriately conservative and more consistent with results for Basin 21a.

Basin 21b South portion of South Coastal Shore

The southern portion of Basin 21b contains the thickest, highest-yield portion of the Plymouth-Carver Aquifer formation. The USGS Sustainable Yield Estimator (SYE) was only run on three small coastal rivers in this area (Town Brook, Eel River, and Beaver Brook). There are only few coastal rivers, not a single mainstem, and the aquifer dominates the basin's hydrology. This portion of Basin 21b comprises 70.35 square miles. The 1965 recharge rate for the Plymouth-Carver Aquifer area used in the USGS ground water model (Masterson, et al., SIR 2009-5063) is recommended as the basis for safe yield in the south portion of Basin 21b. In 1965, recharge was estimated to be 11.18 inches, or 41 percent of average. For consistency with the statewide methodology, we considered that the 1965 recharge rate would be equivalent to the concept of Q90 flows. The 1965 recharge rate equates to 0.532 MGD per square mile. Because of the expansive thickness of this portion of the Plymouth Carver aquifer, its yield would not be significantly affected by a single year's dry conditions. The Plymouth Carver Aquifer holds approximately 500 billion gallons of water (Masterson, et al., SIR 2009-5063.) This is more than Quabbin and Wachusett Reservoirs combined; over three years of average recharge is stored in the Plymouth Carver aquifer like a multi-year surface water reservoir. Therefore, it is proposed to use the entire volume (100 percent) of the driest year's recharge to represent allocatable water in this area. The dry year recharge rate can be multiplied over the land area to arrive at an annual average volume.

The 1965 recharge rate of 0.532 MGD per square mile applied to the Basin 21b South 70.35 square mile area results in **37.4 MGD** . This value would equate to 13.65 billion gallons a year, or approximately 3 percent of the water in storage in the Plymouth Carver aquifer.

TOTAL RECOMMENDED POTENTIALLY ALLOCATABLE WATER FOR BASIN 21B:
North section: 13.8 MGD
South section: 37.4 MGD

TOTAL: 51.2 MGD

Basin 22—Cape Cod; Basin 23—Islands

The Cape Cod Basin comprises 394.80 square miles of land area. The Islands of Nantucket and Martha's Vineyard combined are 142.12 square miles in area. Cape Cod and the Islands' geology is similar in its derivation to that of the Plymouth Carver Aquifer. The sand formation of Cape Cod and the Islands is hundreds to a thousand feet thick. The water table of Cape Cod and the islands are lenses with high points in the center that decline on the outer sides toward the ocean. Thus the aquifers are lenses of fresh water. The outer edges of the aquifers are subject to saltwater intrusion from the ocean. There are very few rivers on Cape Cod and the Islands and many kettle ponds. For these two basins, it was decided that the best available data source for determining Safe Yield parameters was recharge values used in regional USGS ground water models for Cape Cod.

Recharge data for the Sagamore and Monomoy Flow Lenses from USGS SIR 2004-5181 (Walter and Whealan) were used to represent the entire Cape Cod and Islands basins. These models represent the majority of the land area of Cape Cod. Average annual recharge of 27.25 inches per year was used in the ground water models. In 1965, recharge was estimated to be 13.9 inches, or 51 percent of average. For consistency with the statewide methodology, we considered that the 1965 recharge rate would be equivalent to the concept of Q90 flows. Because of the expansive thickness of this portion of the Cape Cod and Islands aquifers, their yield would not be significantly affected by a single year's dry conditions. The Cape Cod aquifer formation alone conservatively holds approximately 2,000 billion gallons of water. This is four times the volume of Quabbin and Wachusett Reservoirs combined; over 11 years of average recharge is stored in the Cape Cod aquifer like a multi-year surface water reservoir. Therefore, it is proposed to use the entire volume (100 percent) of the driest year's recharge to represent allocatable water in these aquifers. The recharge rate can be multiplied over the entire land areas of the Cape Cod and Islands basins to arrive at an annual average volume.

Basin 22--Cape Cod:

1965 Recharge: 0.66 MGD/square mile

Applied over 394.80 square miles, potentially allocatable water for Cape Cod would be **261.1 MGD**.
(2009 WMA authorized withdrawals were 51.6 MGD)

Basin 23—Islands:

1965 Recharge: 0.66 MGD/square mile

Applied over 142.12 square miles, potentially allocatable water for the Islands of Martha's Vineyard and Nantucket would be **94.0 MGD**.
(2009 WMA authorized withdrawals were 7.4 MGD)

Basin 24—Buzzards Bay

The total area of Basin 24 is 374.26 square miles. The Plymouth Carver Aquifer is present in the eastern portion of the Buzzards Bay Basin. Different safe yield methodologies are recommended for the west and east portions of Basin 24. The division of west and east portions of Buzzards Bay basin is based on the limits of the Plymouth-Carver aquifer model area. The division is roughly along the town boundaries between Middleborough/Carver and Rochester/Wareham.

Basin 24 Western Portion of Buzzards Bay

The western portion of the Buzzards Bay basin does not include the Plymouth-Carver Aquifer formation. MWI subbasins cover the 163.77 square mile west portion of the basin. Safe Yield for the western portion of the basin was calculated using the methodology used for the remainder of the state, because SYE values were available for subbasins through the MWI study (Weiskel, et al., SIR 2009-5272). The analysis for that area resulted in area-weighted average annual Monthly Q90 flows of 0.40 MGD per square mile. If 55% of that value were potentially allocatable, the amount would be 36.0 MGD, or 0.22 MGD per square mile.

Basin 24 Eastern Portion of Buzzards Bay

The eastern portion of Buzzards Bay includes the southern part of the Plymouth Carver Aquifer and has an area of 210.49 square miles. The 1965 recharge rate for the Plymouth-Carver Aquifer area used in the USGS ground water model (Masterson, et al., SIR 2009-5063) is recommended as the basis for safe yield in the south portion of Basin 21b. In 1965, recharge was estimated to be 11.18 inches, or 41 percent of average. For consistency with the statewide methodology, we considered that the 1965 recharge rate would be equivalent to the concept of Q90 flows. The 1965 recharge rate equates to 0.532 MGD per square mile. Because of the expansive thickness of this portion of the Plymouth Carver aquifer, its yield would not be significantly affected by a single year's dry conditions. The Plymouth Carver Aquifer holds approximately 500 billion gallons of water (Masterson, et al., SIR 2009-5063.) This is more than Quabbin and Wachusett Reservoirs combined; over three years of average recharge is stored in the Plymouth Carver aquifer like a multi-year surface water reservoir. Therefore, it is proposed to use the entire volume (100 percent) of the driest year's recharge to represent allocatable water in this area. The dry year recharge rate can be multiplied over the land area to arrive at an annual average volume.

The 1965 recharge rate of 0.532 MGD per square mile applied to the Eastern portion of Buzzards Bay that includes the Plymouth Carver Aquifer (210.49 square miles) the potentially allocatable water for the eastern portion of Buzzards Bay would be 112.0 MGD. This value would equate to 41 billion gallons a year, or approximately 9 percent of the water in storage in the Plymouth Carver aquifer.

TOTAL RECOMMENDED POTENTIALLY ALLOCATABLE WATER FOR BASIN 24:

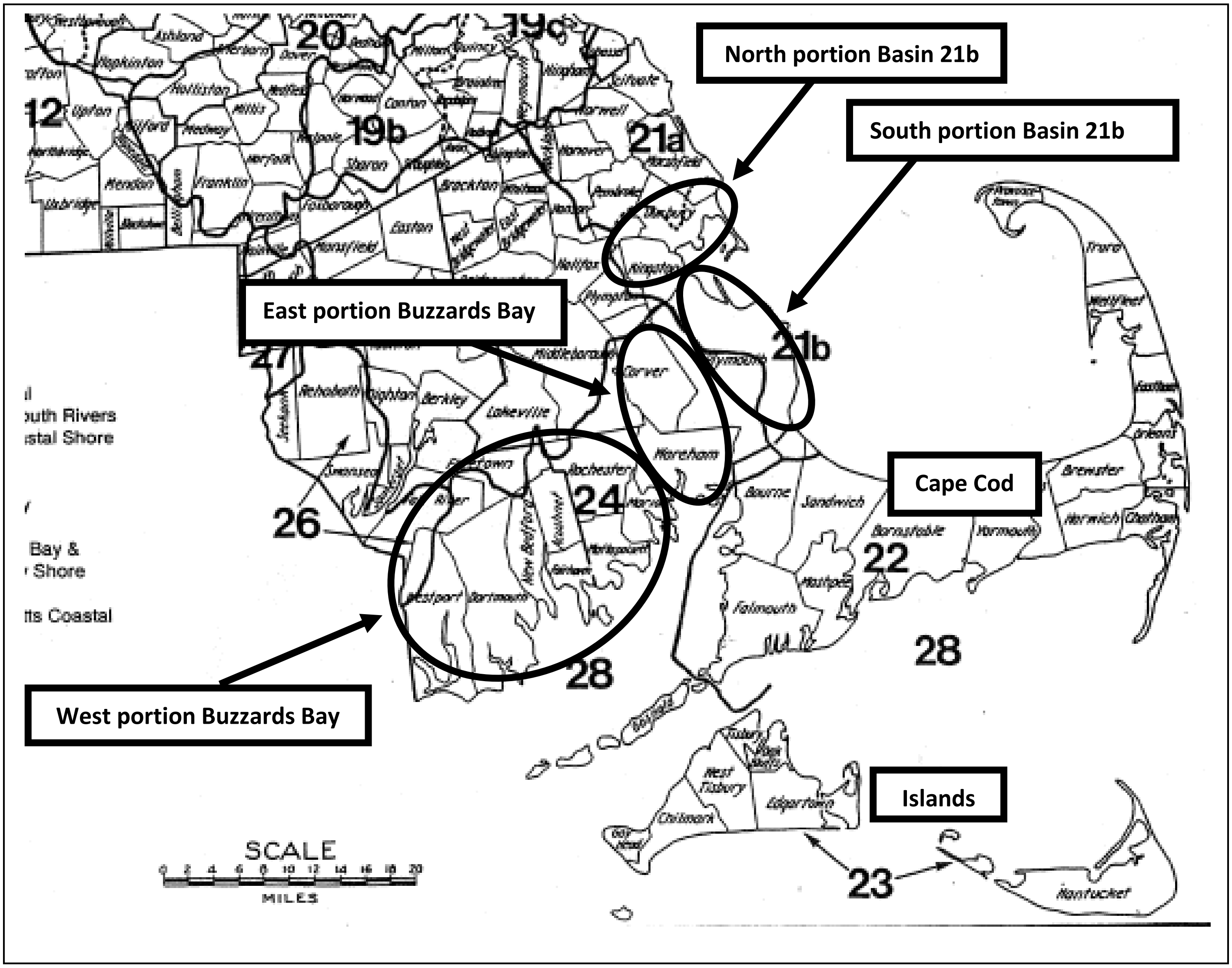
West section: 36.0 MGD
East section: 112.0 MGD

TOTAL: 148.0 MGD
(2009 WMA Authorized Withdrawals 91.2 MGD)

Primary Reports/ Technical Tools:

1. USGS DEP Sustainable Yield Estimator (SYE), SIR 2009-5227
2. USGS Indicators of Streamflow Alteration, Habitat Fragmentation, Impervious Cover, and Water Quality for Massachusetts Stream Basins, (Massachusetts Water Indicators), SIR 2009-5272
3. USGS Massachusetts StreamStats (online)
4. Massachusetts Index Gages (WRC, 2008)
5. USGS Hydrogeology and Simulation of Groundwater Flow in the Plymouth-Carver-Kingston-Duxbury Aquifer System, Southeastern Massachusetts, SIR 2009-5063
6. USGS Simulated Water Sources and Effects of Pumping on Surface and Ground Water, Sagamore and Monomoy Flow Lenses, Cape Cod, Massachusetts, SIR 2004-5181
7. USGS Hydrogeology and Groundwater Resources of the Coastal Aquifers of Southeastern MA Circular 1338
8. USGS Water Resources of Massachusetts WRIR 90-4144
9. USGS Yields and Water Quality of Stratified-Drift Aquifers in the Southeast Coastal Basin, Cohasset to Kingston, MA WRIR 91-4112
10. USGS Geohydrology and Simulated Ground-Water Flow, Plymouth-Carver Aquifer, Southeastern Massachusetts, WRIR 90-4204
11. 2003 GZA Jones River Watershed Study

Figure 1. Massachusetts Basins in Southeast MA, Cape Cod and Islands with approximate areas described in text



Appendix C: Categorization of Massachusetts Streams and Rivers

Purpose of Categorization

As an outcome of several Sustainable Water Management Initiative (SWMI) meetings, both the Technical Subcommittee and Advisory Committee agreed that categorizing existing conditions of Massachusetts flowing water habitats, using fish communities as a surrogate for aquatic habitat integrity, is a necessary first step on the way to development of stream flow criteria. The goal of categorization is to use the best available science to describe the condition of flowing water habitats in Massachusetts. The categorization framework proposed by the interagency workgroup (EOEEA, DFG, DCR, and DEP) and described herein, is informed by the USGS research (Armstrong et al. 2010, Armstrong et al 2011), input from both SWMI committees, and best professional judgment of state agency staff.

Categorization Framework

The USGS Reports conducted statistical analysis of an extensive statewide fisheries database to investigate the relationship between both human stressors (such as flow alteration and impervious cover) and natural variables (such as drainage area and basin slope), and fluvial fish communities (i.e., river fish communities). Quantitative analyses included Quantile Regression and Generalized Linear Modeling (GLM). Several models and variables were found to be statistically significant. The proposed categorization framework relies on statistically significant model results, along with best professional judgment-based concepts supported in the scientific literature (e.g. Biological Conditions Gradient, Davies and Jackson, 2006) to describe the current condition of fisheries resources, as representative of flowing water habitat in Massachusetts. This type of categorization, which looks at alteration-ecological response relationships, is a key element of the Ecological Limits of Hydrological Alteration (ELOHA) framework (Poff et al., 2010).

Fish Metric and Biological Alteration Measure

The fish metric proposed as the foundation for categorization is the relative abundance of fluvial fish, which can be predicted from the statistically significant GLM equation developed in the USGS research. Relative abundance, or catch per unit effort (CPUE), is a widely recognized and accepted fisheries statistic which is an index of fish population density. Generally, for two similar habitats (e.g. gradient, geology, watershed size) the one with the higher CPUE, is considered to be of higher quality. Estimation of relative abundance assumes that the CPUE is proportional to the fish stock density. This assumption was met by standardizing gear, methods and sampling design for all fish surveys. A measure of biological alteration can then be calculated by measuring the loss in the range of the fish metric (relative abundance of fluvial fish) with changes in flow and impervious cover. The fluvial fish relative abundance model illustrates a statistically significant relationship and includes measures or estimates of flow, impervious cover, and natural basin characteristics, and was appropriate for use statewide.

Category Development

Because the fluvial relative abundance model produces smooth curves that do not contain inflection or "break" points (Figure 1) it was necessary to delineate categories for management purposes using a combination of analytical techniques, best available science and best professional judgment. The process to establish category breakpoints relies on two primary concepts illustrated by results from the GLM and quantile regressions. First, there are sensitive fisheries resources that decline immediately and sharply to human alteration (i.e., decreasing flow and/or increasing impervious cover). To illustrate this concept, brook trout (Figure 1) and blacknose dace (Figure 2) will be used as the example sensitive species, but the concept of "most sensitive" applies to other sensitive species and life stages as well. Second, with increasing human alteration the incremental decline (i.e., the biological response) in the relative abundance of the remaining fluvial fish species diminishes. Quantile regression is illustrated using the 90th quantile line in the USGS report as it represents a point at which alterations to the fish community characteristics (Y-axis) are heavily influenced by the alteration characteristics (X-axis) (i.e. flow alteration or impervious cover). Impervious cover and flow alteration were both highly significant variables that can work independently or synergistically to cause significant fish community decline.

This results in a series of categories, described below, with breaks that correspond to the decline in fluvial fish relative abundance, declines in sensitive species, and declines in species richness that are associated with changes in flow and/or impervious surface. It is intended that this model be used as a statewide-screening tool.

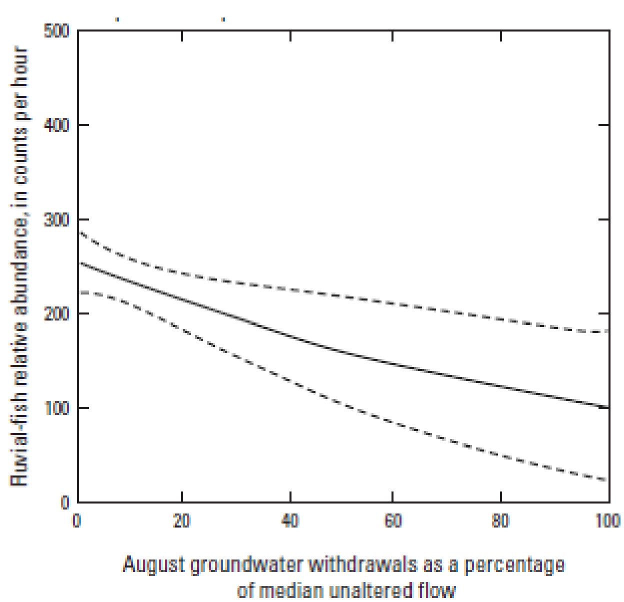


Figure 1. Generalized linear model output for relations between fluvial fish relative abundance and percent alteration of August median flow from groundwater withdrawals.

Relation determined using median values for other variables in the model (Impervious cover, percent wetland in buffer, and channel slope). Solid line is the mean response, dashed lines represent the 95-percent confidence interval.

Category Narratives

Category 1 ***(0 to 5% Alteration of the Range of Fluvial Fish Relative Abundance)***

Category 1 represents high quality aquatic habitat in the Commonwealth, relatively un-impacted by human alteration (as expressed by impervious cover and flow alteration). The quantile regression curves from the USGS/DFW 2010 research for blacknose dace and brook trout relative abundance drop approximately 30% at 5% August alteration (Figures 2 & 3) and 2% impervious cover (Figure 4). Trigger points 1 and 2 correspond to one-third and two-thirds reduction, respectively of the relative abundance of brook trout and blacknose dace; trigger point 3 corresponds to a an approximate 90% loss of brook trout and blacknose dace relative abundance. The same pattern is found for impervious cover, but at lower impervious cover percentages (Figure 4). This illustrates that some species are more sensitive to alteration than the fluvial fish community considered collectively, a concept well supported by the literature (Davies and Jackson, 2006; Baker and King, 2010). Therefore, based on the change within detectable limits for fluvial fish relative abundance and rapid changes in sensitive taxa, a 5% loss of the biological metric (i.e. range of fluvial fish relative abundance) was used as the boundary for Category 1.

Figure 2

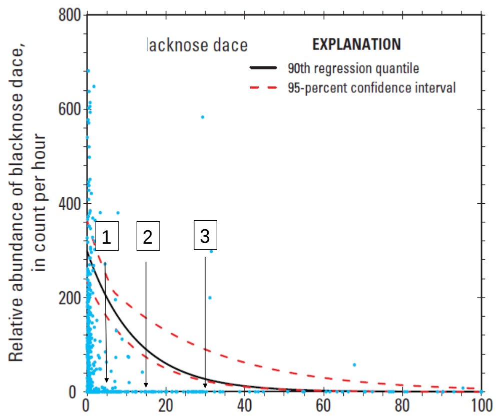
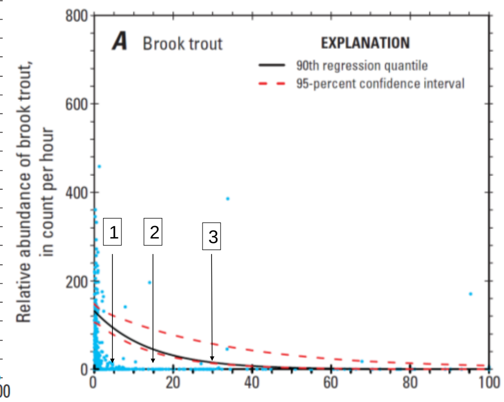


Figure 3



Percent alteration of August median flow at net depleted sites.

Figures 2, 3. Decreases in the 90th quantile for relative abundance of blacknose dace and brook trout in relation to increasing percent alteration of the August median flow. *(graphs modified from Armstrong, et al., 2010)*

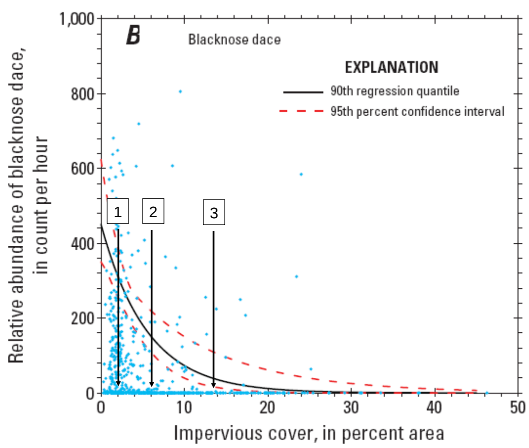
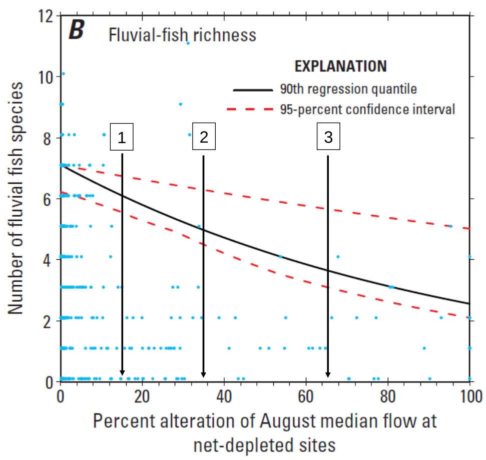


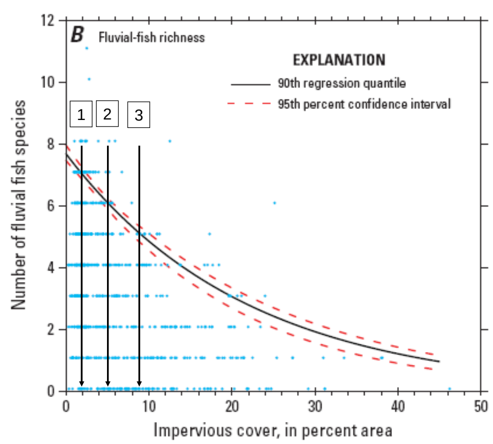
Figure 4

Category 2 *(5 to 15% Alteration of the Range of Fluvial Fish Relative Abundance)*

Category 2 represents quality fisheries resources with good species diversity and balanced, adaptive fish communities. While the most sensitive resources will likely have exhibited some response at this level of alteration (as illustrated by the approximate 1/3 reduction in the relative abundance for both blacknose dace and brook trout with respect to flow alteration – Figures 2 & 3), the diversity of the community is still intact. The likelihood of species loss increases through this category (Figures 5&6).

Therefore, a 15% loss of the range of fluvial fish relative abundance was used to delineate the lower boundary for Category 2 because it incorporates both large scale changes to sensitive taxa as well as the increased probability of fluvial species loss.





Figures 5 and 6. Sequential loss in species diversity with increasing alteration of a) flow; and b) impervious cover. Each vertical line represents a reduction of one species.
(graphs modified from USGS, 2010)

Category 3 *(15 to 35% Alteration of the Range of Fluvial Fish Relative Abundance)*

Category 3 represents fish communities that have exhibited considerable change in the structure of the fish community. Sensitive species may still be maintaining populations but at considerably reduced abundances. More tolerant individuals are likely to dominate fish community structure. Approximately two-thirds of the sensitive taxa have been depleted (Figures 2 & 3) and additional fish species have probably been lost (Figures 5 & 6). Therefore, a 35% loss of the range of fluvial fish relative abundance was used to delineate the lower boundary for Category 3 because it incorporates significant loss of relative abundance of sensitive species, and increased probability of the loss of more than one fluvial fish species.

Category 4 *(35 to 65% Alteration of the Rage of Fluvial Fish Relative Abundance)*

Category 4 represents fish communities that have undergone reductions in sensitive taxa, fluvial species diversity, and substantive reductions to relative abundance. Sensitive species such as the brook trout and blacknose dace (Figures 2 & 3) would be expected to be seriously impaired or eliminated from aquatic systems with this degree of alteration. In addition, the number of fluvial fish species would be expected to decline even further, (Figure 5 & 6) approaching half the expected diversity and a loss of 65% of the overall relative fluvial fish abundance at trigger point 3 (Figures 2 & 3). Therefore, 65% loss in the biological metric was used to delineate the lower boundary for Category 4 to reflect these large scale reductions to fluvial diversity and relative abundance.

Category 5 **(Greater than to 65% Alteration of the Range of Fluvial Fish Relative Abundance)**
The final category, category 5, represents fish communities that have undergone severe changes to their structure and function. Fluvial species diversity is minimal or has been eliminated and relative abundance is approaching the bottom of the biological metric range. Consequently, Category 5 corresponds to greater than 65% loss in the biological metric and considerable loss in overall species diversity (Figures 5& 6).

These categories are illustrated on the GLM curve in Figure 7 below.

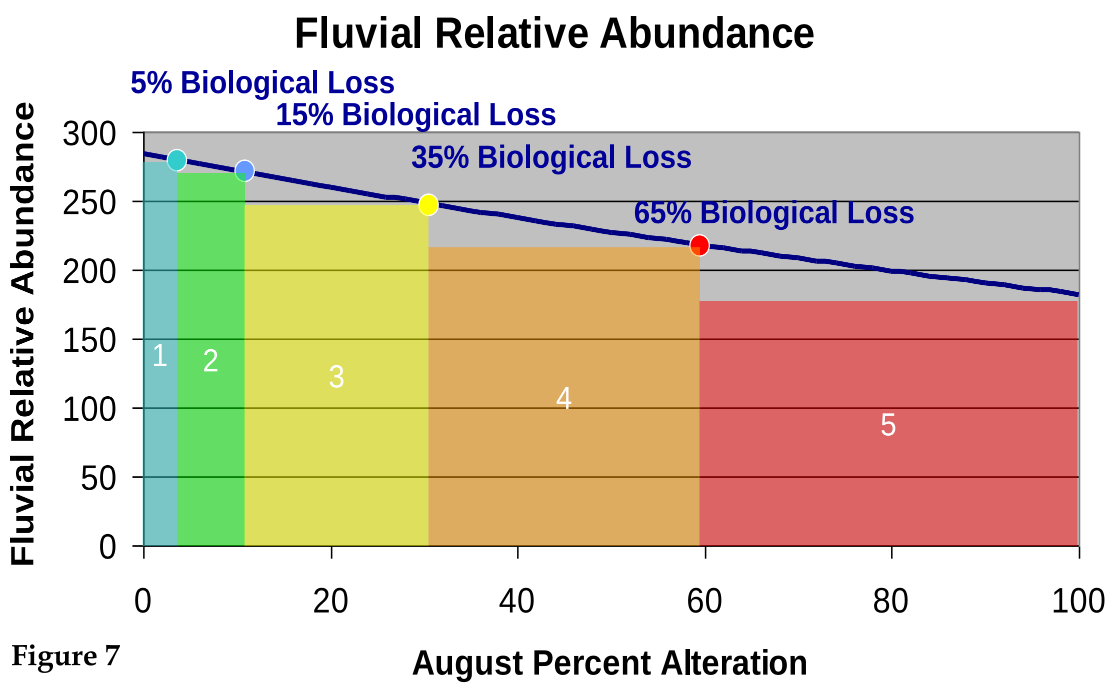


Figure 7

References:

1. Armstrong, D.S., Richards, T.A., and Brandt, S. L., 2010, Preliminary Assessment of factors influencing riverine fish communities in Massachusetts: U.S. Geological Survey Open-File Report 2010-1139, p 43.
2. Baker, M.E., and King, R.S., 2010, A new method for detecting and interpreting biodiversity and ecological community thresholds: Methods in Ecology and Evolution, v. 1, no. 1, p. 25–37.
3. Poff, N.L., Richter, B.D. et al., 2009, The ecological limits of hydrologic alteration (ELOHA): a new framework for developing regional environmental flow standards: Freshwater Biology
4. Davies, S.P. and Jackson, S.J., 2006, The Biological Condition Gradient: A Descriptive Model For Interpreting Change in Aquatic Ecosystems: Ecological Applications 16(4), pp.1251-1266.

Appendix D: Application of Streamflow Criteria in Unassessed Areas

In the Massachusetts Sustainable Water Management Initiative (SWMI) most areas of the state are classified in terms of Groundwater Withdrawal Level (based on August streamflow alteration by ground water withdrawals) and Biological Category (based on a combination of August streamflow alteration by ground water withdrawals and percent impervious cover), using data generated from the "Indicators of Streamflow Alteration, Habitat Fragmentation, Impervious Cover, and Water Quality for Massachusetts Stream Basins" report (2010, USGS Scientific Investigations Report 2009-5272, casually referred to as the Mass. Water Indicators Report or MWI). Relationships between fluvial fish relative abundance, August streamflow alteration, and impervious cover are documented in "Preliminary Assessment of Factors Influencing Riverine Fish Communities in Massachusetts" (2010, USGS Open File Report 2010-1139) and "Factors Influencing Riverine Fish Assemblages in Massachusetts" (2011, USGS Scientific Investigations Report 2011-59193.) Thresholds of flow alteration and biological alteration that corresponded to Groundwater Withdrawal Levels 1 through 5 and Biological Categories 1 through 5 are part of the SWMI framework.

Biological Category and Groundwater Withdrawal Levels could not be developed for the following areas in the state because detailed flow and flow alteration statistics were unavailable. Therefore, an alternative approach is needed for these areas in the SWMI framework.

- Mainstems of the interstate Merrimack and Connecticut Rivers—The Sustainable Yield Estimator tool (SYE, 2010 The Massachusetts Sustainable-Yield Estimator: A decision-support tool to assess water availability at ungaged stream locations in Massachusetts, USGS Scientific Investigations Report 2009-5227) used in the MWI study cannot simulate flows for watersheds of these sizes. In addition, the equations developed for simulating fluvial fish relative abundance are not applicable to rivers of those sizes. However, major rivers and subbasins draining to these mainstems were assessed so the areal coverage of these watersheds is significant and likely adequate for our purposes. Only the mainstem of the two rivers themselves cannot be assessed for fluvial fish relative abundance and its relationship to flow alteration and impervious cover. A separate modeling study is being undertaken for the Connecticut River, and the results of that study may allow for some future classification effort in terms of flow alteration. Along the Merrimack River in Massachusetts, several communities withdraw drinking water from, and return treated wastewater to, the mainstem of the river. It is unlikely that these withdrawals and discharges cause significant impacts to even low summer flows in this large river since the net change in flow is small. One USGS river gage is available on the Merrimack River in Lowell, but the flow measurements there incorporate impacts of upstream influences in Massachusetts and New Hampshire. It is important to note that the drainage area above the Lowell gage is 4,635 square miles, much larger than any of the river basins in Massachusetts.

- Coastal areas that drain to the ocean—These areas include coastal areas of the North Coastal basin, Parker River, Ipswich, Boston Harbor, Charles, Narragansett/Mt Hope, and Buzzards Bay basins. The unassessed areas are immediately proximal to the coast (extend about 1 to 3 miles inland). Because these areas drain directly to the ocean or tidal areas, SYE cannot model streamflow for them. There are few coastal areas suitable for public water supply, as the coast in these areas generally has shallow bedrock and many are highly developed. The coverage in the Mass. Water Indicators Report includes most of the areas of concern with respect to water withdrawals and streamflow impacts. For the few public water supplies in these areas review will be provided on a case by case basis.

- Plymouth-Carver Aquifer (contained within portions of the South Coastal and Buzzards Bay basins), Cape Cod and Islands—The MWI study included 34 "ground water contributing areas" which are land areas that contribute groundwater baseflow to the major streams of Cape Cod and the Plymouth-Carver area. These areas (which include the Jones and Eel River watersheds) were assessed in the Mass. Water indicators report using USGS groundwater model output. However, data are not available to assess the ground water portion of withdrawals; thus, groundwater withdrawal levels cannot be readily determined for these areas. Therefore, an alternative method of assessing this area is needed for the SWMI framework. In the remainder of Cape Cod and the Plymouth-Carver Aquifer, ground water discharges directly to the ocean and does not contribute to river baseflow. Streamflow criteria cannot be applied to these areas because there are no streams to apply the criteria to.

Safe yield was calculated for portions of the South Coastal and Buzzards Bay basins using drought recharge data from the report, "Hydrogeology and Simulation of Groundwater Flow in the Plymouth-Carver-Kingston-Duxbury Aquifer System, Southeastern MA" (2009, Masterson, Carlson, and Walter, USGS Scientific Investigations Report 2009-5063.) For Cape Cod and the Islands, safe yield calculations relied on data contained in the report, "Simulated Water Sources and Effects of Pumping on Surface and Ground Water, Sagamore and Monomoy Flow Lenses, Cape Cod, Massachusetts" (2005, Walter and Whealan, USGS Scientific Investigations Report 2004-5181.) The methodology used for Safe Yield determinations in these areas is documented in a separate memo.

Appendix E: Draft vs. Final USGS Fish and Habitat Report Results and their Application

Variables Evaluated in the Preliminary Study: In order to meet an accelerated schedule at the request of the SWMI process, the preliminary (accelerated) study relied on best professional judgment and literature review to choose a small subset of variables to test for their influence on fish communities.

- Preliminary Results: Impervious cover and net estimated August median flow alteration were the two human-influenced variables that were found to have a significant influence on fish communities. Net estimated August median flow alteration is a combined metric that includes groundwater withdrawals, and septic, NPDES and groundwater returns and was readily available from the MWI study. Four natural variables (channel slope, percent wetland, drainage area and east/west location) were also found to have a significant influence on fish community composition.

Variables Evaluated in the Final Study: The Final study looked at a much broader list of variables that could potentially influence fish communities, further described below.

- Combined vs. individual flow alteration components: Instead of using net August alteration, which is a combination of withdrawal and return data, each component of net alteration was tested individually for significance. Specifically, net alteration is calculated by starting with estimated unimpacted flows, subtracting groundwater withdrawals and adding back in septic returns, NPDES returns and groundwater discharge returns. The preliminary study looked at the combined effect of these variables (i.e., the net), while the final study tested each variable independently.

- Testing Process: More than 150 flow, land use, and landscape variables were tested for inclusion in the modeling effort. A statistical method (Principal Components Analysis-PCA) was used to determine which of these explained the most variability in the dataset and also to remove highly correlated variables from the analysis. Removing highly correlated variables decreases the likelihood of describing spurious relationships. PCA identified impervious cover as the first (strongest) variable to come into the model. Subsequent variables were likewise selected based on the results of the PCA and the correlation to other variables already selected. PCA results indicated that septic returns were a strong variable, but septic was too highly correlated to be included in the same model as impervious cover. The PCA results indicated that NPDES returns did not contribute significantly to the fluvial fish relative abundance model at the statewide scale. Estimated August median flow alteration resulting from groundwater withdrawals was both significant and not highly correlated with other variables in the model. August Net Flow Alteration, the variable used in the preliminary report, was not as strong a variable as August Groundwater Withdrawal Percent, according to the PCA analysis.

- Final Results: In this analysis, the best model explaining the relationship between human alteration variables, landscape variables, and fluvial fish abundance included impervious cover, estimated August median flow alteration resulting from groundwater withdrawals, channel slope, and wetlands buffer area.

Biological categories and groundwater withdrawal levels were revised based on the final report results described herein, and are shown in Figures 1 and 2.

Figure 1: Biological Categories using final USGS results

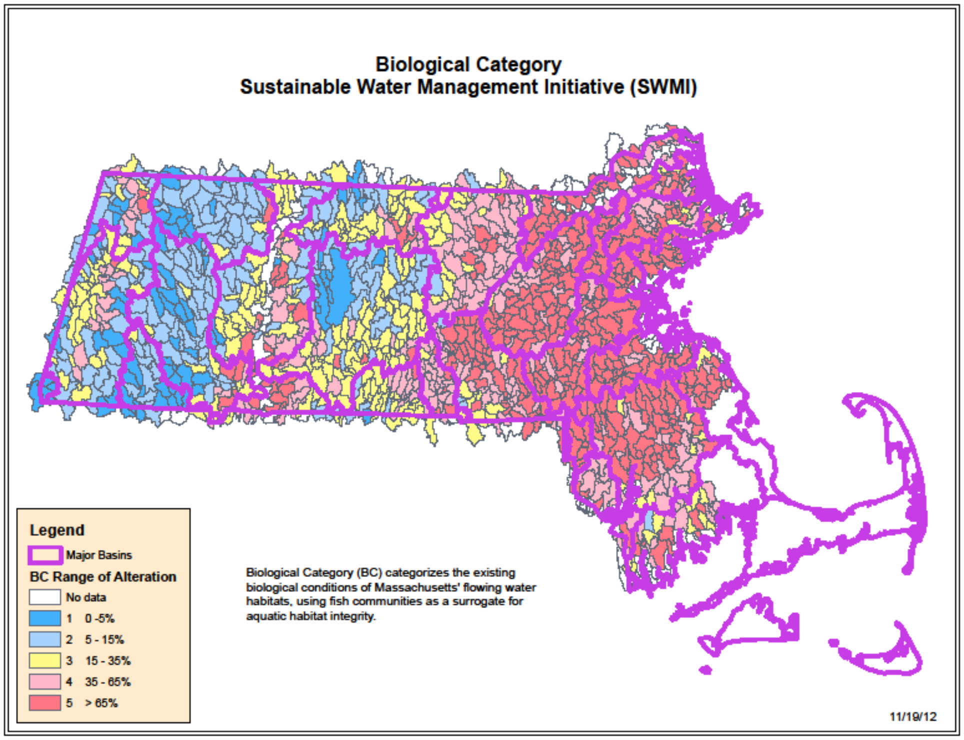
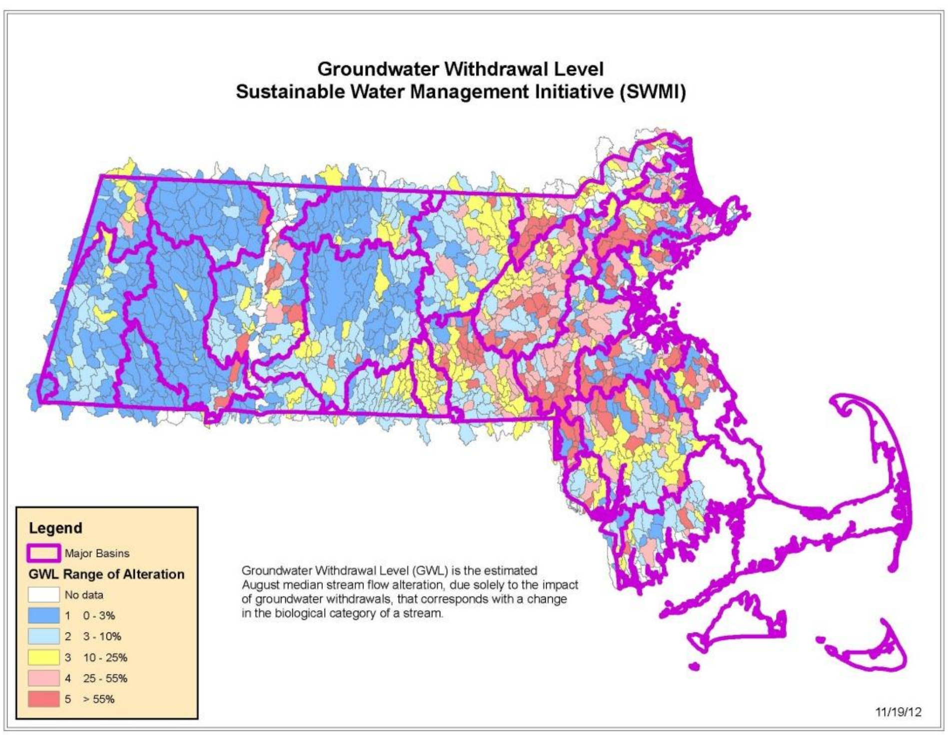


Figure 2: Groundwater Withdrawal Levels using final USGS results



Appendix F: Designation of Coldwater Fishery Resources

This is the background and criteria used by the Division of Fisheries and Wildlife to map coldwater fishery resources:

For nearly a decade, the Division has been involved in identifying waters considered Coldwater Fishery Resources (CFR). Identification of CFRs is based on fish samples collected annually by staff biologists and technicians. The identified CFRs are organized geographically by watershed and the information is updated annually. Currently (2011) there are nearly 900 streams identified statewide.

The CFR lists are useful tools for highlighting environmentally sensitive areas. Conservation commissions, planning commissions, land trusts, consultants and town open space committees may find this information useful for conservation planning.

What is a CFR?
A CFR is defined as a water that meets at least one of the following criteria:

1. Brook, brown or rainbow trout reproduction has been determined;
2. Slimy sculpin, longnose sucker, or lake chub are present;
3. The water is part of the Atlantic salmon restoration effort or is stocked with Atlantic salmon fry or parr.

The criteria are designed to separate coldwater populations that are supported by wild reproduction from those waterbodies that might receive stocked coldwater species.

Any water not identified as a CFR may be:

- Warmwater fisheries habitat;
- Undetermined;
- Not yet sampled by the Division.

Questioning the Basis for a CFR Designation
A party could seek an opportunity to question the basis for a CFR designation by the Division, as summarized below.

The Division's action of designating a CFR is in the nature of a fisheries scientific determination (based on biological sampling data) that, by itself, does not subject a person using the CFR to regulation *by the Division* in a manner that implicates their c. 30A rights.

Thus, while no person has a right to a c. 30A adjudicatory hearing from the Division on its basis for designating a CFR, the Division would offer any person the opportunity to discuss the technical basis for a CFR designation with the Division. This informal process would include the Division committing to review additional biological sampling data that the person requesting the review believes supports their position that a waterbody should not be designated as a CFR – provided, however, that the requestor uses a methodology developed by the Division.

Following a review of the biological sampling data documentation submitted by the person, the Division would inform the requestor of the outcome of its further review of the CFR designation. In cases where the requestor has made a clear showing that the CFR designation is incorrect, the Division would remove the CFR designation and inform other interested parties such as DEP of this change in status.

Appendix G: Outline of Water Management Act Permit Conditions for Public Water Supply Permits

1. **Ground Water Supply Protection Requirements/Surface Water Supply Protection Requirements**
   - PWS ground water sources must have Zone II delineations and Wellhead Protections in place.
   - PWS surface water sources must have a Surface Water Supply Protection Plan in place.
   - Water companies or authorities must demonstrate best efforts to meet these requirements.

2. **Firm Yield Analysis for PWS Surface Water Supply**
   - PWS surface water sources must have a firm yield analysis based on the drought of record.
   - PWS's with a Drought Management Plan may base firm yield on a less severe drought.

3. **Wetlands and Vernal Pool Monitoring**
   - Wells located within an ACEC or Priority Habitat area, may be required to conduct wetlands hydrology monitoring. MassDEP reserves the right to modify the permit to address observed impacts.

4. **Performance Standard for Residential Gallons Per Capita Day Water Use (RGPCD)**
   - The RGPCD performance standard for all PWS permittees is 65 gallons.
     - Not applied on the Cape, Island and in select seasonal communities because large seasonal population fluctuations make calculating RGPCD unreliable
   - Permittees that cannot comply within 2 years must implement either their own RGPCD plan or MassDEP's RGPCD Functional Equivalence Plan and comply within 3 additional years.
   - Permittees unable to meet the std. within 5 years must implement the MassDEP's RGPCD Plan.

5. **Performance Standard for Unaccounted for Water (UAW)**
   - The UAW performance standard for all PWS permittees is 10% of total water withdrawal.
   - Permittees that cannot comply within 2 years must implement either their own UAW plan or MassDEP's UAW Functional Equivalence Plan and comply within 3 additional years.
   - Permittees unable to meet the std. within 5 years must implement the MassDEP UAW Plan.

6. **Seasonal Limits on Nonessential Outdoor Water Use** (detail in Table 1 below)
   - Seasonal restrictions are in place from May 1st through September 30th.
   - Permittees choose either calendar-based restrictions throughout the season, or restrictions implemented whenever streamflow falls below an aquatic base flow (ABF) trigger or the 7-day low flow statistic trigger at an assigned USGS local stream gage
   - ABF triggers are based on groundwater withdrawal levels that are protective of
     - habitat for fish spawning during the spring, and
     - flows for fish rearing and growth during the summer.
   - The restrictions required vary based on the permittee's RGPCD water use.
   - A low flow trigger has been proposed in the SWMI process.

7. **Water Conservation Requirements** (detail in Table 2 below)
   - Permittees must implement measures based on the Water Resources Commission <u>Water Conservation Standards</u>, July 2006, including:
     - water audits and leak detection, metering, pricing, residential and public sector conservation, industrial/commercial conservation, lawn/landscape conservation, and education/outreach

8. **Water Withdrawals that Exceed Baseline Withdrawal Volumes** (baseline has been proposed to be redefined through the SWMI process)
    - Baseline cannot be lower than the registered volume
    - For permittees holding a permit for withdrawals in excess of their registered volume,
        - Baseline cannot be greater than
            - the 2005 permitted volume, or
            - the renewed 20-year WMA permitted volume.
    - For permittees whose actual withdrawals between 2003 and 2005 were greater than the registered volume and lower than the lowest applicable permit volume, baseline is the greater of
        - 2005 use +5%, or
        - 2003-2005 average use +5% .
    - Permittees with withdrawals in two basins will be regulated by baseline withdrawal volumes calculated for each basin, and for system-wide withdrawal volumes.
    - Permittees with withdrawals projected to exceed the baseline withdrawal volume will evaluate measures to mitigate withdrawals in excess of the baseline.
        - Implementation of mitigation measures will be required prior to withdrawals exceeding the baseline (see Table 6 - Offset and Mitigation, on Page 28 of the Framework Summary document).

Table 1. New Proposed Seasonal Limits on Nonessential Outdoor Water Use
Permittees meeting the 65 RGPCD standard for the preceding year, and streamflow is above the low-flow trigger
Either **Calendar Triggered Restrictions** from May 1st through September 30th • Nonessential outdoor water use is prohibited between 9 am and 5 pm
Or **ABF Triggered Restrictions*** from May 1st through September 30th • Nonessential outdoor water use is prohibited between 9 am and 5 pm whenever streamflow is below the ABF trigger
Permittees NOT meeting the 65 RGPCD standard for the preceding year, and streamflow is above the low-flow trigger
Either **Calendar Triggered Restrictions** from May 1st through September 30th • Nonessential outdoor water use is prohibited, except two days per week before 9am and after 5pm
Or **ABF Triggered Restrictions** from May 1st through September 30th • Nonessential outdoor water use is prohibited, except two days per week before 9am and after 5pm whenever streamflow is below the ABF trigger
All Permittees at the Low-Flow Trigger**
• Nonessential outdoor water use is prohibited, except one day per week before 9am and after 5pm

* Aquatic Base Flow (ABF) triggered restrictions are based on groundwater withdrawal levels at the local gage that are protective of aquatic habitat for fish spawning during the spring bioperiod, designated with the June ABF, and protective flows for fish rearing and growth during the summer bioperiod, designated with the August ABF trigger.

**Proposed low-flow trigger is the annual 7 day low-flow, calculated from the period of record for the local gage

Table 2. Summary of Water Conservation Requirements in PWS Water Management Permit
System Water Audits and Leak Detection
1. Conduct a full leak detection survey every three years in accordance with AWWA standards. 2. Full leak detection survey whenever unaccounted for water increases by 5% or more over the percentage reported on the ASR for the prior calendar year. Submit a report detailing the leak detection survey, dates of leak repairs, and estimated water savings. 3. Have repair reports available for inspection by the Department.
Metering
1. Calibrate all source and finished water meters at least annually. 2. Properly sized service lines and meters for all water users. Meters to meet AWWA calibration and accuracy standards. 3. Ongoing program to inspect service meters for accuracy, and repair, replacement and check for tampering to identify and correct illegal connections as needed.
Pricing
1. Establish a water revenue structure that includes the full cost of operating the water supply system including operations, maintenance, capital, and indirect costs (environmental impacts, watershed protection). Evaluate revenues every three to five years and adjust rates as needed. 2. Decreasing block rates are not allowed by M.G.L. Chapter 40 Section 39L.
Residential and Public Sector Conservation
1. Meet the standards of the Federal Energy Policy Act, 1992 and the Massachusetts Plumbing Code. 2. Meter or estimate water used by contractors using fire hydrants for pipe flushing and construction. 3. Municipal buildings • Submit a report of municipally owned public buildings retrofitted with water saving devices • Submit a schedule for retrofitting remaining buildings within 2 years • Water Districts and Water Companies must demonstrate "Best Effort" to work with the Town and complete retrofits. • Municipally owned public buildings scheduled for rehab or demolition may be exempted from this condition.
Industrial and Commercial Water Conservation
1. Review the use records for industrial, commercial and institutional water users and develop an inventory of the largest water users. 2. Develop and implement an outreach program designed to inform and (where appropriate) work with industrial, commercial and institutional water users on ways to reduce water use. 3. Upon request by the Department, submit a report on conservation results. The Department will take whatever action it deems appropriate to promote the interests of the Water Management Act, including requiring additional actions.
Lawn and Landscape
1. Permittees must have a water use restriction bylaw, ordinance or regulation providing authority to implement and enforce required restrictions on outdoor water use.
Education and Outreach
1. Develop and implement a Water Conservation Education Plan to educate customers on ways to conserve water. Permit lists the outreach techniques included in the WRC Conservation Standards.

Appendix H – List of Acronyms

ABF – Aquatic Base Flow (developed by US Fish and Wildlife Service)

ACEC – Area of Critical Environmental Concern

AWWA – American Water Works Association

BC – Biological Category

BMP – best management practice

CFR – coldwater fisheries resource

cfs – cubic feet per second

CMR – Code of Massachusetts Regulations

CPUE – catch per unit effort, total fish catch divided by the total amount of effort used to harvest the catch

DCR – Massachusetts Department of Conservation and Recreation

DEP – Massachusetts Department of Environmental Protection

DFG – Massachusetts Department of Fish and Game

DFW – Massachusetts Division of Fisheries and Wildlife

EEA – Massachusetts Executive Office of Energy and Environmental Affairs

EOEEA – Massachusetts Executive Office of Energy and Environmental Affairs

GLM – Generalized Linear Modeling

GW – groundwater

GWL – Groundwater Withdrawal Level

HUC 12 – Hydrologic Unit Code 12 scale, based on a hierarchical system of hydrologic units developed by USGS

IWRMP – Integrated Water Resource Management Plan

LID – Low Impact Development, a land development approach to managing stormwater runoff

MassDEP – Massachusetts Department of Environmental Protection

MET – Massachusetts Environmental Trust

MG – million gallons

MGD – million gallons per day

M.G.L. – Massachusetts General Laws

MS4 – Municipal Separate Storm Sewer System, a conveyance that is owned by a state, city, town, village, or other public entity that discharges to waters of the U.S.; designed or used to collect or convey stormwater; not a combined sewer; and not part of a sewage treatment plant

MWI – Massachusetts Water Indicators (USGS Scientific Investigations Report 2009-5272)

MWRA – Massachusetts Water Resources Authority

NPDES – National Pollutant Discharge Elimination System, the permit program that controls water pollution by regulating point sources discharging pollutants into waters of the United States, as authorized by the Clean Water Act

PCA – principle components analysis, a statistical method

PWS – public water supply

Q50 (or Q_{50}) – a flow that is exceeded 50% of the time

Q70 (or Q_{75}) – a flow that is exceeded 75% of the time

Q90 (or Q_{90}) – a flow that is exceeded 90% of the time (a low flow)

RGCPD – residential gallons per capita per day, daily consumption of water by the residential sector

sqmi – square mile

SRF – State Revolving Fund, a loan program administered by MassDEP

SWMI – Sustainable Water Management Initiative

SY – safe yield

SYE – Sustainable Yield Estimator, a tool used to estimate streamflow (USGS Scientific Investigations Report 2009–5227)

UAW – unaccounted for water

USGS – United States Geological Survey

WMA – Water Management Act

WRC – Massachusetts Water Resources Commission