Current Knowledge of Drawdown Relevant to Projects in Massachusetts

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The following document is a public service publication generated as a result of a lake management consultation meeting involving the City of Pittsfield, Massachusetts, the Lake Onota Preservation Association (LOPA), the Friends of Pontoosuc (FOP), and Dr. Ken Wagner, PhD, CLM, sponsored jointly by LOPA and FOP on January 13, 2020. During that meeting it became increasingly clear that future permitting of management actions for preservation of our lakes was going to be complex and the "toolbox" for Conservation Commissions as set forth in the Generic Environmental Impact Report for Eutrophication and Aquatic Plant Management in Massachusetts (GEIR) was out of date and lacking a great deal of recent experience. As a result, LOPA and FOP decided to jointly fund Dr. Wagner to write a "white paper" documenting the current "state of the art" concerning the use of drawdown as a management action. It was separately agreed to similarly fund a companion paper relative to application of herbicides. The "white paper" idea evolved into an unofficial update and supplement to the GEIR Section 4.2 on Drawdown (this document) and GEIR Section 4.6 on Herbicides and Algaecides (a companion document). It also required a great deal more time and effort than envisioned and funded by LOPA and FOP which was most graciously provided by Dr. Wagner. This document is detailed and thorough, and consideration of it in its entirety is encouraged, but the key points are embodied in a comprehensive summary near the end of the document. Although begun with parochial interest in the lakes of Pittsfield, we believe it is a document which will be of great benefit to all the Great Ponds of Massachusetts and has applicability to a wide range of waterbodies within the Commonwealth and beyond.

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This document is intended to serve as an unofficial supplement to Eutrophication and Aquatic Plant Management in Massachusetts, the Final Generic Environmental Impact Report, or simply the GEIR. It follows the format of the GEIR and adds to Section 4, control of aquatic plants. Familiarity with the original GEIR is advised before reading this supplement. See https://316zc22p4vyyg59gu2uixxxv-wpengine.netdna-ssl.com/wp-content/uploads/2018/02/GEIR-Eutrophication-and-Aquatic-Plant-Management-in-Mass.pdf.

4.2 DRAWDOWN

4.2.1 Water Level Lowering

Drawdown remains a multipurpose lake management tool that can be used for aquatic plant control. The GEIR adequately covered the intent, history, mechanics and issues relating to drawdown but there were questions about effectiveness, impacts to non-target organisms, and disruption of overall lake function that could not be addressed with data in hand. Research and experience since development of the GEIR have shed some light on impacts, most notably a recent Ph.D. thesis specifically addressing drawdown effects in MA lakes (Carmignani 2020). A revision of Restoration and Management of Lakes and Reservoirs (Cooke et al. 2005) expanded on our knowledge of drawdown but was published only a year after the GEIR. A revision of Biology and Control of Aquatic Plants (Gettys et al. 2014) also provides some more recent input but does not focus on non-target impacts. Most papers published on the topic since 2004 (e.g., Strayer and Findley 2010, White et al. 2011, Zohary and Ostrovsky 2011, Nagid et al. 2015, Trottier et al. 2019) are adequately summarized in the Carmignani thesis and a review article related to that thesis (Carmignani and Roy 2017). Additional direct experience in MA from monitoring of drawdown results have also provided insights (e.g., WRS 2017a, 2017b, ARC 2019, 2020) and are incorporated into this supplement.

The primary benefits of drawdown still include flood control and avoidance of ice damage to shoreline structures and banks, both encompassed by the interests of the Wetlands Protection Act, along with control of susceptible rooted plants (those forms overwintering mainly in a vegetative state as opposed to seed-producing annual species). Drawdown also provides access to the drawdown zone for clean up or structural maintenance, but those activities are not automatically authorized as a condition of drawdown permitting. Where the slope is adequate, drawdown will result in finer sediment moving offshore, coarsening the sediment in the drawdown zone and usually reducing suitability for rooted plants over a long period of time. As there is no shortage of fine grained sediment in the vast majority of Massachusetts lakes, the creation and maintenance of coarse substrate and associated habitat might be viewed as a benefit of drawdown, although there is a tradeoff in habitat suitability for the range of possible aquatic organisms.

The primary drawback remains reduction in lake area and volume and loss of the associated habitat during the period of drawdown. As that period is almost always during winter, this would seem to represent much less impact potential than during other seasons. Lakes are not totally dormant during winter, but many processes are greatly slowed by low temperature and critical events like fish spawning, insect emergence, and migratory bird use should not be directly impacted unless drawdown starts early or finishes late relative to use patterns by aquatic organism and water-dependent wildlife. What constitutes the proper starting and ending points for drawdown has been changed under regulations and policies over the years and the current GEIR could use some revision in that regard.

The other drawdown impact that has received more attention since the GEIR was produced is the change in downstream hydrology. As so much of the Massachusetts lake area and volume has been created by longstanding dams, downstream flows have been altered for many years even without drawdown. But where dams allow drawdown as well, lowering the water level in the fall when flows are usually low can generate peak flows in the fall instead of spring. Spring refill during which less water is passed downstream than if the lake was full or not there at all can make spring a low flow period in downstream channels which are normally subject to much higher flows at that time. Guidance on how much water to pass downstream during lowering or refill is provided in the GEIR. While this guidance is generally helpful, it is not entirely based on appropriate science and also needs revision.

A host of other postulated impacts and factors to consider, found in Table 4-3 of the GEIR, still need to be considered but have not generally turned out to be major issues in most cases. The review by Carmignani and Roy (2017) also lays out potential impacts of drawdown but the Carmignani thesis and another peer reviewed paper (Carmignani et al. 2019) that follow found only a few significant negative effects, most notably lower mussel densities in drawdown zones, something documented in many drawdown lakes for many years (e.g., Fahumiya and Stanley 1986). Indeed, drawdown has been used to control zebra mussels in Laurel Lake for the last decade (WRS 2017b), so the impact on mussels is known and has been found to be temporary with annual recolonization of the drawdown zone from deeper water populations.

What is most evident from a review of research and experience since the GEIR was prepared is that there is no “one-size-fits-all” solution with regard to drawdown. The individual features of each lake and its watershed must be considered when determining if drawdown is an appropriate management technique and in evaluating what adverse impacts might occur. A focused monitoring program can then be devised to track progress and impacts and facilitate adjustments as necessary. Simple guidelines are useful but not universally applicable, and the regulatory process should recognize and accommodate this.

4.2.2 Effectiveness

4.2.2.1 Short-Term Effectiveness

The factors that determine the effectiveness of a drawdown for rooted plant control are covered in the original GEIR. It should be made clear up front that winter drawdown is the topic here, not lowering of water during the growing season. The sensitivity of plant species to exposure (Table 4-2 of the GEIR) has been expanded here somewhat based on experience (Table 4S-1) and it is essential to consider which plants might decrease and which might increase for any given drawdown application. Yet most plants exhibit a range of response, so certainty is not guaranteed in any case and monitoring is needed. Sediment particle size distribution remains important since drawdown is more effective with coarser sediment. Sediment slope is also important, as steeper slopes allow finer sediments to be moved to deeper water and let exposed sediment drain better, enhancing drawdown effectiveness. The depth of drawdown obviously affects performance, but the balance of benefits and possible drawbacks must be considered; having a reliable graph of area exposed and lake volume lost per unit of vertical water level decline is a planning necessity. Elevated seepage and plant density have been listed as factors that can compromise drawdown effectiveness and this intuitively makes sense, at least in the short-term.

Drawdown remains a weather-dependent technique, with warmer winters or early snow cover limiting effectiveness. This has always been the case, but climate change is making winter warmer and wetter in Massachusetts and New England in general. This has led some to suggest that the technique is no longer viable, but while the results over a series of years is variable, there are sufficient periods of below freezing temperatures and dryness that will kill many perennial plants. Additionally, the sediment coarsening function of drawdown is not greatly impacted by warmer temperatures and may be aided by more winter rain. Analysis of air temperatures in Harvard, MA in association with the Bare Hill Pond drawdown (ARC 2019) revealed that the average daily low temperature between mid-November and mid-March ranged from 17.2 to 26.7 F and that the total number of days with the temperature <30 F ranged from 69 to 98 (57-80% of the time). This is adequate to impact susceptible plants, although a complete kill would not be expected. Temperatures in the Berkshires are routinely colder than in Harvard, MA, making drawdown more effective in the western part of the Commonwealth.

Prevention of flooding is a function of supplying enough capacity to hold the anticipated inflow of water during spring thaw. This will be much more important for lakes with large watersheds in areas where snow packs can be substantial and soils do not readily absorb spring rains. This means that drawdown as a flood control technique will be of greater value in the Berkshires than on Cape Cod, with gradation in between those ends of the Commonwealth as dictated by watershed to lake area ratios, slopes, and soil conditions. It is possible to calculate how much capacity is needed and set a drawdown level accordingly. For example, a study of drawdown needs for Onota Lake in 1996 by Fugro East determined that 724 acre-feet of storage are needed to hold the runoff from a storm with a ten-year frequency. Using that as a surrogate for spring runoff, with Onota Lake at 617 acres, holding that water would require a drawdown of at least 1.2 feet. Providing a margin of safety (storm stats have changed with more runoff currently), a drawdown of Onota Lake of 1.5 to 2.0 feet would be recommended to prevent spring flooding both around the lake and downstream.

Prevention of ice damage to shorelines and structures is a matter of lowering the water level to a point where the movement of the edge of the ice sheet during winter will not be impacting sensitive areas. For structures in Great Ponds, there is a permitting system that needs to be followed (Chapter 91) and this may not always allow for drawdown for structure protection. In other waterbodies of the Commonwealth, the tradeoff between protecting structures than cannot be removed in winter with potential adverse impacts to the lake or cost of altering structures must be considered. Otis Reservoir has one of the largest winter drawdowns in Massachusetts, conducted in part to protect the dam, but this also serves to protect many permanent docks that could be replaced with seasonal docks if the drawdown was not needed to protect the dam. Drawdown over more than 50 years has resulted in very coarse substrate in the drawdown zone except in two areas (Dismal Swamp and State Beach Cove) where the slope is minimal and fine sediment has not moved into deeper water.

It is not essential at this point to have an annual drawdown to limit plant growths around the reservoir periphery, but damage to structures would be considerable if drawdown was not conducted.

Retaining walls are a touchy subject with regard to lake ecology but are subject to damage from ice. Walls that create a sharp and usually vertical boundary between the lake and adjacent land are ecologically less valuable than gradual slopes of rock or soil. If erosion is an issue, use of rocks or other hard materials that stabilize the slope and absorb wave energy may be warranted, but are ecologically more sound when they grade from land to water with a milder slope than presented by walls. Yet where retaining walls have been permitted, protection of those walls is afforded by drawdown.

For natural shorelines, just a foot or two of drawdown would be sufficient in the vast majority of cases to prevent damage. Many “soft” shorelines can sustain substantial damage. Some shorelines are naturally armored with rocks in a manner that can minimize ice damage, but rocks can be moved by ice and such shorelines are also often damaged. In Vermont, where drawdowns are rarely permitted, ice damage to the shoreline is considered to represent a major threat to ecological integrity and shoreline properties (Picotte 2016). Onota Lake in the Berkshires was not drawn down over the winter of 2109-2020 for the first time in many years and the Lake Onota Preservation Association documented considerable damage around the lake to both natural shoreline and structurally supported shoreline (Riordan 2020). While ice formation is natural, the impacts are counter to the intent of the Wetlands Protection Act (WPA) and are worth avoiding. Where drawdown for flood control is practiced there should be no major threat to shorelines, but where a lake is maintained at full level through the winter, susceptibility of shoreline to ice damage should be evaluated.

The effectiveness of annual winter drawdown as an aquatic plant control technique was properly noted in the GEIR but additional data from monitoring in Massachusetts have reinforced what was known. For susceptible target species, drawdown has provided a high degree of control at nominal cost. Probably the most common invasive plant species in Massachusetts, Eurasian watermilfoil (*Myriophyllum spicatum*) overwinters in vegetative form, has limited seed production and viability, and has been kept from dominating the nearshore zone of many lakes by drawdown. Lake Garfield in Monterey, MA, with a 6-foot drawdown among the larger ones in Massachusetts, has minimal milfoil in over 100 acres of water shallower than 8 feet (the drawdown depth plus about 2 feet of ice thickness) but has 10+ acres of milfoil in water between 8 and 14 feet deep that is being managed by other means at considerably greater cost. Laurel Lake in Lee and Lenox, MA has conducted a 3-foot drawdown for the last decade (WRS 2017b), resulting in much reduced milfoil abundance in water <5 feet deep. In the one year that drawdown was not conducted due to permitting issues, the expansion of milfoil in the following growing season was alarming.

Other susceptible species can be controlled through annual winter drawdown as well. Invasive variable watermilfoil (*Myriophyllum heterophyllum*) was controlled in water shallower than 4 feet by drawdown in Bare Hill Pond in Harvard, MA (ARC 2019). Results were impressive enough to lead to pumping to expand the drawdown to 6 feet. Invasive fanwort (*Cabomba carolinina*) was also controlled to a substantial degree, although there was substantial variation over space

Table 4S-1 Anticipated response of common aquatic plants to winter drawdown.
(After Cooke et al. 2005 and Mjelde et al. 2012 as amended by experience in MA)

	Change in Relative Abundance		
	Increase	No Change	Decrease
Brasenia schreberi (watershield)		F	F
***Cabomba caroliniana* (fanwort)**			S
Callitriche spp. (water starwort)	S/F	S/F	S/F
Ceratophyllum demersum (coontail)			S
Chara spp. (muskgrass)	S		
***Egeria densa* (Brazilian Elodea)**			S
***Eichhornia crassipes* (water hyacinth)**		E/S	
Elatine spp. (waterwort)		S	S
Eleocharis spp. (spikerush)	S	S	S
Elodea canadensis (waterweed)	S	S	S
Gratiola neglecta (hedge hyssop)	S	S	
***Hydrilla verticllata* (hydrilla)**	S	S	
Isoetes lacustris (quillwort)			S
Juncus spp. (rushes)	E	E	
Lemna minor (duckweed)		F	F
Lobelia dortmanna (water lobelia)			S
***Lythrum salicaria* (purple loosestrife)**	E	E	
Myriophyllum alterniflorum (alternate milfoil)			S
***Myriophyllum aquaticum* (parrotfeather)**		E/S	S
***Myriophyllum heterophyllum* (variable leaved milfoil)**			S
Myriophyllum sibiricum (northern milfoil)			S
***Myriophyllum spicatum* (Eurasian milfoil)**			S
Myriophyllum verticillatum (whorled milfoil)			S
Najas flexilis (bushy pondweed)	S		
Najas guadalupensis (southern naiad)		S	S
***Najas minor* (spiny naiad)**	S		
Nelumbo lutea (American lotus)		E	
***Nelumbo nucifera* (Indian lotus)**		E	
Nitella spp. (stonewort)	S	S	
Nuphar advena (yellow water lily)		E	
Nuphar variegata (yellow water lily)		F	F
Nymphaea odorata (white water lily)		F	F
Nymphoides cordata (little floating heart)	F/S	F/S	
***Nymphoides peltata* (yellow floating heart)**	F/S	F/S	
Persicaria amphibium (water smartweed)		F/S	F/S
***Phragmites australis* (common reed)**	E		
Potamogeton amplifolius (bigleaf pondweed)	S/F	S/F	
Potamogeton berchtoldii (small pondweed)		S/F	S/F
***Potamogeton crispus* (curlyleaf pondweed)**		S	
Potamogeton epihydrus (leafy pondweed)	S/F	S/F	
Potamogeton natans (broadleaf pondweed)		S/F	S/F
Potamogeton pusillus (thinleaf pondweed)	S/F	S/F	
Potamogeton richardsonii (clasping leaf pondweed)	S	S	
Potamogeton robbinsii (Robbins' pondweed)		S	S
Potamogeton zosteriformis (flatstem pondweed)	S	S	
Ranunculus trichophyllus (threadleaf crowfoot)	S	S	S
Sagittaria latifolia. (emergent arrowhead)		E	
Sagittaria graminea. (submergent arrowhead)			S

Table 4S-1 (continued). Anticipated response of common aquatic plants to winter drawdown.

	Change in Relative Abundance		
	Increase	No Change	Decrease
Schoeoplectus americanus (three square rush)	E		
Schoenoplectus lacustris (common club rush)	E		
Scirpus cyperinus (wooly grass)	E		
Sparganium angustifolium (bur-reed)	E/F	E/F	
Sparganium emersum (bur-reed)		E/F	E/F
Sparganium hyperboreum (bur-reed)	E/F	E/F	
Sparganium natans (northern bur-reed)		E/F	E/F
Stuckenia pectinata (Sago pondweed)	S	S	
***Trapa natans* (water chestnut)**		F/S	
Typha latifolia (common cattail)	E	E	
Utricularia spp. (bladderwort)		S	
Vallisneria americana (water celery)		S	S
Wolffia columbiana (watermeal)		F	

E=emergent growth form; S=submergent growth form; F=floating leaved form; bolded names signify invasive species.

(sediment features) and time (milder vs colder winters). Native assemblages that get dense enough to constitute nuisances can often be reduced in biomass without being eliminated by drawdown. Indian Lake in Becket, MA has conducted a drawdown for the last two decades to limit plant density around the periphery of this shallow lake (maximum depth is <15 feet, so the entire lake is potentially littoral zone) with varied but generally acceptable success (WRS 2017a). Otis Woodlands Lake (OWL) in Otis, MA also uses an annual winter drawdown to suppress native plants in a lake with a maximum depth of 13 feet, although feeding by abundant crayfish is also a potent plant control force in this lake (WRS 2020).

Species susceptibility and weather dependency are limiting factors for drawdown effectiveness, however. Species with an annual life cycle that depend on seeds, winter buds or turions to re-establish the population each spring are not likely to be controlled in the short-term by drawdown and may even be stimulated by drawdown through less competition by susceptible plants and enhanced germination of reproductive propagules after drying and/or freezing. Mild winters, which have become more frequent over the last 50 years, may provide insufficient drying or freezing to kill even susceptible plants. A study by Lonergan et al. (2014) demonstrated the need for sub-freezing temperatures or low moisture content to kill Eurasian watermilfoil and the difficulty of achieving a complete kill in most lake situations. It is highly unlikely that drawdown will provide a complete kill of any species in any given year and drawdown can be expected to exhibit a wide range of impacts on plants over a series of years based on weather variation, at least until coarser substrate is developed in the drawdown zone. The range of responses in Table 4S-1 testifies to the difficulty in predicting drawdown results; we know that some invasive species are impacted and that overall density of aquatic plants tends to be reduced by drawdown, but variation in results remains high.

Algal control by drawdown is dependent upon oxidation of sediments to reduce the potential for internal recycling in subsequent growing seasons. As noted in the GEIR, nutrient concentrations may increase or decrease after drawdown, mainly as a function flushing rate, so short-term impacts of drawdown on algae are therefore not reliably predictable. Drawdown has not generally been regarded as a primary means to control algae, but statements that drawdown routinely increases algae blooms are also not supported by experience.

4.2.2.2 Long-Term Effectiveness

The original GEIR covers the expected long-term effectiveness of drawdown adequately and provides examples of Massachusetts drawdowns that generally support claims of reductions in target species and overall plant biomass in the drawdown zone. The need for annual winter drawdown to achieve plant control goals is evident, as the results of any one drawdown are not predictable as a function of dependence on the weather. Past permits that called for drawdowns on an every other to every third year or varied the depth of drawdown among years limited effectiveness of drawdown and may have increased adverse impacts in some cases. Annual winter drawdown is needed to gradually shift the composition of the sediment in the drawdown zone to coarser particles that will support less plant growth, and this can be expected to take at least a decade where the slope is sufficient. Once less hospitable substrate conditions are attained, annual drawdown may not be necessary for plant control but continues to provide flood control and shoreline/structure protection, so is often continued on an annual basis.

Lake Garfield in Monterey, Otis Reservoir in Otis and Tolland, and Indian Lake in Becket were all mentioned in the GEIR as drawdown examples with general success in controlling plant nuisances. Ongoing monitoring in each has expanded those stories. Lake Garfield has applied a 6-foot drawdown for the last decade and has minimal Eurasian watermilfoil in water shallower than 8 feet (WRS 2019). A patch of milfoil developed in 8 to 10 feet of water in 2014, and in the absence of any management, expanded to 10-12 acres over the next two years. Management by suction harvesting has limited further expansion and reduced milfoil density but has not eliminated milfoil in deeper water that still provides fragments for colonization in shallower water. The annual drawdown counters such colonization, but as in most lakes with drawdowns of <6 feet and milfoil extending to at least 14 feet of water depth, the threat is ongoing. Multiple pondweed species, most notably bigleaf pondweed, have become abundant in the shallow water of the northern basin of the lake, prompting some interest in a mechanical harvesting program to maintain open water, but no such action has yet been taken although it was permitted under the WPA through the town, DEP and NHESP. The endangered Vasey's pondweed continues to be found in shallow water, suggesting no significant impact on that protected, annual, seed-producing species by drawdown.

Otis Reservoir has a remarkably cobbly nearshore area as the result of over 50 years of a roughly 8-foot drawdown. The drawdown zone has proven very resistant to invasive species and hosts only a very limited plant community, providing rocky habitat not common in Massachusetts lakes. The lakewide band of submergent plants growing between about 8 and 14 feet of water depth is unprotected, however, and variable watermilfoil invaded the lake sometime around 2015, with spiny (aka brittle) naiad and Eurasian watermilfoil detected in 2019 (ESS 2020). Assessment and physical management have ensued, and the distribution of invasive species is limited, with drawdown seemingly preventing expansion into shallower water except in areas of low slope

(<1:10). The native plant community includes multiple pondweeds, naiads, waterweed, bladderwort, water celery and stonewort but is largely limited to the zone between the drawdown depth and the point of limiting light (about 14 feet of water depth).

Indian Lake in Becket has employed a drawdown of 3-5 feet since the late 1990s to limit the density of native plants around the periphery of this manmade pond with a maximum depth of 10 feet (WRS 2017a). Since 2017 the lake association has settled into a standardized 4-foot annual winter drawdown with a water level and downstream flow tracking program. About 16% of the bottom of the pond, technically all littoral zone, is exposed, but this requires >50% reduction in water volume in the lake. Drawdown was only conducted on an average of 2 out of 3 years from 1999 through 2017.

The pattern of biovolume (Figure 4S-1, top panel) demonstrates the decline in the portion of the water column filled by plants in the 4-foot drawdown zone in response to drawdown, with resurgence in years when no drawdown was attempted. The decline is not extreme; plant biovolume ratings decline by no more than one quartile (25% increments) between years when a drawdown is conducted, but this is enough in most years to create acceptable accessibility for human lake users at the three beaches or private shoreline properties. There is a similar decline in biovolume in the 4-6 foot zone; some years the drawdown was 5 ft, but even when only 2-3 feet there would be ice damage in the 4-6 foot zone. There is actually an increase in plant biovolume in the >6 foot zone, possibly related to greater light at greater depth when the water level is low.

Cover by plants increased slightly at all depth ranges over the years (Figure 4S-1, middle panel). More area is covered by plants by virtue of less competition for light, but plants tend to be smaller. This seems to be reflected in an increase in the number of species present as well (Figure 4S-1, bottom panel), with a striking increase at all depths in the early years of drawdown, followed by a levelling off and decline in recent years, although the current species richness is still higher than at the start of the drawdown program. No invasive species have been found in Indian Lake.

Bare Hill Pond in Harvard, MA was invaded by both variable watermilfoil and fanwort and multiple means have been applied to combat these infestations. Drawdown of 3.5 feet by gravity in 2003-2006 minimized invasive plants in the drawdown zone, dropping the frequency of occurrence for both milfoil and fanwort from >75% to 5% over three years (ARC 2019). This prompted evaluation of expanding drawdown by pumping. A pump system was installed, and drawdown has been as deep as 7 feet over the last decade. Reduction in plant biomass in the drawdown zone has been documented and resurgence of plants has also been noticed after two separate years in which no drawdown was conducted to see if effects from the deeper drawdown were lasting (ARC 2019). Short-term effectiveness is apparent with weather-based variation, but long-term effectiveness requires continued annual application of winter drawdown.

ESS helped institute a program of occasional deeper drawdowns (6 feet) over the normal 2 to 3-foot drawdown practiced for many years at that lake and has been monitoring Nabnasset Lake in Westford, MA for about 17 years. A report card format (Table 4S-2) was developed based on quantitative and semi-quantitative monitoring data for many lake features (ESS 2017). Deep drawdowns were conducted in 2003, 2006, 2009, 2011 and 2012 in response mainly to invasive

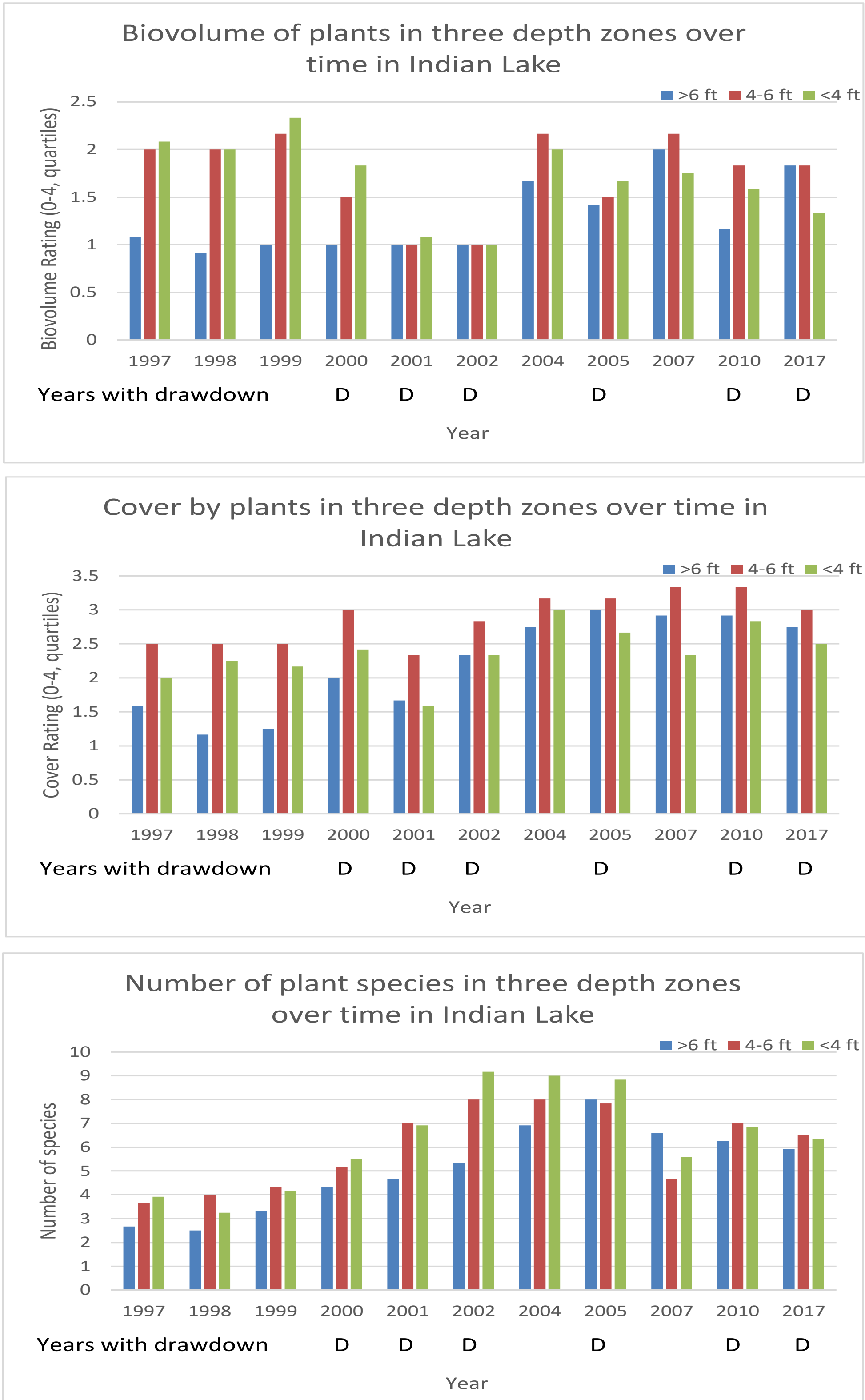

Figure 4S-1. Plant community features of Indian Lake relative to a 4-foot drawdown over time.

4.2 Drawdown

plant abundance in shallow water. Invasive species have been controlled to a large degree in the drawdown zone over time, although there is variation that may be caused by only having the deeper drawdown every three years on average. The abundance of invasive species in water deeper than 6 feet is greater than in shallower water but is not elevated and this may minimize recolonization of shallower areas, allowing a shallower drawdown for shoreline protection and flood control in most years.

Table 4S-2. Nabnasset Lake report card for drawdown impacts.

RESOURCE	A	B	C	D	F	GRADE								
						'07	'09	'11	'12	'13	'14	'15	'16	'17
Plant Community (<6' deep)														
Aquatic Native Plants	Dominant	Common	Occasional	Rare	Absent	B	B	B	B	B	A	A	A	A
Emergent Native Plants	Dominant	Common	Occasional	Rare	Absent	B	B	B	B	B	A	A	A	A
Aquatic Exotic/Invasive Plants	Absent	Rare	Occasional	Common	Dominant	B	B	B	B	B	A	B	C	A
Emergent Exotic/Invasive Plants	Absent	Rare	Occasional	Common	Dominant	B	B	B	B	B	B	B	B	B
Plant Community (>6' deep)														
Submerged Aquatic Native Plants	Dominant	Common	Occasional	Rare	Absent	B	A	B	B	B	A	A	A	A
Aquatic Exotic/Invasive Plants	Absent	Rare	Occasional	Common	Dominant	NS	B	C	C	B	A	C	C	A
Invertebrate Community (<6' deep)														
Freshwater Mussels	>0.5/ft2	0.2-0.5/ft2	0.1-0.2/ft2	0-0.1/ft2	Absent	D	D	D*	B	D	D**	C	C	C
Other Macroinvertebrates	>8 taxa	6-8 taxa	3-5 taxa	1-2 taxa	Absent	B	B	C	C	C	A	A	B	C
Invertebrate Community (>6' deep)														
Freshwater Mussels	>0.5/ft2	0.2-0.5/ft2	0.1-0.2/ft2	0-0.1/ft2	Absent	B	C	D	A	D	D**	D	D	A
Other Macroinvertebrates	>8 taxa	6-8 taxa	3-8 taxa	1-2 taxa	Absent	B	B	B	B	C	C	C	C	C
Water Quality														
Clarity (turbidity/Secchi depth)	<1 NTU or >4m	1-2 NTU or 3-4m	2-5 NTU or 2-3m	5-10 NTU or 1.2-2m	>10 NTU or <1.2m	A	B	C	B	B	B	B	B	B
Phosphorus Concentration (mg/L)	<0.01	0.01-0.02	0.02-0.03	0.03-0.05	>0.05	B	A	C	B	B	A	A	A	C
Nitrogen Concentration (mg/L)	<0.5	0.5-0.8	0.8-1.0	1.0-2.0	>2.0	D	B	C	D	B	B	B	B	B
Dissolved Oxygen at surface (mg/L)	>10.0	7.0-10.0	6.0-7.0	5.0-6.0	<5.0	B	B	B	B	B	B	B	C	B
Erosion														
Shoreline	No evidence	Wave erosion only	Undercut banks	Bank failures	Numerous bank failings	B	B	B	B	B	B	B	B	B
Downstream of Dam	No evidence	Limited undercut banks	Extensive undercut banks	Loss of minor shoreline vegetation	Loss of trees and roots	B	B	B	B	B	B	B	B	B
Shipley Swamp														
Plant Community (<6' deep)														
Aquatic Native Plants	Dominant	Common	Occasional	Rare	Absent	A	A	A	A	A	A	A	A	A
Emergent Native Plants	Dominant	Common	Occasional	Rare	Absent	A	A	A	A	A	A	A	A	A
Aquatic Exotic/Invasive Plants	Absent	Rare	Occasional	Common	Dominant	B	B	C	B	A	A	B	C	B
Emergent Exotic/Invasive Plants	Absent	Rare	Occasional	Common	Dominant	C	C	C	C	C	C	C	C	C
Invertebrate Community (<6' deep)														
Freshwater Mussels	>0.5/ft2	0.2-0.5/ft2	0.1-0.2/ft2	0-0.1/ft2	Absent	D	D	D*	D	D	D	D	D	D
Other Macroinvertebrates	>8 taxa	6-8 taxa	3-8 taxa	1-2 taxa	Absent	B	B	C	C	C	C	C	C	C

NS: Not scored; *Based on observations by NLPA volunteers; **Based on observation of recently spent valves near muskrat middens

The GEIR noted that long-term control of algae by drawdown depends on reduced release of nutrients from the sediment to the water column, potentially by focusing of sediments into deeper areas where the slope is adequate, leading to a smaller area of contributing sediment. Yet there have been no clearly documented successful cases and nutrient recycling from shallow water is usually low compared to release from sediment in deeper water that experiences low oxygen.

4.2.3 Impacts to Non-Target Organisms

Undesirable possible side effects of drawdown noted in the GEIR include loss or reduction of desirable plant species, facilitation of invasion by drawdown-resistant, undesirable plants, reduced attractiveness to waterfowl (considered an advantage by some), possible fish kills if oxygen demand exceeds input under the ice, altered littoral habitat for fish and invertebrates, mortality among hibernating reptiles and amphibians, impacts to connected wetlands, shoreline erosion during drawdown, loss of aesthetic appeal during drawdown, more frequent algal blooms after refill in some cases, reduction in water supply, impairment of recreational access during the drawdown, and downstream flow impacts. Remarkably few of these postulated impacts have turned out to be common or even occasional in the research performed and experience gained in Massachusetts since the GEIR was produced. All are possible, but any assumption that these negative effects will occur has minimal support in the literature or from monitoring in Massachusetts.

Certainly the drawdown zone will be less visually attractive than when the lake is full until it gets snow cover, and access can be impeded if there is a substantial distance between the land and water or ice at the access point, but the entire lake periphery is rarely subject to these conditions. Yet one can find photos of entire coves or shallow expanses with exposed mudflats that are unappealing and inaccessible until freezing temperatures set in. Visual aesthetics and human accessibility are not, however, interests of the Wetlands Protection Act and are not justification for decisions in the permitting process.

Algae

Decay of exposed organic matter during drawdown will lead to more nutrients being available in the water once the area is inundated again. Whether or not this has any impact on nutrient levels during the growing season is largely a function of how much organic matter decayed during drawdown and flushing rate. Where drawdown has not been conducted before, the amount of nutrient-rich organic material exposed is likely to be greatest, while lakes where drawdown has been implemented annually for more than a few years are less likely to have much nutrient-rich organic sediment that can contribute during drawdown. If the refill period requires most of the spring and the water captured during refill remains in the lake over summer, the potential for nutrients made available during drawdown to fuel algae blooms will increase. However, as refill is usually complete by late April in Massachusetts lakes, there may be considerable flushing before flows subside, typically by late June. An assessment of the exposed sediment features and system hydrology are therefore needed to make predictions regarding drawdown impacts on algae the following year.

The record does not suggest a major impact of drawdown on algae abundance. Of the 40 lakes for which the DPH reported cyanobacteria blooms in 2019, no more than 5 were subject to a drawdown. A large portion of the lakes reported to have algae blooms are on Cape Cod where the lakes are mostly kettlehole ponds with no outlet other than an unregulated overflow and no ability to conduct drawdowns. Phosphorus that supports excessive algae can come from the watershed or internal recycling of past watershed loadings. Where the watershed is more than about 20 times the area of the lake, watershed inputs are likely to dominate, and flushing will be great enough to minimize the impact of any release of nutrients in the exposed area during drawdown. The primary mechanism of internal recycling is release from sediments exposed to low oxygen, something that happens mainly in deeper water during summer stratification (Steinman and Spears 2020).

Once the drawdown zone substrate has been coarsened by repeated annual drawdowns, the potential for nutrient release as a result of drawdown will be lessened. Yet there are parts of most lakes that do not have great enough bottom slope to facilitate that coarsening process and it can take a decade or more to minimize nutrient-rich organic sediment in the drawdown zone even where the slope is adequate, so potential impact will be related to how much area is exposed and how much of the nutrient content of exposed sediments is released. Theoretical calculations for a 100 hectare (250 acre) lake with a maximum depth of 10 m (33 ft) and a volume of 3.33 million m^3 (2700 acre-feet) and a drawdown exposure of 10% with a typical range of sediment phosphorus content (50-500 mg/kg) and the top 2.5 cm (1 inch) affected at 1-10% release suggest a possible phosphorus concentration increase of 0.3 to 28 ug/L. If the exposed area is as much as 30% of the lake area, the phosphorus concentration increase could be 0.8 to 84 ug/L. The plausible range is very wide and impacts are not impossible, but it is not at all certain that a measurable change in water quality will occur.

Considering actual data from lakes in Massachusetts, monitoring of Lake Garfield in Monterey with 35% of the lake bottom exposed (the largest exposure listed in Carmignani 2020) as part of a 604b project sponsored by the MA DEP (WRS 2018) revealed phosphorus at 18 ug/L in April, declining to 13 ug/L in May, 12 ug/L in June, and <10 ug/L in July and August of 2016. This might suggest some impact from drawdown, but the phosphorus content of the snowmelt largely responsible for refill was almost 30 ug/L and represents a more likely source of the increased spring phosphorus concentration. Internal loading during summer was found to be significant, with deep water phosphorus concentrations exceeding 400 ug/L in August and cyanobacteria forming a surface scum on some dates. The sediments that contribute most to phosphorus in Lake Garfield are in deep water and not subject to exposure during drawdown. There was a bloom of the golden alga *Dinobryon* in April and May of 2016 during the 604b study. This alga can make use of organic compounds that might have been suspended in the water as a function of refill, but considerable organic matter also enters from the many small tributaries around the lake with snowmelt.

Onota Lake in Pittsfield has a drawdown that has exposed 11-33% of the lake bottom (Carmignani 2020). From monitoring conducted by volunteers between 1999 and 2010 (WRS 2011), the average monthly phosphorus concentration varies little, ranging from 14 to 17 ug/L, and is not higher in April after refill than other months. Variability in spring values appears related to watershed influences, not drawdown. The highest individual values are from deep water in later summer, an indication of some internal loading from sediment exposed to low oxygen. Algae blooms have not been a serious issue in Onota Lake.

Otis Reservoir in Otis has a drawdown that exposes about 21% of the lake bottom (Carmignani 2020). Algae blooms have not been an issue in Otis Reservoir as documented by the diagnostic/feasibility study by ENSR (2001) and a lack of reported blooms since then. Goose Pond in Lee and Tyringham has a drawdown that exposes about 11% of the lake bottom (Carmignani 2020). Goose Pond has high water clarity and algae blooms have been rare over the last two decades (WRS 2016), although there is recent evidence of cyanobacteria increasing in summer.

There appears to be a lack of measured direct impact on phosphorus and algae levels in drawdown lakes in Massachusetts. However, some deep water organic sediments that contribute to internal loading during summer have been transported from shallow water in part as a consequence of drawdown. The addition of phosphorus-rich organic matter to deep water adds to oxygen demand in a zone that often experiences low oxygen and represents a long-term contribution to internal loading. It is not known if drawdown-induced movement of fine sediment to deeper water ever represents a significant fraction of deep-water sediment, but many lakes without drawdowns experience problems with internal release of phosphorus from sediment exposed to low oxygen in deeper water. While drawdown is likely to contribute to the accumulation of organic, nutrient-rich sediment in deeper water, the potential loss of oxygen, release of nutrients, and related algae blooms are not problems caused specifically by drawdown.

Any assumption of drawdown inducing algae blooms in Massachusetts lakes appears unjustified. However, any assumption that drawdown will improve water quality and prevent algae blooms also has minimal support from actual studies of Massachusetts lakes. The primary causes of excessive algae are inputs from the watershed and internal recycling of phosphorus from sediment in water deeper than drawdown can directly impact. The coarsening of the sediment in the drawdown zone may limit some algal mat development, and drawdown that flushes accumulate nutrients downstream may improve water quality over many years (ENSR 2008), but the dominant influences on algae blooms are not substantially impacted by drawdown on a year to year basis.

Plants

Non-target species of plants that depend on vegetative means of overwintering or reproducing may indeed be reduced in abundance along with the targeted species, but significant losses are uncommon based on the available monitoring data. Given the range of responses for individual species (Table 4S-1) and difficulty in killing off an entire population in a lake by a partial lake drawdown, this is not surprising.

Resistant species, mainly those overwintering by seed, or species abundant below the drawdown zone, may become more abundant in the drawdown zone over time. Open substrate created through drawdown may be colonized by invasive species, although many of the problematic nuisance species are sensitive to drawdown. Drawdown for nuisance plant control is intended to cause shifts in plant assemblage composition and abundance, but not all shifts will necessarily be desirable.

The Carmignani thesis (2020) reviews extensive literature on drawdown impact on plants in general, documenting the effectiveness of drawdown for reducing biomass of rooted plants in the drawdown zone, but notes varying impact on species richness with different drawdown depths. Loss of species is generally associated with drawdowns deeper than what are applied in Massachusetts and drawdowns of up to 5 feet have been found to increase species richness, consistent with the general trend found through monitoring in Massachusetts. Species richness has increased or remained stable in most Massachusetts lakes subject to drawdown for which monitoring data are available. Indian Lake in Becket (Figure 4S-1), with a 4-foot drawdown, provides an example.

While species do not tend to be lost, shifts in species composition and relative abundance are expected. Fast growing species with a high annual seed production are favored; annual plants spread seeds all over a lake and can appear anywhere that conditions are favorable in any given year. Such species include naiads, waterweed and charophytes (*Chara* and *Nitella*, both macroalgae) that establish populations each year from seeds/spores that may be dormant for years. Species that are adapted to life at the edge of lakes with fluctuating water levels, such as hedge hyssop and some species of bur-reed that can grow inundated or on moist substrate, can also expand within drawdown lakes. Most emergent species like cattail, rushes, and sedges are not greatly affected by drawdown. The response of many species is variable (Table 4S-1), however, depending on the duration and severity of exposure, weather conditions, and substrate features. This variability is embodied in the primary pondweed genus (*Potamogeton*), which includes many species common to Massachusetts lakes. Where the species depends on mature plants or root structures to overwinter (most notably *P. robbinsii*), reductions are distinctly possible, and if suppressed to a large degree recovery may be very slow. Where the species is a typical annual plant (most thinleaf pondweeds like *P. pusillus*), minimal impact is likely, and populations can expand rapidly. For species that can be perennial by virtue of overwintering root structures but also produce abundant seeds (e.g., *P. amplifolius, P. epihydrus*), results can be very variable, but over a multi-year period these species tend to increase in relative abundance in response to drawdown.

Drawdown of Lake Garfield in Monterey over many years has resulted in a diverse assemblage of pondweeds in the lake overall and particularly in the smaller, western basin that is largely drained over the winter (WRS 2017c). Bigleaf pondweed (*Potamogeton amplifolius*) and Robbins pondweed (*Potamogeton robbinsii*) are the most abundant large leaved species, although a mix of thin leaved species is abundant in many areas as well. Bigleaf pondweed has become more abundant despite being a perennial species and Robbins pondweed has remained abundant despite not producing seeds in this system. Thin leaved pondweed species included sago pondweed (*Stuckenia pectinata*), slender pondweed (*P. pusillus*), and Vasey's pondweed (*P. vaseyii*). Additional pondweeds found in Lake Garfield include flatstem pondweed (*P. zosteriformis*), Richardson's pondweed (*P. richardsonii*) and boat-tipped pondweed (*P. praelongus*). Common naiad (*Najas flexilis*) is in the pondweed family and is also common in Lake Garfield, mostly in shallow water. Drawdown has not caused any loss of pondweed species or even a decline in relative abundance in the drawdown zone.

Drawdown of Laurel Lake in Lee has been used to limit colonization of nearshore areas by zebra mussels and Eurasian watermilfoil since 2010. Where the slope is moderate to steep, coarse substrate has been increased and plant densities have declined. Many members of the pondweed family (e.g., *P. amplifolius, P. richardsonii, P. zosteriformis, P. gramineus*) are largely restricted to water depths >6 feet where the slope is great enough to allow peripheral sediment coarsening. However, two areas of the lake include large expanses of shallow (<5 feet) water that have retained dense vegetation in most years while undergoing plant assemblage changes (WRS 2017b). In some years, sago pondweed (*Stuckenia pectinata*) has been dense while there has been an overall increase in the invasive spiny naiad (*Najas minor*). Both species are copious seed producers that appear stimulated by drawdown. These areas of the lake are relatively flat with organic sediment hospitable to plant growth. While milfoil and zebra mussels have indeed been limited in shallow water, the shallow zones with minimal bottom slope have continued to experience nuisance conditions and to some extent one invasive species has been traded for another.

Indian Lake in Becket has a 4-foot drawdown each winter to control native species around the periphery of the pond (WRS 2017a). The Indian Lake data suggest no loss of any species and an increase in the number of species in each defined depth zone of the lake. No invasive species have entered the lake. Plant density has decreased (Figure 4S-1) but there have been no major shifts in the relative abundance of plant species clearly attributable to the drawdown.

Drawdown of Bare Hill Pond in Harvard, Massachusetts has ranged from 0 to 7 feet over the last 22 years and detailed plant monitoring data are available for 12 of those years (ARC 2019, Figure 4S-2). Except for one year where no drawdown was conducted as an experiment in results longevity, the drawdown was 3.5 feet in the first few years and then 4.5-6.0 feet in other monitored years. Plants were not monitored in the one year of 7-foot drawdown, conducted to support swim area alteration. There has been no change in the frequency or abundance of plants in water deeper than the drawdown limit, but there has been an overall reduction in plant biovolume (portion of the water column filled by plants) in the drawdown zone. Aside from frequency reductions in variable watermilfoil and fanwort, the main target plants, non-target species shifts have included reduction in Robbins' pondweed (*P. robbinsii*) and to some extent bladderwort (*Utricularia*). Variability is substantial among years and generally corresponds to colder/drier vs warmer/wetter winters. Increases have been observed in the frequency of watershield (*Brasenia*), macroalgae (*Chara/Nitella*), and tapegrass (*Vallisneria*). Based on Table 4S-1, only the reduction in Robbins' pondweed and increase in macroalgae would have been expected, but there are many other factors influencing these plants, including the reduction in competition from milfoil and fanwort supported by drawdown.

Drawdown of Lake Shirley in Lunenberg, Massachusetts has been conducted for many years, averaging about 6 feet (ARC 2020). The lake was expanded many years ago from <20 acres to 354 acres by dam construction but has an average depth of just over 7 feet, so the littoral zone is substantial. Natural color in the water limits plant growth at >12 feet. Plant abundance in the drawdown zone is significantly higher than in deeper water where light is more limiting, but it is believed that the density of plants would be even higher in the drawdown zone if drawdown was not conducted. Monitoring has been conducted each year since 2002. Plant species richness is significantly higher in the drawdown zone than in deeper water, with an average of 14.5 species detected each year in the drawdown zone and 8.7 species found in deeper water. Other factors such as light and substrate may restrict some species to shallower water, but there is no evidence that drawdown has reduced the number of species present. Evenness, a measure of the relative abundance of species, is not significantly different between the drawdown zone and deeper water, suggesting that drawdown is not strongly favoring one or a few species over the others. Decreases in the frequency of coontail (*Ceratophyllum*), waterweed (*Elodea*) and Robbins' pondweed (*P. robbinsii*), increases in bushy naiad (*Najas flexilis*), and high variability in bladderwort (*Utricularia*) and macroalgae (*Chara/Nitella*) were observed over time, but many shifts were more coincident with the timing of herbicide treatments and cannot be clearly attributed to drawdown.

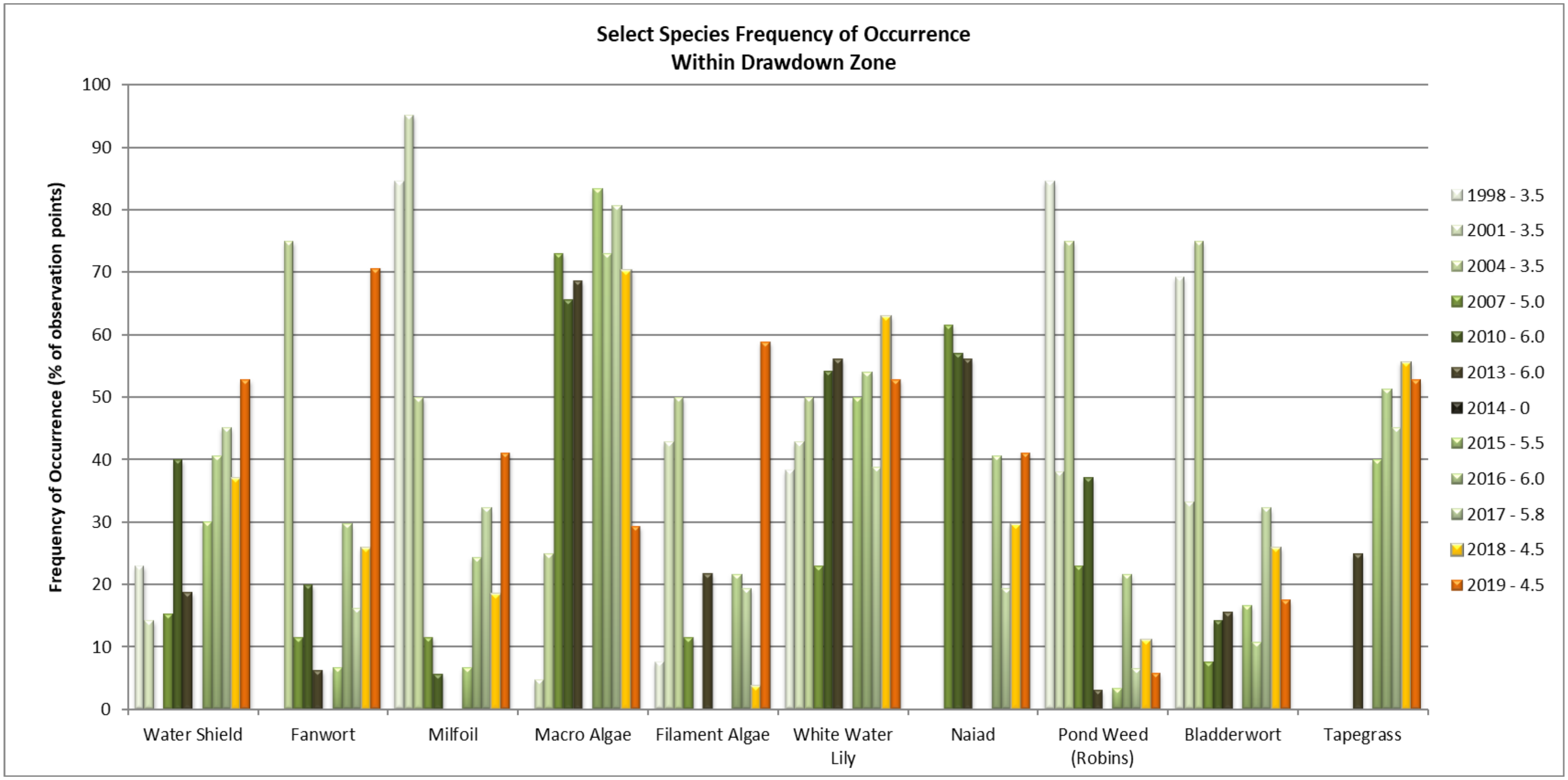

Figure 4S-2. Frequency of common species in the drawdown zone of Bare Hill Pond over time.

Drawdown of Nabnasset Lake in Westford, MA does not suggest any significantly negative impact on native plants (Table 4S-2) by an annual drawdown of at least 2 feet with expansion to 6 feet whenever invasive species become too abundant in shallower water (ESS 2017). However, the deeper drawdown has not been conducted since winter 2012-2013 and native plants have become more abundant since 2014 in water <6 feet deep with only a 2 to 3-foot drawdown.

There may be cascading effects of drawdown with regard to plants, with indirect effects potentially substantial. The Bare Hill Pond drawdown described above has caused a few increases in native species that may be related to reduced competition between native species and invasive plants controlled by drawdown, even though the native species are ones known to have some susceptibility to drawdown. A 2-foot drawdown of Otis Woodlands Lake in Otis for flood and plant control was expanded in two successive winters to about 7 feet for dredging and dam repairs (WRS 2020). Plants had not been a serious problem for some years after drawdown was initiated, but part of the control came from a large crayfish population that had few predators in this system with no gamefish. The expanded drawdown greatly reduced the crayfish population, resulting in rapid and excessive growth of a thinleaf pondweed (*P. spirillus*) in two successive summers in water 2-4 feet deep. Growths were extensive outside the area that was dredged. The crayfish population recovered and plant control resumed in the third summer, but it is evident that not all impacts of drawdown are direct and plant biomass will not always be reduced by drawdown. The specifics of each case are important, and assumptions based on results in nearby waterbodies may not be reliable.

The Carmignani thesis (2020) found that winter drawdown decreased plant biomass in the drawdown zone, as intended, and noted decreases in white water lily, watershield, and Robbins' pondweed as would be expected based on Table 4S-1. Increases in naiads and the macroalga *Chara* were also noted, again consistent with Table 4S-1. No other strong relationships between drawdown and non-target plant species were documented. This part of the thesis was devoted to structural complexity of littoral habitat, and any changes in the plant community were considered within the context of other nearshore influences, including woody debris, shoreline development, and other watershed features. The coarsening of sediment in the drawdown zone was documented, but its role in providing habitat not available elsewhere in the study lakes was not explored. The loss of woody debris, not a permitted aspect of drawdown but facilitated by it by increased access for shoreline property owners, represents collateral damage that is avoidable under the permit system. The need to preserve ecological integrity and to consider littoral zone management within the context of all environmental variables is well stated, but the data do not suggest that the impact of drawdown on non-target plant species is a particularly influential factor.

Contiguous emergent wetlands

The impact of drawdowns on wetlands that are hydraulically connected to the lake was a major concern of environmental agencies in the years leading up to the production of the GEIR. Available data did not suggest major impacts from winter drawdowns, largely a result of dormancy by most plants and frozen soil conditions. Wetlands are generally adapted to fluctuating water levels and fluctuations in the winter are of least concern. The naturally occurring hydrologic regime is a critical determinant for the establishment and maintenance of specific types of wetlands and most drawdowns constitute only a temporary influence on hydrologic regime with very limited effects.

Still, there was considerable concern and monitoring programs sometimes included emergent wetland evaluations.

Evaluation of emergent wetlands contiguous with Indian Lake in Becket for 3 years before and 4 years after drawdown commenced (WRS 2017a) found no discernible impacts on those wetlands. Similar results were obtained from a similar study of wetlands adjacent to Laurel Lake in Lee and Lenox (WRS 2017b). Assessment of wetlands contiguous to Bare Hill Pond (ARC 2019) prior to and after expansion of the drawdown suggested no major changes clearly attributable to drawdown. However, the appearance of invasive common reed (*Phragmites australis*) was detected in the 3rd year of post-expanded drawdown monitoring. At the edge of the lake, proliferation of yellow iris (*Iris pseudacorus*) and some expansion of cattail (*Typha latifolia*) was documented; while not part of the wetland study, this encroachment is likely aided by drawdown to some degree. Evaluation of Shipley Swamp adjacent to Nabnasset Lake (ESS 2017) over a decade of drawdown influence suggests no directional change in the generally healthy plant community of that wetland. There are some invasive species present in Shipley Swamp but no indication that their abundance has been altered by drawdown.

While the wetland protection act places great emphasis on emergent wetlands, there have been almost no peer reviewed studies suggesting major impacts on connected emergent wetlands from drawdowns of the magnitude conducted in Massachusetts since the preparation of the GEIR. Such impacts can be hypothesized, but detection within the context of many other factors affecting wetlands (e.g., climate change, species invasions, watershed alteration) is very difficult and there is nothing inherent in an annual winter drawdown that is expected to have a major or rapid adverse effect on emergent wetlands. Most emergent species at the periphery of a lake increase or remain stable after drawdown, so there is no obvious reason to believe that contiguous wetlands would be negatively impacted, although drawdown could have more subtle, long-term effects that would be very hard to clearly associate with drawdown.

A drawdown of Richmond Pond in Richmond and Pittsfield was reduced in depth through its permit around 2006 after the NHESP determined that there were rare plants in contiguous wetlands that might be affected. Drawdown of Richmond Pond had been an annual winter event under the auspices of flood control for over 40 years prior to that decision. If the rare plants were not affected over that 40-year period, it is unclear why drawdown would be considered a threat to be minimized. Further, the presence of those rare species might actually be linked to drawdown in a positive manner. No study has been made publicly available to either document negative impacts of the Richmond Pond drawdown or evaluate the effect of limiting that drawdown on the rare plants of concern. It is reasonable to question impacts and develop appropriate monitoring programs, but assumptions that go into permitting decisions should be thoroughly examined before being relied upon.

Mussels

The primary documented impact to non-target organisms by drawdown is mussel mortality in the drawdown zone. Mussels tend to burrow into the sediment rather than move to deeper water when water levels get low in many cases and they don't move very fast when they do move toward deeper water, so there is a definite risk of mortality in the drawdown zone of which lake managers have been aware for decades. However, mussels reappear in the drawdown zone virtually every year, indicating that some portion of the population in that zone is not killed or there is ongoing recolonization from deeper water. Carmignani (2020) investigated the impact of drawdown on mussel populations and found that non-drawdown lakes had more mussels per unit area than drawdown lakes from shore to the depth of drawdown. He also found that there were more mussels in the next similar increment of depth beyond the drawdown zone than within it. It was concluded that if the drawdown zone population of mussels was a substantial fraction of the total lake population, the loss of those mussels might constitute a significant ecological impact, given the role of mussels in filtering the water column and other aspects of lake ecology.

However, that study did not quantify the mussel population of any lake and the evidence is fairly strong that the bulk of the mussel populations in Massachusetts lakes are in water deeper than ever subjected to drawdown. Given natural water level declines on the order of 2-3 feet in Massachusetts, mussel populations would be at great risk if they concentrated in shallow water. Surveys of mussels in 20 Berkshire County lakes found higher densities in water >5 feet deep than in the shallow zone (Biodrawversity 2008), with 11 of those lakes subject to no drawdown. Similar results were found in a pair of Cape Cod lakes (Biodrawversity 2017) where there is no drawdown. Carmignani (2020) found that the average size of mussels in the drawdown zone was smaller than those in the next increment of deeper water, suggesting colonization from deeper water, and live mussels have been found in virtually every drawdown zone each summer after decades of drawdown. There is no question that mussels can be killed by drawdown, but there also seems to be no evidence that this is a major threat to the overall population or lake ecology.

The average portion of the lake bottom exposed during drawdown for the lakes studied by Carmignani was 12.7%, likely to represent considerably less than 10% of the mussel population given greater density at greater depths. On average, it is hard to envision a significant ecological impact by drawdown as a result. However, not all of each lake is viable mussel habitat even when full. At depths of 20 to 30 feet most lakes in Massachusetts experience low oxygen by late summer and will not support mussels, so the portion of the lake potentially colonizable is often <100%. Based on 12 lakes from the Carmignani study for which accurate depth maps and oxygen profiles were available, the range of viable mussel habitat lost during drawdown ranges from 6.5 to 50.4% (Table 4S-3). Actual loss of mussels will be considerably less, given higher densities in water deeper than the drawdown, but it is apparent that some impact is possible for lakes where a higher portion of the lake is exposed by drawdown and low oxygen limits mussel populations in the deepest water. It is entirely reasonable for permitting authorities to request a mussel survey if it appears that there could be a significant impact. It is not reasonable, however, to assume an impact because someone saw some dead mussel shells in the drawdown zone.

Near annual monitoring of mussels in Nabnasset Lake in Westford, MA by ESS (2017) in response to drawdowns of 2-6 feet over a decade indicate that mussels are more abundant at water depths >6 feet (Table 4S-2) but that mussels are not particularly abundant in this lake (usually <0.5/sq. ft and often <0.2/sq. ft). There is no indication of any decreasing trend in the mussel community of the lake. Mussels were also limited in the shallow water of the adjacent Shipley Swamp. The application of a 6-foot drawdown only 5 times over 15 years may allow greater recolonization of shallower water, but the application of a 2 to 3-foot drawdown on a regular basis will still limit shallow water mussel populations and the deeper drawdown every few years is expected to have a greater impact.

4.2 Drawdown

Table 4S-3. Calculation of viable mussel habitat lost during drawdown.

Lake	% Lake Area Exposed by Drawdown	% Lake Area with Low DO	% Viable Mussel Habitat Lost by Drawdown
Ashmere	17.4	5	18.3
Boon	6.5	16	7.7
Buel	6.1	25	8.1
Garfield	35.3	30	50.4
Goose	11.3	36	17.7
Greenwater	3.9	50	7.8
Onota	20.0	35	30.8
Otis	20.5	40	34.2
Richmond	6.9	20	8.6
Stockbridge	13.9	50	27.8
Wickaboag	6.5	0	6.5
Wyola	9.0	22	11.5

One large exception to the above estimation of limited impact of drawdown on mussel populations is the presence of an endangered species. Mussels listed by the Natural Heritage and Endangered Species Program are protected and any "take" of such mussels is subject to approval by the NHESP. An estimate of 10% loss would undoubtedly be considered unacceptable and a more detailed population evaluation would be needed if a drawdown was even to be considered. The Carmignani study lakes contained no listed mussel species and the Biodrawversity study of 20 Berkshire lakes (2008), 8 of which were in common with the Carmignani study lakes, also contained no listed mussel species. The NHESP keeps records of listed species locations and that database should be consulted when considering lake projects.

Other Invertebrates

Evaluations of invertebrates beyond mussels have been carried out on many drawdown lakes in the course of monitoring, but rarely in a quantitative fashion that supports treatment vs reference or before vs after comparisons. All of the expected invertebrate faunal components have remained present in assessed drawdown lakes (e.g., ARC 2019, WRS 2017a, 2017b), but it is not clear that there have been no shifts in relative abundance. Changing substrate conditions, as with coarsening of the drawdown zone sediment, would be expected to cause such shifts. Damselflies (Zygoptera) and scud (Amphipoda) are more abundant in plant stands, which require at least some finer grained sediment, while certain snails (Gastropoda) and caenid mayflies (Ephemeroptera) would be more abundant on coarse substrates such as gravel or cobble. Many dragonfly larvae (Anisoptera) are associated with organic sediments, while adult whirligig beetles (Gyrinidae) and water striders (Gerridae, Mesoveliidae) cruise the water surface and are less dependent on substrate type. The types of plants present may indeed matter to many species of invertebrates, but substrate is generally the most powerful determinant of invertebrate fauna composition (Ward 1992).

Carmignani (2020) found that drawdown magnitude showed only weak correlation with macroinvertebrate abundance, richness, and diversity; there were not fewer invertebrates from fewer taxa or a skewing of distribution as a result of drawdown. Other environmental factors, including availability of algae growing on substrates, overall lake fertility, and shoreline residential development, were at least as important as drawdown in shaping invertebrate communities. While the invertebrates in the drawdown may not survive the winter, recolonization is apparently rapid, on the order of 2-3 months. Carmignani (2020) did find that non-swimming invertebrates and insects with larval development times greater than a year were less abundant in the drawdown zone, and the snail *Amnicola* had an abundance that negatively correlated with drawdown magnitude. This latter finding is somewhat at odds with snail surveys in Laurel Lake, not one of the Carmignani study lakes, where monitoring consistently found *Amnicola* to be the most abundant snail in the drawdown zone (WRS 2017b) with a relatively stable population over 4 years of assessment (Figure 4S-3). Amnicola is also known to be abundant in the drawdown zone of Stockbridge Bowl, which was a Carmignani study lake (Coote and Roeder 2000). Perhaps *Amnicola* is even more abundant beyond the drawdown zone, but its abundance within drawdown zones does not suggest a strong negative impact by drawdown.

The drawdown zone for Laurel Lake was surveyed in December after the drawdown depth was achieved in each of 6 years following initiation of drawdown in 2010 (WRS 2017b). Recently dead snails of the types found in summer were indeed found in December (Figure 4S-4), and while some natural die off is expected, it is reasonable to conclude that drawdown will kill some snails at it does some mussels. However, the proportions of the total represented by the different taxa varied from the summer sampling and there were more snails found in each successive December after drawdown was initiated as an annual event. The response to drawdown appears to vary among snail species and drawdown does not appear to result in an extermination of snails in the drawdown zone. As with mussels, the bulk of the snail populations may be in deeper water, with annual colonization of shallow areas subject to drawdown impact. The habitat in the drawdown zone is not so altered that colonization ceases and the abundance of snails in the drawdown zone is not substantially depressed over time.

The richness of non-mussel invertebrate taxa in Nabnasset Lake in water <6 feet deep is similar to or higher than that at depths >6 feet and shows no apparent temporal trend (ESS 2017, Table 4S-2). The overall abundance of macroinvertebrates is not addressed in the report card, and there may be some shifts in the taxonomic and functional aspects of the macroinvertebrate community in shallower water, but the drawdown does not eliminate or greatly depress macroinvertebrates. At least two snail species are among the invertebrates encountered. There is a slight decrease in richness in water >6 feet deep in the lake and in the adjacent Shipley Swamp over the decade of monitoring, but this does not appear to link to the drawdown.

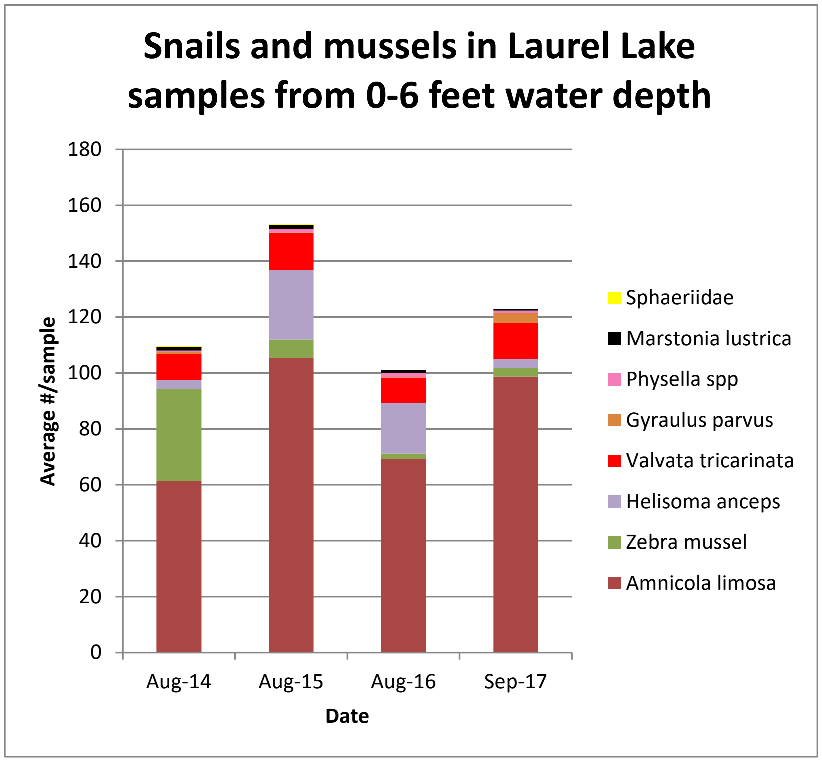

Figure 4S-3. Summer mollusc abundance in the drawdown impact zone of Laurel Lake

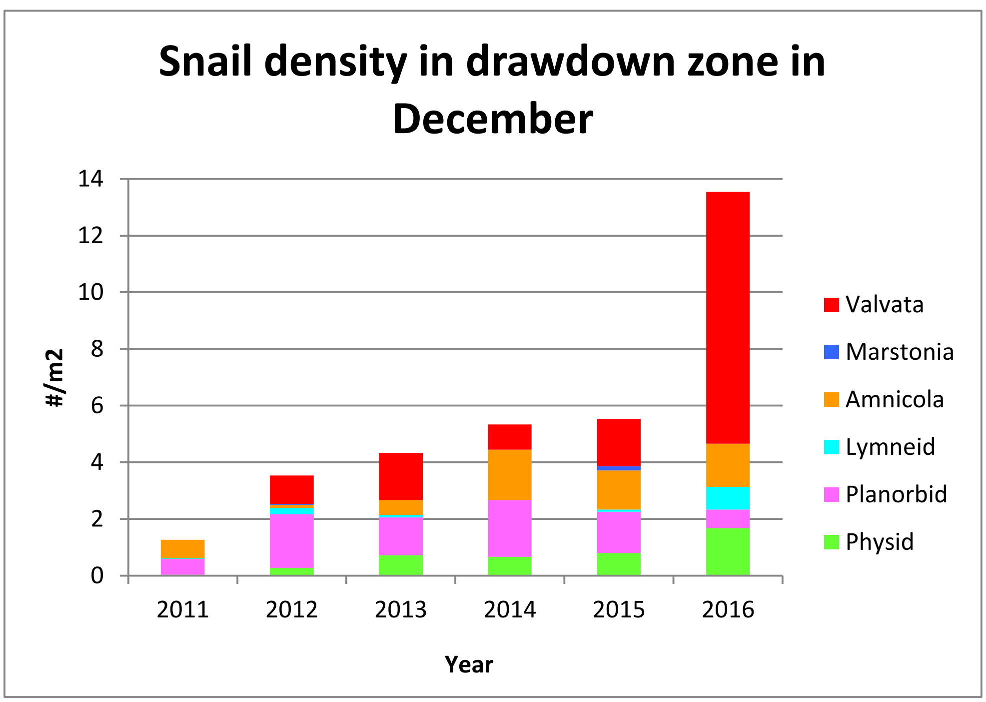

Figure 4S-4. December dead snail abundance in the drawdown zone of Laurel Lake

4.2 Drawdown

Fish

The GEIR outlined some ways in which fish populations could be benefitted or harmed by drawdown. Drawdown was partly developed as a fishery management technique, allowing better access to prey populations by gamefish species during a winter period of concentration. Movement of fine sediment into deeper water can improve egg survival in the spawning areas used by centrarchids (e.g., bass and sunfish). A reduction in vegetative density in many lakes can be considered a habitat enhancement for at least some fish species. However, the actual loss of lake volume limits winter habitat, there is potential for the smaller water volume to experience lower oxygen levels, limitation on spawning area access could be detrimental, loss of some possible food resources in the drawdown zone may limit fish food the following spring, and lower plant density may constitute habitat impairment for some species of fish. The combination of factors influencing the fish community is complex and sorting out the impact of repeated winter drawdown has been a challenge. The recent research program by Carmignani and colleagues at UMASS was a welcome addition in its stated goals.

Carmignani and Roy (2017) reviewed literature on drawdown impacts and discussed the mechanisms by which the fish community may be affected. While fish are less directly impacted by drawdown, factors of decreased food resources and limited access to desirable spawning habitat are the primary modes of indirect impact based on a literature review that included a wide range of drawdown scenarios, many more severe than applied in Massachusetts. Areas of needed study were laid out, addressing bigger picture issues that may require longer term study. Yet the uncertainty and variability of drawdown impacts on fish was clear in this paper, which is the peer reviewed version of the first chapter of the thesis (Carmignani 2020). From this paper and work plans from the research group, it was expected that fishery impacts of drawdown would be emphasized in the completed program.

During the 2015-2018 period of study, fish surveys were performed on most of the study lakes and an analysis of fish community features was undertaken relative to possible influence of drawdown. Aside from fish population assessments, fish tissues were sampled to facilitate an assessment of carbon sources for fish, allowing evaluation of any shifts in food resources in drawdown lakes. Progress was reported at several conferences and in DFW (a sponsor of the research) progress reports. For example, the Michigan Shoreline Partners website has a copy of an undated presentation detailing the UMASS work that includes fish impact assessment (https://www.mishorelinepartnership.org/uploads/4/6/8/6/46869113/drawdowns_carmignani.pdf) A presentation at the 2018 American Fishery Society conference in Atlantic City, NJ by Carmignani was entitled "Do annual winter drawdowns alter trophic pathways for common lake fish species?" From the presentation it was clear that drawdowns could alter fish feeding and energetics, and thereby affect fish populations and lake ecology overall, but that no such impacts were detected at statistically significant levels in the Massachusetts lakes studied. Given the lack of a significant decrease in benthic macroinvertebrate availability in the drawdown zone (see invertebrate impact section), this may partly explain the lack of fish impact, but there have been shifts in the types of invertebrates that may affect fish diet and growth. The presence of young-of-the-year in fish surveys suggests that spawning has been successful in the drawdown lakes, but more and longer term data would be needed to evaluate impacts more subtle than complete failure of spawning.

The Carmignani (2020) thesis contains none of the fish data generated for drawdown lakes in Massachusetts and provides no analysis of the research team's effort to evaluate drawdown impacts on fish. The conclusion of the thesis reiterates the plausible impact mechanisms on fish feeding and spawning, but states that these "were not addressed in this project." The thesis and various publications and presentations that came out of it note the lake-specific nature of drawdown impacts, citing the interaction of the magnitude of drawdown with the bathymetry, sediment features, and biological resources of each lake as a key influence, and this seems to be a justifiable conclusion. Massachusetts study lakes are at the low end of the scale for possible drawdown magnitude, with an average of 2.2 feet. Only 3 lakes of the Massachusetts study lakes are subject to drawdown >5 feet on an annual basis (Otis Reservoir, Lake Garfield and Goose Pond), and all 3 are popular fishing lakes with substantial populations of gamefish based on the available survey data and personal experience of the author of this document. While a lack of documented impact on fish communities in drawdown lakes cannot be taken as reliable evidence of no impact, any assumption of impact without supporting data is unjustified.

Reptiles and Amphibians

The GEIR addressed possible impacts to reptiles and amphibians, but there is considerable uncertainty surrounding such impacts. The policy for when to initiate drawdowns in Massachusetts has changed several times in the last 40 years, with impacts to reptiles and amphibians as one of the factors considered. Current thinking is that drawdowns should not begin until hibernating organisms have settled in for the winter, typically sometime in late September through October, dependent on temperature, leading to a recommended November 1st start of drawdown. In the 1980s the policy was to start drawdown in early September and reach the target depth by mid-October, allowing hibernating animals to seek appropriate overwintering areas. There is logic in both approaches but neither seems completely sufficient by itself.

Different aquatic organisms seek different conditions for overwintering and the magnitude of the drawdown and how long such a drawdown has been in place are likely to matter. For aquatic organisms that burrow into soft sediment, they will most likely move into a deeper zone than will be impacted by a drawdown that has been conducted for many years, as the drawdown zone will have coarser sediment. This may not be true, however, where the lake bottom slope is very slight and there are still substantial soft sediment deposits in shallow water. Few organisms would be expected to burrow near the edge of the lake, given natural water level fluctuations and ice formation, so drawdowns of a foot or two are not likely to expose hibernation areas. Yet some turtles are known to seek undercut banks and may be completely exposed by even a small drawdown. There is simply too much variability to make blanket statements about drawdown impact on reptiles and amphibians and any policy tied to calendar dates for starting drawdown or achieving the target depth of drawdown is not likely to work for all Massachusetts lakes.

There are relatively few monitoring programs that have been set up to evaluate impacts of drawdowns on reptiles and amphibians. An approach whereby frog counts could be made along shoreline sections was developed in concert with NHESP in preparation for a deeper drawdown of Stockbridge Bowl, but that drawdown was never conducted. Frog and turtle counts at Bare Hill Pond over a decade of drawdown assessments have detected no changes in populations (ARC 2019). Less quantitative observations at Indian Lake (Becket), Goose Pond (Lee/Tyringham), Otis Woodland Lake (Otis), Laurel Lake (Lee/Lenox), Lake Garfield (Monterey), and Stockbridge

Bowl (Stockbridge/Lenox) have not suggested any loss of reptile or amphibian populations. Lack of an obvious decline in populations is not evidence of a lack of impact, but it is clear that drawdowns do not wipe out reptile and amphibian populations. The often-cited study of Lake Bomoseen in Vermont (VANR 1990), where major changes to multiple components of the aquatic ecosystem were attributed to drawdown, involved a single winter of drawdown and a single year of assessment with confounding influences that were not properly factored into the analysis. It is fair to say that drawdown is unlikely to benefit reptiles or amphibians, as the changes in substrate and plant community achieved by drawdown are not clearly beneficial to these animals and there is potential for direct and indirect adverse impact. But there do not appear to be any reliable studies of impacts in Massachusetts lakes that justify an assumption of significant negative impacts by drawdown on reptiles and amphibians.

Water dependent birds

For the most part, water-dependent birds (e.g., wading birds, ducks, geese, osprey, kingfishers, loons) will have left the area by the time most drawdowns are initiated (rarely before mid-October under permits currently granted in Massachusetts). Overwintering birds that fish and hunt at lakes (e.g., eagles, owls) may actually benefit by drawdowns that expose possible food items, and there is no clear detrimental aspect of drawdown for these birds. It is not clear that the spring refill period holds any particular benefits or disadvantages for water dependent birds. Lakes subject to drawdown typically reach full status in March or April and returning migratory birds may arrive before refill is complete, but the lake status at that time does not seem to have a strong effect on feeding or breeding. Coarsening of substrate and reduction in plant density may influence hunting by wading birds, but the lack of demonstrated impact on non-mollusk invertebrate (see invertebrate impact section) and fish (see fish impact section) abundance does not suggest obvious influence on food supply. Observations at drawdown lakes have revealed a full complement of water dependent birds during summer, although quantitative studies are lacking.

Other water dependent wildlife

Beaver, muskrat, otter and mink are among the water dependent wildlife found at many Massachusetts lakes. Otter and mink do not live in the lakes themselves, and while access and hunting could be impacted by drawdown over the winter, it is not clear that a lake at a lower water level presents any significant challenges to those wildlife. Fish-eating wildlife may be benefitted by the concentration of fish into a smaller volume of lake water, much as gamefish are benefitted by baitfish concentration through drawdown (Baker et al. 1993). Many forms of wildlife may benefit from exposed food items during the early stage of drawdown and there are many anecdotal accounts of muskrat, raccoon, and other wildlife scavenging in the drawdown zone during fall.

Beaver and muskrat live in the lake and lowered water level may expose entryways or limit access from the lodge/burrow to open water. There has been no quantitative study of the impact of drawdown on beaver or muskrat in Massachusetts, and most drawdown lakes in at least western Massachusetts host populations of each, but anecdotally it does appear that at least beaver populations may be limited by drawdown. Congamond Lake in Southwick and the ponds in the Sherwood Greens development in Becket, none subjected to drawdown, have many beaver lodges and a high level of beaver activity as evidenced by downed trees around these lakes. Indian Lake in Becket, Otis Reservoir in Otis and Tolland, Lake Garfield in Monterey, and Goose Pond in Lee and Tyringham, with drawdowns of at least 4 feet, have few beaver lodges, although at least one can be found in each drawdown lake in any given year.

Smith and Peterson (1991) studied beavers in lakes with and without drawdown. They found that winter use of lodges and feeding behavior was altered for beavers in drawdown lakes, and that beavers in drawdown lakes entered the spring ice-out period in poorer physical condition than beavers from lakes without drawdown, but that beavers from drawdown lakes survived. It was recommended that the maximum water level fluctuation not be more than 5 feet (only 3 lakes in the Massachusetts study set exceed that level) and that drawdowns of up to 2.3 feet (slightly larger than the average for Massachusetts study lakes) were not problematic.

The impacts of drawdown on water dependent wildlife are therefore variable and dependent on the magnitude of drawdown and lake-specific factors, much as suggested by Carmignani (2020) for components of aquatic systems studied in that research effort. There is no evidence of population extirpation, but neither is there indication of significant benefits of drawdown to wildlife.

Downstream flows

The GEIR discussed potential impacts of drawdown on downstream flow, but research and regulatory interest in hydrologic impacts of lakes overall and drawdown in particular increased markedly since the GEIR was developed. Our understanding of the natural flow regime and its role in structuring and maintaining aquatic communities in flow water habitats has been greatly expanded over the last two decades, starting with some seminal concept works (Poff et al. 1997, Richter et al. 1997, Annear et al. 2004) and progressing through state level applications (e.g., Armstrong et al. 2004 for southern New England). As these insights have made their way into state policies, instream flow considerations for habitat maintenance have been given greater weight. However, the permit system is not well suited to addressing these needs, especially where power-producing facilities operate (often with 50-year permits), and the very existence of dams that increase lake area disrupts downstream flows in often significant ways. Those dams would be unlikely to be permitted today if construction was proposed, but their existence for decades or even centuries and their role in creating lake area that is highly valued sets up conflicts not easily resolved.

More than half the lake area in Massachusetts exists because of dam construction, equating to more than two thirds the lake volume in the Commonwealth, based on an analysis conducted by ENSR Corporation staff in the 1990s that was never published anywhere. While one can quibble over the exact amounts, the vast majority of lakes have been created or expanded by dams, such that much of the lake habitat did not exist prior to human intervention. This created lake area provides a wide variety of human and ecological services (e.g., recreation, power, flood control, fish habitat) and has real value in terms of real estate and related taxes. Created lake area is subject to natural processes but is not truly “natural” in origin. Where dams do not impound large areas or are not integral to maintaining a lake of perceived value, there have been efforts to remove those dams and multiple stream restoration projects have been conducted in Massachusetts. This advances restoration of the natural flow regime and allows greater movement of aquatic organisms, including migratory fish like eels and herring. But where dams have enlarged lakes with obvious societal value, the flow regime would appear to be forever altered.

Impounding water creates additional water holding capacity during high flows, even if the water level is not manipulated, increases losses due to evaporation from the larger surface area, raises the water level above the natural groundwater table under the surrounding land, and generally moderates downstream flows. The flow regime downstream of a lake with a dam may bear some resemblance to the natural regime prior to dam construction, but it will generally be shifted toward lower peak and low flows. Additionally, alteration of watersheds by humans have changed the drainage characteristics and flow regimes have been substantially altered even where no dams exist. Achieving a truly natural flow regime is an elusive goal, and the role of dams in flood prevention should not be undervalued where watersheds have been developed into residential areas.

Adding drawdown into the mix, water is released during autumn to lower the water level and held in the spring to refill the lake. If the lake volume to be discharged or replenished is small relative to watershed flows, this may not represent a major shift in the flow regime. Otis Woodland Lake in Otis has a drawdown of up to 2.5 feet over an area of 25 acres (almost 60 ac-ft of volume), but drains a 1200-acre watershed with an average flow of about 3 cfs and a range of about 0.1 to 50 cfs. Drawdown occurring throughout the month of November requires an extra 1 cfs of discharge. Refill in spring can be accomplished in <15 days while still allowing plenty of flow to pass downstream. The lake is a small feature in a large watershed (48 times the lake area) and drawdown represents a minor disruption to the natural flow regime.

In comparison, drawdown of Otis Reservoir, also in Otis, involves lowering a 1041-acre lake by over 8 feet (over 7000 ac-ft). The 8814-acre watershed supplies an average flow of about 20 cfs. Conducted from mid-October through late April, this drawdown requires an additional 80 cfs of discharge during that active drawdown phase. As the natural flow in the downstream channel, a tributary to the Farmington River, would be <20 cfs at the time of the drawdown, this is a major increase in flow for about 6 weeks. Such a flow might occur for a few days at this time of year in natural response to a major storm in the absence of the dam and reservoir, but not for 6 weeks. Spring refill is initiated in February and takes >100 days in most years. Outflow is much lower than would be the case if the dam and reservoir did not exist and refill lasts through May or even longer in some years. Otis Reservoir represents a large feature in a relatively small watershed (<9 times the lake area) and the disruption to the flow regime of the connector channel to the Farmington River is substantial.

Each case will be different, but where the alteration of the downstream flow regime is large, the potential for impacts should be considered. If there are state listed species present downstream within the zone of influence, the NHESP will be involved in any permitting decision and the drawdown may not be allowed if there are significant impacts to those listed species. Downstream flooding should not be allowed to conduct a drawdown, so the capacity of the downstream flow channel and any associated structures (e.g., bridges) or sensitive erosion areas must be considered. Just how much impact can be allowed to biological resources not afforded any special protection under the law is unclear, however, and current drawdown guidance does not promote a level of creative management that could minimize impacts. Restricting drawdown to the month of November and setting flow limits based on watershed area are two examples of guidance that needs to change to optimize drawdown results and minimize impacts.

Flushing flows are desirable in a stream environment, but those flows normally occur in the spring and aquatic organisms have evolved to have reproductive, growth, and activity patterns keyed to the seasons. Suddenly changing the flow regime may indeed be detrimental, but the level of change that is tolerable has not been well defined. The RVA analysis promoted by Richter et al. (1997) suggests that changes of 40% or more in any of the major characteristics of the flow regime (magnitude, timing, duration, frequency, rate of change) will have adverse impacts, but these have not been conclusively linked to biological responses. Smaller changes do not appear to have much impact, but on a case by case basis there could be exceptions.

Lakes subject to drawdown nearly all have dams and operable outlet structures (rare drawdowns by pumping or siphon are the exceptions) that have already altered the downstream flow regime to some extent. The conduct of a drawdown further alters the flow regime, and in cases where the volume of water involved is large relative to the average watershed yield, the changes can be rather extreme. Whether or not this constitutes an unacceptable impact on the downstream environment may require case by case evaluation. Assumptions of impact are not justified without at least an examination of the magnitude of flow change involved, as with Otis Woodland Lake and Otis Reservoir above. Comparing the biota of a stream subject to flow regime changes from drawdown to a reference stream below a lake not subject to drawdown would be a reasonable approach to assessing impact. Comparing flows below a drawdown lake to those from unregulated, closest-to-natural streams, as has been suggested in some permitting cases, is not appropriate.

4.2.4 Impacts to Water Quality

The GEIR adequately covered the possible water quality changes relating to drawdown. The primary possible negative consequences include increased turbidity from either resuspended sediment or nutrient increases that support additional algae growth and lower oxygen under the ice during drawdown. Neither of these potential impacts has been observed based on monitoring since the GEIR was produced. Assessment of Bare Hill Pond over two decades of drawdown (ARC 2019) suggests some improvement in water quality, possibly related to fall discharge of accumulated nutrients in the water column, but no significant changes in key features such as phosphorus and water clarity were detected. No deterioration of water quality has been observed in Goose Pond or Laurel Lake (WRS 2016, 2017b). Lake Garfield has shown signs of developing cyanobacteria blooms in the deepest part of the lake (WRS 2018), but any connection to drawdown is unclear. Otis Woodlands Lake has had relatively stable water quality for almost 30 years, with just one period of several years of water quality issues relating to upstream collapse of a beaver dam and a major influx of sediment into the lake that resulted in a dredging project. The drawdown was not to blame, and drawdown capability was critical to conducting the restoration program. Water quality changes in Nabnasset Lake are not substantial overall (ESS 2017, Table 4S-2), but where there have been changes they do not appear to link to drawdown in any apparent way.

Phosphorus and nitrogen released from sediment during summer cause the concentrations of these nutrients to rise substantially in many lakes, leading to late summer and early autumn peaks in nutrient levels and algae. The movement of accumulated nutrients and algae out of a lake with fall drawdown appears to improve lake water quality and may, over years, reduce the internal reserves of nutrients and more permanently enhance water quality. This process has been suggested for

Bare Hill Pond above and documented for Neponset Reservoir (ENSR 2008), but this is a slow process and the discharge of water with elevated nutrient concentrations has ramifications for downstream resources that warrant consideration.

Where inflows are small relative to lake volume and that volume is reduced by drawdown, ongoing oxygen consumption by decay of organic matter under the ice can substantially lower oxygen concentration and lead to fish kills (Cooke et al. 2005). Such occurrences appear rare in Massachusetts, based on fish kill reports on file with the MA DFW. Decreased detention time in response to lower lake volume and colder water temperatures are expected to counter the potentially elevated impact of sediment oxygen demand on a smaller lake volume. Winter monitoring of drawdown lakes has become uncommon in Massachusetts, but the limited data available do not suggest widespread anoxia that would cause significant impacts.

Measurements in Indian Lake in Becket and related calculations of expectations for winter dissolved oxygen (WRS 2017a) illustrate the limited likelihood of an oxygen problem in Massachusetts lakes. Indian Lake has a 4-foot drawdown that represents a loss of more than half the lake volume while exposing 16% of the lake bottom. The watershed is about 14 times the lake area, providing a low to moderate flushing rate. The potential for low oxygen during winter is higher for Indian Lake than for many other drawdown lakes in Massachusetts.

With ice cover there is no atmospheric reaeration of the lake during winter, so the amount of available oxygen is the starting amount at the time of freezing plus whatever enters with inflow. With the winter volume of Indian Lake replaced once by ongoing inflow over 3 months, the quantity of oxygen available would be that contained in about twice the volume of the winter pool. At a winter water temperature of 4-5 C, oxygen concentration will be about 13 mg/L at saturation. At an average of 90% oxygen saturation for water in the lake at the time of freezing and water entering during winter, for a minimum 7.2 million cubic feet of pool, that represents over 4800 kg of oxygen. At an oxygen demand of 100 mg/m^2/day (a typical value for winter) over 3 months of ice cover over 50 acres of pool area, total demand would be 1820 kg. This is enough to lower the oxygen concentration noticeably, but not enough to depress oxygen to the point where aquatic life would be threatened. Estimated late winter oxygen concentration is consistent with measured values in Indian Lake and no fishkills have been observed.

It would be reasonable to check late winter oxygen levels in drawdown lakes as a permit condition, but any assumption of impact is not justified by available data and calculations. The potential for an oxygen problem exists where there is a large portion of the lake bottom covered by organic sediment, the volume of the lake is greatly reduced, and inflows are low during ice cover. This is condition more typical of prairie pothole lakes and agricultural dugouts in central USA and Canada, where winter fishkills due to low oxygen have been reported (Cooke et al. 2005) and not indicative of conditions for most Massachusetts lakes subject to drawdown.

4.2.5 Applicability to Saltwater Ponds

The GEIR notes that drawdowns are generally not applicable or advisable for saltwater ponds as a function of lack of outlet controls and the potential to harm economically and ecologically valuable shellfish. However, breaching of barrier dams has been conducted on Cape Cod and the associated islands for the purpose of maintaining saltwater conditions where the ponds have been cut off from the ocean. Barrier beach breaching functionally causes drawdown. While these drawdowns have resulted in higher salinity and maintenance of saltwater conditions, the related flushing has not prevented algae blooms and the drawdown has not prevented nuisance plant growths (e.g., WRS 2017d). There has been a shift toward annual plant species that repopulate from seeds after being killed by incoming saltwater, and that trend may be augmented by drawdown effects. More saltwater algae, invertebrates and fish are found in these ponds, but cyanobacteria blooms also occur and greatly impair uses.

4.2.6 Implementation Guidance

4.2.6.1 Key Data Requirements

Key considerations for drawdown were provided in Table 4-3 of the GEIR. The listing below repeats those considerations with additional notes based on experience gained since the GEIR was produced.

Reasons for Drawdown

1. Access to structures for maintenance or construction – note that other permits may apply and that wherever possible structures such as docks should be removable to avoid the need for winter protection.
2. Access to sediments for removal (dredging) – additional permits apply, some difficult to obtain; be sure the dredging project can be permitted before working on drawdown permitting.
3. Flood control – a major late winter benefit, but minimally available in spring if refill date set as April 1, an arbitrary and often inappropriate date.
4. Prevention of ice damage to shoreline and structures – avoid vertical retaining walls that sustain more ice damage and reflect waves; use of rip-rap provides better habitat and less maintenance need. Maintain shoreline vegetation that provides roots that can stabilize soft shorelines. Yet recognize the power of moving ice and the ability to avoid bank damage through drawdown.
5. Sediment compaction – only if sediments dewater sufficiently, but coarsening of exposed sediments is expected where the slope is >1:10 through movement of finer sediments to deeper water.
6. Rooted plant control – for species that rely on vegetative forms to overwinter; will also reduce overall plant density in drawdown zone.
7. Fish reclamation – if the community is extremely out of balance and a management program exists; this is generally not currently practiced in MA and the MA DFW would prefer to avoid drawdowns where possible.

Necessary Drawdown Planning Information

1. Target level of drawdown – depth of water lost; very important to calculation of refill potential.
2. Pond bathymetry – detailed contours for calculation of exposed area; important to consider the amount of water that must be replaced in spring to gain the benefits to the exposed target area.

3. Area to be exposed – area of sediment at water depth < target depth, plus ice contact zone; consider reason for drawdown and how much the water needs to be lowered to achieve goals.
4. Volume to remain – quantity of water available for habitat and supply during drawdown; concentration of fish and other organisms may have positive and negative impacts.
5. Timing and frequency of drawdown – initiation/duration and whether annual or less frequent event; for coarser sediment and plant control, annual drawdown is almost essential. Not all winters will provide appropriate conditions and we have no way to reliably predict those conditions.
6. Outlet control features – method for controlling outflow; important to monitor outflow and adjust as needed.
7. Climatological data – frequency of sub-freezing weather, precipitation and snow cover data; winters are becoming warmer, but conditions for successful drawdown still occur in most years.
8. Normal range of outflow – maximum, minimum and average over expected time of drawdown; best to understand degree of pre-existing alteration of hydrologic regime and to stay within range of known flows when conducting drawdown and refill.
9. Outflow during drawdown and refill – provisions for downstream flow control (high and low); important to consider channel capacity and possible impacts to downstream resources. Altered flow regime unavoidable.
10. Time to drawdown or refill – rate of water level change, number of days to achieve target level; can be calculated without a lot of actual flow data, important to consider likely range of time needed. Guidance on start and end dates is largely arbitrary and needs reconsideration.

In-Lake and Downstream Water Quality

1. Possible change in nutrient levels – any expected increases due to oxidation of sediments; possible in early years of drawdown, not shown to be a long-term issue.
2. Possible change in oxygen levels – any expected increase through oxidation or decrease under ice; not shown to be a major factor in MA lakes.
3. Possible change in pH levels – any expected shift due to interactions with smaller volume; not known to be an issue in MA lakes.
4. Other water quality issues – any expected changes as a function of drawdown; possible reduction in nutrient reserves by repeated fall drawdown and discharge of high nutrient water, a slow process with possible downstream impacts.

Water Supply

1. Use of lake water as a supply – dependence on water availability and impact of drawdown; likely to limit drawdown depth where supply has higher priority than other uses.
2. Presence/depths of supply wells – potential for supply impairment; has been an issue in a few cases, need to understand well situation within about 300 feet of lake.
3. Alternative water supplies – options for supplying water to impacted parties.
4. Emergency response system – ability to detect and address supply problems during drawdown; need designated contact person with direct line of communication.
5. Downstream flow restrictions – maintenance of appropriate flows for downstream habitat and uses; instream flow needs should be considered, but it may be very difficult to mimic natural flow regime.

Sediments

1. Particle size distribution (or general sediment type) – dewatering potential; will affect plant control.
2. Solids and organic content – dewatering potential, nutrient content; has not been shown to have major impact on water quality but possible.

3. Potential for sloughing – potential for coarse sediment to be exposed in drawdown zone; a generally desirable consequence of drawdown, appears linked to slopes of >1:10.
4. Potential for shoreline erosion – threat of erosive impacts to bank resources; has not generally been an issue. Lack of drawdown has tended to promote ice damage and related erosion.
5. Potential for dewatering and compaction – possibility of sediment alteration and depth increase; loss of finer sediment to deeper water found to be more important than compaction.
6. Potential for odors – emissions from exposed area; not typically a reported issue for winter drawdown.
7. Access and safety considerations – issues for use of lake during drawdown; can be a problem until any soft sediment freezes. May need to control access points and/or provide walkways.

Flood Control

1. Anticipated storage needs – ability to meet needs with target drawdown; needed capacity is calculable and use of 10-year storm is a reasonable starting point.
2. Flood storage gained – volume available to hold incoming runoff; runoff volumes associated with design storms have been increasing with climate change; margin of safety needed.
3. Effects on peak flows – dampening effect on downstream velocities and discharge; can be achieved with limited additional capacity, but be aware of need for downstream flushing flows, preferably in spring.

Protected Species

1. Presence of protected species – NHESP designated species may require special protection; pre-permitting input essential.
2. Potential for impact – assessment of possible damage to protected populations; NHESP has generally adhered to 3-foot drawdown guideline as acceptable without more study but will review each case.
3. Possible mitigative measures – options for avoiding adverse impacts; creativity has not been fostered by permit process.

In-lake Vegetation

1. Composition of plant community – details of species present and susceptibility to drawdown; see Table 4S-1 and consider what future plant community will look like in the drawdown zone. Note that where nuisance species thrive in water beyond drawdown zone, recolonization may be expected.
2. Areal distribution of plants – mapping of plant locations relative to drawdown impact zone
3. Plant density – quantity of plants present vs. expected reduction in density after drawdown and range of likely conditions with weather variation.
4. Seed-bearing vs. vegetative propagation – drawdown will only control vegetative propagators but will reduce overall density in most cases.

5. Impacts to target and non-target species – analysis of which species will be impacted; see Table 4S-1 but recognize variability based on multiple factors.

Vegetation of Connected Wetlands

1. Composition of plant community – details of species present and susceptibility to drawdown; has not been generally shown to be an issue in MA.
2. Areal distribution of plants – mapping of plant locations relative to drawdown impact zone; has not been generally shown to be an issue in MA.
3. Plant density – quantity of plants present; has not been generally shown to be an issue in MA.
4. Temporal dormancy of key species – potential for seasonal impacts; has not been generally shown to be an issue in MA.
5. Anticipated impacts – analysis of likely effects of drawdown; has not been generally shown to be an issue in MA.
6. Species invasions – invasive species such as *Phragmites* and *Lythrum* have appeared in contiguous wetlands after initiation of drawdown. Link uncertain, best to carefully document plant community of connected wetlands before drawdown initiation.

Macroinvertebrates, Fish and Wildlife

1. Composition of fauna – types of animals present; will get some shifts due to drawdown, but no major loss of abundance documented.
2. Association with areas to be exposed – when and how drawdown zone is used on a regular basis; consider shifts as a function of gradual sediment changes.
3. Breeding and feeding considerations – use of drawdown for breeding or food on intermittent basis; spring access to spawning areas most important but not tied to April 1 target date; temperature is key variable that should be considered.
4. Expected effects on target and non-target species – analysis of likely faunal impacts; can control zebra mussels but will kill other mussels and some snails as well. Recolonization from deeper water populations expected; may need to survey distribution. Impacts on fish not demonstrated to date. Non-lethal impact to beaver and muskrat condition expected.

Downstream Resources

1. Erosion or flooding potential – susceptibility to impacts from varying flow; survey recommended before and after drawdown.
2. Possible habitat alterations – potential for impacts; flow regime will be altered, some impact expected.
3. Water quality impacts – potential for alteration; nutrients and solids content may be elevated by drawdown but no documented impacts.
4. Direct biotic impacts – possible scour or low flow effects on biota; possible during drawdown and refill.
5. Recreational impacts – effects on downstream recreational uses.
6. Supply impacts – effects on downstream supply uses.

Access to the Pond

1. Alteration of normal accessibility – issues for seasonal use of pond by humans and wildlife; soft sediment expanses a possible issue until deeper freeze sets in.

2. Possible mitigation measures – options for minimizing impacts; boards, mats or other walkways at public access points.

Associated Costs

1. Structural alteration to facilitate drawdown by gravity – expense for any needed changes to outlet; where operable structure exists, drawdown is inexpensive.
2. Pumping or alternative technology – operational expense for pumped or siphoned outflow; costs can be substantial, need to consider benefit gained for drawdown vs alternative measures.
3. Monitoring program – cost of adequate tracking of drawdown and assessment of impacts should be allocated; water level monitoring and biological surveys may be needed, but needs are case-specific and there is no appropriate one-size-fits-all program.

Other Mitigating Factors

1. Monitoring program elements – may be very lake specific and vary over years; most critical needs are compliance with drawdown and refill targets, compliance with any downstream flow requirements, drawdown zone substrate and plant features, and distribution of mussels in lake.
2. Watershed management needs – additional actions beyond drawdown may be warranted but are not tightly linked to reasons for drawdown in most cases; permitting agencies should avoid imposing conditions not relevant to purpose of drawdown.
3. Ancillary project plans (dredging, shoreline stabilization) – additional actions may require separate planning and permitting. Note that structure maintenance, sediment removal, and clearing of woody debris are not necessarily part of a drawdown permit and allowable activities should be specified in the permit.

4.2.6.2 Factors that Favor this Approach

The GEIR listed the following considerations as indicative of appropriate application of drawdown for the control of plants in lakes. They are repeated here with notes based on experience since the development of the GEIR.

1. The lake periphery is dominated by undesirable species that are susceptible to drying and freezing. Overall plant density will also be reduced over time as the sediment in the drawdown zone coarsens, but this can take a decade or more.
2. Drawdown can be achieved by gravity outflow via an existing outlet structure, or such a structure can be established for a reasonable cost. Where a structure exists, the corresponding portion of the lake was artificially created at some point and some consideration of the need to manage the created lake habitat is warranted.
3. Drawdown can reach a depth that impacts enough of the targeted plants to detectably improve recreation (e.g., allow more access, increase safety) and enhance habitat (provide nearshore open water, reduce density of invasive species of limited habitat value). It is rare that the entire target population of a nuisance plant can be controlled by drawdown and recolonization may occur; that does not negate the value of annual control in the drawdown zone but does indicate the continued annual need for drawdown.
4. Areas to be exposed have sediments and slopes that facilitate proper draining and freezing. Areas with a slope of at least 1 foot of depth gained for each 10 feet of lateral distance from shore are good candidates for sediment coarsening by drawdown and are likely to respond well in terms of target plant control.

5. Drawdown and refill can be accomplished within a few weeks under typical flow conditions and without causing downstream flows outside the natural range. This condition is largely a function of the relative size of the watershed and lake. Where the watershed is large relative to the lake (area ratio of >25:1), rapid refill will be facilitated but maintaining the drawdown may be challenging during storms. Where the watershed to lake area ratio is smaller (<10:1), drawdown should be relatively easy to accomplish but refill may require an extended time period.
6. Drawdown can be timed to avoid key migration and spawning periods for non-target organisms. Fall drawdown beginning after about mid-October and refill that is complete by early April should generally avoid impacts, but the dates are approximate and vary with temperature and lake biota; flexibility in drawdown and refill dates is needed for best results.
7. Populations of mollusks or other nearshore-dwelling organisms of limited mobility are not significant. Lakewide impact on such populations have not been documented in MA but the potential for impact exists; survey of potentially sensitive organisms, most notably mussels, is advisable over the entire depth of the lake to assess distribution.
8. The lake is not used for water supply, and nearby wells are deep. Drawdowns of a few feet are not likely to create problems for properly installed modern wells or intakes, but problems with older shallow wells are possible.
9. Flood storage capacity generated by drawdown prevents downstream flood impacts. The flood control function of lakes in general and drawdowns specifically has very real value. Consideration of timing for drawdown and refill is warranted, especially where more than one lake in the same river basin is subject to drawdown.

4.2.6.3 Performance Guidelines

The GEIR offered guidelines in the areas of planning and implementation, monitoring and maintenance, and mitigation. Issues have arisen with these guidelines, mostly relating to the convenience of a single number or date that is not really applicable across the Commonwealth or within a lake among years. Drawdown is largely a weather-dependent technique. We cannot accurately predict the weather even a few days ahead of time and the variation among years is great enough to affect drawdown performance. If there was a low cost, reliable, easily permitted method for rooted plant control around the entire lake, drawdown would be less practiced. The only practical option for a similar level of plant control is herbicides, which are not necessarily inexpensive, are not reliable for all target species, and are difficult to permit in many towns. The main substitute for shoreline protection is armoring or “soft engineering”, both with advantages and drawbacks and neither inexpensive. The only substitute for changing the nearshore sediment composition is dredging, which is very expensive and difficult to permit. There is no substitute for flood control within the lake, although detention facilities could be constructed upstream at great cost. Drawdown offers an economical means to accomplish multiple goals with a single technique.

Flexibility is needed for best results and should include variation in starting and ending dates to adjust to weather and related hydrologic factors. As one cannot predict the weather for a coming winter with an adequate degree of reliability, drawdown must be started each year to get maximum benefit but may be terminated either after a month of desirable conditions (cold and dry) or when it is apparent that such conditions are unlikely to be achieved in the available time before refill should commence. Guidelines for minimizing undesirable impacts were outlined in the GEIR and are repeated here with a critique of each and any suggested changes.

1. Limit drawdown to 3 feet.
   Based on all available data, this is a reasonable limit before additional review is applied. The water level in Massachusetts lakes does not usually decline to >2 feet below normal full pool, but natural drawdowns to at least 2 feet can be expected, usually during summer. Reducing the water level to the limit of natural drawdown on an annual basis will reinforce the characteristics fostered by the natural lower water level but should not have major adverse impacts lakewide. All data from monitoring programs for drawdown lakes and the recent UMASS thesis on the topic (Carmignani 2020) suggest no significant impacts of drawdowns up to at least 3 feet. From Carmignani (2020) the average drawdown depth is about 2.2 feet, exposing 12.7% of the lake bottom and 25.8% of the littoral (plant growth) zone. Only 4 of 18 study lakes have drawdowns >3 feet. Larger drawdowns may be warranted but the application of further review is reasonable beyond the 3-foot limit.

2. Commence drawdown after the beginning of November.
   A date of November 1 makes compliance monitoring easy, but its scientific basis does not account for variation between lakes or years. The intent is to allow hibernating organisms to settle in for the winter, allow migratory birds to move on, and to let fall mixing occur before sending more water downstream at a potentially warmer temperature. The theory is appropriate, but important details are lost for the convenience of a single date. The presumed target conditions are mostly keyed to temperature, with a value between 15 and 18 C (60-65 F) representing achievement of desired conditions. This may happen well before November 1 or slightly after in any given year. Deeper lakes will hold heat longer and turn over later than shallow lakes. As a guideline, it may be adequate, but there are reasons to allow drawdowns to start earlier or later, including multiple drawdowns in a river basin (where coincident drawdown may cause flooding), a cooler or warmer fall, and fall spawning fish (whose eggs may be exposed if the drawdown starts after eggs are laid but before the fry hatch). Each case can be different and permitting agencies should be open to science-based deviation from a standardized starting date for drawdown.

3. Achieve the target drawdown depth by the beginning of December.
   If a drawdown of up to 3 feet is initiated at the start of November it should be possible to reach the target drawdown depth by December 1 at a rate not in excess of 3 inches per day (30 days at 3 inches per day = 7.5 feet). Even with a few storms during November it should be workable, but where the watershed is large relative to the lake and the outlet does not pass high flows, it is possible that the lake will refill at times during November and the target depth will not be reached by December 1. For a larger drawdown, the probability of not being able to achieve the target depth by December 1 increases. With another guideline of no more than 3 inches per day of water level decline and outlets with finite capacity to pass water, the probability of failing to meet the target drawdown in November increases further. But there is nothing magical about December 1st as a target date. If there are late fall spawning fish in the lake, the December 1st target date could minimize the chance that eggs will be exposed by further lowering in December, but the presence of such spawners and their use of shallow water to spawn is not a given. The date for achieving the target drawdown depth should be set on a lake

by lake basis, allowing for consideration of all factors, including migration times, turnover dates, fish spawning, and coordination with other drawdowns discharging to the same river. It may be reasonable to continue active drawdown through much of December, although the target of December 1 is advantageous in that the coldest temperatures without snow cover typically occur in December and drawdown may be most effective in that month.

4. Lower the water level by no more than 3 inches per day.
   This guideline has two consequences: it allows more time for organisms to move into deeper water and limits the amount of water passing downstream on any given day. Both are reasonable goals, but it is not clear that these guidelines are appropriately protective. The Carmignani (2020) study placed water level sensors in 18 drawdown lakes and found that while the average rate of drawdown was in compliance in all cases, only 2 of 18 lakes did not exceed the 3 inch/day limit on at least one day. Managing outlets can be challenging, with wide swings in flow possible when a single flashboard is pulled and frequent adjustment of subsurface pipe valves necessary to keep outflow near constant. Despite the exceedance of the drawdown rate in 89% of the study lakes, minimal adverse impacts on biota were found. Mussels tend to burrow rather than move toward deeper water or move randomly and not in the right direction, so mussel stranding is to be expected independent of the rate of drawdown. Stranded fish are uncommon and not likely to be a significant fraction of any population. Varying the outflow is more in keeping with the natural flow regime than holding it constant, although there is no way to claim that a fall drawdown is representative of the fall flow regime in any Massachusetts stream. The guidance is valid, but not an important point of compliance beyond the average over the period of active drawdown.

5. Keep outflow during drawdown below a discharge equivalent to 4 cfs per square mile of watershed.
   This guideline is based on the Aquatic Baseflow Policy, a national level directive intended mainly to keep key aspects of natural hydrology below power-producing dams. One of those key hydrologic factors is a flushing flow, intended to move fine sediment downstream and reset habitat features. These usually occur in spring, but may be beneficial in the fall as well, just not ideal in terms of aquatic organism evolution and ecology. However, the ABF rule is that a flow of at least 4 cfs per square mile of watershed be delivered. This was altered to be an upper limit on fall flows in association with drawdown, further minimizing its value and making some drawdowns difficult to achieve in a timely manner. Where the watershed to lake area ratio is small (<10:1), this guidance may not provide enough flow to achieve the drawdown target within the suggested month of November. Otis Reservoir, with an 8-foot drawdown target, must pass an average of 80 cfs above the background which is somewhere between 10 and 20 cfs in November. With a watershed of 13.8 square miles, the upper limit on flow based on this guidance would be 55 cfs. Otis Reservoir has an unusually large drawdown and a relatively small watershed, but many of the drawdown lakes in Massachusetts have difficulty adhering to the 4 cfs per square mile guideline. For some lakes with a large watershed to lake area ratio (>25:1), application of this guideline could result in extreme flows and rapid water level decline. Targeting an average 3-inch vertical water level decline per day is a better guideline and is more appropriately linked to impact minimization goals as long as the peak flow can be handled by the downstream channel.

6. Once the target water level is achieved, match outflow to inflow to the greatest extent possible, maintaining a stable water level.
   Maintaining a stable water level is desirable during winter, especially for lakes with recreation on the ice. This will mean managing outflow, however, and with varying inflows and finite outflow capacity through a pipe or over a narrow spillway where flashboards have been removed it may not be possible to match outflow to inflow. Lakes with larger watersheds may fill at least partway in response to storms even with all outlet boards removed and/or any gate valve wide open. Yet the guideline is sound as long as it is recognized that "to the greatest extent possible" has very real limits in many cases.

7. Keep outflow during refill above a discharge equivalent to 0.5 cfs per square mile of watershed.
   This is a reasonable guideline but may not be sufficiently protective in the spring and is really an approximate average based on Massachusetts flow regimes. The ABF noted in connection with the maximum outflow during drawdown also prescribes this minimum flow during low flow periods downstream of hydropower facilities. The 0.5 cfs per square mile value is an average from a distribution that ranges from about 0.2-0.3 cfs per square mile in lakes in watersheds with minimally pervious soils to 0.6-0.8 cfs per square mile in sandier soils (Kulik 1990). Using data for southern New England, Armstrong et al. (2004) found summer low flows ranging from 0.2 to 1.3 cfs per square mile, also along a gradient of soil permeability and therefore groundwater influence on maintenance of flows during hotter, drier periods. Watersheds in the Berkshires will likely have lower low flows than the 0.5 cfs per square mile release rate during refill dictates, but that release is occurring at a time when flows should be much higher. In some watersheds in the eastern part of Massachusetts, 0.5 cfs per square mile is less than would be expected even in summer. A case could be made for applying a region-specific minimum outflow, but in any case it will be much less than would be expected in the spring and there is no way to claim that management of drawdown or refill periods is not a measurable disruption of natural hydrology. Some amount of flow should be going downstream during refill and monitoring of downstream flows to ensure that the stream is at least wet is a reasonable condition of permitting.

8. Achieve full lake level by the beginning of April.
   Much like the November 1 and December 1 dates for start of drawdown and achievement of the target depth, the April 1 guideline provides a convenient means for compliance that is not properly linked to lake features or biological processes. The intention is to have the lake full before fish spawn, and most fish in Massachusetts lakes are spring spawners with spawning keyed mainly to temperature. Among the common fish in Massachusetts lakes, chain pickerel and yellow perch are among the earliest spawners at temperatures of 7-12 C (40-54 F) (Scott and Crossman 1973, Smith 1985), usually in April and May. But it is temperature that matters, not date, and spawning does not occur before ice out. Centrarchids (bass and sunfish) spawn later, with bass usually first at temperatures of 15-19 C (59-66 F, late April and May) and sunfish at 20-24 C (68-75 F, May into July). The important questions revolve around how full the lake needs to be to allow access to spawning areas and the suitability of spawning areas conditioned by drawdown.

   Esocids (pickerel family) can spawn in water as shallow as a foot, as can sunfish, while bass tend to be in slightly deeper water (2-5 feet) and perch prefer water deeper than 5 feet. Perch and pickerel prefer weedy habitat while bass and sunfish prefer clean sandy to gravelly substrate. There are other fish in most lakes, but these species represent a useful range when considering needed refill dates. The likelihood of negative impacts on bass and sunfish is minimal, but there is a risk to perch and more to pickerel if the water level precludes access to suitable habitat by the time the preferred water temperature is reached. The water level needs to be several feet deeper than the overwintering weed beds by the time perch spawn and needs to be high enough to allow access for pickerel into adjacent marshes where they tend to spawn. Pickerel are not expected to spawn around the typical margin of a lake even without drawdown, but with repeated drawdown that habitat will be unsuitable (coarser substrate). Areas that have low slope and retain their organic base and plant growths are preferred spawning areas and the lake may need to be close to full within a couple of weeks after ice out if pickerel is a target of management or regulation.

Many lakes in the Berkshires still have ice on them on April 1st. In 2016 and 2020 many lakes in other parts of Massachusetts had no ice in early March. The range is large and the goal of fishery management should be made clear where drawdown is being considered. The proper target for refill date would be best keyed to temperature, but it would be sufficient to set the refill target date as some number of days after ice out. Yet refill cannot be tightly controlled, being dependent on precipitation and snowmelt and subject to downstream flow requirements, so refill may need to start before ice out. A calculation of the mean and maximum time to refill based on watershed hydrology should be made and compared to ice out dates. Refill then should start at a time which offers a high probability of full status within a couple of weeks after ice out. The specifics can vary by lake and management objectives. While there will not be any easy way to guarantee compliance by this approach more than by setting the date at April 1, the refill target will be linked to key events like ice out and fish spawning. It makes no sense to attempt to completely refill a lake in need of flood control, shoreline protection, or structure protection before the ice goes out. But consistently late refill may damage certain fish populations. Again, a statement of goals that acknowledges all interests is needed in the planning process.

Additional guidelines based on experience since the GEIR was produced are offered.

9. Monitor water levels and/or downstream flows at a level commensurate with possible impacts and to inform adjustments to the drawdown program. Water level sensors as applied by Carmignani (2020) can be very useful, but simple gauge readings by volunteer are sufficient if done properly at a responsive frequency. Keep accurate records and summarize findings each year.

10. A basic water quality program should be in place for all managed lakes, probably standardized to some degree but with elements linked to specific management approaches. Late spring and late summer nutrient assessment at the top and bottom of the lake in the deepest area is recommended, and a temperature and dissolved oxygen profile at 1-2 m depth increments should be obtained at the same time. For drawdowns, it would be appropriate to perform this assessment once in late winter as well, just to document nutrient levels and any oxygen depression. Plankton assessment as fluorometric determination of chlorophyll-a is desirable, and possibly with a phycobilin sensor as well for possible cyanobacteria detection. Sampling of algae and zooplankton, while not essential and requiring more expertise, are also useful in

assessing overall lake condition. Occasional sampling for pH, alkalinity, and conductivity is also useful, but does not tend to change drastically over time in most lakes and does not have to be done as often as nutrients and the T/DO profile.

11. Fish surveys would be extremely useful at 5-year intervals, at least for lakes with clear fishery goals. There is entirely too much conjecture about fishery impacts of lake management for algae or plant control and particularly with regard to drawdown. The MA DFW is well equipped to do these surveys but is not adequately staffed and such surveys have not been established as a priority for several decades. Support of that agency through whatever channels necessary to allow a resumption of the surveys conducted from the 1960s into the 1980s, at least on Great Ponds with fishery management goals, should be offered. Conduct of a fish survey is beyond the realm of reasonable obligation for a lake association or town wishing to conduct a lake drawdown and should not be a condition imposed in permits without state support.

12. Where mollusks are present in a lake subject to drawdown, survey populations along transects over the complete range of depths. This could be a one-day survey and does not have to be overly complex. An underwater camera from a boat can facilitate collection of data that will allow estimation of mussel population status and evaluate the importance of losses in the drawdown zone. There is entirely too much speculation about impacts on mussel populations from inadequate data. There is no question that at least some mussels in the drawdown zone will be killed, but the fraction of the total population represented by those mussels is unknown and the annual repopulation of the drawdown zone suggests that there are more mussels in deeper water.

13. Plan for drawdown every year and permit it as an annual activity, particularly where flood control is a stated goal and while sediment coarsening in the drawdown zone is still underway, but be prepared to cancel or terminate drawdowns when conditions are not suitable, and reduce drawdowns permitted for >3 feet to 3 feet if the need is not evident. Weather prediction is not reliable enough to be used months ahead of time, but where monitoring indicates that drawdown is not likely to provide the desired benefits in any given year, adjust the program accordingly. Where drawdown indicates that target conditions have been satisfied, consider reducing the magnitude of drawdown as warranted. Build flexibility into permits to allow adaptive management and incorporation of new information as it becomes known.

4.2.7 Regulations

4.2.7.1 Applicable Statutes

The GEIR explains the permitting steps and these remain valid, but there are some changes. A Notice of Intent must be filed with the local conservation commission and the MA DEP under the Wetlands Protection Act and an Order of Conditions must be received to perform a drawdown, as before. One important change is that the regulations were revised in 2014 and limited project status is only accorded to projects that qualify as ecological restoration. If an invasive species is present, this option is available and may facilitate easier compliance with performance standards. Where drawdown is used control native species, limited project status is not available, and all performance standards must be met. This is not usually difficult to do, as the regulations allow for two growing seasons for recovery from any adverse impacts, and very few adverse impacts have been documented for drawdowns.

If a state listed species under the Massachusetts Endangered Species Act is present, the NHESP must approve of the project, and that approval must be in hand before the hearing under the Wetlands Protection Act is closed. Proof that the NHESP has been sent a copy of the NOI is needed for the MA DEP to issue a file number, also needed before a hearing can be closed.

If a NOI is submitted to the NHESP it will also be reviewed by staff of the MA DFW, but if there are no listed species and the drawdown is not >3 feet, no submission to MA DFW is necessary. If the proposed drawdown is >3 feet, MA DFW should receive a copy of the NOI for review.

Technically, drawdowns in Great Ponds (>10 acres in natural area, property of the Commonwealth) have always required a Chapter 91 Waterways License from a separate section of the MA DEP, but for many years drawdowns were not addressed by this program and potential applicants were told not to submit anything to the Chapter 91 office. This has changed in recent years and drawdowns of Great Ponds are now reviewed for Chapter 91 licenses. The primary thrust of this program is avoiding impediments to navigation and damage to structures in Great Ponds.

4.2.7.2 Impacts Specific to Wetlands Protection Act

The following overall impact classification was offered in the GEIR as a generalization of impacts from drawdown, with clarifying notes and caveats as warranted from more recent research and experience.

1. Protection of public and private water supply – Potential detriment if adequate water for supply is not maintained but can be neutral with proper management.
2. Protection of groundwater supply – Potential detriment if lowered lake level lowers the groundwater table but can be neutral if adequate groundwater level is maintained or there is no significant interaction. Note that with a dam present, the lake will be elevated above the normal groundwater table and the only threat would be to shallow wells installed after the dam was constructed.
3. Flood control – Benefit around the lake and downstream through increased flood storage potential.
4. Storm damage prevention – Benefit through increased flood storage potential, both around the lake and downstream. Some potential for perceived detriment as exposed areas may be subject to erosion by storms, but the coarsening of exposed sediment is perceived as a longer term benefit to multiple lake uses.
5. Prevention of pollution – May provide benefit through water quality enhancement when suspended solids and nutrients are removed from the lake or detriment through water quality deterioration downstream by those same outflows, but impacts have generally been limited or non-existent. Concern over lowered oxygen under the ice has generally proven unfounded in Massachusetts lakes but warrants monitoring. Prevention of ice damage to natural shorelines limits the amount of soil and associated nutrients entering the lake.

6. Protection of land containing shellfish – Detriment, as shellfish are potentially exposed, but impacts on entire populations are not evident. Habitat for some shellfish may be improved by sediment coarsening in the drawdown zone.
7. Protection of fisheries - Potential detriment by temporary habitat loss, potential benefit by habitat improvement; may have benefit and detriment to different species in the same lake from the same drawdown. However, no significant impacts have been demonstrated in Massachusetts studies to date. There is a possible detriment to downstream fish populations from high or low flows associated with drawdown and refill that may bear investigation in specific cases.
8. Protection of wildlife habitat - Potential detriment by temporary habitat loss, potential benefit by habitat improvement; may have benefit and detriment to different species in the same lake from the same drawdown. However, note that areas of organic sediment are not in short supply in most Massachusetts lakes and the coarsening of sediment in the drawdown zone represents an increase in habitat diversity. Increases in diversity of plants and invertebrates have been demonstrated and may lead to improved wildlife habitat. Beaver and muskrat may be adversely affected but not eliminated by drawdowns deeper than 5 feet. However, prevention of ice damage to shorelines preserves bank habitat that can be lost by disruption by shifting ice.

The general perception of drawdown impacts is that they are not significant for drawdowns up to 3 feet, which is at the deep end of natural water level fluctuations in Massachusetts lakes. For deeper drawdowns, there have been very few documented impacts that can be said to be detrimental on a lakewide basis, but a case by case analysis during the permitting process is appropriate.

4.2.8 Costs

The GEIR assessment of costs remains accurate. Drawdown is a relatively inexpensive lake management technique, if the means to conduct a drawdown are present. No capital costs are necessary under those circumstances and maintenance is not likely to average more than a few thousand dollars per year over the long term. Costs to obtain permits, open and close the discharge structure, and monitor would be considered operational and would not likely exceed a few thousand dollars per year on average. The relatively low cost for multiple benefits represents an attractive aspect of drawdown. If pumps are required to lower the water level, or an outlet structure must be built, the drawdown will be considerably more expensive, usually well in excess of $100,000 in capital cost.

4.2.9 Future Research Needs

This supplement has summarized a lot of new information about drawdown and generally reflects positively on the technique. While presentations by Carmignani have indicated no significant impacts on the fish community, getting those data into the public record and validating them is an obvious need. Assessment of impacts on entire mussel populations in lakes is needed and can be obtained through relatively simple monitoring as part of drawdown projects. More work on downstream impacts of flow during drawdown and refill is warranted as well but it is unlikely that a natural flow regime can be mimicked downstream of a lake subjected to drawdown.

4.2.10 Summary

Distilling the information from the GEIR and what we have learned since then into a concise summary is challenging, but the following succinct statements are offered to guide applicants and regulators considering drawdowns. Readers are encouraged to read corresponding sections of this supplement for further justification and caveats.

1. The vast majority of drawdowns are conducted on lakes with a dam that created or expanded the lake. This manmade lake area is still subject to natural processes and regulations but often requires management to maintain designated uses.
2. Drawdown over multiple years is expected to cause a coarsening of sediments and reduction of nuisance plant growths in the drawdown zone. There will be some shifts in the relative abundance of plant species, but species are not usually lost. Most affected are species that overwinter in vegetative form. Least affected are species that repopulate annually mainly by seeds. Best control is achieved with annual drawdown; variation in weather negates the value of skipping years on a predetermined schedule.
3. Drawdown provides flood control options that are valued. The greatest need is in late winter and early spring when flows are usually highest, and this coincides roughly with the targeted refill period. Wherever possible, refill should not start until ice out to maintain maximum flood control capacity, but other issues may affect the refill start date.
4. Drawdown can protect the shoreline and nearshore structures from ice damage. Alternative protection includes removal of structures for the winter and use of less susceptible armoring approaches such as rip-rap placed in a sloping arrangement from land into water. Where sensitive shorelines, dams and other permanent structures are present, refill should not start until there is reasonable certainly that ice damage will not be caused.
5. Multiple invasive species can be controlled by drawdown, which then qualifies for limited project status as an ecological restoration project under the Wetlands Protection Act. Reduction in density of native vegetation does not qualify for limited status and must meet all relevant performance standards but this has not proven difficult in most cases.
6. Proposed drawdown in a lake with any state listed species under the Massachusetts Endangered Species Act must be reviewed by the NHESP prior to any decision under the Wetlands Protection Act.
7. The primary, documented, negative impact of drawdown within a lake is the death of minimally motile organisms in the drawdown zone, most notably mussels. Impacted organisms may not represent a significant portion of the overall population but monitoring to determine the distribution of organisms at risk over the range of lake depth is an appropriate permit condition.
8. There is very little evidence of any major or lasting impact to algae, most invertebrates, fish, or water dependent wildlife in a lake from drawdowns of the magnitude conducted in Massachusetts. There may be reason to evaluate possible impacts on a case by case basis but no reason to assume impacts based on research and experience to date.
9. There is very little evidence of any major or lasting impact to upgradient wetlands connected to the lake from winter drawdown.
10. Water quality has not been demonstrated to be altered by drawdown. The possibility of low oxygen under the ice and consequent impacts is not common but it is reasonable to require a

late winter check of water quality as a permit condition. Monitoring in late spring and late summer, as a minimum program is also recommended for any lake management program.

11. There may be temporary access limitations due to drawdown. These can be mitigated by walkways or other aids at key public access points as warranted.
12. Creation or expansion of a lake by dam construction alters system hydrology. Drawdown and refill further alter that hydrology in ways that may impact the downstream environment. It is important to avoid flooding or drying of the downstream channel but significant alteration of downstream flows in terms of timing of high and low flows appears unavoidable. Evaluation of downstream resources may be warranted.
13. Permits should specify any additional activities allowed during the drawdown period. Removal of woody debris that does not represent a public safety hazard should be discouraged and removal of sediment requires additional permits.
14. Planning a drawdown program includes a careful evaluation of the area to be exposed, the volume of the lake to be discharged, the time it will take to achieve the target drawdown depth and refill the lake later, the benefits to be accrued, and the possible negative impacts that could occur. Details should be provided in a NOI narrative that allows regulators to understand the need and basis for drawdown and how non-target impacts will be minimized.
15. The application of a 3-foot limit for drawdown without additional review by regulatory agencies outside the normally applied WPA and MESA processes is appropriate. Very little evidence of lakewide impact has been detected from drawdowns <3 feet in Massachusetts and elsewhere. Greater drawdowns may be warranted and should be considered but may require more background information and more extensive monitoring programs.
16. The appropriate timing of the start of drawdown and achievement of the target drawdown depth can be specific to a lake and its river basin, depending on hydrology, watershed to lake area ratio, biological resources, and downstream conditions. Targeting November as the month in which all drawdown activities are completed is a reasonable guideline but not an appropriate restriction in many cases. Each drawdown program should be crafted to meet stated goals and minimize potential impacts and this may involve an earlier start or later achievement of the target water level.
17. Lowering the water level at an average rate of 3 inches per day is an appropriate guideline, but lower or higher rates have not been shown to produce significant impacts in Massachusetts as long as the average is near 3 inches per day. This will necessitate a period of drawdown proportional to the target water level decline as modified by local hydrology. For a 3-foot drawdown, completion within a month should be possible, but storms can reverse the drawdown and require a longer period of elevated discharge. Flexibility to deal with variable weather is needed in permits.
18. The guidance relating to maximum drawdown outflows at 4 cfs/square mile of watershed is not properly supported and ignores variation in watershed to lake area ratios. Smaller lakes with larger watersheds could discharge at excessive rates under this guidance and larger lakes with smaller watersheds may be unable to achieve the target drawdown. The average 3 inch per day guidance and prevention of downstream flooding are more appropriate regulators of rate of drawdown.
19. Matching outflow to inflow during the winter drawdown period is preferred for reasons of public safety and a stable drawdown but is not always possible. This should guide flow management during drawdown to the extent possible but should not be a compliance issue, as

inflows can exceed outflow capacity and higher outflow may be needed later to restore the drawdown.

20. The guidance relating to minimum outflow during refill of 0.5 cfs/square mile is reasonable in that downstream flows would normally be higher without the need to refill the lake and this value is based on an average low flow period for Massachusetts lakes. This may cause the refill period to be extended, however, during a relatively dry spring or where the watershed to lake area ratio is low (<10:1) and there may be basin-specific reasons to vary from this guidance (e.g., confluence with other streams shortly downstream of the lake).
21. Achieving full lake status by April 1 is a convenient compliance target but not realistic or necessary in all years. Impacts of later refill are mostly linked to temperature and the ideal refill date can vary from about mid-March to late April in any given year. Drawdown programs should be crafted to refill as quickly as possible after ice out while maintaining reasonable downstream flows (see #20). This may necessitate starting the refill before ice out and will require calculations based on anticipated weather and flow conditions that cannot be controlled. Achieving refill by any date in any given year is a probability distribution and not a manageable certainty. As such it should not be subject to annual compliance but should be considered in any permit renewal.
22. A monitoring program for water level and outflow during the drawdown and refill period is recommended. Sophisticated, automated systems are available but not essential as long as the monitoring frequency is appropriate to rates of change, reliable records are kept, and management of the drawdown is suitably informed by the data.

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