Town of Bedford
Fawn Lake
Preservation Study

Completed for
Town of Bedford
Bedford, MA 01730

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1.0 Background and Introduction

Fawn Lake is a 12-acre man-made impounded lake with an average water depth of 3 to 4 feet. The Fawn Lake Watershed is 86 acres with half of that designated as forested land and the other half as low-density residential land (**Figure 1-1).** Fawn Lake has sustained problematic densities of floating and submerged aquatic vegetation for many years. Large densities of aquatic plants have limited the use of the lake as a recreational site for fishing, canoeing and other recreational activities. In 2001, a restoration goal was established for the lake based on public input and how residents wanted to use this community resource. The goal, which is still the same today, is to establish conditions at Fawn Lake that enhance aesthetic, recreational and wildlife habitat values by restoring open water areas free of excessive plant growth.

Historically several management strategies have been implemented to improve the conditions in Fawn Lake. Previous aquatic vegetation management has included numerous hydroraking and herbicide treatments. In addition, the Town has put forth several efforts to help prevent contaminants from entering the lake from sources such as birds and stormwater runoff. This has included installing a fence along the open field side of the lake, distributing brochures to educate residents and visitors about various lake pollutants, and seeking funds for nearby stormwater system improvements. Potential sources of stormwater pollution include fertilizers and pesticides from lawn applications, runoff from pet and other animal wastes, and discharge from road and vehicle maintenance activities. Drainage to the lake, which includes overland runoff and discharge from one outfall from the town's stormwater system (**Figure 1-2**), is not treated. Other historical improvements to the lake include: clearing trail obstructions, beaver controls, signs, maps, and a solar trash compactor.

The Town of Bedford has spent over $300,000 to preserve Fawn Lake through aquatic vegetation control from 2001-2010. **Table 1-1** below provides a timeline of these efforts. As shown in Table 1-1 herbicide applications and vegetation surveys have been completed six times and areas of the lake have been hydroraked three times over this period. These efforts have resulted in more open water in the short-term, however, the aquatic vegetation has returned. In addition, the Bedford Conservation Commission has been hesitant to continue annual herbiciding in a resource area without certainty of the long-term effects in, around and downstream of the Lake. For these reasons, a longer term management plan that provides effective treatment is sought to achieve the community goal of Fawn Lake.

Table 1-1. Fawn Lake Historic Vegetation Control

Date	Activity
2001	Vegetation survey (identified 9 species)
June 2003	Diquat application to 7-8 acres
September-October 2003	Hydroraked (over 5 week period)
July 2004	Vegetation survey (identified 7 species)

Table 1-1. Fawn Lake Historic Vegetation Control	
Date	**Activity**
October-November 2004	Hydroraked (over 3 week period)
July 2005	Vegetation survey (identified 9 species)
July 2005	Diquat application to 8-9 acres
2006-2007	Vegetation surveys (identified 8 species)
August 2006	Diquat application
July 2007	Diquat application
August 2007	Glyphosate application
September 2007	Glyphosate application
September 2008	Vegetation survey (identified 15 species)
July 2010	Vegetation survey (identified 10 species)
September-October 2010	Hydroraked 5-6 acres (over 3.5 week period)

With funding from Community Preservation, the Bedford Conservation Commission and the Department of Public Works initiated the Fawn Lake Preservation Study. This study was tasked with determining the lake bathymetry, sediment depth throughout the lake, relative densities of floating and submerged species, collecting composite sediment samples, and evaluating various management strategies for a viable long-term plan to restore Fawn Lake. The management strategies, in addition to the fieldwork results, will be used to help guide residents of the Town of Bedford towards the best management treatment given Fawn Lake's specific characteristics and any other constraints. Comprehensive Environmental, Inc (CEI) was hired in September 2014 to assist the Town in determining a solution to the aquatic vegetation issue.

2.0 Sediment Mapping and Analysis

This Section describes sediment characteristics and distribution in Fawn Lake investigated by CEI. The study included mapping of the sediment thickness, and sampling and laboratory analysis of sediment.

During CEI's fieldwork in mid-October, the wildlife activity observed around the lake included one non-native swan, several Canada geese, and native ducks. Other general observations included one abandoned beaver lodge (but no signs of recent activity), a turtle near the southwest corner, labeled "Limited Management Area" on attached maps, minnows, and numerous visitors mainly dog walkers. The water was more turbid near the southwest corner, but much clearer near the outlet at Springs Road. The water level was high at the time of the survey, and the lake elevation was higher than the road at the lake outlet.

Sediment depths were measured in Fawn Lake to determine the extent of sedimentation. A field crew using a boat performed the field work equipped with a Global Positioning System (GPS) unit, a Secchi disk, and a calibrated bar to locate points and record water and sediment depths. The data collected by the field crew was used to create a bathymetry and sediment profile map of Fawn Lake showing the water and sediment depths in the lake.

Two composite sediment samples were also collected, each made up of three locations, for laboratory analysis of various physical and chemical properties. The map and analysis information were used to estimate the quantity and quality of sediment and assist in determining potential removal and disposal options and the associated costs.

2.1 Sediment Depth and Volume Measurements

Sediment depth measurements were recorded at 57 locations to determine the relative thickness of the lake's sediment layer. A transect map, with nine transects, was used with a GPS unit to help guide the field crew to locations where the sediment depth measurements were conducted (**Figure 2-1**). Estimated lake bathymetry and sediment thickness throughout the lake are outlined using contours in **Figure 2-2** and **Figure 2-3**. The sediment thickness was estimated by measuring the depth of water at the sediment surface and again at the firm underlying bottom below the sediment. Top of sediment/lake bottom depths were measured by dropping a Secchi disc until it rested on top of the sediment and recording the associated water depth. A calibrated rod was then driven into the sediment until a firm bottom was reached and this second depth was recorded. The sediment surface depth was subtracted from the firm bottom depth to estimate the sediment thickness for each measurement location. **Table 2-1** includes water and sediment depths recorded during field measurements.

Field measurements indicate Fawn Lake has an average water depth of 3.3 feet and a maximum depth of 9.3 feet. Dredging all sediments could return this to an average depth of 6 feet with a maximum of 10 feet (**Figure 2-4**). The area in which dredging operations would occur is approximately 11.5 acres; this is the entire surface area of impounded water, less any areas where limited management is proposed. The total accumulated sediment volume is approximately 48,000 cubic yards.

2.2 Mapping

Geographic Information System (GIS) software was used to create a bathymetry contour map, a sediment depth contour map, and a bathymetry post sediment removal contour map for Fawn Lake. The field crew used a GPS unit to record position data at the location where each sediment depth was

recorded. This information was downloaded to create the map. Using this information, sediment distribution was estimated for the remaining area throughout the lake. **Figure 2-3** identifies the estimated sediment thickness contours in Fawn Lake.

2.3 Sediment Analysis

Sediment samples were collected at six of the 57 locations and composited into two samples to characterize the physical and chemical composition of sediments found in Fawn Lake. Each sample submitted for laboratory analysis was a composite made up of three monitoring sites on the west and east sides of the lake. **Figure 2-5** shows the monitoring sites that were chosen for the West Composite and the East Composite samples. A clamshell was used to collect the samples by dropping the sampler into the sediment surface and driving through the bottom layer. The composite samples were analyzed for grain size (sieve analysis), arsenic, cadmium, chromium, copper, lead, mercury, nickel, zinc, PCBs, polynuclear aromatic hydrocarbons (PAHs), total petroleum hydrocarbons (TPHs), extractable petroleum hydrocarbons (EPHs), volatile organic compounds (VOCs), total volatile solids, and percent water content.

Table 2-1 provides the sediment sample results at Fawn Lake. These results were used to evaluate potential disposal/reuse options should the lake sediment be dredged; therefore, Table 2-1 compares these results to contaminant limits for soil reuse at Massachusetts unlined landfills. All levels found in Fawn Lake are below these limits. A copy of the laboratory report is provided in **Appendix B.** These results are only cursory to inform what, if any, potential issues could arrive if sediment disposal is required. If dredging is the selected management option in the future, additional samples throughout the lake would be warranted.

Table 2-1. Sediment Sample Results

Parameter	Unit	West Composite	East Composite	Reuse Level for Unlined Landfills
Water Content	%	94	93	--
Total Volatile Solids (Organic Solids)	mg/L dry	64.3	51.7	--
Arsenic	mg/kg dry	ND	ND	40
Cadmium	mg/kg dry	ND	ND	30
Chromium	mg/kg dry	ND	ND	1,000
Copper	mg/kg dry	ND	ND	--
Lead	mg/kg dry	158	225	1,000
Nickel	mg/kg dry	ND	ND	--
Zinc	mg/kg dry	226	284	--
Mercury	mg/kg dry	ND	ND	10
PCBs	mg/kg dry	ND	ND	<2
TPH	mg/kg dry	ND	ND	2,500
EPH	mg/kg dry	ND	ND	--
PAHs	mg/kg dry	ND	ND	--
VOCs	mg/kg dry	ND	ND	4

The material collected for each sample included a mixture of lake bottom gravel, sands and silts; organic material (decomposed plant and animal matter); and water. The results indicate that the

samples have a very high water content, as is expected from lakebed sediment samples. The total volatile solids analysis results indicate that the sediment also has a very high organic matter content. Total volatiles solids represent the amount of organic solids (generally plant or dead animal matter) present. Lead and zinc were the only parameters detected in the sediment, and their levels were well below the reuse levels for unlined landfills.

The sieve analysis showed that overall the sediment is well graded and made up of mostly sand and gravel (**Table 2-2**) with some fine particles. Fine particles average 14% in the East Composite and 9.2% in the West Composite passing through a #200 sieve. The laboratory analysis also gave the average water (moisture) content, which was 94 and 93 percent in the West and East Composite sites. These laboratory results indicate the material would generate a large volume of residual water if dewatering the sediment is one of the considerations

Table 2-2. Composite Sample Sieve Analysis

Sieve Name	Sieve Size (mm)	Percent Finer	
		West Composite	East Composite
0.5 in	12.50	100	100
0.375 in	9.50	99	96
#4	4.75	90	71
#10	2.00	42	41
#20	0.85	25	28
#40	0.42	17	22
#60	0.25	13	19
#100	0.15	10	15
#200	0.075	9.2	14
	% Cobble	0	0
	% Gravel	9.7	29.3
	% Sand	81.1	57.2
	% Silt & Clay Size	9.2	13.5

3.0 Vegetation Survey

This Section describes the investigative survey of floating and submerged aquatic plant species in Fawn Lake. At each of the 57 monitoring sites the field crew also identified all aquatic plant species present and estimated the relative density. Overall, the middle of the lake to the east had more open water, and the most filamentous algae was observed in the northeastern portion of the lake. During the survey no non-native invasive aquatic plants were observed.

3.1 Relative Densities

Five floating and eight submerged aquatic plant species were identified within the entire lake. Filamentous algae was observed floating and within the water column. The results of the presence and relative densities of each floating and submerged species are found below in **Table 3-1** and **Table 3-2**. A species presence was based on the number of monitoring sites in which the species was identified out of the total 57 monitoring stations. The relative densities for each species were calculated by compiling the relative densities of the species at each monitoring stations. White water lily and yellow water lily were the dominant floating species and slender water nymph and coontail were the dominant submerged species observed in the highest relative densities throughout the entire lake.

Table 3-1 Floating Species Relative Densities

Species	Latin Name	Presence	Relative Density	Presence (Previous Surveys)
White Water Lily	*Nymphaea odorata*	52 of 57	32%	Yes
Yellow Water Lily	*Nuphar variegatum*	39 of 57	18%	Yes
Watershield	*Brasenia schreberi*	21 of 57	8.1%	Yes
Bur-Reed	*Sparganium sp.*	4 of 57	2.5%	Yes
Lesser Duckweed	*Lemna minor*	1 of 57	0.2%	Yes
Filamentous Algae		14 of 57	8.8%	Yes

Table 3-2 Submerged Species Relative Densities

Species	Latin Name	Presence	Relative Density	Presence (Previous Surveys)
Slender Waternymph	*Najas gracillima*	48 of 57	35%	Yes
Coontail	*Ceratophyllum demersum*	32 of 57	18%	Yes
Bushy Pondweed	*Najas flexilis*	16 of 57	10%	Yes
Common Bladderwort	*Utricularia vulgaris*	18 of 57	8.8%	Yes
Stonewort	*Nitella sp.*	13 of 57	4.6%	Yes
Ribbonleaf Pondweed	*Potamogeton ephiydrus*	4 of 57	2.2%	Yes
Purple Bladderwort	*Utricularia purpurea*	4 of 57	0.9%	Yes
Eel Grass/Tape Grass		2 of 57	0.4%	Yes
Filamentous Algae		3 of 57	0.7%	Yes

4.0 Alternative Strategies

This Section describes various alternative strategies to help return Fawn Lake back to an open water resource free of excessive plant growth and one that enhances aesthetic, recreational and wildlife habitat. A "No Action" alternative strategy is also included as a baseline. Each strategy is outlined below and a more detailed matrix is included in **Appendix C**.

4.1 No Action

Description:

This management technique would require no future action to prevent the growth of aquatic vegetation in Fawn Lake. This would eliminate any additional intervention and investment, however, over time the lake will eventually fill in with sediment and plant biomass.

One of the primary sources of sediment in Fawn Lake is attributed to the annual die off of aquatic vegetation. A "no action" alternative will allow sediment accumulation from plant die-off in the Lake to continue. This continued plant die-off can contribute to internal recycling of nutrients from bottom sediments, which promote the further growth of plants. Sedimentation can eventually change the lake environment to a marsh community. Based on the estimated previous rate of sedimentation, it is possible that the lake would be virtually unusable for recreation in about 60 years because the average depth would be around one foot. Recreation usability was determined only by the available water depth and it does not take into account aquatic vegetation growth rates or changing water quality. All of these other factors will also influence the functionality of the lake and should be taken into account when evaluating how quickly the lake will change to a marsh community. Further water quality monitoring and environmental sampling would be necessary to determine when the lake would become unsuitable for existing flora and fauna. In addition, the rate of sedimentation could intensify over previous sedimentation rates if development of surrounding properties increases without mitigation (such as TSS reduction measures or BMPs) and additional erosion stressors increase.

Environmental Impacts:

Benefits: No adverse impacts from machinery, chemicals or other types of land alteration as a result of implementing this management technique.

Detriments: The gradual filling in of the lake will reduce the lake's storage volume and degrade water quality. This will result in the loss of fresh water habitat for fish and other organisms. Most of the previous recreational uses (fishing, skating, canoeing, etc.) will be lost.

Time to Complete Treatment:

N/A

How Long Strategy is Effective:

N/A

Estimated Total Costs:

None.

Potential Permits Required:

N/A

Future Operations and Maintenance Tasks:

None.

Additional Considerations:

No cost associated with this treatment.
More frequent winter fish kill.

- Odor from large amounts of decaying plant matter.
- Loss of most recreational uses of the lake.
- Would not achieve community's desired goal for Fawn Lake.

4.2 Mechanical Dry Dredging

Description:

Mechanical dry dredging involves the removal of sediment and plant material using standard construction equipment. It is performed by scraping and removing sediment and plant material usually with a backhoe, excavator, or a front-end loader. First, the lake is drained to a predetermined level and then a machine is brought in to remove plants and sediments to a predetermined depth. The dredged material is collected and deposited on shore, where it is staged and dewatered. The plant species removal is non-selective and can be performed in any season. Mechanical dry dredging is most effective in reducing sediment levels and plant growth in shallow lakes to increase recreational use or reservoir storage.

The purpose of mechanical dry dredging is to return a lake to its pre-sedimentation or other manageable levels. It can help control excessive growth of aquatic plants by increasing the water depth to create a light limitation on plant growth and reducing the amount of growth-stimulating nutrients available in the lake sediment. The increase in water depth can also control excessive algae and invasive growth of macrophytes. This type of dredging can reduce benthic mat formation and some filamentous green and blue-green algae. Removing large amounts of sediment can also dramatically reduce the available seed bank and resting cysts previously established by existing aquatic plant and algae species.

Environmental Impacts:

Benefits: Water quality improvement, improved recreational uses, enhanced pollutant trapping capabilities, dilution of nutrient loads, control of growth rate in rooted plants, and removal of unwanted material in sediment. Temporary increased flood capacity may become available if the lake does not immediately fill to its new capacity after it is dredged. Potential long term benefit to fisheries and wildlife habitat from water quality enhancement, aquatic plant control, and physical habitat enhancement. This type of dredging can create larger depth gradients and opportunities to create habitat diversity.

Detriments: Mechanical dredging deepens the lake, thereby temporarily destroying shallow habitats. All other associated environmental impacts from drawdown which include short term habitat loss. Additionally, a potential loss of most of the biological communities in the drained portion of the lake through physical disturbance. Potential for increased amounts of downstream turbidity from drawdown if erosion control is not well maintained which would be true for any method. Some land disturbance from dredging equipment moving in/out of the lake. Temporary alteration of upland area used for staging/sediment storage. Lakes that remain less than 10-12 feet in depth will have minimal light limitation benefits.

Time to Complete Treatment:

Permitting - one to two years dependent on agency review times; implementation of dredging is dependent on amount; to dredge the entire lake is estimated to take two months to drawdown the lake and then approximately one year to complete the dredging operation (assuming 48,000 cubic yards) dependent on available storage/re-use options.

How Long Strategy is Effective:

Results can be long term depending on the efficiency of the dredge. Some projects have seen

significantly lower plant biomass for up to 10 years after dredging.[1]

Estimated Total Cost:

Very expensive management technique. Costs will include equipment, labor, construction of staging area, sedimentation and erosion controls, contract dredging costs including material processing (storage and/or hauling costs), final loaming, grading, and seeding of processing area. Associated permitting costs are approximately $100,000. Costs vary depending on the amount of material removed. Typically costs range between $8 to $25/cubic yard (cy) but some smaller projects (<50,000 cy) have sustained costs more than $30/cy.[2] Based on those prices the total cost of dredging all of the sediment in Fawn Lake could range from $384,000 to $1,440,000. There may be off-setting costs if the dredged material can be reused in producing loam or compost or if the Town of Bedford provides all the hauling services themselves. In this case a disposal or storage fill area would need to be identified.

Potential Permits Required:

- Order of Conditions – MA Wetlands Protection Act/ Bedford Wetlands Protection Bylaw
- MassDEP Water Quality Certification
- MassDEP Water Quality Certification- Dredge and Fill
- Possible Chapter 91 Permit
- Army Corps of Engineers Individual Permit
- Massachusetts Environmental Policy Act review (MEPA) ENF
- Potential archeological or historical documentation

Future Operations and Maintenance Tasks:

No maintenance.

Additional Considerations:

- The additional time and expense to construct temporary access roads and staging areas.
- Odor impacts from dredge area.
- Loss of all lake recreational use during work.
- Impacts from construction noise and increased truck traffic.

[1] Tobiessen, P., Swart, J., and Benjamin, S. 1992. Dredging to control curly-leaf pondweed: A decade later. Journal of Aquatic Plant Management 18, 19-23.
[2] Wagner, Kenneth J. 2004. The Practical Guide to Lake Management in Massachusetts: A Companion to the Final Generic Environmental Impact Report on Eutrophication and Aquatic Plant Management in Massachusetts. Massachusetts Department of Environmental Protection and Department of Conservation and Recreation.

4.3 Mechanical Wet Dredging

Description:

Mechanical wet dredging utilizes machinery to excavate sediment from areas under water. It is performed by scraping sediment and plant material, usually with a clamshell, bucket dredge, or dragline. A partial drawdown may be performed prior to dredging to limit the flow of turbid water downstream. The dredged material is typically very wet and approximately 10-30% solids.[3] The dredged sediment is then collected/deposited on shore where it is staged and dewatered. The plant species removal is non-selective.

Similar to dry dredging the purpose of mechanical wet dredging is to return a lake back to its previous conditions prior to significant sedimentation levels. Mechanical wet dredging helps to control excessive growth of aquatic plants by increasing the water depth to create a light limitation on plant growth and to reduce the amount of growth-stimulating nutrients available in the lake sediment that can limit the internal loading in the lake. The increase in water depth can also control excessive algae and invasive growth of macrophytes. This type of dredging can reduce benthic mat formation and some filamentous green and blue-green algae. Removing large amounts of sediment can also dramatically reduce the available seed bank and resting cysts previously established by existing aquatic plant and algae species.

Unlike dry dredging, wet dredging does not require a full drawdown of the lake and sediments are not fully exposed therefore potentially preserving existing aquatic species. This technique requires an intermediate holding area for sediment because of its high water content before the sediment is brought to a containment area or processed. This type of dredging typically requires the least amount of preparation and is typically the cheapest dredging approach.

Environmental Impacts:

Benefits: Similar to dry dredging, water quality improvement, improved recreational uses, enhanced pollutant trapping capabilities, dilution of nutrient loads, control of growth rate in rooted plants, and removal of unwanted material in sediment. Potential long term benefit to fisheries and wildlife habitat from water quality enhancement, aquatic plant control, and physical habitat enhancement. Larger depth gradients from this type of treatment can also create a more diverse plant community.[4]

Detriments: Similar to dry dredging, mechanical wet dredging deepens the lake thereby potentially destroying shallow habitats. Additionally, wet dredging causes a potential loss of some of the biological communities in the drained portion of the lake through physical disturbance. Additionally, there is a potential for increased amounts of downstream turbidity from drawdown and movement of sediments downstream of the water body if not carefully controlled. Other impacts include land disturbance from dredging equipment and temporary alteration of the upland area used for staging. Lakes that remain less than 10 -12 feet in depth will have minimal light limitation benefits.[3]

Time to Complete Treatment:

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[3] Wagner, Kenneth J. 2004. The Practical Guide to Lake Management in Massachusetts: A Companion to the Final Generic Environmental Impact Report on Eutrophication and Aquatic Plant Management in Massachusetts. Massachusetts Department of Environmental Protection and Department of Conservation and Recreation.
[4] Nichols, S. A. 1984. Macrophyte community dynamics in a dredged Wisconsin lake. Water Resources Bulletin 20, 573-576.

Permitting - one year; implementation of dredging is dependent on amount; to dredge the entire lake estimated to take a month to set up for wet dredging, a month to perform a partial draw down and less than one year to dredge the material. It could then take several years to drain and to dry out the sediment unless it is mechanically processed.

How Long Strategy is Effective:

Results can be long term depending on the efficiency of the dredge. Some projects have seen significantly lower plant biomass for up to 10 years after dredging.[5]

Estimated Total Cost:

Very expensive management technique. Costs will include equipment, labor, construction of staging area, sedimentation and erosion controls, contract dredging costs including material processing, final loaming, grading, and seeding of processing area. Associated permitting costs are approximately $100,000. Typically costs are dependent on the amount of material removed where the larger the project the smaller the cost per cubic yard and range $15 to $25/cy.[6] Based on those prices the total cost of dredging all of the sediment in Fawn Lake could range from $720,000 to $1,200,000. There may be off-setting costs if the dredged material can be reused in producing loam or compost or if the Town of Bedford provides all the hauling services themselves.

Potential Permits Required:

- Order of Conditions – MA Wetlands Protection Act/ Bedford Wetlands Protection Bylaw
- MassDEP Water Quality Certification
- MassDEP Water Quality Certification- Dredge and Fill
- Possible Chapter 91 Permit
- Army Corps of Engineers Individual Permit
- Massachusetts Environmental Policy Act review (MEPA) ENF
- Potential archeological or historical documentation

Future Operations and Maintenance Tasks:

No maintenance.

Additional Considerations:

- The additional time and expenses to construct temporary access roads and staging areas can make this method cost prohibitive.
- Odor impacts from dredge area.
- Loss of all lake recreational use during work.
- Impacts from construction noise and increased truck traffic.

[5] Tobiessen, P., Swart, J., and Benjamin, S. 1992. Dredging to control curly-leaf pondweed: A decade later. Journal of Aquatic Plant Management 18, 19-23.
[6] Wagner, Kenneth J. 2004. The Practical Guide to Lake Management in Massachusetts: A Companion to the Final Generic Environmental Impact Report on Eutrophication and Aquatic Plant Management in Massachusetts. Massachusetts Department of Environmental Protection and Department of Conservation and Recreation.

4.4 Hydraulic or Pneumatic Dredging

Description:

Hydraulic or pneumatic dredging utilizes machinery to excavate sediment from areas under water. It is a more advanced form of wet dredging where the sediment debris is agitated and then vacuumed out through a pipeline to the collection area from a floating structure or a barge. Hydraulic dredging is performed by a suction dredge that has a cutter head. Pneumatic dredging is used for sediments with higher solid contents where air pressure is used to pump the sediments out of the lake. A barge with a suction line is used to suck out the plants and sediment to a specific depth. The lake does not need to be dewatered before employing either method but should be performed during the summer months to avoid any freezing of the pump systems. The dredged material is typically very wet with approximately 15-20% solids.[7] The dredged sediment is then collected/deposited on shore where it is staged and dewatered. The water may be returned to the lake. The plant species removal is not selective. This technique is favored at sites with large amounts of organic sediments with few rocks or other obstructions, such as those found at Fawn Lake.

Similar to dry and wet dredging, the purpose of hydraulic and pneumatic dredging is to return a lake back to its previous conditions prior to significant sedimentation levels. This type of dredging helps to control excess growth of aquatic plants by increasing the water depth. The increased depth creates a light limitation on plant growth and which then reduces the amount of growth-stimulating nutrients available in the lake sediment, limiting the internal loading in the lake. The increased water depth also controls excessive algae and invasive growth of macrophytes. This type of dredging can reduce benthic mat formation and some filamentous green and blue-green algae. Removing large amounts of sediment can also dramatically reduce the available seed bank and resting cysts previously established by existing aquatic plant and algae species.

Unlike dry dredging and wet dredging, hydraulic dredging does not require the lake to be lowered reducing turbidity and impacts to aquatic organisms, but may leave some sediment behind. It requires more sophisticated, expensive equipment than the other two types of dredging. Limited lake use may be possible during dredging operations.

Environmental Impacts:

Benefits: Associate environmental benefits from hydraulic dredging include water quality improvements, improved recreational uses, enhanced pollutant trapping capabilities, dilution of nutrient loads, control of increased growth rate of rooted plants, and removal of unwanted material in sediment. The potential long term benefit to fisheries and wildlife habitat from water quality enhancement, aquatic plant control, and physical habitat enhancement are also possible by this method. Larger depth gradients from this type of treatment can also create a more diverse plant community.[8] No lake drawdown required: can easily be phased.

Detriments: Hydraulic and pneumatic dredging deepens the lake, thereby potentially destroying shallow habitats. Additionally, a potential loss of many of the biological communities through

[7] Wagner, Kenneth J. 2004. The Practical Guide to Lake Management in Massachusetts: A Companion to the Final Generic Environmental Impact Report on Eutrophication and Aquatic Plant Management in Massachusetts. Massachusetts Department of Environmental Protection and Department of Conservation and Recreation.
[8] Nichols, S. A. 1984. Macrophyte community dynamics in a dredged Wisconsin lake. Water Resources Bulletin 20, 573-576.

physical disturbance and high turbidity may occur. Increased amounts of turbidity downstream of the waterbody could be expected. Temporary alteration of upland area used for staging sediment and land disturbance from dredging equipment. Lakes that remain less than 10-12 feet in depth will have minimal light limitation benefits.[7]

Time to Complete Treatment:

Permitting - one year; implementation of dredging is dependent on amount, to dredge the entire lake (48,000 cy) it is estimated to take one to two years.

How Long Strategy is Effective:

Results can be long term depending on the efficiency of the dredge. One project, in particular, saw significantly lower curly-leaf pondweed 10 years after dredging.[9]

Estimated Total Cost:

Very expensive management technique. Important cost variables include the volume of material dredged, distance to containment area, size of containment area, obstructions and clogging agents. Costs will include equipment, labor, construction of staging area, sedimentation and erosion controls, contract dredging costs including material processing, final loaming, grading, and seeding of processing area. Associated permitting costs are approximately $100,000. Typically costs are dependent on the amount of material removed and range $7 to $20/cy but some smaller projects (<50,000 cy) have sustained costs more than $30/cy.[10] Based on those prices the total cost of dredging all of the sediment in Fawn Lake could range from $336,000 to $1,440,000.

Potential Permits Required:

- Order of Conditions – MA Wetlands Protection Act/ Bedford Wetlands Protection Bylaw
- MassDEP Water Quality Certification
- MassDEP Water Quality Certification- Dredge and Fill
- Possible Chapter 91 Permit
- Army Corps of Engineers Individual Permit
- Massachusetts Environmental Policy Act review (MEPA) ENF
- Potential archeological or historical documentation

Future Operations and Maintenance Tasks:

No maintenance.

Additional Considerations:

- Odor issues confined to staging and processing area.
- Impacts from increased truck traffic.

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[9] Tobiessen, P., Swart, J., and Benjamin, S. 1992. Dredging to control curly-leaf pondweed: A decade later. Journal of Aquatic Plant Management 18, 19-23.
[10] Wagner, Kenneth J. 2004. The Practical Guide to Lake Management in Massachusetts: A Companion to the Final Generic Environmental Impact Report on Eutrophication and Aquatic Plant Management in Massachusetts. Massachusetts Department of Environmental Protection and Department of Conservation and Recreation.

- Less effective than other forms of dredging when there are large obstructions present, however, based on sediment sampling, large rocks/boulders were not present in Fawn Lake.

4.5 Bio-Dredging

Description:

Biological Dredging (Bio-Dredging) utilizes large amounts of beneficial bacteria to reduce organic sediments in lakes and ponds by processing the organic compounds in various ways. Bio-Dredging is performed by introducing a large dose of bacteria to the lake and then maintenance doses later on in the treatment to keep up the bacteria population. The bacteria thrive throughout the water column breaking up excess amounts of organic matter. Some types of bacteria produce enzymes that break down the organic material and take it into their cells as nutrients. Other bacteria perform denitrification, where they transform nitrate in the sediment into nitrogen gas, releasing it from the waterbody system. Other types of bacteria can convert phosphorus into insoluble minerals unavailable to most types of algae. Bio-dredging does not affect the aquatic plants directly but it will alter sediment totals and possibly change the N-P ratio resulting in the indirect alteration of plant growth.[11]

The purpose of Bio-Dredging is to reduce the amount of organic material in a waterbody and remove excess nutrients from the aquatic system. The addition of the beneficial bacteria is intended to increase the rate at which dead plant and animal matter decompose. The bacteria will degrade organic matter into CO_2, water, and bacterial biomass. The amount of organic sediment in the lake will decrease, increasing the total depth of the lake. Bio-Dredging helps to limit excessive plant growth by removing large amounts of organic sediments. It can also increase lake depth by reducing the amount of organic bottom sediment. By removing additional nutrients, Bio-Dredging can improve water quality and the overall aesthetics of a lake. This option is typically used in older ponds with a very thick layer of organic sediment.[11]

Environmental Impacts:

Benefits: Associated benefits from Bio-Dredging include water quality improvements, improved recreational uses, dilution of nutrient loads, reduced growth rate of rooted plants, and removal of unwanted organic material in sediment. Other long term benefits include enhanced fisheries and wildlife habitat from water quality enhancement, aquatic plant control due to the decreased nutrients present to fuel new growth, and physical habitat enhancement.

Detriments: Bio-Dredging deepens the lake thereby potentially destroying previously shallow habitats. It also can accumulate large amounts of bacteria. Reduces the organic sediment which may be providing food for plants and a rooting layer but does not address the vegetation removal directly.

Time to Complete Treatment:

Ongoing application: some sites respond in one treatment; others after several treatments.

How Long Strategy is Effective:

There is little documentation as to long term effectiveness.

Estimated Total Cost:

Typically much less expensive than mechanical dredging with costs estimated at 1/3 to ½ mechanical

[11] http://www.solitudelakemanagement.com/solitude-lake-management-blog/bid/292835/Bio-Dredging-Dredging-With-Bacteria

dredging).[12] Associated permitting costs are approximately $25,000. The total estimated cost of bio-dredging Fawn Lake is from $128,000 to $720,000.

Potential Permits Required:

Due to the unique nature of this application exact permitting requirements would have to be established after in-depth consultations with various state and federal agencies. We assume at a minimum the following:

- Order of Conditions – MA Wetlands Protection Act/ Bedford Wetlands Protection Bylaw
- Army Corps of Engineers Programmatic General Permit
- Massachusetts Environmental Policy Act review (MEPA)

Future Operations and Maintenance Tasks:

Low maintenance.

Additional Considerations:

- Must be applied multiple times per season (~every 2 weeks).
- Limited testing and documentation and very little data on effectiveness.
- Few experienced applicators.
- Results are very dependent on specific mixture of organics/sediments and ambient conditions but have gotten reductions of 25%-50% organics within 6 months.

[12] http://www.dscaquaticsolutions.com/biodredge.html

4.6 Chemical Treatment: Diquat (Reward)

Description:

Chemical treatment techniques are used as primary control agents for a wide-range of macrophytes. Diquat is a fast-acting broad range contact herbicide typically applied as a follow-up management technique to other more targeted chemical treatments or after other herbicides were less effective at removing problem species, like milfoil.[13] Treatment is recommended early in the season to target a plant's early growth stages. Diquat kills the plant by disrupting photosynthesis. Diquat is used effectively at sites along shorelines or localized treatment areas with high exchange rates. (**Appendix D** provides summary information sheets by the Massachusetts Department of Conservation and Recreation on Diquat and the other herbicides evaluated in this study.)

Environmental Impacts:

Benefits: Diquat can provide an environmental benefit to fisheries through habitat enhancement by removing dense aquatic growths. It is also effective against a wide variety of problem species (invasives). It does not disturb sediment or seeds.

Detriments: Diquat's non-specific vegetation application can result in the death of most of the other plant species it comes in contact with, in turn, potentially altering the amount of vegetation available for aquatic organisms that depend on that specific vegetation as their food source . Some negative environmental impacts have occurred from Diquat application in amphipods such as Daphnia by resulting in reduced number and observed lower reproductive success in snails.[14] Potential fish toxicity may occur after being treated by Diquat but these impacts are highly variable and are dependent on the fish species, age of fish, and hardness of the water.[15]

Time to Complete Treatment:

Previous Massachusetts applications have seen the effects of Diquat after 2-3 days, with plants generally controlled around 7-10 days after treatment.[16] On average Diquat produces results 2 weeks after the start of the treatment.

How Long Strategy is Effective:

Typically 1-2 years to reach previous densities.

Estimated Total Cost:

Diquat treatments typically cost $200-$500 per acre.[16] The previous Fawn Lake Diquat application

[13] Wagner, Kenneth J. 2004. The Practical Guide to Lake Management in Massachusetts: A Companion to the Final Generic Environmental Impact Report on Eutrophication and Aquatic Plant Management in Massachusetts. Massachusetts Department of Environmental Protection and Department of Conservation and Recreation.
[14] Wisconsin Department of Natural Resources. January 2012. Diquat Chemical Fact Sheet. http://dnr.wi.gov/lakes/plants/factsheets/DiquatFactsheet.pdf
[15] Wagner, Kenneth J. 2004. The Practical Guide to Lake Management in Massachusetts: A Companion to the Final Generic Environmental Impact Report on Eutrophication and Aquatic Plant Management in Massachusetts. Massachusetts Department of Environmental Protection and Department of Conservation and Recreation.
[16] Wagner, Kenneth J. 2004. The Practical Guide to Lake Management in Massachusetts: A Companion to the Final Generic Environmental Impact Report on Eutrophication and Aquatic Plant Management in Massachusetts. Massachusetts Department of Environmental Protection and Department of Conservation and Recreation.

cost was $4,500 to treat 8 acres of submerged species. This total includes advertisements to announce the application, signs, and contracted labor, which could contribute to a slightly higher per acre cost; with inflation assume $6,500. Associated permitting costs are estimated at $5,000.

Potential Permits Required:

- Order of Conditions – MA Wetlands Protection Act/ Bedford Wetlands Protection Bylaw
- Application to Apply Herbicides to Waters of the Commonwealth

Future Operations and Maintenance Tasks:

Maintenance includes follow-up inspections in spring after applications and associated water quality monitoring.

Additional Considerations:

- Rapid results with limited drift to non-application areas.
- Treatment does not apply to underground portion of the plant, resulting in potential regeneration.

4.7 Chemical Treatment: Glyphosate (Rodeo)

Description:

Chemical treatment techniques are used as primary control agents for a wide-range of macrophytes. Glyphosate is a systemic broad spectrum herbicide. It disrupts a plant's metabolic pathway preventing it from synthesizing protein and producing new plant tissue. Glyphosate is applied using broadcast sprays (either ground-rig or aerial) or handgun or backpack sprays. This application technique makes it easy to treat large areas and for more localized application.[17]

Systems where Glyphosate has been applied effectively include nature preserves and refuges with emergent and floating plants. Glyphosate is most effective at controlling emergent and floating leaf species such as water lilies, reed grass, purple loosestrife and cattail. It is an area-targeted herbicide and does not treat most submergent species effectively.

Environmental Impacts:

Benefits: Glyphosate can provide an environmental benefit to fisheries through habitat enhancement by removing dense aquatic growths. It is also effective against a wide variety of problem species. When applied to susceptible species the entire plant is killed and treatment does not disturb sediment or disperse seeds.

Detriments: Glyphosate's non-specific treatment can result in the unintended death of other floating and emergent species it comes in contact with. This can result in a food source alteration for species consuming vegetation treated with Glyphosate. Large plant die-offs could reduce oxygen at the bottom of the lake. Recently the World Health Organization announced the results of a study indicating that it may cause or contribute to cancer in humans.[18]

Time to Complete Treatment:

Glyphosate treatment takes about 7 days to kill herbaceous plants and up to 30 days for woody plants.[17] Woody plants are not included in the targeted species for management in Fawn Lake.

How Long Strategy is Effective:

Typically the treatment results are expected to last 1-2 years after each successful treatment to reach previous densities.

Estimated Total Cost:

Treatments cost around $500-$1,000 per acre.[19] A previous Fawn Lake application that targeted floating species cost $1,300. This total includes advertisements to announce the application, signs and

[17] Mattson, M.D., P.J. Godfrey, R.A. Barletta and A. Aiello. 2004. Eutrophication and Aquatic Plant Management in Massachusetts. Final Generic Environmental Impact Report. Edited by Kenneth J Wagner. Department of Environmental Protection and Department of Conservation and Recreation, Executive Office of Environmental Affairs, Commonwealth of Massachusetts. http://www.mass.gov/dcr/waterSupply/lakepond/geir.htm

[18] http://www.iarc.fr/en/media-centre/iarcnews/pdf/MonographVolume112.pdf

[19] Wagner, Kenneth J. 2004. The Practical Guide to Lake Management in Massachusetts: A Companion to the Final Generic Environmental Impact Report on Eutrophication and Aquatic Plant Management in Massachusetts. Massachusetts Department of Environmental Protection and Department of Conservation and Recreation.

contracted labor. Associated permitting costs are estimated at $5,000. The estimated total cost of treating Fawn Lake entirely ranges from $5,750 to $11,500.

Potential Permits Required:

- Order of Conditions – MA Wetlands Protection Act/ Bedford Wetlands Protection Bylaw
- Application to Apply Herbicides to Waters of the Commonwealth

Future Operations and Maintenance Tasks:

Maintenance includes follow-up inspections in spring after applications and associated water quality monitoring.

Additional Considerations:

- Ineffective against submergent species.
- Very slow response.
- Rainfall after application can negate the chemical effectiveness.
- No restrictions for irrigation, recreation, or domestic application.
- Cannot be applied within 0.5 miles upstream of potable water intakes and on the retreatment of an area within 24 hours.[20]
- Typically glyphosate in natural waters dissipates in 1.5 to 14 days and is broken down through microbial degradation. Glyphosate is highly adsorbed by particulates in the water column and soils with high organic content making the herbicide inactivated. Studies have shown very low toxicity in aquatic fish and invertebrates. In mammals, there has been very little studies on the acute toxicity of glyphosate but, in one study, dogs administered 60 mg/kg a day saw no significant changes compared to the control. [21]

[20] Monsanto. 1990. Rodeo Aquatic Herbicide. (EPA registration label).
[21] Mattson, M.D., P.J. Godfrey, R.A. Barletta and A. Aiello. 2004. Eutrophication and Aquatic Plant Management in Massachusetts. Final Generic Environmental Impact Report. Edited by Kenneth J Wagner. Department of Environmental Protection and Department of Conservation and Recreation, Executive Office of Environmental Affairs, Commonwealth of Massachusetts. http://www.mass.gov/dcr/waterSupply/lakepond/geir.htm

4.8 Chemical Treatment: Fluridone (Sonar)

Description:

Chemical treatment techniques are used as primary control agents for a wide-range of macrophytes. Fluridone is a selective systemic herbicide that has two formations, an aqueous suspension and a slow release pellet. It disrupts a plant's ability to synthesize carotene thus exposing its chlorophyll to photodegradation, which results in the inability of the plant to produce carbohydrates inevitably resulting in species death. Certain species are more sensitive to Fluridone treatments, and will require a lower dose application.

Systems where Fluridone has been applied effectively include small lakes and slow-flowing systems. Fluridone is most effective at controlling broad-leaved and submerged aquatic species like Eurasian water milfoil, curly-leaf pondweed and other native pondweeds. Plants absorb Fluridone through the water by their shoots for submerged plants and by the hydrosoil through the roots of aquatic vascular plants.

Environmental Impacts:

Benefits: Fluridone can provide an environmental benefit to fisheries through habitat enhancement by removing dense aquatic growths. It kills the entire plant of susceptible species. Selective treatment is possible for some major invasive species. Treatment does not disturb sediment or disperse seeds. It results in slow plant death minimizing any negative water quality impacts like reductions in dissolved oxygen and nutrient release. There are minimal direct risks to fauna.

Detriments: Fluridone treatment may kill vegetation that other organisms were relying on as a food source and destroy habitat from loss of cover for surrounding species.

Time to Complete:

The time it takes to complete the treatment is approximately 6 months which includes permitting through application. Control of floating vegetation is not expected to be achieved through the application of Fluridone only.

How Long Strategy is Effective:

Plants respond in approximately 30-90 days after chemical application.[22] Typically the treatment results are expected to last 1-2 years after each successful treatment.

Estimated Total Cost:

Treatments typically cost $500-$1,000 per acre for a single liquid treatment. For sequential treatments the cost rises to $1,000-$2,000 per acre. Treatment with the pelletized form is approximately $800-$1,200 per acre.[22] Associated permitting costs are estimated at $5,000. The estimated total cost of treating Fawn Lake entirely ranges from $5,750 to $23,000.

[22] Wagner, Kenneth J. 2004. The Practical Guide to Lake Management in Massachusetts: A Companion to the Final Generic Environmental Impact Report on Eutrophication and Aquatic Plant Management in Massachusetts. Massachusetts Department of Environmental Protection and Department of Conservation and Recreation.

Potential Permits Required:

- Order of Conditions – MA Wetlands Protection Act/ Bedford Wetlands Protection Bylaw
- Application to Apply Herbicides to Waters of the Commonwealth

Future Operations and Maintenance Tasks:

Follow-up inspections in the spring after chemical application. Future water quality monitoring is also advised if in a drinking water supply watershed, which does not apply to Fawn Lake.

Additional Considerations:

- Low dose application required.
- Few label restrictions.
- Slowly activating chemical.
- Highly diffusive, ineffective in areas with high dilution and flushing activity.

4.9 Hydroraking

Description:

Hydroraking directly removes aquatic vegetation through a quick non-selective treatment technique. It involves a mechanical rake that pulls out thick root masses and the surrounding sediment and debris. It is most effective at removing lilies (white or yellow) and other species with large root masses. This management technique removes targeted vegetation immediately, thereby eliminating their nutrients from entering the waterbody.

Environmental Impacts:

Benefits: Hydroraking removes hard to remove nuisance vegetation and large scale obstructions improving overall water quality and recreational uses. Plant masses can be disposed of in compost piles and breakdown is relatively quick.

Detriments: Hydroraking is a very disruptive technique that can inadvertently kill benthic invertebrates and drastically alter existing aquatic fish and wildlife habitat. It can also cause high turbidity and an extensive sediment disturbance.

Time to Complete Treatment:

Permitting time plus about 3.5 weeks to hydrorake 5 to 6 acres of Fawn Lake.

How Long Strategy is Effective:

Typically 3-5 years and then would have to be repeated**.**

Estimated Total Cost:

The cost per acre is typically around $1,500-$4,000 for submergent plant treatments and $6,000-$10,000 for emergent growths.[23] Associated permitting costs are estimated at $7,500. The estimated total cost of treating Fawn Lake entirely is around $140,000. This cost includes a hydrorake, barge, and shore-based equipment. This option is typically more expensive than harvesting (cut and remove).

Potential Permits Required:

- Order of Conditions – MA Wetlands Protection Act/ Bedford Wetlands Protection Bylaw

Future Operations and Maintenance Tasks:

No maintenance, unless repeated hydroraking is required.

Additional Considerations:

- Not as effective at removing submergent species that can re-root from fragments.
- Sediment collected will have additional disposal or reuse considerations.

[23] Wagner, Kenneth J. 2004. The Practical Guide to Lake Management in Massachusetts: A Companion to the Final Generic Environmental Impact Report on Eutrophication and Aquatic Plant Management in Massachusetts. Massachusetts Department of Environmental Protection and Department of Conservation and Recreation.

- Beneficial for treatment in one specific area.
- Most effective in lakes 1-12 feet deep.
- Impacts from construction noise, use disturbance, and traffic from trucks.

4.10 Weed Harvesting/Mechanical Harvesting

Description:

Mechanical harvesting is a selective area control technique that consists of large machines cutting the plants in place and collecting them for disposal, often described as an "underwater lawnmower". Most often large machines on pontoons cut and collect the vegetation. The plants are removed from the water by a conveyor belt system and sometimes stored on a temporary barge adjacent to the site location until they are ready for disposal. Harvested plants can be disposed of in landfills, composts, or reclaimed spent gravel pits.

Mechanical harvesting is best used in lakes that have excessive macrophytes throughout the littoral zone and where underwater obstructions are minimal. It is most effective when treating problems with annual plants. Treatment results in immediate access to open water. This type of management removes plant matter from the lake reducing the associated nutrients (*i.e.,* nitrogen and phosphorus), to the system.

Environmental Impacts:

Benefits: Mechanical harvesting's environmental benefits include immediate access to open water, reduction in plant nutrients, and lower sedimentation rate of the waterbody by removing large amounts of organic material. Management is targeted allowing designated conservancy areas to be protected from unintended impacts.

Detriments: Harvesting does not kill the entire plant and provides little to no reduction in plant density. Significant numbers of fish, invertebrates and amphibians are inadvertently collected and killed. Habitat for fish and other species still exists post-harvest, but at reduced amounts. Harvesting may increase the spread of nuisance species throughout the lake by creating many plant fragments. Re-suspended sediments post-harvest can result in increased turbidity. Since the plants are cut but not removed they can still reduce dissolved oxygen and release excess amounts of nutrients to the water.

Time to Complete Treatment:

Associated permitting time plus 3-5 additional days of harvesting.

How Long Strategy is Effective:

Treatment must be applied annually because of regrowth of perennial plants.

Future Operations and Maintenance Tasks:

No maintenance, unless repeated harvesting is required.

Estimated Total Cost:

The associated cost of mechanical harvesting is dependent on the target species, density of growth, travel distance from disposal, and the number of obstructions. On average the cost per acre ranges from $350-$550, which includes trucking and disposal costs. Very dense vegetation may cost around $1,000-$1,500 per acre.[24] Associated permitting costs are estimated at $7,500. The estimated total cost of treating Fawn Lake entirely ranges from $4,025 to $17,250. Harvesters are expensive and require routine maintenance.

Potential Permits Required:

- Order of Conditions – MA Wetlands Protection Act/ Bedford Wetlands Protection Bylaw

Additional Considerations:

- Regrowth is expected and is inevitable.
- For some species regrowth is so rapid it almost negates the management technique altogether.
- Harvesting not suitable for shallow lakes (3-5 feet of water) with loose sediments.
- No temporary water use restrictions.
- Treatment is most effective when performed before plants drop their seeds.
- Impacts from construction noise, use disturbance, and traffic from trucks.

[24] Wagner, Kenneth J. 2004. The Practical Guide to Lake Management in Massachusetts: A Companion to the Final Generic Environmental Impact Report on Eutrophication and Aquatic Plant Management in Massachusetts. Massachusetts Department of Environmental Protection and Department of Conservation and Recreation.

4.11 Water Level Drawdown

Description:

Water level drawdown describes a process where a lake is dewatered for an extended period of time, typically greater than 6 to 8 weeks and usually over the winter. This treatment is achieved when water is either pumped or siphoned and water is removed from the lake to a certain depth usually over the winter. The depth will vary for each lake but should include the depth range of the targeted species. After the desired drawdown level is reached then the outflow is matched to the inflow. Water level drawdown is often included with other management techniques as mentioned in this Section (*i.e.,* mechanical dry dredging, wet dredging, hydraulic/pneumatic dredging, and with benthic barriers).

Water level drawdown is used to alter a lake's plant community and the substrate composition. In this treatment, aquatic plants are exposed to facilitate drying and freezing of the plants and their roots.

Environmental Impacts:

Benefits: Drawdown kills the vegetative portions of nuisance plants and is typically very effective. It may increase species richness and can reduce the sediment oxygen demand, sediment volume, and available nutrient content from the oxidation of sediments. It also can reduce fine sediments especially in lakes with a sufficient slope in the drawdown area. This can facilitate additional plant control and provides new exposed habitat for other organisms.

Detriments: Water level drawdown is non-selective and will impact all surrounding vegetation and wildlife. It has the potential for severe environmental impacts by stranding and harming non-target flora and fauna. In addition, it may facilitate the growth of certain species and may not be very effective on hearty species like lilies that are not as susceptible to drying/freezing. If groundwater seepage keeps substrate moist it may not kill off roots. Nutrient release from exposed sediment can increase algal growth if not properly drained before the subsequent growing season. This treatment does not kill seeds or any other non-vegetative overwintering plant component.

Time to Complete Treatment:

Dewatering typically lasts 6-8 weeks. Most effective time is during the late fall until the early winter to guarantee freezing will occur. The drawdown must be done for at least one month to ensure drying of sediment, or if in winter, long enough for sediment to freeze.

How Long Strategy is Effective:

This process would be repeated annually indefinitely.

Estimated Total Cost:

Inexpensive to execute but will depend on the ability to control water inflow and outflow. If a dam is easily controllable, it typically costs $5,000-$10,000 per year for actual execution with permitting and agency coordination estimated at $100,000. Additional costs are incurred if pumping is required. If a dam needs to be altered the associated cost can be well upwards of $100,000.[25]

[25] Wagner, Kenneth J. 2004. The Practical Guide to Lake Management in Massachusetts: A Companion to the Final Generic Environmental Impact Report on Eutrophication and Aquatic Plant Management in Massachusetts. Massachusetts Department of Environmental Protection and Department of Conservation and Recreation.

Potential Permits Required:

- Order of Conditions – MA Wetlands Protection Act/ Bedford Wetlands Protection Bylaw
- MassDEP Water Quality Certification
- Possible Chapter 91 Permit
- Army Corps of Engineers Individual Permit
- Massachusetts Environmental Policy Act review (MEPA) ENF
- Potential archeological or historical documentation

Future Operations and Maintenance Tasks:

Future maintenance of the dam to control water level if continuous drawdown is required annually. If only one drawdown is anticipated there would not be any additional future operations and maintenance costs.

Additional Considerations:

- Very difficult to permit especially in shallow lakes because Massachusetts Department of Fish and Game (MDFG) recommends limiting drawdown to no less than 3 feet of remaining water depth.[26] Since Fawn Lake already averages around 3 feet deep additional communication with MDFG will be required to evaluate any potential risk to the surrounding ecosystem from a proposed drawdown.
- Detailed hydrology and lake morphology is required to estimate the drawdown and refill times.
- Must complete biological surveys of populations at risk and local well depths, if any.
- More useful for man-made lakes with a dam or water control structure.
- Odor issues during drawdown before sediment/vegetation dries out, nearby stabilization and odor control can help mitigate problem.

[26] Mattson, M.D., P.J. Godfrey, R.A. Barletta and A. Aiello. 2004. Eutrophication and Aquatic Plant Management in Massachusetts. Final Generic Environmental Impact Report. Edited by Kenneth J Wagner. Department of Environmental Protection and Department of Conservation and Recreation, Executive Office of Environmental Affairs, Commonwealth of Massachusetts. http://www.mass.gov/dcr/waterSupply/lakepond/geir.htm

4.12 Sub-surface/Benthic Barriers

Description:

Sub-surface/Benthic Barriers use natural or synthetic materials to cover submerged plants preventing growth and disrupting necessary light levels required for survival. Typically, artificial sediment materials like polyethylene, polypropylene, fiberglass, and nylon are used. The barrier must be placed directly on top of the sediment, either during drawdown or by a diver, and should be secured with a stake or anchor. This growth-inhibiting substance (sheet, screen) is used to cover areas for at least 1 to 2 months. After a period of time, barriers are removed to prevent sediment buildup and colonization on the top of the synthetic substrate.

The purpose of sub-surface barriers is to kill benthic communities in targeted areas. The barriers are applied on top of the targeted plants to limit light, physically disrupt growth, and allow unfavorable chemical reactions to interfere with further development of the plants. These barriers are most effective around docks, boat launches, swimming areas, and other small intensive use areas.

Environmental Impacts:

Benefits: These barriers provide direct and effective treatment to targeted areas. They reduce turbidity and can create an enhanced habitat for species previously limited by dense growth of aquatic nuisance species.

Detriments: Potential negative impact to benthic invertebrates exposed to benthic barriers. This treatment does not remove plant biomass from the system, keeping all remaining nutrients and potentially fueling additional vegetative growths. The non-specific species results in all species under the mats killed.

Time to Complete Treatment:

Non-selective plant mortality within one month under barrier.

How Long Strategy is Effective:

Results may last several seasons. Might have to flip barrier over every 6-8 weeks, remove and replace barrier, or remove build-up of sediment on top of barrier.

Estimated Total Cost:

This treatment is high maintenance and expensive. Commonly used materials for benthic barriers cost around $0.25/sq.ft. for Texel, $0.40/sq.ft. for Palco, and $0.60/sq.ft. for Aquatic Weed Net. Cost per acre typically range from $20,000 to $50,000 for installation, design, permitting, materials and labor for the year.[27] Estimated cost for permitting is approximately $50,000. The estimated total cost of treating Fawn Lake entirely ranges from $230,000 to $575,000.

Potential Permits Required:

[27] Wagner, Kenneth J. 2004. The Practical Guide to Lake Management in Massachusetts: A Companion to the Final Generic Environmental Impact Report on Eutrophication and Aquatic Plant Management in Massachusetts. Massachusetts Department of Environmental Protection and Department of Conservation and Recreation.

- Order of Conditions – MA Wetlands Protection Act/ Bedford Wetlands Protection Bylaw
- Potential Chapter 91 Permit
- Army Corps of Engineers Permit
- MEPA ENF

Future Operations and Maintenance Tasks:

Maintenance includes continuous maintenance of barriers including the need to flip barrier over every 6-8 weeks, remove and replace barrier, or remove build-up of sediment on top of the barrier.

Additional Considerations:

- This treatment works best if followed by mechanical harvesting method.
- Not effective for large-scale treatment.
- Difficulties deploying technique.
- Problems of long term integrity of the barrier.
- Billowing from trapped gases requires use of porous barrier or frequent venting.
- Able to reuse same barrier throughout different sections reducing costs.

4.13 Aeration/Artificial Circulation

Description:

Aeration puts air back into an aquatic system typically with an air pumps or compressor systems to achieve whole lake circulation. Accomplishing aeration in lakes less than 20 feet in depth requires installation of a fountain, surface aerators, bottom diffusers, water pumps or other submerged aeration system. For deeper lakes, circulation is achieved through the injection of compressed air into lake water through a diffuser at the lake's bottom.

Aeration is typically used to control algae growth in lakes by altering the nutrient levels available. Aeration increases the level of dissolved oxygen in the lake which may affect photosynthesis in submerged plants. By introducing more oxygen, the internal recycling of phosphorus is also limited, thereby controlling algae growth. Artificial circulation also reduces stratification in the lake which can control algal blooms by inhibiting phosphorus release from sediments, reducing photosynthesis for light-limited algal communities. This results in increased amounts of carbon dioxide and a lower pH favoring less toxic algal forms. Systems that use aeration effectively are typically larger stratified lakes or reservoirs with water quality issues.

Environmental Impacts:

Benefits: Aeration and circulation can suppress and disperse nuisance algae growth and improve oxygen levels for fish. Increasing turbulence can shift algae species to diatoms. Zooplankton are less likely to be consumed by fish when they are evenly distributed throughout the water column. It improves habitat for fish and invertebrates. Aeration can prevent winterkills of fish in eutrophic lakes and increase die-off rates of bacteria.

Detriments: Aeration can increase turbidity and resuspend sediments. It could mix unwanted substances throughout the lake and potentially increase algal growth. With the limited depth of Fawn Lake it is unlikely that aeration would substantially curb other aquatic plant growth.

Time to Complete Treatment:

Associated time to install device about 2 months.

How Long Strategy is Effective:

Treatment is expected to last as long as the device is in operation and maintained.

Estimated Total Cost:

Average capital costs for artificial circulation range from $200 to $3,000 per acre and annual costs range from $50 to $800 per acre.[28] This cost includes initial purchase and installation of the pumps, pipes, and diffusers and annual maintenance costs and annual electricity costs. Estimated cost for permitting alone is around $50,000. The estimated total capital cost of treating Fawn Lake entirely ranges from $2,300 to $34,500 with annual costs ranging from $575 to $9,200. The cost variability is associated with the amount of water required and high electricity operating cost.

[28] Wagner, Kenneth J. 2004. The Practical Guide to Lake Management in Massachusetts: A Companion to the Final Generic Environmental Impact Report on Eutrophication and Aquatic Plant Management in Massachusetts. Massachusetts Department of Environmental Protection and Department of Conservation and Recreation.

Potential Permits Required:

- Order of Conditions – MA Wetlands Protection Act/ Bedford Wetlands Protection Bylaw
- Potential Chapter 91 Permit
- Army Corps of Engineers Permit
- MEPA ENF

Future Operations and Maintenance Tasks:

Depending on the type of aeration device, it may need to be removed for the winter and replaced in spring; other O&M of specific device to keep it in proper working order.

Additional Considerations:

- Very little direct impact to plants densities, effect will be indirect through minimal impact on phosphorus and dissolved oxygen levels.
- Low efficiency.
- Fountains used in smaller waterbodies have high associated costs.

4.14 Remove Dam-Revert to Natural System

Description:

Remove the dam at the lake's outlet near Springs Road to allow the lake to return to a natural system. Following removal of the dam, over time the lake will eventually drain and sediments and plant biomass may become an emergent wetland community with hydraulic inputs from the springs and local drainage. This option is identical to the "No Action" strategy after the dam is physically removed. Dam removal is normally reserved for a river/stream restoration to re-establish a fish passage, which may not be the case at Fawn Lake.

Environmental Impacts:

Benefits: Supports wetlands succession and a natural emergent wetland system. May promote a natural riverine system as long as hydrologic input can be quantified.

Detriments: Wetland succession processes will eventually change the environment from a lake to an emergent wetland community causing a loss of fish habitat and the potential for invasive species to opportunistically grow in the changing environment.

Time to Complete Treatment:

Permitting - one year; dam removal 2 months.

How Long Strategy is Effective:

Forever.

Estimated Total Cost:

Costs can include a feasibility study, engineering design, permitting, and project implementation and construction. Feasibility study between $30,000 and $40,000, engineering design between $40,000 and $50,000, and construction $200,000. Estimated cost for permitting is approximately $100,000. The estimated total cost for removing the dam at Fawn Lake ranges from $270,000 to $290,000.

Potential Permits Required:

- Order of Conditions – MA Wetlands Protection Act/ Bedford Wetlands Protection Bylaw
- MassDEP Water Quality Certification
- MassDEP Water Quality Certification- Dredge and Fill
- Possible Chapter 91 Permit
- Army Corps of Engineers Individual Permit
- Massachusetts Environmental Policy Act review (MEPA) ENF
- Potential archeological or historical documentation

Future Operations and Maintenance Tasks:

Seeding with rye after lake is initially drained is recommended to help minimize/prevent invasives and odor issues. Future reseeding may be necessary. Continue to monitor the transition to insure control of potential invasives.

Additional Considerations:

- Odor issues from exposed sediments and decaying plant matter.
- Loss of most recreational uses of the Fawn Lake, against the overall goal.
- Department of Conservation and Recreation is encouraging dam removal throughout the state.

4.15 Rehabilitate/Raise Dam

Description:

Fawn Lake Dam is an earthen structure that was classified in 2007 as a small size, low hazard potential structure in poor condition. At the time of classification the abutments were in fair condition from vegetation growing at the contacts, the upstream slope had evidence of being undercut, and the crest was in poor condition. [29]

The methods involved in rehabilitating the dam include extending and elevating the berm, adding berms in low lying areas and performing construction to raise the dam elevation and inundate more land area. Also, additional soil material will be added to the dam to raise the elevation. This will increase the water depth and make it more difficult for light to reach submerged aquatic plants. Systems that implement this strategy effectively are typically isolated lakes or reservoirs where additional storage is desired and surrounding development is limited.

Environmental Impacts:

Benefits: Improve the condition of the dam preventing potential future collapse and roadway/property flooding. Can increase submerged resource areas. Increases the area of the lake, and increases lake depth.

Detriments: Potential negative impacts to environment during construction. Temporary land disturbance in the area of the dam and berm installations. Permanent land loss in inundated areas. Destruction of bordering vegetated resource areas. Raising the dam submerges adjacent property; difficult to permit; expensive; plants not removed; if light reaches the bottom will not be effective and plants will still be present.

Time to Complete Treatment:

Permitting - one year; dam rehabilitation - less than one year.

How Long Strategy is Effective:

Until sediment depth and plant die-off catches up with raised elevation. Typical sedimentation from plant die-off ranges from 1-10 millimeters per year.[30]

Estimated Total Costs:

Minor repairs were estimated at $4,000 to $6,000 in 2007, remedial measures at $120,000 to $170,000 for design, permitting and construction.[29] Estimated cost for permitting is approximately $100,000.

Potential Permits Required:

- Order of Conditions – MA Wetlands Protection Act/ Bedford Wetlands Protection Bylaw
- MassDEP Water Quality Certification

[29] Weston & Sampson. 2007. Fawn Lake Dam: Inspection/Evaluation Report.
[30] University of Florida: IFAS Extension Center for Aquatic and Invasive Plants. 2011. Decomposition and Sedimentation. http://plants.ifas.ufl.edu/manage/overview-of-florida-waters/water-quality/decomposition-and-sedimentation

- MassDEP Water Quality Certification- Dredge and Fill
- Possible Chapter 91 Permit
- Army Corps of Engineers Individual Permit
- Massachusetts Environmental Policy Act review (MEPA) ENF
- Potential archeological or historical documentation

Future Operations and Maintenance Tasks:

High maintenance, increases in the size of the dam or installation of other berms will necessitate regular inspection and maintenance of increased size.

Additional Considerations:

- Temporary impacts from construction noise and increased truck traffic.
- Substantial permitting process, would require feasibility study with detailed topographic survey to assess impacts to surrounding property.

5.0 Conclusions and Other Considerations

The intent of the Fawn Lake Preservation Study is to evaluate various potential management techniques for the Town of Bedford to consider. The Town has an existing management goal for Fawn Lake that includes "restoring open water areas free of excessive plant growth", which may affect the applicability of some techniques evaluated. The "No Action" and "Dam Removal" management strategies would eventually eliminate the lake as a recreational resource. This outcome seems to be in direct conflict with the portion of the goal of achieving open water, but it may promote other portions of the goal including "enhancing aesthetic, recreational and wildlife habitat". The lake itself may be gone, but wildlife habitat and terrestrial recreational opportunities may increase. These considerations in context with the overall goal for Fawn Lake should be explored when deciding on a management technique.

Additional considerations when selecting a management technique and after one has been selected:

- The conditions of the lake as a system will greatly impact the effectiveness of each management alternative. Lake characteristics such as water balance (water inflow versus water outflow), nutrient exchange rate, water quality (phosphorus levels, dissolved oxygen levels) and stormwater impacts may require additional studies to ensure the appropriate option is selected. For example, if additional chemical treatment is selected, a better understanding of the lake's exchange rate may lead the Town to use a different herbicide than one used in the past. If a study show's the lake's exchange rate is very low, the use of a longer contact time herbicide may be more appropriate and may achieve longer term results.

- If dredging is the chosen method of treatment, then proper installation of erosion and sediment controls before and during the dredging project must be completed. Effective erosion and sediment control techniques are also required to prevent dredging projects from introducing suspended sediment in the waterbody and downstream from the operation. Using appropriate erosion and sediment controls to dewater or divert residual water from dredging activities can prevent potential water resource impacts. A plan for erosion and siltation controls and spill prevention should be developed to identify potential contaminant sources prior to commencing work for a dredging project.

- A decision as to which management technique will be implemented should be made simultaneously with a decision on how to maintain the "Limited Management Area" of Fawn Lake. Fawn Lake provides habitat for a wide variety of wildlife including invertebrates, fish, amphibians, and birds which will be impacted in different ways by the removal of vegetation, potential water level drops and chemical treatments under both temporary and permanent conditions. It has been observed over the years that the Limited Management Area may be home to a larger concentration of these animals due to the limited disturbance. The preservation of this area can impact the implementation of some of the management techniques evaluated in this report and in turn the various alternatives may have different effects on the area.

    - Mechanical Dredging Options – If the Limited Management Area is not dredged along with the rest of the lakebed sediments, there will be some slough off from that area into the adjacent area. This will re-introduce sediment into an area which was selected for removal, resulting in the ability for plants to regrow quickly and a reduction in overall depth in that area. It is possible that with a three foot deep dredge adjacent to this area that 10-15' horizontally will slough off into the dredged area with

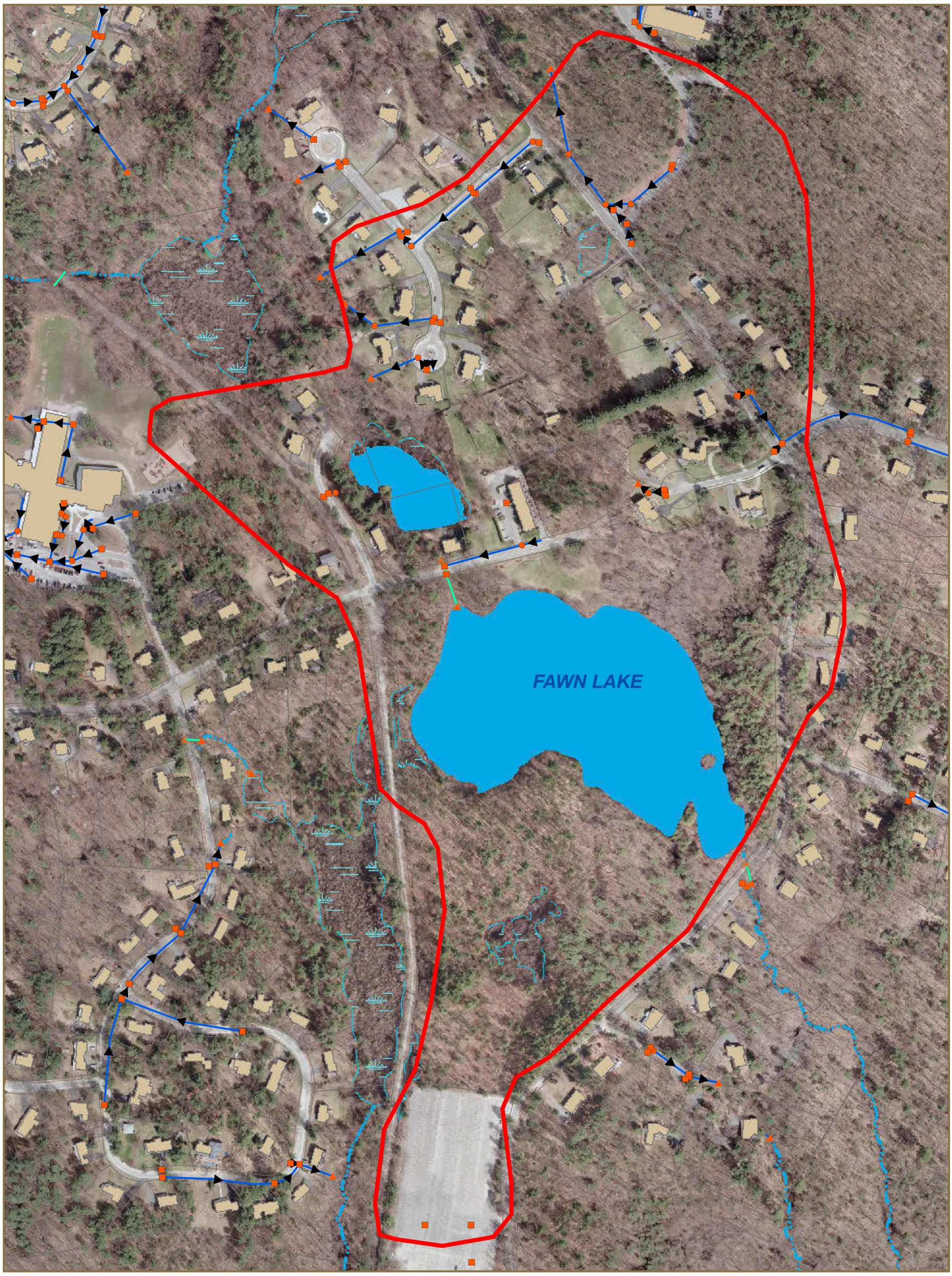
this in turn impacting 10-15' of the Limited Management Area. Actions can be taken to limit impacts during construction. For instance, during wet mechanical or hydraulic dredging, floating sediment booms can be installed to help limit turbidity in the Limited Management Area. However, this may limit the ability of aquatic animals from accessing the Limited Management Area as refuge during the work. Dry dredging would substantially reduce the fish population throughout the lake and would impact the Limited Management Areas ability to maintain populations of dragonfly, frog, turtle, etc.

- Chemical Treatment Options – Any herbicide used in the lake has the potential to drift into the Limited Management Area. Fluridone works best in slow-moving systems such as Fawn Lake and targets most submerged species; however, it requires a very long contact time (30-60 days), which means the herbicide will have time to drift into the Limited Management Area. Diquat has fairly limited drift because it breaks down quickly. This may be a preferred option for a more localized treatment approach with less risk of the herbicide spreading unintentionally to the Limited Management Area; however a localized approach may not provide the desired results of large areas of open water.

- Other Miscellaneous Management Options – A permanent, lined barrier (berm) would have to be installed in order to implement the Water Level Drawdown option and preserve the Limited Management Area. Adequate hydraulic connectivity would need to be confirmed or implemented. The fish and other aquatic animals would be permanently impacted by the loss of water. The Rehabilitation of the Dam option would raise the water level in the Limited Management Area but it would not be expected to cause any negative impacts to the wildlife in the area. The implementation of the Bio-Dredging, Subsurface Barriers, or Aeration options also would not have a negative impact on the Limited Management Area and no additional measures would need to be taken.

Appendix A

Figures



Legend

- Watershed Boundary
- Building

Drainage Structure

TYPE

- Catch Basin
- Drain Manhole

Drainage Outlets

- Inlet
- Outlet

Drain Pipes

TYPE

- Drain Pipe
- Culvert

Hydrology

Type

- River
- Wetland / Marsh
- Pond
- Swale
- Stream

Data Source: MassGIS, Town of Bedford, CEI

N
W E
S

0 0.02 0.04 0.06 0.08 Miles

0 300 600 Feet

Figure 1-1

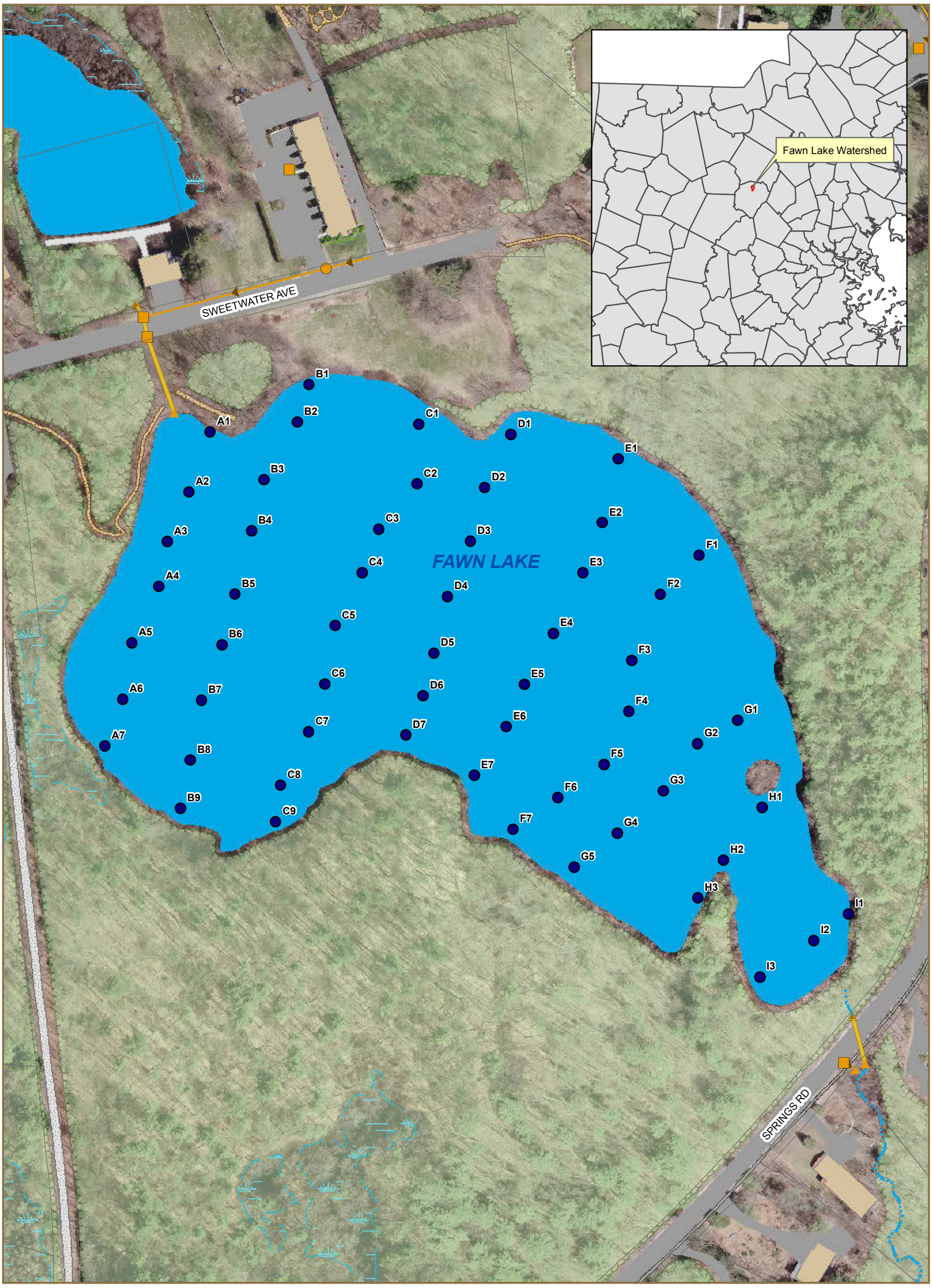
Fawn Lake Watershed Map

Fawn Lake Preservation Study

Bedford, MA

April 2015

Comprehensive Environmental Incorporated



Legend

- Sample Locations

Drainage Structure

TYPE

- Catch Basin
- Drain Manhole

Drainage Outlets

- Inlet
- Outlet

Drain Pipes

TYPE

- Drain Pipe
- Culvert
- Building

Hydrology

Type

- River
- Wetland / Marsh
- Pond
- Swale
- Stream

Data Source: MassGIS, Town of Bedford, CEI

N
W E
S

0 0.01 0.02 0.03 0.04 Miles

0 125 250 Feet

Figure 2-1

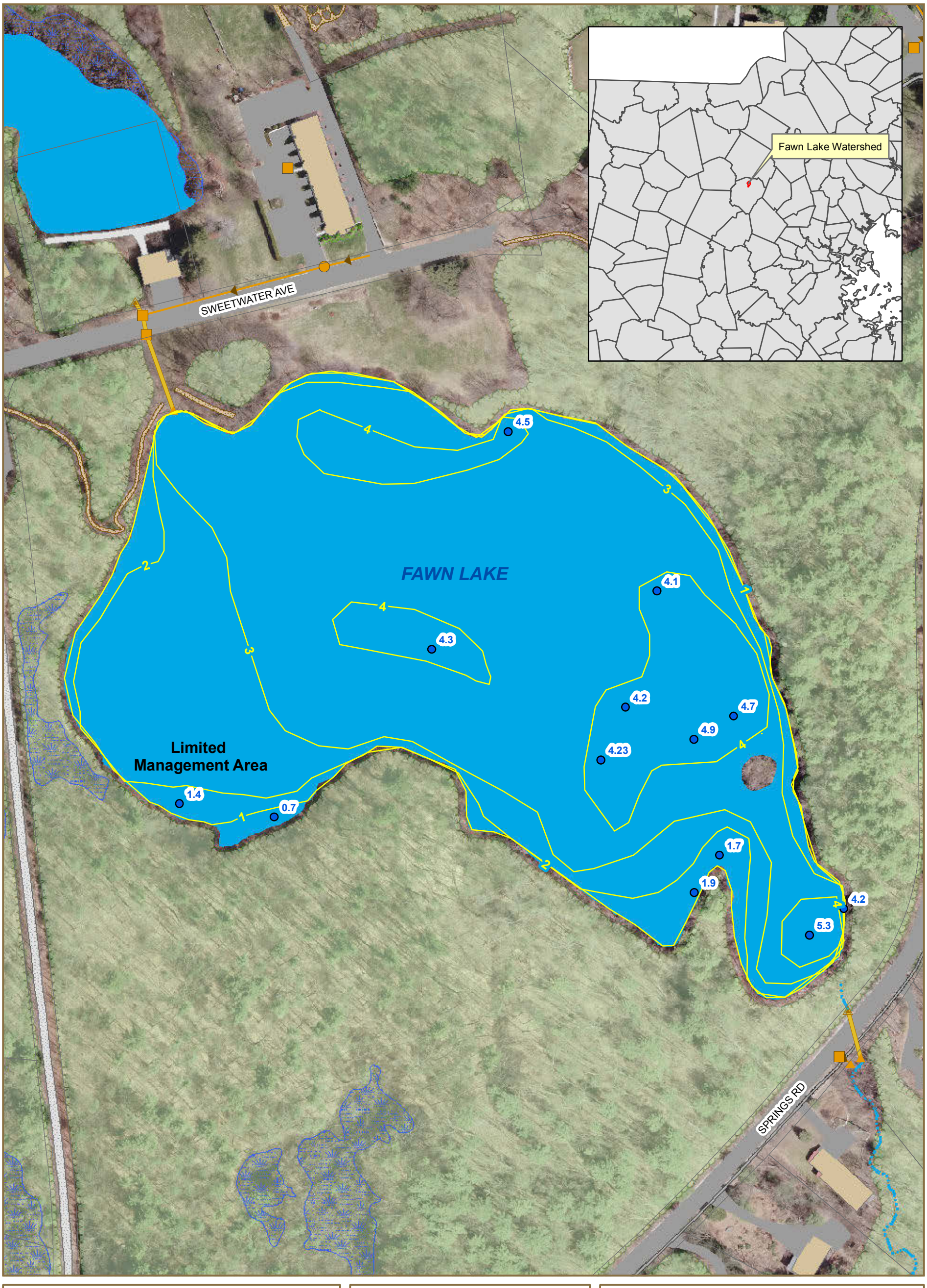
Transect Map

Fawn Lake Preservation Study

Bedford, MA

April 2015

Comprehensive Environmental Incorporated



Legend

- Sample Locations
- Bathymetric Contours (ft)

Drainage Structure

TYPE
- Catch Basin
- Drain Manhole

Drainage Outlets
- Inlet
- Outlet

Drain Pipes

TYPE
- Drain Pipe
- Culvert
- Building

Hydrology

Type
- River
- Wetland / Marsh
- Pond
- Swale
- Stream

Data Source: MassGIS, Town of Bedford, CEI

N W E S

0 0.01 0.02 0.03 0.04 Miles

0 125 250 Feet

Figure 2-2

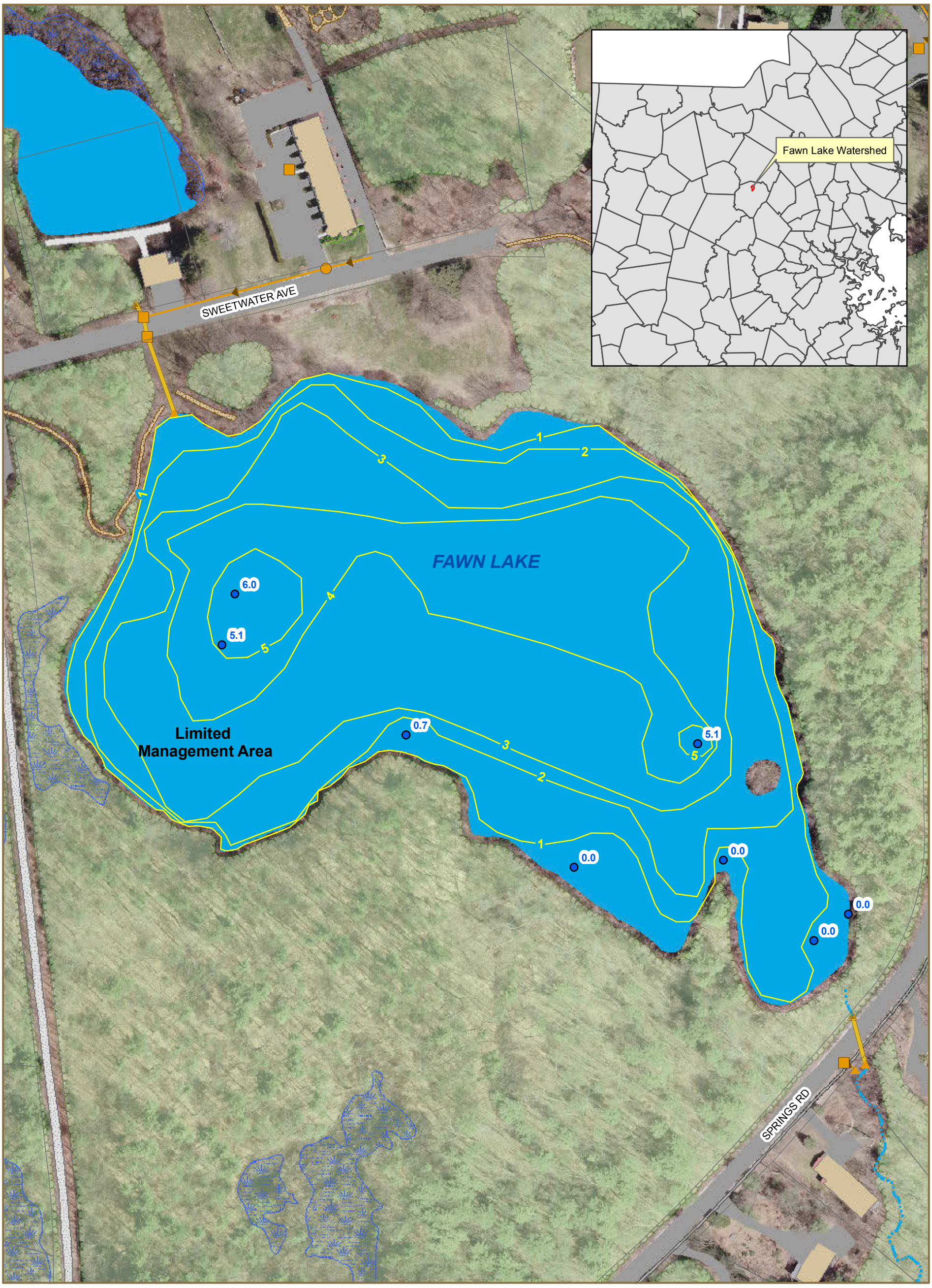
Bathymetry Map

Fawn Lake Preservation Study

Bedford, MA

April 2015

Comprehensive Environmental Incorporated



Legend

- Sample Locations
- Sediment Contours (ft)

Drainage Structure

TYPE

- Catch Basin
- Drain Manhole

Drainage Outlets

- Inlet
- Outlet

Drain Pipes

TYPE

- Drain Pipe
- Culvert
- Building

Hydrology

Type

- River
- Wetland / Marsh
- Pond
- Swale
- Stream

Data Source: MassGIS, Town of Bedford, CEI

N
W E
S

0 0.01 0.02 0.03 0.04 Miles

0 125 250 Feet

Figure 2-3

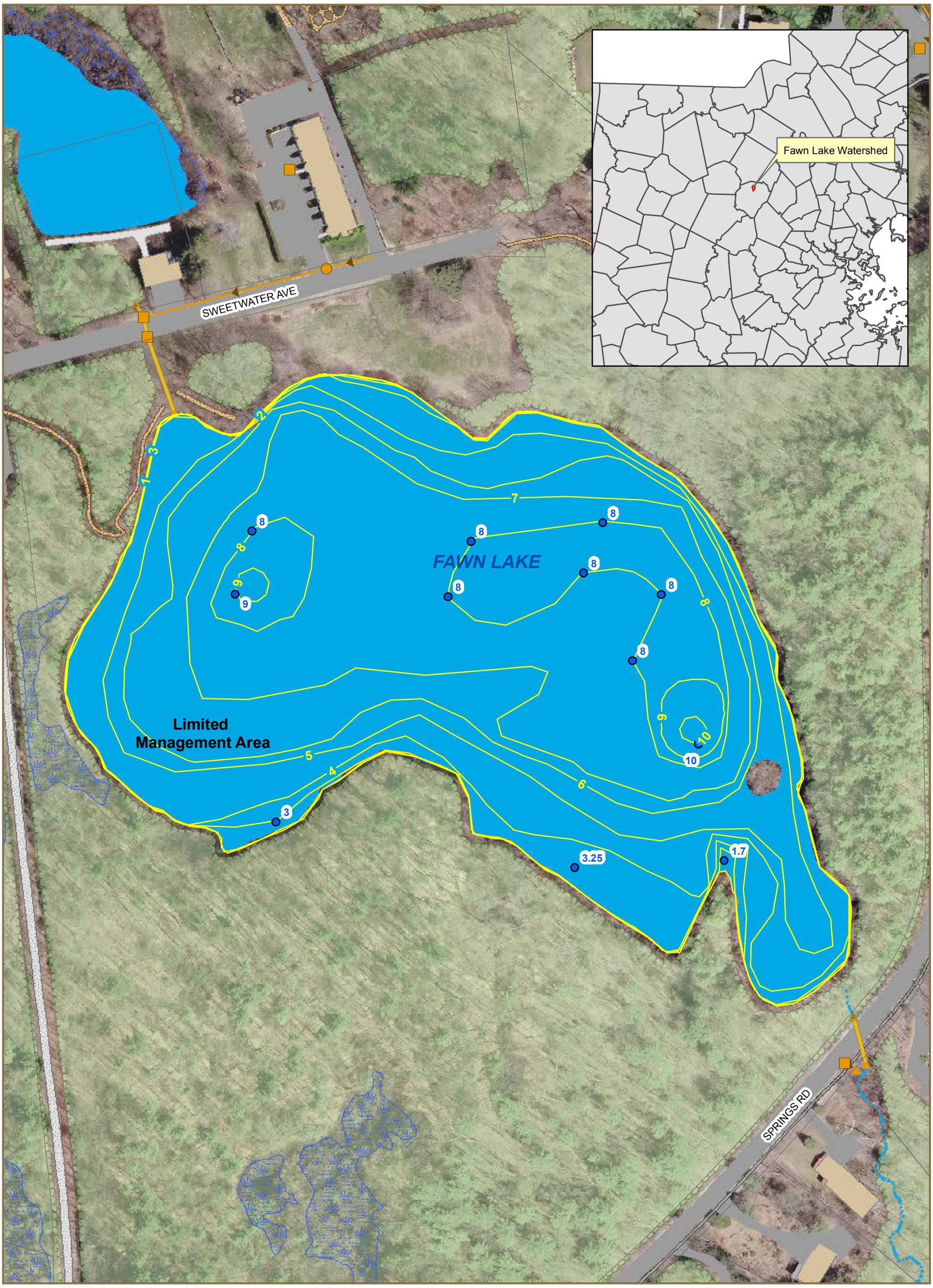
Sediment Depth Map

Fawn Lake Preservation Study

Bedford, MA

April 2015

Comprehensive Environmental Incorporated



Legend

- Sample Locations
- Contours (ft)

Drainage Structure

TYPE

- Catch Basin
- Drain Manhole

Drainage Outlets

- Inlet
- Outlet

Drain Pipes

TYPE

- Drain Pipe
- Culvert
- Building

Hydrology

Type

- River
- Wetland / Marsh
- Pond
- Swale
- Stream

Data Source: MassGIS, Town of Bedford, CEI

N
W E
S

0 0.01 0.02 0.03 0.04 Miles

0 125 250 Feet

Figure 2-4

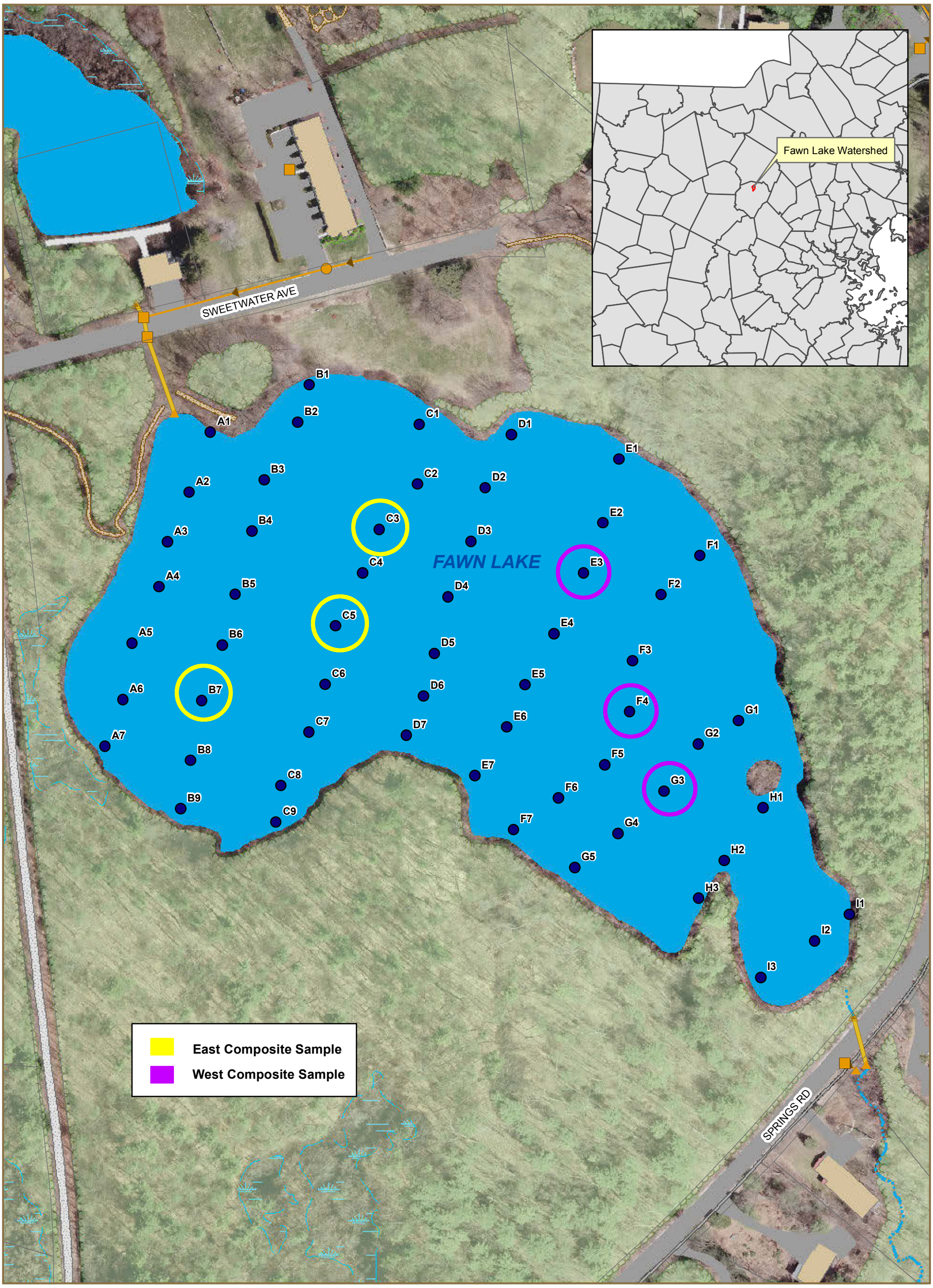
Lake Bathymetry Post Sediment Removal Map

Fawn Lake Preservation Study

Bedford, MA

April 2015

Comprehensive Environmental Incorporated



Legend

- Sample Locations

Drainage Structure

TYPE

- Catch Basin
- Drain Manhole

Drainage Outlets

- Inlet
- Outlet

Drain Pipes

TYPE

- Drain Pipe
- Culvert
- Building

Hydrology

Type

- River
- Wetland / Marsh
- Pond
- Swale
- Stream

Data Source: MassGIS, Town of Bedford, CEI

N W E S

0 0.01 0.02 0.03 0.04 Miles

0 125 250 Feet

Figure 2-5

Transect Map with Composite Sample Locations

Fawn Lake Preservation Study

Bedford, MA

April 2015

Comprehensive Environmental Incorporated

Appendix B

Laboratory Results

ANALYTICAL REPORT

Monday, November 03, 2014

GeoLabs, Inc.
45 Johnson Lane
Braintree MA 02184
Tele: 781 848 7844
Fax: 781 848 7811

Jessica Cajigas
CEI
225 Cedar Hill St
Marlborough, MA 01752

TEL: (508) 281-5160
FAX:

Project: 227-3
Location: Fawn Lake, Bedford MA

Order No.: 1410139

Dear Jessica Cajigas:

GeoLabs, Inc. received 2 sample(s) on 10/21/2014 for the analyses presented in the following report.

The laboratory results in this report relate only to samples submitted.

All data for associated QC met method or laboratory specifications, except when noted in the Case Narrative.

If you have any questions regarding these tests results, please feel free to call.

Sincerely,

David Mick
Laboratory Director

For current certifications, please visit our website at www.geolabs.com

Certifications:

CT (PH-0148) - MA (M-MA015) - NH (2508) - RI (LA000252)

Date: *03-Nov-14*

CLIENT: CEI
Project: 227-3
Lab Order: 1410139

CASE NARRATIVE

Physical Condition of Samples

The project was received by the laboratory in satisfactory condition. The sample(s) were received undamaged, in appropriate containers with the correct preservation.

Project Documentation

The project was accompanied by satisfactory Chain of Custody documentation.

Analysis of Sample(s)

All extractable samples were extracted and analyzed and any Volatile samples were analyzed within method specified holding times and according to GeoLabs documented Standard Operating Procedure. No analytical anomalies or non-conformances were noted by the laboratory during the processing of these samples.

SIGNATURE: David Mick LAB DIRECTOR

PRINTED NAME: David Mick DATE: 11/03/14

ANALYTICAL REPORT

Reported Date: 03-Nov-14

CLIENT:	CEI	**Client Sample ID:**	East Composite
Lab Order:	1410139	**Collection Date:**	10/20/2014
Project:	227-3	**Date Received:**	10/21/2014
Lab ID:	1410139-001	**Matrix:**	SEDIMENT

Analyses	Result	RL	Qual	Units	DF	Date Analyzed
WATER (MOISTURE) CONTENT - ASTM-D2216-05						Analyst: **CR**
Prep Method:		**Prep Date:**				
Water (Moisture) Content	*93*	0		%	1	10/24/2014
TOTAL VOLATILE SOLIDS - E160.4						Analyst: **CR**
Prep Method:		**Prep Date:**				
Total Volatile Solids	*51.7*	10.0		mg/L-dry	1	10/24/2014
POLYCHLORINATED BIPHENYLS - SW8082						Analyst: **KG**
Prep Method: (SW3545A)		**Prep Date:** 10/22/2014 1:13:09 PM				
Aroclor 1016	ND	714		µg/Kg-dry	1	10/24/2014
Aroclor 1221	ND	1430		µg/Kg-dry	1	10/24/2014
Aroclor 1232	ND	714		µg/Kg-dry	1	10/24/2014
Aroclor 1242	ND	714		µg/Kg-dry	1	10/24/2014
Aroclor 1248	ND	714		µg/Kg-dry	1	10/24/2014
Aroclor 1254	ND	714		µg/Kg-dry	1	10/24/2014
Aroclor 1260	ND	714		µg/Kg-dry	1	10/24/2014
Surr: Decachlorobiphenyl Sig 1	34.1	30-150		%REC	1	10/24/2014
Surr: Decachlorobiphenyl Sig 2	61.4	30-150		%REC	1	10/24/2014
Surr: Tetrachloro-m-Xylene Sig 1	55.8	30-150		%REC	1	10/24/2014
Surr: Tetrachloro-m-Xylene Sig 2	77.6	30-150		%REC	1	10/24/2014
EPH RANGES - MADEP EPH						Analyst: **KG**
Prep Method: (eph_Spr)		**Prep Date:** 10/22/2014 1:00:51 PM				
Adjusted C11-C22 Aromatics	ND	214		mg/Kg-dry	1	10/23/2014
C09-C18 Aliphatics	ND	214		mg/Kg-dry	1	10/23/2014
C19-C36 Aliphatics	ND	214		mg/Kg-dry	1	10/23/2014
Unadjusted C11-C22 Aromatics	ND	214		mg/Kg-dry	1	10/23/2014
Surr: 1-Chlorooctadecane	58.6	40-140		%REC	1	10/23/2014
Surr: o-Terphenyl	63.0	40-140		%REC	1	10/23/2014

Qualifiers:

B	Analyte detected in the associated Method Blank	BRL	Below Reporting Limit
E	Value above quantitation range	H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits	ND	Not Detected at the Reporting Limit
RL	Reporting Limit	S	Spike Recovery outside recovery limits

GeoLabs, Inc.
45 Johnson Lane ~ Braintree MA 02184 ~ 781 848 7844 ~ 781 848 7811

ANALYTICAL REPORT

Reported Date: 03-Nov-14

CLIENT:	CEI	**Client Sample ID:**	East Composite
Lab Order:	1410139	**Collection Date:**	10/20/2014
Project:	227-3	**Date Received:**	10/21/2014
Lab ID:	1410139-001	**Matrix:**	SEDIMENT

Analyses	Result	RL	Qual	Units	DF	Date Analyzed
TOTAL PETROLEUM HYDROCARBONS - 8100M						Analyst: **KG**
Prep Method: (8100M)		**Prep Date: 10/21/2014 9:39:59 AM**				
Total Petroleum Hydrocarbons	ND	714		mg/Kg-dry	1	10/23/2014
Surr: o-Terphenyl	58.1	40-140		%REC	1	10/23/2014
TOTAL METALS BY ICP - SW6010C						Analyst: **QS**
Prep Method: (SW3050B)		**Prep Date: 10/23/2014 3:12:15 PM**				
Arsenic	ND	70.0		mg/Kg-dry	1	10/23/2014
Cadmium	ND	14.0		mg/Kg-dry	1	10/23/2014
Chromium	ND	70.0		mg/Kg-dry	1	10/23/2014
Copper	ND	70.0		mg/Kg-dry	1	10/23/2014
Lead	***225***	70.0		mg/Kg-dry	1	10/23/2014
Nickel	ND	70.0		mg/Kg-dry	1	10/23/2014
Zinc	***284***	70.0		mg/Kg-dry	1	10/23/2014
MERCURY - SW7471A						Analyst: **EC**
Prep Method: (SW7471A)		**Prep Date: 10/21/2014 4:53:27 PM**				
Mercury	ND	3.57		mg/Kg-dry	1	10/21/2014
PAH - SW8270C						Analyst: **ZYZ**
Prep Method: (SW3545A)		**Prep Date: 10/23/2014 9:58:27 AM**				
2-Methylnaphthalene	ND	1430		µg/Kg-dry	1	10/24/2014 3:10:00 PM
Acenaphthene	ND	1430		µg/Kg-dry	1	10/24/2014 3:10:00 PM
Acenaphthylene	ND	1430		µg/Kg-dry	1	10/24/2014 3:10:00 PM
Anthracene	ND	1430		µg/Kg-dry	1	10/24/2014 3:10:00 PM
Benz(a)Anthracene	ND	143		µg/Kg-dry	1	10/24/2014 3:10:00 PM
Benzo(a)Pyrene	ND	143		µg/Kg-dry	1	10/24/2014 3:10:00 PM
Benzo(b)Fluoranthene	ND	1430		µg/Kg-dry	1	10/24/2014 3:10:00 PM
Benzo(g,h,i)Perylene	ND	1430		µg/Kg-dry	1	10/24/2014 3:10:00 PM
Benzo(k)Fluoranthene	ND	1430		µg/Kg-dry	1	10/24/2014 3:10:00 PM
Chrysene	ND	1430		µg/Kg-dry	1	10/24/2014 3:10:00 PM
Dibenz(a,h)Anthracene	ND	143		µg/Kg-dry	1	10/24/2014 3:10:00 PM
Fluoranthene	ND	1430		µg/Kg-dry	1	10/24/2014 3:10:00 PM

Qualifiers:

B	Analyte detected in the associated Method Blank	BRL	Below Reporting Limit
E	Value above quantitation range	H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits	ND	Not Detected at the Reporting Limit
RL	Reporting Limit	S	Spike Recovery outside recovery limits

GeoLabs, Inc.
45 Johnson Lane ~ Braintree MA 02184 ~ 781 848 7844 ~ 781 848 7811

ANALYTICAL REPORT

Reported Date: 03-Nov-14

CLIENT:	CEI	**Client Sample ID:**	East Composite
Lab Order:	1410139	**Collection Date:**	10/20/2014
Project:	227-3	**Date Received:**	10/21/2014
Lab ID:	1410139-001	**Matrix:**	SEDIMENT

Analyses	Result	RL	Qual	Units	DF	Date Analyzed
PAH - SW8270C						Analyst: **ZYZ**
Prep Method: (SW3545A)		**Prep Date: 10/23/2014 9:58:27 AM**				
Fluorene	ND	1430		µg/Kg-dry	1	10/24/2014 3:10:00 PM
Indeno(1,2,3-cd)Pyrene	ND	143		µg/Kg-dry	1	10/24/2014 3:10:00 PM
Naphthalene	ND	1430		µg/Kg-dry	1	10/24/2014 3:10:00 PM
Phenanthrene	ND	1430		µg/Kg-dry	1	10/24/2014 3:10:00 PM
Pyrene	ND	1430		µg/Kg-dry	1	10/24/2014 3:10:00 PM
Surr: 2-Fluorobiphenyl	32.8	30-130		%REC	1	10/24/2014 3:10:00 PM
Surr: Nitrobenzene-d5	30.9	30-130		%REC	1	10/24/2014 3:10:00 PM
Surr: Terphenyl-d14	42.6	30-130		%REC	1	10/24/2014 3:10:00 PM
EPH TARGET ANALYTES - MADEP EPH						Analyst: **ZYZ**
Prep Method: (eph_Spr)		**Prep Date: 10/22/2014 1:00:51 PM**				
Naphthalene	ND	1.43		mg/Kg-dry	1	10/24/2014 1:30:00 PM
2-Methylnaphthalene	ND	1.43		mg/Kg-dry	1	10/24/2014 1:30:00 PM
Acenaphthene	ND	1.43		mg/Kg-dry	1	10/24/2014 1:30:00 PM
Phenanthrene	ND	1.43		mg/Kg-dry	1	10/24/2014 1:30:00 PM
Acenaphthylene	ND	1.43		mg/Kg-dry	1	10/24/2014 1:30:00 PM
Fluorene	ND	1.43		mg/Kg-dry	1	10/24/2014 1:30:00 PM
Anthracene	ND	1.43		mg/Kg-dry	1	10/24/2014 1:30:00 PM
Fluoranthene	ND	1.43		mg/Kg-dry	1	10/24/2014 1:30:00 PM
Pyrene	ND	1.43		mg/Kg-dry	1	10/24/2014 1:30:00 PM
Benzo(a)Anthracene	ND	1.43		mg/Kg-dry	1	10/24/2014 1:30:00 PM
Chrysene	ND	1.43		mg/Kg-dry	1	10/24/2014 1:30:00 PM
Benzo(b)Fluoranthene	ND	1.43		mg/Kg-dry	1	10/24/2014 1:30:00 PM
Benzo(k)Fluoranthene	ND	1.43		mg/Kg-dry	1	10/24/2014 1:30:00 PM
Benzo(a)Pyrene	ND	1.43		mg/Kg-dry	1	10/24/2014 1:30:00 PM
Indeno(1,2,3-cd)Pyrene	ND	1.43		mg/Kg-dry	1	10/24/2014 1:30:00 PM
Dibenz(a,h)Anthracene	ND	1.43		mg/Kg-dry	1	10/24/2014 1:30:00 PM
Benzo(g,h,i)Perylene	ND	1.43		mg/Kg-dry	1	10/24/2014 1:30:00 PM
Total PAH Target Concentration	ND	1.43		mg/Kg-dry	1	10/24/2014 1:30:00 PM
Surr: 2,2-Difluorobiphenyl	57.6	40-140		%REC	1	10/24/2014 1:30:00 PM
Surr: 2-Fluorobiphenyl	77.9	40-140		%REC	1	10/24/2014 1:30:00 PM

Qualifiers:

B	Analyte detected in the associated Method Blank	BRL	Below Reporting Limit
E	Value above quantitation range	H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits	ND	Not Detected at the Reporting Limit
RL	Reporting Limit	S	Spike Recovery outside recovery limits

ANALYTICAL REPORT

Reported Date: 03-Nov-14

CLIENT:	CEI	**Client Sample ID:**	East Composite
Lab Order:	1410139	**Collection Date:**	10/20/2014
Project:	227-3	**Date Received:**	10/21/2014
Lab ID:	1410139-001	**Matrix:**	SEDIMENT

VOLATILE ORGANIC COMPOUNDS - 8260B Analyst: **ZC**

Prep Method: **Prep Date:**

Analyses	Result	RL	Qual	Units	DF	Date Analyzed
1,1,1,2-Tetrachloroethane	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
1,1,1-Trichloroethane	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
1,1,2,2-Tetrachloroethane	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
1,1,2-Trichloroethane	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
1,1-Dichloroethane	ND	1790		µg/Kg-dry	1	10/24/2014 2:37:00 PM
1,1-Dichloroethene	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
1,1-Dichloropropene	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
1,2,3-Trichlorobenzene	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
1,2,4-Trichlorobenzene	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
1,2,4-Trimethylbenzene	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
1,2-Dibromo-3-Chloropropane	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
1,2-Dibromoethane	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
1,2-Dichlorobenzene	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
1,2-Dichloroethane	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
1,2-Dichloropropane	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
1,3,5-Trimethylbenzene	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
1,3-Dichlorobenzene	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
1,3-Dichloropropane	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
1,4-Dichlorobenzene	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
2,2-Dichloropropane	ND	1790		µg/Kg-dry	1	10/24/2014 2:37:00 PM
2-Butanone	ND	1790		µg/Kg-dry	1	10/24/2014 2:37:00 PM
2-Chloroethyl Vinyl Ether	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
2-Chlorotoluene	ND	1790		µg/Kg-dry	1	10/24/2014 2:37:00 PM
2-Hexanone	ND	1790		µg/Kg-dry	1	10/24/2014 2:37:00 PM
2-Methoxy-2-Methylbutane (TAME)	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
4-Chlorotoluene	ND	1790		µg/Kg-dry	1	10/24/2014 2:37:00 PM
4-Isopropyltoluene	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
4-Methyl-2-Pentanone	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Acetone	ND	1790		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Acrylonitrile	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Benzene	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Bromobenzene	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Bromochloromethane	ND	1790		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Bromodichloromethane	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Bromoform	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Bromomethane	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM

Qualifiers:

B	Analyte detected in the associated Method Blank	BRL	Below Reporting Limit
E	Value above quantitation range	H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits	ND	Not Detected at the Reporting Limit
RL	Reporting Limit	S	Spike Recovery outside recovery limits

ANALYTICAL REPORT

Reported Date: 03-Nov-14

CLIENT:	CEI	**Client Sample ID:**	East Composite
Lab Order:	1410139	**Collection Date:**	10/20/2014
Project:	227-3	**Date Received:**	10/21/2014
Lab ID:	1410139-001	**Matrix:**	SEDIMENT

Analyses	Result	RL	Qual	Units	DF	Date Analyzed
VOLATILE ORGANIC COMPOUNDS - 8260B						Analyst: **ZC**
Prep Method:		**Prep Date:**				
Carbon Disulfide	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Carbon Tetrachloride	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Chlorobenzene	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Chloroethane	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Chloroform	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Chloromethane	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
cis-1,2-Dichloroethene	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
cis-1,3-Dichloropropene	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Dibromochloromethane	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Dibromomethane	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Dichlorodifluoromethane	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Diethyl Ether	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Diisopropyl Ether	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Ethylbenzene	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Ethyl-t-Butyl Ether	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Hexachlorobutadiene	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Isopropylbenzene	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Methyl Tert-Butyl Ether	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Methylene Chloride	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Naphthalene	ND	1790		µg/Kg-dry	1	10/24/2014 2:37:00 PM
n-Butylbenzene	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
n-Propylbenzene	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
sec-Butylbenzene	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Styrene	ND	1790		µg/Kg-dry	1	10/24/2014 2:37:00 PM
tert-Butylbenzene	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Tetrachloroethene	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Tetrahydrofuran	ND	1790		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Toluene	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
trans-1,2-Dichloroethene	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
trans-1,3-Dichloropropene	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Trichloroethene	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Trichlorofluoromethane	ND	1790		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Vinyl Chloride	ND	714		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Xylenes, Total	ND	1790		µg/Kg-dry	1	10/24/2014 2:37:00 PM
Surr: 1,2-Dichloroethane-d4	81.3	70-130		%REC	1	10/24/2014 2:37:00 PM
Surr: 4-Bromofluorobenzene	117	70-130		%REC	1	10/24/2014 2:37:00 PM

Qualifiers:

B	Analyte detected in the associated Method Blank	BRL	Below Reporting Limit
E	Value above quantitation range	H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits	ND	Not Detected at the Reporting Limit
RL	Reporting Limit	S	Spike Recovery outside recovery limits

GeoLabs, Inc.
45 Johnson Lane ~ Braintree MA 02184 ~ 781 848 7844 ~ 781 848 7811

ANALYTICAL REPORT

Reported Date: 03-Nov-14

CLIENT:	CEI	**Client Sample ID:**	East Composite
Lab Order:	1410139	**Collection Date:**	10/20/2014
Project:	227-3	**Date Received:**	10/21/2014
Lab ID:	1410139-001	**Matrix:**	SEDIMENT

Analyses	Result	RL	Qual	Units	DF	Date Analyzed
VOLATILE ORGANIC COMPOUNDS - 8260B						Analyst: **ZC**
Prep Method:		**Prep Date:**				
Surr: Dibromofluoromethane	94.4	70-130		%REC	1	10/24/2014 2:37:00 PM
Surr: Toluene-d8	101	70-130		%REC	1	10/24/2014 2:37:00 PM
TOTAL PHOSPHOROUS - L10-115-01-1-E						Analyst: **RP**
Prep Method:		**Prep Date:**				
Phosphorus, Total (As P)	*644*	16.0		mg/Kg-dry	1	11/3/2014

Qualifiers:

B	Analyte detected in the associated Method Blank	BRL	Below Reporting Limit
E	Value above quantitation range	H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits	ND	Not Detected at the Reporting Limit
RL	Reporting Limit	S	Spike Recovery outside recovery limits

ANALYTICAL REPORT

Reported Date: 03-Nov-14

CLIENT:	CEI	**Client Sample ID:**	West Composite
Lab Order:	1410139	**Collection Date:**	10/20/2014
Project:	227-3	**Date Received:**	10/21/2014
Lab ID:	1410139-002	**Matrix:**	SEDIMENT

Analyses	Result	RL	Qual	Units	DF	Date Analyzed
WATER (MOISTURE) CONTENT - ASTM-D2216-05						Analyst: **CR**
Prep Method:		**Prep Date:**				
Water (Moisture) Content	*94*	0		%	1	10/24/2014
TOTAL VOLATILE SOLIDS - E160.4						Analyst: **CR**
Prep Method:		**Prep Date:**				
Total Volatile Solids	*64.3*	10.0		mg/L-dry	1	10/24/2014
POLYCHLORINATED BIPHENYLS - SW8082						Analyst: **KG**
Prep Method: (SW3545A)		**Prep Date:** 10/22/2014 1:13:09 PM				
Aroclor 1016	ND	833		µg/Kg-dry	1	10/24/2014
Aroclor 1221	ND	1670		µg/Kg-dry	1	10/24/2014
Aroclor 1232	ND	833		µg/Kg-dry	1	10/24/2014
Aroclor 1242	ND	833		µg/Kg-dry	1	10/24/2014
Aroclor 1248	ND	833		µg/Kg-dry	1	10/24/2014
Aroclor 1254	ND	833		µg/Kg-dry	1	10/24/2014
Aroclor 1260	ND	833		µg/Kg-dry	1	10/24/2014
Surr: Decachlorobiphenyl Sig 1	87.6	30-150		%REC	1	10/24/2014
Surr: Decachlorobiphenyl Sig 2	134	30-150		%REC	1	10/24/2014
Surr: Tetrachloro-m-Xylene Sig 1	91.6	30-150		%REC	1	10/24/2014
Surr: Tetrachloro-m-Xylene Sig 2	92.0	30-150		%REC	1	10/24/2014
EPH RANGES - MADEP EPH						Analyst: **KG**
Prep Method: (eph_Spr)		**Prep Date:** 10/22/2014 1:00:51 PM				
Adjusted C11-C22 Aromatics	ND	250		mg/Kg-dry	1	10/23/2014
C09-C18 Aliphatics	ND	250		mg/Kg-dry	1	10/23/2014
C19-C36 Aliphatics	ND	250		mg/Kg-dry	1	10/23/2014
Unadjusted C11-C22 Aromatics	ND	250		mg/Kg-dry	1	10/23/2014
Surr: 1-Chlorooctadecane	47.8	40-140		%REC	1	10/23/2014
Surr: o-Terphenyl	70.5	40-140		%REC	1	10/23/2014

Qualifiers:

B	Analyte detected in the associated Method Blank	BRL	Below Reporting Limit
E	Value above quantitation range	H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits	ND	Not Detected at the Reporting Limit
RL	Reporting Limit	S	Spike Recovery outside recovery limits

GeoLabs, Inc.
45 Johnson Lane ~ Braintree MA 02184 ~ 781 848 7844 ~ 781 848 7811

ANALYTICAL REPORT

Reported Date: 03-Nov-14

CLIENT:	CEI	**Client Sample ID:**	West Composite
Lab Order:	1410139	**Collection Date:**	10/20/2014
Project:	227-3	**Date Received:**	10/21/2014
Lab ID:	1410139-002	**Matrix:**	SEDIMENT

Analyses	Result	RL	Qual	Units	DF	Date Analyzed
TOTAL PETROLEUM HYDROCARBONS - 8100M						Analyst: **KG**
Prep Method: (8100M)		**Prep Date: 10/21/2014 9:39:59 AM**				
Total Petroleum Hydrocarbons	ND	833		mg/Kg-dry	1	10/23/2014
Surr: o-Terphenyl	58.1	40-140		%REC	1	10/23/2014
TOTAL METALS BY ICP - SW6010C						Analyst: **QS**
Prep Method: (SW3050B)		**Prep Date: 10/23/2014 3:12:15 PM**				
Arsenic	ND	79.6		mg/Kg-dry	1	10/23/2014
Cadmium	ND	15.9		mg/Kg-dry	1	10/23/2014
Chromium	ND	79.6		mg/Kg-dry	1	10/23/2014
Copper	ND	79.6		mg/Kg-dry	1	10/23/2014
Lead	***158***	79.6		mg/Kg-dry	1	10/23/2014
Nickel	ND	79.6		mg/Kg-dry	1	10/23/2014
Zinc	***226***	79.6		mg/Kg-dry	1	10/23/2014
MERCURY - SW7471A						Analyst: **EC**
Prep Method: (SW7471A)		**Prep Date: 10/21/2014 4:53:27 PM**				
Mercury	ND	4.17		mg/Kg-dry	1	10/21/2014
PAH - SW8270C						Analyst: **ZYZ**
Prep Method: (SW3545A)		**Prep Date: 10/23/2014 9:58:27 AM**				
2-Methylnaphthalene	ND	1670		µg/Kg-dry	1	10/24/2014 3:44:00 PM
Acenaphthene	ND	1670		µg/Kg-dry	1	10/24/2014 3:44:00 PM
Acenaphthylene	ND	1670		µg/Kg-dry	1	10/24/2014 3:44:00 PM
Anthracene	ND	1670		µg/Kg-dry	1	10/24/2014 3:44:00 PM
Benz(a)Anthracene	ND	167		µg/Kg-dry	1	10/24/2014 3:44:00 PM
Benzo(a)Pyrene	ND	167		µg/Kg-dry	1	10/24/2014 3:44:00 PM
Benzo(b)Fluoranthene	ND	1670		µg/Kg-dry	1	10/24/2014 3:44:00 PM
Benzo(g,h,i)Perylene	ND	1670		µg/Kg-dry	1	10/24/2014 3:44:00 PM
Benzo(k)Fluoranthene	ND	1670		µg/Kg-dry	1	10/24/2014 3:44:00 PM
Chrysene	ND	1670		µg/Kg-dry	1	10/24/2014 3:44:00 PM
Dibenz(a,h)Anthracene	ND	167		µg/Kg-dry	1	10/24/2014 3:44:00 PM
Fluoranthene	ND	1670		µg/Kg-dry	1	10/24/2014 3:44:00 PM

Qualifiers:

B	Analyte detected in the associated Method Blank	BRL	Below Reporting Limit
E	Value above quantitation range	H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits	ND	Not Detected at the Reporting Limit
RL	Reporting Limit	S	Spike Recovery outside recovery limits

GeoLabs, Inc.
45 Johnson Lane ~ Braintree MA 02184 ~ 781 848 7844 ~ 781 848 7811

ANALYTICAL REPORT

Reported Date: 03-Nov-14

CLIENT:	CEI	**Client Sample ID:**	West Composite
Lab Order:	1410139	**Collection Date:**	10/20/2014
Project:	227-3	**Date Received:**	10/21/2014
Lab ID:	1410139-002	**Matrix:**	SEDIMENT

Analyses	Result	RL	Qual	Units	DF	Date Analyzed
PAH - SW8270C						Analyst: **ZYZ**
Prep Method:	**(SW3545A)**		**Prep Date:**	**10/23/2014 9:58:27 AM**		
Fluorene	ND	1670		µg/Kg-dry	1	10/24/2014 3:44:00 PM
Indeno(1,2,3-cd)Pyrene	ND	167		µg/Kg-dry	1	10/24/2014 3:44:00 PM
Naphthalene	ND	1670		µg/Kg-dry	1	10/24/2014 3:44:00 PM
Phenanthrene	ND	1670		µg/Kg-dry	1	10/24/2014 3:44:00 PM
Pyrene	ND	1670		µg/Kg-dry	1	10/24/2014 3:44:00 PM
Surr: 2-Fluorobiphenyl	33.4	30-130		%REC	1	10/24/2014 3:44:00 PM
Surr: Nitrobenzene-d5	30.9	30-130		%REC	1	10/24/2014 3:44:00 PM
Surr: Terphenyl-d14	40.4	30-130		%REC	1	10/24/2014 3:44:00 PM
EPH TARGET ANALYTES - MADEP EPH						Analyst: **ZYZ**
Prep Method:	**(eph_Spr)**		**Prep Date:**	**10/22/2014 1:00:51 PM**		
Naphthalene	ND	1.67		mg/Kg-dry	1	10/24/2014 2:04:00 PM
2-Methylnaphthalene	ND	1.67		mg/Kg-dry	1	10/24/2014 2:04:00 PM
Acenaphthene	ND	1.67		mg/Kg-dry	1	10/24/2014 2:04:00 PM
Phenanthrene	ND	1.67		mg/Kg-dry	1	10/24/2014 2:04:00 PM
Acenaphthylene	ND	1.67		mg/Kg-dry	1	10/24/2014 2:04:00 PM
Fluorene	ND	1.67		mg/Kg-dry	1	10/24/2014 2:04:00 PM
Anthracene	ND	1.67		mg/Kg-dry	1	10/24/2014 2:04:00 PM
Fluoranthene	ND	1.67		mg/Kg-dry	1	10/24/2014 2:04:00 PM
Pyrene	ND	1.67		mg/Kg-dry	1	10/24/2014 2:04:00 PM
Benzo(a)Anthracene	ND	1.67		mg/Kg-dry	1	10/24/2014 2:04:00 PM
Chrysene	ND	1.67		mg/Kg-dry	1	10/24/2014 2:04:00 PM
Benzo(b)Fluoranthene	ND	1.67		mg/Kg-dry	1	10/24/2014 2:04:00 PM
Benzo(k)Fluoranthene	ND	1.67		mg/Kg-dry	1	10/24/2014 2:04:00 PM
Benzo(a)Pyrene	ND	1.67		mg/Kg-dry	1	10/24/2014 2:04:00 PM
Indeno(1,2,3-cd)Pyrene	ND	1.67		mg/Kg-dry	1	10/24/2014 2:04:00 PM
Dibenz(a,h)Anthracene	ND	1.67		mg/Kg-dry	1	10/24/2014 2:04:00 PM
Benzo(g,h,i)Perylene	ND	1.67		mg/Kg-dry	1	10/24/2014 2:04:00 PM
Total PAH Target Concentration	ND	1.67		mg/Kg-dry	1	10/24/2014 2:04:00 PM
Surr: 2,2-Difluorobiphenyl	55.4	40-140		%REC	1	10/24/2014 2:04:00 PM
Surr: 2-Fluorobiphenyl	74.3	40-140		%REC	1	10/24/2014 2:04:00 PM

Qualifiers:

B	Analyte detected in the associated Method Blank	BRL	Below Reporting Limit
E	Value above quantitation range	H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits	ND	Not Detected at the Reporting Limit
RL	Reporting Limit	S	Spike Recovery outside recovery limits

ANALYTICAL REPORT

Reported Date: 03-Nov-14

CLIENT:	CEI	**Client Sample ID:**	West Composite
Lab Order:	1410139	**Collection Date:**	10/20/2014
Project:	227-3	**Date Received:**	10/21/2014
Lab ID:	1410139-002	**Matrix:**	SEDIMENT

Analyses	Result	RL	Qual	Units	DF	Date Analyzed
VOLATILE ORGANIC COMPOUNDS - 8260B						Analyst: **ZC**
Prep Method:		**Prep Date:**				
1,1,1,2-Tetrachloroethane	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
1,1,1-Trichloroethane	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
1,1,2,2-Tetrachloroethane	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
1,1,2-Trichloroethane	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
1,1-Dichloroethane	ND	2080		µg/Kg-dry	1	10/24/2014 3:12:00 PM
1,1-Dichloroethene	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
1,1-Dichloropropene	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
1,2,3-Trichlorobenzene	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
1,2,4-Trichlorobenzene	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
1,2,4-Trimethylbenzene	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
1,2-Dibromo-3-Chloropropane	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
1,2-Dibromoethane	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
1,2-Dichlorobenzene	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
1,2-Dichloroethane	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
1,2-Dichloropropane	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
1,3,5-Trimethylbenzene	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
1,3-Dichlorobenzene	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
1,3-Dichloropropane	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
1,4-Dichlorobenzene	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
2,2-Dichloropropane	ND	2080		µg/Kg-dry	1	10/24/2014 3:12:00 PM
2-Butanone	ND	2080		µg/Kg-dry	1	10/24/2014 3:12:00 PM
2-Chloroethyl Vinyl Ether	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
2-Chlorotoluene	ND	2080		µg/Kg-dry	1	10/24/2014 3:12:00 PM
2-Hexanone	ND	2080		µg/Kg-dry	1	10/24/2014 3:12:00 PM
2-Methoxy-2-Methylbutane (TAME)	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
4-Chlorotoluene	ND	2080		µg/Kg-dry	1	10/24/2014 3:12:00 PM
4-Isopropyltoluene	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
4-Methyl-2-Pentanone	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Acetone	ND	2080		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Acrylonitrile	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Benzene	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Bromobenzene	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Bromochloromethane	ND	2080		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Bromodichloromethane	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Bromoform	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Bromomethane	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM

Qualifiers:

B	Analyte detected in the associated Method Blank	BRL	Below Reporting Limit
E	Value above quantitation range	H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits	ND	Not Detected at the Reporting Limit
RL	Reporting Limit	S	Spike Recovery outside recovery limits

ANALYTICAL REPORT

Reported Date: 03-Nov-14

CLIENT:	CEI	**Client Sample ID:**	West Composite
Lab Order:	1410139	**Collection Date:**	10/20/2014
Project:	227-3	**Date Received:**	10/21/2014
Lab ID:	1410139-002	**Matrix:**	SEDIMENT

Analyses	Result	RL	Qual	Units	DF	Date Analyzed
VOLATILE ORGANIC COMPOUNDS - 8260B						Analyst: **ZC**
Prep Method:		**Prep Date:**				
Carbon Disulfide	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Carbon Tetrachloride	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Chlorobenzene	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Chloroethane	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Chloroform	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Chloromethane	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
cis-1,2-Dichloroethene	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
cis-1,3-Dichloropropene	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Dibromochloromethane	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Dibromomethane	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Dichlorodifluoromethane	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Diethyl Ether	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Diisopropyl Ether	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Ethylbenzene	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Ethyl-t-Butyl Ether	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Hexachlorobutadiene	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Isopropylbenzene	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Methyl Tert-Butyl Ether	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Methylene Chloride	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Naphthalene	ND	2080		µg/Kg-dry	1	10/24/2014 3:12:00 PM
n-Butylbenzene	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
n-Propylbenzene	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
sec-Butylbenzene	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Styrene	ND	2080		µg/Kg-dry	1	10/24/2014 3:12:00 PM
tert-Butylbenzene	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Tetrachloroethene	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Tetrahydrofuran	ND	2080		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Toluene	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
trans-1,2-Dichloroethene	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
trans-1,3-Dichloropropene	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Trichloroethene	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Trichlorofluoromethane	ND	2080		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Vinyl Chloride	ND	833		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Xylenes, Total	ND	2080		µg/Kg-dry	1	10/24/2014 3:12:00 PM
Surr: 1,2-Dichloroethane-d4	81.7	70-130		%REC	1	10/24/2014 3:12:00 PM
Surr: 4-Bromofluorobenzene	115	70-130		%REC	1	10/24/2014 3:12:00 PM

Qualifiers:

B	Analyte detected in the associated Method Blank	BRL	Below Reporting Limit
E	Value above quantitation range	H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits	ND	Not Detected at the Reporting Limit
RL	Reporting Limit	S	Spike Recovery outside recovery limits

GeoLabs, Inc.
45 Johnson Lane ~ Braintree MA 02184 ~ 781 848 7844 ~ 781 848 7811

ANALYTICAL REPORT

Reported Date: 03-Nov-14

CLIENT:	CEI	**Client Sample ID:**	West Composite
Lab Order:	1410139	**Collection Date:**	10/20/2014
Project:	227-3	**Date Received:**	10/21/2014
Lab ID:	1410139-002	**Matrix:**	SEDIMENT

Analyses	Result	RL	Qual	Units	DF	Date Analyzed
VOLATILE ORGANIC COMPOUNDS - 8260B						Analyst: **ZC**
Prep Method:		**Prep Date:**				
Surr: Dibromofluoromethane	95.2	70-130		%REC	1	10/24/2014 3:12:00 PM
Surr: Toluene-d8	102	70-130		%REC	1	10/24/2014 3:12:00 PM
TOTAL PHOSPHOROUS - L10-115-01-1-E						Analyst: **RP**
Prep Method:		**Prep Date:**				
Phosphorus, Total (As P)	*613*	18.7		mg/Kg-dry	1	11/3/2014

Qualifiers:

B	Analyte detected in the associated Method Blank	BRL	Below Reporting Limit
E	Value above quantitation range	H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits	ND	Not Detected at the Reporting Limit
RL	Reporting Limit	S	Spike Recovery outside recovery limits

GeoLabs, Inc.
45 Johnson Lane ~ Braintree MA 02184 ~ 781 848 7844 ~ 781 848 7811

1410139

GeoLabs, Inc.
Environmental Laboratories
45 Johnson Lane
Braintree, MA 02184
Office: 781-848-7844
Fax: 781-848-7811

Turnaround Time
RUSH: 24hrs ☐ 48hrs ☐ 72hrs ☐
STANDARD: 5 Days __X__ Rush Approved By: ____

Page__1__of__1__

SPECIAL INSTRUCTIONS
Total Phos added per Jessica - 10/22/14 (CD)

Client: CEI
Address: 225 Cedar Hill Street, Marlborough, MA 01752
Phone: 978-281-5160
Fax:
Contact: Jessica Cajigas
E-mail: jcajigas@ceiengineers.com

Project Number: 227-3
Project Location: Fawn Lake, Bedford, MA
Purchase Order #: 227-3
Collected By: N. Koncki and C. Busto

ANALYSES REQUESTED

SAMPLE ID	COLLECTION DATE	COLLECTION TIME	SAMPLED BY	SAMPLE LOCATION	CONTAINER TYPE	CONTAINER QUANT	MATRIX	COMP	GRAB	PRES	GEOLABS SAMPLE NUMBER 10139	Metals / T-Phos	PCBs	PAHs	TPHs	EPH	VOCs*	Volatile Solids %	Water Content %	TEMPERATURE	LAB pH
East Composite	10/21/14		NK		7 G, 1 V	8	Sed	X		7,*6	-001	X	X	X	X	X	X	X	X	7/F	
West Composite	10/21/14		NK		7 G, 1 V	8	Sed	X		7,*6	-002	X	X	X	X	X	X	X	X		

CONTAINER CODES:
A = Amber
B = Bag
G = Glass
P = Plastic
S = Summa Canister
O = Other V = VOA

MATRIX CODES:
GW = Ground Water
WW = Wastewater
DW = Drinking Water
SL = Sludge Sed = Sediment
S = Soil A = Air
O = Oil OT = Other

PRESERVATIVE CODES:
1 = HCl 7 = ICE
2 = HNO_3
3 = H_2SO_4
4 = $Na_2S_2O_3$
5 = NaOH
6 = MeOH

Relinquished By:	Date/Time	Received By:	Date/Time:
[signature]	10/21/14	[signature]	
Relinquished By: [signature]	10/21/14	Received By: [signature]	10-21-14 11:17
Relinquished By: [signature]	10-21-14 11:15	Received By GeoLabs: [signature]	10/21/14 1240

GEOLABS CHAIN OF CUSTODY

GeoTesting
EXPRESS

Technologies to manage risk for infrastructure

Boston
Atlanta
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Los Angeles
New York

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Transmittal

TO:

Jessica Cajigas
Comprehensive Environmental
225 Cedar Hill Road
Marlborough, MA 01752

DATE: 12/2/2014	GTX NO: 302464
RE: Fawn Lake	

COPIES	DATE	DESCRIPTION
	12/2/2014	**November 2014 Laboratory Test Report**

REMARKS:

SIGNED: Joe Tomei, Laboratory Manager

CC:

APPROVED BY: Nancy Hubbard, Project Manager

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December 2, 2014

Jessica Cajigas
Comprehensive Environmental
225 Cedar Hill Road
Marlborough, MA 01752

RE: Fawn Lake, Bedford, MA (GTX-302464)

Dear Jessica:

Enclosed are the test results you requested for the above referenced project. GeoTesting Express, Inc. (GTX) received two samples from you on 10/20/2014. These samples were labeled as follows:

East Composite
West Composite

GTX performed the following test on each of these samples:

ASTM D422 - Grain Size Analysis - Sieve Only

A copy of your test request is attached.

The results presented in this report apply only to the items tested. This report shall not be reproduced except in full, without written approval from GeoTesting Express. The remainder of these samples will be retained for a period of sixty (60) days and will then be discarded unless otherwise notified by you. Please call me if you have any questions or require additional information. Thank you for allowing GeoTesting Express the opportunity of providing you with testing services. We look forward to working with you again in the future.

Respectfully yours,

Joe Tomei
Laboratory Manager

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Geotechnical Test Report

12/2/2014

GTX-302464
Fawn Lake

Bedford, MA

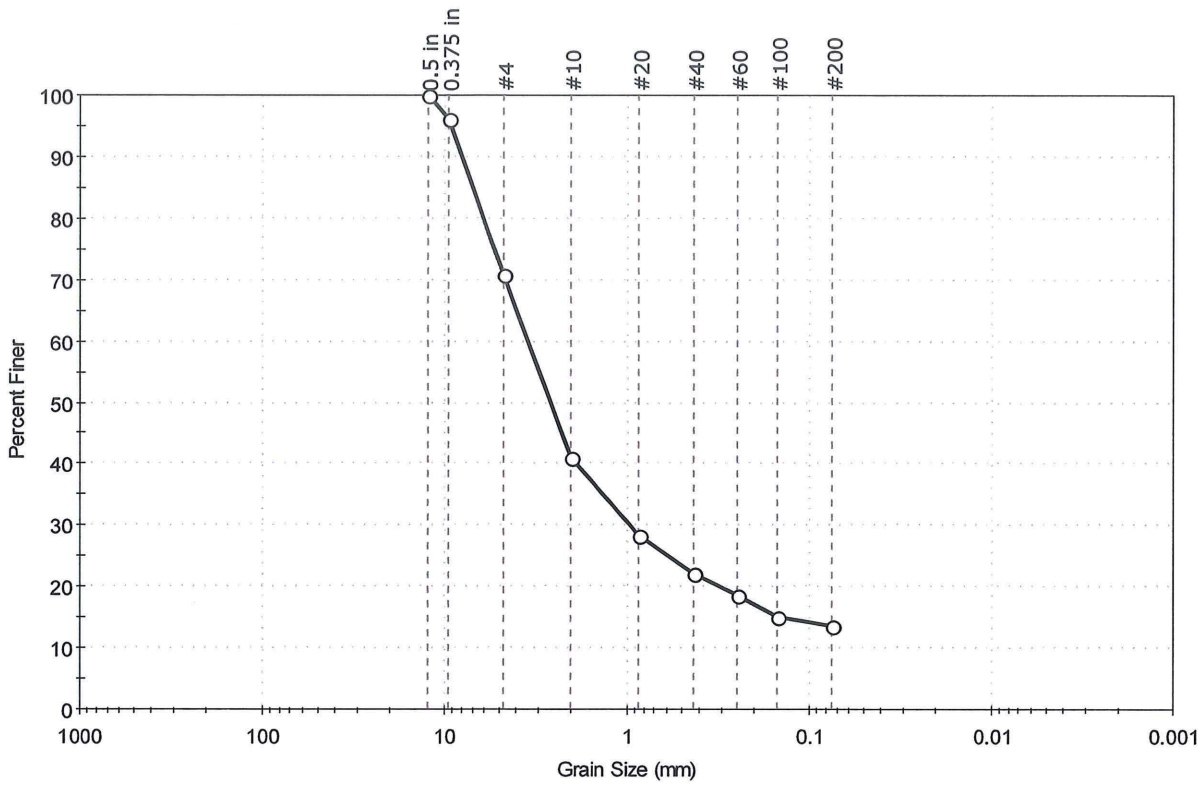
Client Project No.: 227-3

Prepared for:

Comprehensive Environmental

Client:	Comprehensive Environmental				
Project:	Fawn Lake				
Location:	Bedford, MA			Project No:	GTX-302464
Boring ID:	---	Sample Type:	bag	Tested By:	jbr
Sample ID:	East Composite	Test Date:	11/03/14	Checked By:	jdt
Depth :	---	Test Id:	312319		
Test Comment:	---				
Sample Description:	Wet, very dark brown silty sand with gravel and organics				
Sample Comment:	---				

Particle Size Analysis - ASTM D422



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	29.3	57.2	13.5

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
0.5 in	12.50	100		
0.375 in	9.50	96		
#4	4.75	71		
#10	2.00	41		
#20	0.85	28		
#40	0.42	22		
#60	0.25	19		
#100	0.15	15		
#200	0.075	14		

Coefficients

D_{85} = 6.9926 mm D_{30} = 0.9483 mm

D_{60} = 3.4730 mm D_{15} = 0.1411 mm

D_{50} = 2.5945 mm D_{10} = 0.0168 mm

C_u = 206.726 C_c = 15.413

Classification

ASTM N/A

AASHTO Stone Fragments, Gravel and Sand (A-1-a (0))

Sample/Test Description

Sand/Gravel Particle Shape : ROUNDED

Sand/Gravel Hardness : SOFT

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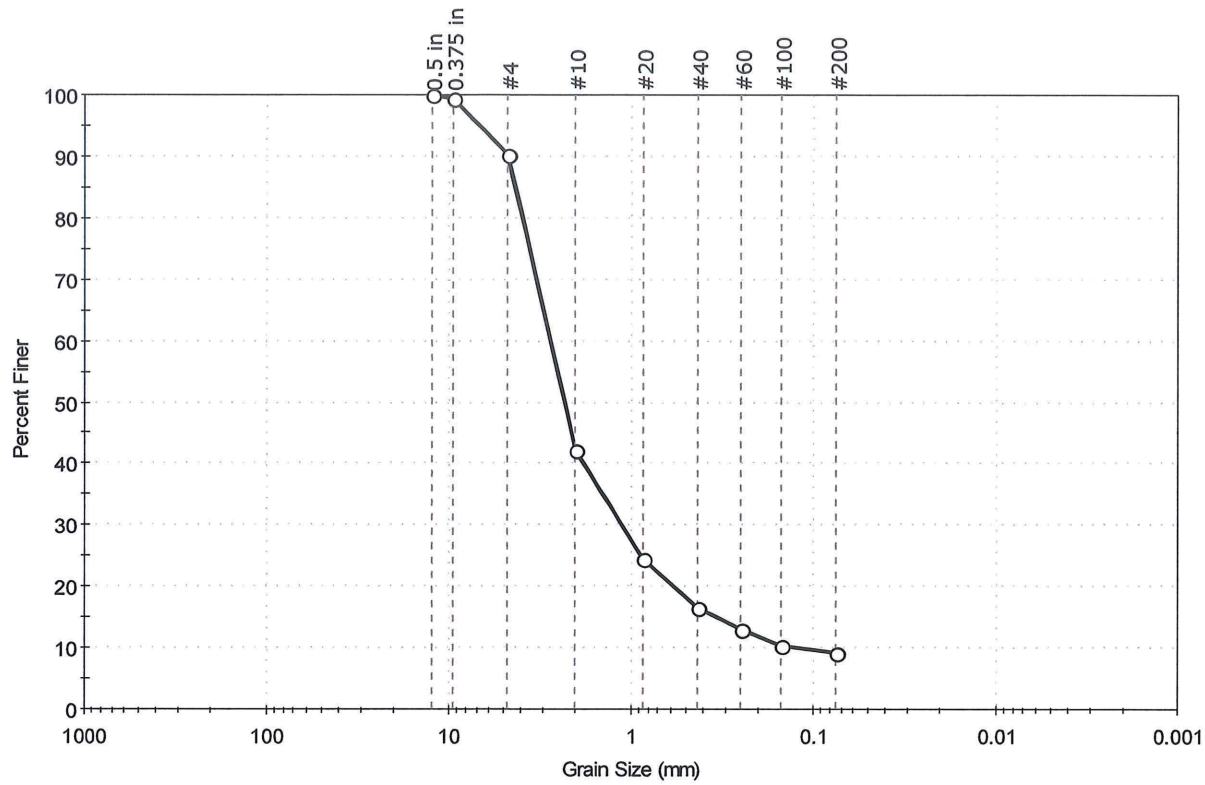
Client:	Comprehensive Environmental				
Project:	Fawn Lake				
Location:	Bedford, MA			Project No:	GTX-302464
Boring ID:	---	Sample Type:	bag	Tested By:	jbr
Sample ID:	West Composite	Test Date:	11/03/14	Checked By:	jdt
Depth :	---	Test Id:	312320		
Test Comment:	---				
Sample Description:	Wet, very dark brown sand with silt and organics				
Sample Comment:	---				

Particle Size Analysis - ASTM D422



% Cobble	% Gravel	% Sand	% Silt & Clay Size
—	9.7	81.1	9.2

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
0.5 in	12.50	100		
0.375 in	9.50	99		
#4	4.75	90		
#10	2.00	42		
#20	0.85	25		
#40	0.42	17		
#60	0.25	13		
#100	0.15	10		
#200	0.075	9.2		

Coefficients

D_{85} = 4.3202 mm D_{30} = 1.1074 mm

D_{60} = 2.7596 mm D_{15} = 0.3364 mm

D_{50} = 2.3067 mm D_{10} = 0.1201 mm

C_u = 22.978 C_c = 3.700

Classification

ASTM N/A

AASHTO Stone Fragments, Gravel and Sand (A-1-a (1))

Sample/Test Description

Sand/Gravel Particle Shape : ROUNDED

Sand/Gravel Hardness : SOFT

printed 11/4/2014 1:42:52 PM

GeoTesting EXPRESS

SOIL CHAIN OF CUSTODY & TEST REQUEST

GeoTesting Express, Inc.
125 Nagog Park
Acton, MA 01720
800 434 1062 Toll Free
978 635 0266 Fax

2358 Perimeter Park Drive, Suite 320
Atlanta, GA 30341
770 645 6575 Tel
770 645 6570 Fax

www.geotesting.com

CLIENT		INVOICE (complete if different from Client)	
Company: Comprehensive Environmental Inc.		Company:	
Address: 225 Cedar Hill Street		Address:	
City, State, Zip: Marlborough, MA 01752		City, State, Zip:	
Contact: Jessica Cajigas	Phone: 508-281-5160	Contact:	Phone:
E-mail: jcajigas@ceiengineers.com	Cell:	E-mail:	Cell:

PROJECT		
Project Name: Fawn Lake	Client Project #: 227-3	Purchase Order#: 227-3
Project Location: Bedford, MA	GTX Sales Order #:	Requested Turnaround: 5 days
On-site Contact: Natalie Koncki	E-mail: nkoncki@ceiengineers.com	Phone:508-281-5160

SOIL																					
Boring ID	Sample ID	Depth	Atterberg Limits (ASTM D 4318)	USCS – Classification (ASTM D 2487)	Grain Size (ASTM D 422) (Sieve Only) (Sieve & Hydrometer) – please circle one	Density (ASTM D 2937) (ASTM D 7263) please circle one	Moisture Content (ASTM D 2216)	Organic Content (ASTM D 2974)	pH (ASTM D 4972)	Specific Gravity (ASTM D 854)	Electrical Resistivity (ASTM G 57)	Proctor Compaction (Standard – ASTM D 698) (Modified – ASTM D 1557) please circle one	California Bearing Ratio * (ASTM D 1883)	Direct Shear* (ASTM D 3080)	Triaxial Shear* (UU – ASTM D 2850) (CU – ASTM D 4767) (CD – ASTM D7181) Please circle one	Incremental Consolidation* (ASTM D 2435)	Permeability/ Hydraulic Conductivity* (Fixed Wall – ASTM D 2434) (Flexible Wall – ASTM D 5084) Please circle one	Unconfined Compression (ASTM D 2166)	Other:	Other:
	East Composite				X																
	West Composite				X																

*Specify Test Conditions (Undisturbed or Remolded, Density and moisture, Test Normal Loads, Test Confining Stresses, etc.):

AUTHORIZE BY SIGNING AND DATING:

SIGNATURE: [signature] PRINT NAME: Natalie Koncki DATE: 10/20/14

For GTX Use Only
Incoming Sample Inspection Performed ☐
Adverse conditions:

Relinquished By:	DATE:	Received By:	DATE: 10/20/14
	TIME:		TIME: 1411
Relinquished By:	DATE:	Received By:	DATE:
	TIME:		TIME:

GeoTesting EXPRESS

WARRANTY and LIABILITY

GeoTesting Express (GTX) warrants that all tests it performs are run in general accordance with the specified test procedures and accepted industry practice. GTX will correct or repeat any test that does not comply with this warranty. GTX has no specific knowledge as to conditioning, origin, sampling procedure or intended use of the material.

GTX may report engineering parameters that require us to interpret the test data. Such parameters are determined using accepted engineering procedures. However, GTX does not warrant that these parameters accurately reflect the true engineering properties of the *in situ* material. Responsibility for interpretation and use of the test data and these parameters for engineering and/or construction purposes rests solely with the user and not with GTX or any of its employees.

GTX's liability will be limited to correcting or repeating a test which fails our warranty. GTX's liability for damages to the Purchaser of testing services for any cause whatsoever shall be limited to the amount GTX received for the testing services. GTX will not be liable for any damages, or for any lost benefits or other consequential damages resulting from the use of these test results, even if GTX has been advised of the possibility of such damages. GTX will not be responsible for any liability of the Purchaser to any third party.

Commonly Used Symbols

A	pore pressure parameter for $\Delta\sigma_1 - \Delta\sigma_3$
B	pore pressure parameter for $\Delta\sigma_3$
CIU	isotropically consolidated undrained triaxial shear test
CR	compression ratio for one dimensional consolidation
C_c	coefficient of curvature, $(D_{30})^2 / (D_{10} \times D_{60})$
C_u	coefficient of uniformity, D_{60}/D_{10}
C_c	compression index for one dimensional consolidation
C_α	coefficient of secondary compression
c_v	coefficient of consolidation
c	cohesion intercept for total stresses
c'	cohesion intercept for effective stresses
D	diameter of specimen
D_{10}	diameter at which 10% of soil is finer
D_{15}	diameter at which 15% of soil is finer
D_{30}	diameter at which 30% of soil is finer
D_{50}	diameter at which 50% of soil is finer
D_{60}	diameter at which 60% of soil is finer
D_{85}	diameter at which 85% of soil is finer
d_{50}	displacement for 50% consolidation
d_{90}	displacement for 90% consolidation
d_{100}	displacement for 100% consolidation
E	Young's modulus
e	void ratio
e_c	void ratio after consolidation
e_o	initial void ratio
G	shear modulus
G_s	specific gravity of soil particles
H	height of specimen
PI	plasticity index
i	gradient
K_o	lateral stress ratio for one dimensional strain
k	permeability
LI	Liquidity Index
m_v	coefficient of volume change
n	porosity
PI	plasticity index
P_c	preconsolidation pressure
p	$(\sigma_1 + \sigma_3) / 2$, $(\sigma_v + \sigma_h) / 2$
p'	$(\sigma'_1 + \sigma'_3) / 2$, $(\sigma'_v + \sigma'_h) / 2$
p'_c	p' at consolidation
Q	quantity of flow
q	$(\sigma_1 - \sigma_3) / 2$
q_f	q at failure
q_o, q_i	initial q
q_c	q at consolidation
S	degree of saturation
SL	shrinkage limit
s_u	undrained shear strength
T	time factor for consolidation
T	temperature
t	time
U, UC	unconfined compression test
UU, Q	unconsolidated undrained triaxial test
u_a	pore gas pressure
u_e	excess pore water pressure
u, u_w	pore water pressure
V	total volume
V_g	volume of gas
V_s	volume of solids
V_v	volume of voids
V_w	volume of water
V_o	initial volume
v	velocity
W	total weight
W_s	weight of solids
W_w	weight of water
w	water content
w_c	water content at consolidation
w_f	final water content
w_l	liquid limit
w_n	natural water content
w_p	plastic limit
w_s	shrinkage limit
w_o, w_i	initial water content
α	slope of q_f versus p_f
α'	slope of q_f versus p_f'
γ_t	total unit weight
γ_d	dry unit weight
γ_s	unit weight of solids
γ_w	unit weight of water
ε	strain
ε_{vol}	volume strain
ε_h, ε_v	horizontal strain, vertical strain
μ	Poisson's ratio, also viscosity
σ	normal stress
σ'	effective normal stress
σ_c, σ'_c	consolidation stress in isotropic stress system
σ_h, σ'_h	horizontal normal stress
σ_v, σ'_v	vertical normal stress
σ_1	major principal stress
σ_2	intermediate principal stress
σ_3	minor principal stress
τ	shear stress
φ	friction angle based on total stresses
φ'	friction angle based on effective stresses
φ'_r	residual friction angle
φ_{ult}	φ for ultimate strength

Appendix C

Fawn Lake Alternative Strategies Matrix

Fawn Lake Preservation Study
Pond Management Strategies Matrix

		1	2	3	4	5	6	7
	Management Alternatives: →	Dredging			Bio-dredging	Chemical Treatment		
	Considerations: ↓	**Mechanical dry dredging**	**Mechanical wet dredging**	**Hydraulic dredging**		**Diquat (Reward)**	**Glyphosate (Rodeo)**	**Fluridone (Sonar)**
A	Description	Mechanical scraping of the sediment and plant material, usually with a bulldozer,large excavator or front-end loader. Materials are deposited/ collected on shore	Mechanical scraping of the sediment and plant material, usually with a clamshell, bucket dredge, or dragline. Materials are deposited/ collected on shore	Similar to mechanical dredging but the sediment debris is agitated and then sucked out through a pipeline to the collection area from a floating structure or a barge	Digesting organic sediments in situ through the introduction of bacteria, often using bio-stimulants/enzymes	Area-targeted application of herbicides for submersed/floating vegetation	Area-targeted application of herbicides for emergent/floating vegetation	Area-targeted application of herbicides for submersed vegetation
B	Environmental Impacts	Deepening of lake; water quality improvements, temporary destruction of shallow habitats	Deepening of lake; water quality improvements, temporary destruction of shallow habitats	Deepening of lake; water quality improvements, temporary destruction of shallow habitats	Bacteria will degrade organic matter into CO2, water, and bacterial biomass, reducing the amount of organic sediment and increasing depth of the lake	Habitat enhancement, kills nuisance species and any other aquatic species it comes in contact with, doesn't disturb sediment or seeds, food source alteration	Habitat enhancement, doesn't disturb sediment or disperse seeds, can cause unintended death of other plants, can reduce DO, potential food source alteration	Habitat enhancement, doesn't disturb sediment or disperse seeds, can reduce DO and nutrient release, potential food source alteration
C	Logistics of Strategy	Dewater the lake, use backhoe/excavator to remove plants and sediments to specified depth, dredged material is staged and dewatered; water may be returned to lake. Can be performed in any season	Lake doesn't have to be dewatered first. Use clamshell, bucket dredge, or dragline to remove plants and sediments to specified depth, dredged material is staged and dewatered; water may be returned to lake	Lake is not dewatered. Barge with a suction line used to suck out plants and sediments to specified depth, dredged material is pumpeed to shore, staged and dewatered; water may be returned to lake. Perform during summer months to avoid freezing of pump systems	Large inoculation dose added to get bacterial population established, then maintenance doses applied to ensure they continue to thrive	Treatment applied early in the season to target early growth stages	Complete permitting in spring, pre-treatment inspection, apply herbicide early in growing season, post-treatment inspection	Complete permitting in spring, pre-treatment inspection, apply herbicide early in growing season, post-treatment inspection
D	Sediment Disposal Options (if needed)	Disposal, reuse	Disposal, reuse	Disposal, reuse	N/A	N/A	N/A	N/A
E	Impacts to Surrounding Properties	Odor issues throughout the entire lake and staging processing area. Construction noise, increased truck traffic	Odor issues throughout the entire lake and staging processing area. Construction noise, increased truck traffic	Odor issues confined to staging/processing area. Increased truck traffic	None	None	None	None
F	Future O&M Associated with the Strategy	No Maintenance	No Maintenance	No Maintenance	Low Maintenance	Low Maintenance	Low Maintenance	Low Maintenance
G	Time to Complete Treatment	Permitting - one year; implementation of dredging is dependent on amount, to dredge the entire lake it is estimated to take one-two years	Permitting - one year; implementation of dredging is dependent on amount, to dredge the entire lake it is estimated to take one-two years	Permitting - one year; implementation of dredging is dependent on amount, to dredge the entire lake it is estimated to take one-two years	Dependent on how bacteria responds to aquatic plants.	Depends on the area treated, plants generally controlled after 7-10 days, 6 months (permitting to application)	Depends on the area treated, typically 7 days herbaceous and 30 for woody, 6 months (permitting to application)	Depends on the area treated, typically plants respond after 30-90 days, 6 months (permitting to application)
H	How Long Strategy is Effective	Some projects have seen lower species for 10 years	Some projects have seen lower species for 10 years	Some projects have seen lower species for 10 years	Little documentation on long term effectiveness.	Typically 1-2 years	Typically 1-2 years	Typically 1-2 years; but control of floating veg is not expected to be achieved thru herbicide only
I	Potential Permits Required	NOI/Order of Conditions - MA Wetlands Protection Act/Bedford Wetland Protection Bylaw; MassDEP Water Quality Certification; MassDEP 401 Water Quality Certification-Dredge and Fill; Possible Chapter 91 Permit; Army Corps of Engineers Individual Permit; MEPA ENF, Potential archeological and/or historical documentation	NOI/Order of Conditions - MA Wetlands Protection Act/Bedford Wetland Protection Bylaw; MassDEP Water Quality Certification; MassDEP 401 Water Quality Certification-Dredge and Fill; Possible Chapter 91 Permit; Army Corps of Engineers Individual Permit; MEPA ENF, Potential archeological and/or historical documentation	NOI/Order of Conditions - MA Wetlands Protection Act/Bedford Wetland Protection Bylaw; MassDEP Water Quality Certification; MassDEP 401 Water Quality Certification-Dredge and Fill; Possible Chapter 91 Permit; Army Corps of Engineers Individual Permit; MEPA ENF, Potential archeological and/or historical documentation	NOI/Order of Conditions - MA Wetlands Protection Act/Bedford Wetland Protection Bylaw; ACOE Programmatic General Permit; MEPA	NOI/Order of Conditions - MA Wetlands Protection Act/Bedford Wetland Protection Bylaw; Application to Apply Herbicides to Waters of the Commonwealth	NOI/Order of Conditions - MA Wetlands Protection Act/Bedford Wetland Protection Bylaw; Application to Apply Herbicides to Waters of the Commonwealth	NOI/Order of Conditions - MA Wetlands Protection Act/Bedford Wetland Protection Bylaw; Application to Apply Herbicides to Waters of the Commonwealth
J	Permitting Complexity	High	High	High	Low-medium	Low	Low	Low
K	Estimated Cost for Permitting	$100,000	$100,000	$100,000	$25,000	$5,000	$5,000	$5,000
L	Estimated Total Cost	$384,000-$1,440,000/Fawn Lake.	$720,000-$1,200,000/Fawn Lake	$336,000-$1,440,000/Fawn Lake	$128,000-$720,000/Fawn Lake	$6,500/Fawn Lake	$5,750-$11,500/Fawn Lake	$5,750-$23,000/Fawn Lake
M	Plant Response	Entire plants are removed; Often creates large usable areas of lake; nonselective vegetation application	Entire plants are removed; Often creates large usable areas of lake; nonselective vegetation application	Entire plants are removed; Often creates large usable areas of lake; nonselective vegetation application	Will not affect plants directly, will affect sediment depth, but can change the N-P ratio and indirectly alter plant growth	acts in 7 days	acts in 7-10 days, up to 4 weeks	Plant response in 30-90 days
N	Advantages	Results can be very long term; creates deeper water; may also create more diversity in plant community	Results can be very long term; creates deeper water; may also create more diversity in plant community	Creates minimal turbidity; less impact on biota; allows removal with limited access or shoreline disturbance; can still use other portions of lake while working in another area. No lake drawdown required, can easily be phased.	Reduce "muck" on bottom; may improve water clarity;	Rapid action, limited drift; no disturbance of sediment or spreading of seeds	Widely used, few label restrictions, systemic; no disturbance of sediment or spreading of seeds	Very low dosage required, few label restrictions, systemic; no disturbance of sediment or spreading of seeds, no impacts to fish and wildlife after application
O	Disadvantages	Very expensive; causes turbidity; environmental impacts; disposal of dredge sediment; loss of all use of lake during work; odor issues during all work; potential colonization by invasive species; no guarantee plants won't return, especially when sunlight can still reach bottom.	Very expensive; causes turbidity; environmental impacts; disposal of dredge sediment; loss of all use of lake during work; odor issues during all work; potential colonization by invasive species; no guarantee plants won't return, especially when sunlight can still reach bottom.	Leaves some sediment behind; difficult with coarse sediment; requires containment area and disposal of dredge sediment; odor issues as staging location; no guarantee plants won't return, especially when sunlight can still reach bottom.	Must be applied multiple times per season (~every 2 weeks); Limited testing and documentation; few experienced applicators; very little data on effectiveness; very dependent on specific mixture and conditions.	Does not affect underground portions	Very slow action, no submersed control	Very long contact period
P	Systems Where Used Effectively	Shallow ponds and lakes, particularly those filled in by sedimentation. Best if used as a multipurpose lake remediation technique. Dredging alone is best for water depth issue (recreation or reservoir storage), not for plant control.	Shallow ponds and lakes, particularly those filled in by sedimentation. Best if used as a multipurpose lake remediation technique. Dredging alone is best for water depth issue (recreation or reservoir storage), not for plant control.	Shallow ponds and lakes, particularly those filled in by sedimentation. Best if used as a multipurpose lake remediation technique. Dredging alone is best for water depth issue (recreation or reservoir storage), not for plant control.	In older ponds with a thick layer of dark organic "muck"	Shoreline, localized treatment, higher exchange rate areas	Nature preserves and refuges; best results on emergent and floating plants	Small lakes, slow-flowing systems

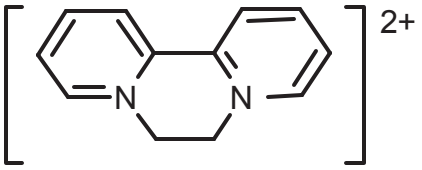
Fawn Lake Preservation Study
Pond Management Strategies Matrix

	8	9	10	11	12	13	14	15
						Dam		
	Hydroraking	**Weed harvesting/mechanical harvesting**	**Water level drawdown**	**Sub-surface barriers**	**Aeration/Artificial Circulation**	**Remove dam-revert to natural system**	**Rehab/raise dam**	**Do nothing**
A	Mechanical rake used to disturb sediment and debris, then collection/removal of floating and/or submerged vegetation and organic debris	Mechanical cutting and removal of weeds	"De-water" the lake for an extended period of time, typically >6-8 weeks	Use of natural or synthetic materials to cover submersed plants (and may prevent light from reaching plants)	Aeration increases the level of dissolved oxygen in the lake which may affect photosynthesis in submersed plants	Remove the dam which will speed up the process of succession.	Add soil materials to the dam to raise the elevation, increasing the depth of water and making it more difficult for light to reach the plants.	Take no action to prevent the growth of aquatic vegetation
B	Can reduce aquatic fish and wildlife habitat. Removes plants so the nutrients provided from their decomposition are also removed from the cycle	Can reduce aquatic fish and wildlife habitat. Removes plants so the nutrients provided from their decomposition are also removed from the cycle	Non-selective, will impact all wildlife, can reduce sediment volume, available nutrients	Heavily affects benthic communities	Improve oxygen levels, increase turbulence, improved habitats, increase die-off rates of bacteria, resuspend solids, can increase algal growth by mixing unwanted substances throughout the lake	Wetland succession processes will eventually change the environment from a lake to an emergent wetland/riverine community. Loss of fish habitat, potential for invasive species to opportunistically grow in the quickly changing environment	Destruction of bordering vegetated resource areas but increase in submerged resource areas	Wetland succession processes will eventually change the environment from a lake to an emergent wetland community. Loss of fish habitat
C	Permitting in the winter/spring, hydrorake in the early fall	Permitting in the winter/spring, harvesting in the early fall	Pump or siphon to remove all water to a given depth usually over the winter. Depth should include depth range of target species. Plants are exposed which facilitates drying and freezing or plants and roots	Cover areas with a growth-inhibiting substance (sheets, screens) for at least 1 to 2 months. Remove barriers to prevent sediment buildup and colonization on top. Best if followed by harvesting method	Install fountain or other submersed aeration system, aeration and circulation can suppress and disperse nuisance growth of algae and improve oxygen levels for fish	The dam will be removed to facilitate/speed up draining of the lake. It will not dry immediately. Over time, the lake will eventually fill in with sediment and plant biomass	Extend and elevate berm, add berms in low lying areas and perform construction to raise dam elevation and inundate more land area	No action will be take to remove plants or prevent their growth. Over time, the lake will eventually fill in with sediment and plant biomass
D	Disposal, reuse, composting	Disposal, reuse, composting	N/A	N/A	N/A	N/A	N/A	N/A
E	Minor noise, use disturbance, truck traffic to truck material out	Minor noise, use disturbance, truck traffic to truck material out	Odor issues during drawdown before sediment/vegetation dries out, nearby stabilization and odor control can help mitigate problem	None	During installation and maintenance	Odor issues of decaying plant matter, increased truck traffic	Construction noise, increased truck traffic	No impact
F	No Maintenance	No Maintenance	Low Maintenance	High Maintenance	Medium Maintenance	Medium Maintenance	High Maintenance	No Maintenance
G	Permitting, plus about 3.5 weeks to hydrorake 5-6 acres of Fawn Lake	Permitting, plus about 3.5 weeks to harvest 5-6 acres of Fawn Lake	Drawdown needs to be at least 1 month long to ensure drying, or if in winter, long enough for sediment to freeze.	Non-selective, plant mortality within 1 month under barrier	2 month installation	Permitting - one year; dam removal 2 months	Permitting - one year; dam rehab 1-2 years depending on size	N/A
H	Typically 3-5 years, then would have to be repeated	Annually because aquatic plants present are perennials and will regrow	Process would be repeated annually indefinitely	Can last several seasons. Might have to flip barrier over every 6-8 weeks, remove and replace barrier, or remove build-up of sediment on top.	As long as the device is in operation and maintained	Forever	Until sediment depth and plant die-off catches up with raised elevation, typical sedimentation ranges from 1-10 millimeters per year	N/A
I	NOI/Order of Conditions - MA Wetlands Protection Act/Bedford Wetland Protection Bylaw	NOI/Order of Conditions - MA Wetlands Protection Act/Bedford Wetland Protection Bylaw	NOI/Order of Conditions - MA Wetlands Protection Act/Bedford Wetland Protection Bylaw; MassDEP Water Quality Certification; Possible Chapter 91 Permit; Army Corps of Engineers Individual Permit; MEPA ENF, Potential archeological or historical documentation	NOI/Order of Conditions - MA Wetlands Protection Act/Bedford Wetland Protection Bylaw; Potential Chapter 91 Permit; Army Corps of Engineers Permit; MEPA ENF	NOI/Order of Conditions - MA Wetlands Protection Act/Bedford Wetland Protection Bylaw; Potential Chapter 91 Permit; Army Corps of Engineers Permit; MEPA ENF	NOI/Order of Conditions - MA Wetlands Protection Act/Bedford Wetland Protection Bylaw; MassDEP Water Quality Certification; MassDEP 401 Water Quality Certification-Dredge and Fill; Possible Chapter 91 Permit; Army Corps of Engineers Individual Permit; MEPA ENF, Potential archeological and/or historical documentation	NOI/Order of Conditions - MA Wetlands Protection Act/Bedford Wetland Protection Bylaw; MassDEP Water Quality Certification; MassDEP 401 Water Quality Certification-Dredge and Fill; Possible Chapter 91 Permit; Army Corps of Engineers Individual Permit; MEPA ENF, Potential archeological and/or historical documentation	N/A
J	Low	Low	High	Medium	Medium	High	High	N/A
K	$7,500	$7,500	$100,000	$50,000	$50,000	$100,000	$100,000	N/A
L	$140,000/Fawn Lake	$4,025-$17,250/Fawn Lake *Removal of plant masses during previous treatment was performed by Bedford DPW and did not add to the overall project cost	$3,000-$10,000 per year for execution and monitoring. If need to alter dam, typically at least $100,000.	$230,000-$575,000/Fawn Lake	Capital Costs $2,300-$34,500/Fawn Lake plus $575-$9,200/Fawn Lake annually	$270,000-$290,000/Fawn Lake	Engineering $100,000. Minor repairs were estimated at $4,000 to $6,000, remedial measures at $120,000 to $170,000 for design and construction	N/A
M	Immediately removes/kills entire plant; nonselective vegetation application	Immediately removes/kills entire plant; nonselective; short-term effect if perennial plants - will just regrow.	Plants dry out and/or freeze and die; most effective on evergreen perennials, less effective on herbaceous perennials; but others may increase after. Decrease - lilies, watershield, coontail; Increase - bushy	Non-selective, plant mortality within 1 month under barrier	Very little impact to plants, effect will be indirect through minimal impact on P and DO. Aeration is effective for algae which is not a problem in Fawn Lake.	Favors wetland succession and alters previous plant community	Only impacts plants if water depth can be increased to 10 feet or greater.	Favors emergent species. No direct impact to plants.
N	Removes entire plant, root, and some sediment; selective area control	Removes plant biomass; selective area control; no temporary water use restrictions	Kills vegetative portions of plants; inexpensive, can be very effective, moderate term; requires only outlet control; complements other strategies	Direct and effective; may last several seasons; reduces turbidity	Increased oxygen levels, decreases the release of phosphorus from sediment; improves habitat for fish and invertebrates	Promotes natural riverine system as long as hydrologic input can be quantified	Increases the area of the lake, increases the depth	No cost
O	Can leave fragments which can re-root; may impact lake biota; non-selective; creates turbidity; more expensive than harvesting (cut and remove)	Slower; leaves roots; resuspension of sediments; required disposal; also removes large numbers of macroinvertebrates, fish, and other wildlife	Can have severe environmental impacts, stranding and harming non-target flora and fauna; recreational impacts (no/limited use during drawdown);may not be effective on all emergent species and may facilitate the growth of others; lilies are very hearty and not very susceptible to drying/freezing; presence of groundwater seepage may mitigate or negate and keep area moist and unfrozen; does not kill seeds	High maintenance; expensive and small-scale; non-selective; too expensive to use over widespread areas; limits benthic invertebrates and fish species; does not remove the plant biomass	Power and O&M costs; low efficiency; no real direct impact on number or type of plants present in Fawn Lake.	This is against the goal for Fawn Lake; Loss of most recreational uses of the lake; likely introduction of opportunistic invasive species (purple loosestrife).	Submerges adjacent property; difficult to permit; expensive; plants not removed; if light reaches the bottom will not be effective and plants will still be present; more effective to combine with other management technique	This is against the goal for Fawn Lake; Loss of most recreational uses of the lake
P	Most effective in lakes 1-12 feet deep; overall effectiveness depends on the goals for the lake; can do in cycles over several years	Best used when problem is with annual plants, otherwise just regrow. Best if done prior to dropping of seeds.	Only useful for man-made lakes with a dam or water control structure; best in lakes with low organic sediments because organics minimize drying/freezing	Best around docks, boat launches, swimming areas, and other small, intensive use areas. This treatment works best if followed by mechanical harvesting	Most systems are typically used in larger stratified lakes or reservoirs dealing with water quality (algae, Fe, Mn, DO) issues. Fountains can be used in smaller systems, but high expense; not for colder climates where need to remove in winter	Dam removal is normally reserved for river/stream restoration to re-establish fish passage	More isolated lakes or reservoirs where additional storage is desired	N/A

Appendix D

MassDCR Herbicide Information Sheets

III.2 DIQUAT



DIQUAT

SUMMARY

Diquat (6,7-dihydrodipyridol[1,2-a:2',1'-c] pyrazinediium ion) is a water-soluble contact type, nonselective herbicide that is used to control many submerged and floating aquatic macrophytes and some types of filamentous algae in static and low-turbidity water (Klingman, Aston and Noordhoff, 1975 as cited in Aquatic Plant Identification and Herbicide Use Guide, 1988). Diquat binds very strongly and rapidly to sediments and once bound, it is very persistent (Reinert and Rodgers, 1987). When used as an aquatic herbicide at recommended application rates, diquat residues in water decrease rapidly to essentially undetectable levels within 7-14 days (State of Washington, 1984). The rate of diquat bioconcentration in fish is negligible (Reinert and Rodgers, 1987).

The common name, diquat, refers to the cation, which is responsible for the herbicidal action of the salt. The associated anion (i.e., bromide) has no effect on the herbicidal activity.

Many studies have been conducted using diquat addressing both toxicity and environmental fate and persistence. The EPA approved a Reregistration Eligibility Decision (RED) for diquat dibromide in July, 1995.

REGISTERED PRODUCTS IN MASSACHUSETTS

The current list of aquatic herbicides containing diquat that are registered in Massachusetts can be accessed at http://www.state.ma.us/dfa/pesticides/water/Aquatic/Herbicides.htm

on the Massachusetts Department of Agricultural Resources (DAR) Aquatic Pesticide Website. The DAR updates this list regularly with changes. In addition, the DAR can be contacted directly at (617) 626-1700 for more specific questions regarding these products.

DIQUAT USES AND APPLICATION

Diquat can be used to control both submerged and floating weeds. For submerged weeds, the diquat can be injected below the water surface or it can be applied directly into the water while moving slowly over the water surface in a boat. For floating plants, the foliage should be thoroughly wetted with diquat using either surface or aerial spraying (Herbicide Handbook, 1983; Aquatic Plant Identification and Herbicide Use Guide, 1988). Turbid or muddy water or mud-coated vegetation greatly reduces the effectiveness of diquat as the herbicide becomes adsorbed to particles (Aquatic Plant Identification and Herbicide Use Guide, 1988). Improved efficacy of diquat can often be achieved when applied in a mixture with complexed copper formulations (Aquatic Plant Identification and Herbicide Use Guide, 1988). In some cases it is recommended that diquat be applied with water carrier, thickener or invert emulsion carrier. The following adjuvants are recommended for use with diquat: for aerial applications, a nonionic surfactant to improve the ability of diquat to penetrate waxy plant cuticles (e.g., Ortho X-77 Spreader); for submersed growth, a polymeric thickener to improve sinking, herbicide confinement and contact properties (e.g., Nalquatic) (Aquatic Plant Identification and Herbicide Use Guide, 1988).

A formulation of diquat dibromide aquatic herbicide) targets the list of aquatic plants in Table III-2-1 (Zeneca, 1994). This herbicide controls the aquatic plants in Table III 2-1.

Diquat can be used at anytime during the growing season although control of early growth is recommended. Treatment of dense weed areas may result in oxygen loss from decomposition of dead weeds. The loss of oxygen may cause fish suffocation. Therefore, treat only 1/3 to 1/2 of the dense weed areas at a time and wait 14 days between treatments (Zeneca, 1994).

For specific information on recommended application rates for a particular product, the product label should be consulted. The USEPA Office of Pesticide Programs (OPP) has a link to a database of product pesticide labels at http://www.epa.gov/pesticides/pestlabels/. A list of the weeds that these products control, which has been compiled from the Environmental Protection Agency (EPA) registration labels for these products, is contained in Table III.2-1.

MECHANISM OF ACTION

Diquat's herbicidal activity and organic chemical reactions of diquat formulations are dependent only on the diquat cation and are not influenced by the nature of the associated anion, since the salts are mostly dissociated in aqueous solution (Herbicide Handbook, 1983). Diquat is absorbed readily by foliage through the cuticle of the leaf. Absorption is rapid, resulting in concentrations in plant tissues well above that in surrounding water so that very low concentrations (i.e., 0.1-1.5 ppm) in water will give effective control (HSDB, 1994). No absorption through buried plant roots occurs due to the rapid binding and inactivation of diquat by sediments (Aquatic Plant Identification and Herbicide Use Guide, 1988). Diquat is translocated only locally in plant tissues (Aquatic Plant Identification and Herbicide Use Guide, 1988). Diquat's mode of action is not clear but it is known that the mechanism is light-dependent (USEPA, 1992a; HSDB, 1994). Diquat interferes with the photosynthetic process, releasing strong oxidizers that rapidly disrupt and inactivate cells and cellular functions (Aquatic Plants Management Program for Washington State, 1992). This action results in the rapid death of the foliar parts of practically all plant species (HSDB, 1994).

ENVIRONMENTAL FATE/TRANSPORT

The available database for diquat indicates that dissipation following application is very rapid, initially by mixing and subsequently by adsorption by plants and sediments (USEPA, 1994). Once diquat reaches the sediments, it is tightly bound and is biologically unavailable.

Diquat is stable in neutral or acid conditions but hydrolyzes in the presence of alkaline materials including alkaline waters (Herbicide Handbook, 1979 as cited in HSDB, 1994). Volatilization and oxidation of diquat are insignificant fate processes.

Diquat is subject to photochemical degradation in surface layers of water in 1-3 or more weeks when not adsorbed to particulate matter (Sanborn, 1977). A 50% loss of diquat was noted within 48 hours when exposed to a UV source (Simsiman *et al.*, 1976 as cited by Reinert and Rodgers, 1987). A photodecomposition half-life of 1.6 weeks was calculated from the results of a study in which diquat in 20-cm glass petri plates was subjected to natural sunlight (Smith and Grove, 1969 as cited in Reinert and Rodgers, 1987). Diquat has a reported photolysis half-life of 2-11 days (Reinert and Rodgers, 1987). Despite the above information, photodegradation is not considered a major fate process for diquat in aquatic environments (Simsiman *et al.*, 1976 as cited by Reinert and Rodgers, 1987).

The photochemical breakdown of diquat on plant surfaces and in water exposed to sunlight releases 1,2,3,4-tetrahydro-1-oxopyrido-[1,2-a]-5-pyrazinium ion (TOPPS) as the major degradation product.

Further irradiation produces picolinamide and then degrades further via picolinic acid to volatile fragments (Smith and Grove, 1969 as cited in Aquatic Plants Management Program for Washington State, 1992). When a solution containing 5 ppm of diquat was exposed to sunlight during May and June, 70% of the diquat was degraded in 3 weeks. Picolinic acid and TOPPS were major photodegradation products (Smith and Grove, 1969 as cited in HSDB, 1994). A secondary degradation pathway results in diones and, to a limited extent, to monopyridone (Aquatic Plants Management Program for Washington State, 1992).

The major fate process for diquat in water is its propensity for rapidly binding to sediments. This property is due to its double positively charged diquat cation and clay minerals present in soil. The diquat cation may also insert itself between the layer planes of certain minerals such as montmorillonite (Reinert and Rodgers, 1987). Diquat may also incorporate into humus and/or become physically adsorbed to organic matter and particles (Aquatic Plants Management Program for Washington State, 1992). About 80-95% of diquat introduced into a flask containing sediment/water was sorbed to the sediment within 2 days (Simsiman and Chesters, 1976). Diquat is characterized by a fairly high octanol-water (K_{ow}) partition coefficient of 603 and adsorption coefficients (K_{oc}) ranging from 205-691ml/g based on various sediment types (Reinert and Rodgers, 1987). Once bound, diquat is no longer bioavailable. See Table III.2-4 for a list of environmental parameters of diquat.

Studies have shown that unbound, biologically available diquat can be biodegraded by bacteria in the laboratory. However, because of the rapid adsorption of diquat to sediments in the environment which renders it unavailable to biodegradation, the opportunity for microbial decomposition is not very great (Calderbank, 1968 as cited in Hamer, 1994). Thus, while diquat may disappear relatively quickly from water, it does tend to persist in sediments. In one study conducted with diquat in pond water, diquat disappeared from the water within days of treatment but persisted in the sediments for over 160 days (Frank and Comes, 1967 as cited in Reinert and Rodgers, 1987). Nevertheless, it has been shown that biodegradation does occur in various sediment/water systems although at a very slow rate. After 65 days, only 0.88% and 0.21% of diquat was converted to CO_2 and water under aerobic and anaerobic conditions using water and sediment from a eutrophic lake and negligible using water from an oligotrophic lake (Simsiman and Chesters, 1976 as cited by HSDB, 1994).

Table III.2-1. List of Weeds Controlled by Diquat

Common Name	Scientific Name
SUBMERSED AQUATICS:	
Bladderwort	*Utricularia*
Coontail	*Ceratophyllum demersum*
Elodea	*Elodea* spp.
Naiad	*Najas* spp.
Watermilfoil	*Myriophyllum* spp.
Hydrilla	*Hydrilla verticillata*
Pondweeds	*Potamogeton* spp.
FLOATING AQUATICS:	
Salvinia	*Salvinia* spp.
Water Hyacinth	*Eichhornia crassipes*
Water Lettuce	*Pistia stratiotes*
Duckweed	*Lemna* spp.
Pennywort	*Hydrocotyle* spp.
MARGINAL WEEDS:	
Cattails	*Typha* spp.
ALGAE:	
Filamentous green algae	*Pithophora* spp.
	Spirogyra spp.

(Zeneca, 1994)

Diquat does not tend to bioconcentrate to an appreciable degree in fish and other aquatic organisms. No diquat residues were detected in channel catfish collected from pools five months after a single application or two months after a second treatment of 1 ppm diquat (HSDB, 1994). Diquat did not significantly accumulate in fish with bioconcentration factors of $\leq$2.5X with rapid depuration once fish are in pesticide-free water. In laboratory flow-through systems, diquat did not accumulate to a significant degree in *Daphnia*, mayfly nymphs and oysters, with maximum bioconcentration factors of 32X. Depuration was rapid for all organisms (USEPA, 1994). Reported bioconcentration factors for aquatic (non-plant) organisms range from <1 - 62 (USEPA, 1994).

When sprayed on the surface of ponds in a dissipation study conducted in Florida, diquat mixed quickly both laterally and by depth in the water column. Diquat was removed from the water column with a half-life of $\leq$ 2 weeks. Most of the recovered diquat was bound to the first five centimeters of soil, with small amounts recovered from the 5-10 cm layer. Diquat is very persistent but due to its strong soil absorptive properties, it is unlikely to be a groundwater contaminant. When applied to surface water systems, diquat will most likely be associated with the sediment (USEPA, 1994).

PHARMACOKINETICS

In rats given oral doses of ^{14}C-labeled diquat dibromide or diquat dichloride, absorption of diquat through the gastrointestinal tract was very low. About 4-11% of the original dose was excreted within 48 hours in the urine and about 84-97% of the original dose was excreted in the feces. Biliary excretion in rats administered an oral dose of diquat was less than 5% of the administered dose within 24 hours. Most of the recovered radioactivity in rats was found to be unchanged diquat. Metabolic breakdown products of diquat include diquat monopyridone and diquat dipyridone in the urine and diquat monopyridone in the feces (USEPA, 1992a).

Absorption of diquat in dogs was somewhat higher than in rats. 29-32% of the orally administered dose was recovered in the urine within 3 days after dosing. 51-62% was recovered in feces (USEPA, 1992a).

Absorbed diquat tends to preferentially accumulate in the kidney, although it was also detected in other tissues. Single oral doses of 116-230 mg diquat ion/kg/day of diquat in dogs yielded diquat tissue concentrations of less than 3 µg/g and kidney concentrations of up to 10 µg/g after 4 hrs. Four to 48 hours after the dose was administered, the diquat residues decreased (USEPA, 1992a).

In an 8-week feeding study with rats administered 12.5 mg diquat ion/kg/day, tissue concentrations of diquat were less than 1 µg/g in the brain, liver, lung, stomach and small and large intestines. During the latter part of the experimental exposure period, diquat concentrations in the kidney and large intestine increased to greater than 1 µg/g. Within one week of return to a control diet, no diquat was detected in any tissue (USEPA, 1992a).

In rats given 116-125 mg diquat ion/kg/day, absorbed diquat was relatively uniformly distributed among tissues. At 2-30 hours postexposure, concentrations were slightly higher in the kidney than in other tissues. In rats given an oral dose of 231 mg diquat ion/kg/day, elevated levels of diquat were found in heart and lung tissue 2 hours after dosing but by 24 hours these levels had decreased and the levels in the kidney had increased between 24-48 hours. *In vitro* studies indicate that diquat accumulates in the kidney but not in the other tissues (USEPA, 1992b).

HEALTH EFFECTS

Avian:

A series of lethal doses and lethal concentrations of diquat were identified for birds in acute toxicity studies. A number of these have been summarized below:

Table III.2-2. Acute Toxicity Studies with Diquat in Birds

SPECIES	TYPE	RESULTS	REFERENCE
3-4 mo. old mallard chicks	oral LD50	564 mg/kg	USDWFS, 1984
mallard	oral LC50	>5,000 ppm	USDIFWS, 1975
bobwhite chicks	oral LC50	2932 ppm	USDIFWS, 1975
14-day old Japanese quail chicks	oral LC50	1346 ppm	USDIFWS, 1975
10-day old ring-necked pheasants	oral LC50	3742 ppm	USDIFWS, 1975

Mammalian:

Acute:

Symptoms of diquat poisoning include vomiting, diarrhea, general malaise, possible kidney and liver damage, dyspnea and pulmonary edema. Tremor and convulsions may occur with very large doses (Herbicide Handbook, 1979 as cited in HSDB, 1994). Workers who have skin contact with concentrated diquat solutions have shown a change in color and softening of one or more fingernails. Inhalation of dust or mist of the compound has led to nosebleeds and the mists may also cause skin irritation, irritation of the mouth and upper respiratory tract, cough and chest pain (Booth and McDonald, 1982 as cited in HSDB, 1994). Ingestion of concentrated solutions of diquat can cause severe irritation to the mucous membranes of the mouth, pharynx, esophagus and stomach. Ulceration and perforation may follow (Arena, 1979 as cited in HSDB, 1994).

Diquat is known to have a profound effect on the distribution of body water. Oral exposure with diquat increases gastrointestinal water content and results in hemoconcentration (USEPA, 1992a). Ingestion of diquat results in dehydration and gastrointestinal ulceration resulting in the vomiting of blood. Acute tubular necrosis of the kidney has also been reported resulting in anuria and increased blood levels of BUN and creatinine (USEPA, 1982 as cited in HSDB, 1994). Dehydration usually plays a key role in causing death from ingestion of diquat (USEPA, 1992a). Diquat administered subcutaneously is expected to be up to 20 times more toxic than via the oral route (USEPA, 1992a).

A number of cases of acute diquat poisoning in humans were reported in the literature. Of ten cases involving ingestion of diquat, six resulted in death. All six cases involved ingestion of at least 15 ml diquat and were characterized by clinical symptoms of toxicity involving the gastrointestinal tract, the brain and the kidney. The quantities ingested by these individuals were much higher than the amounts individuals swimming in waters treated at recommended application rates would ingest or absorb. In the remaining cases, which were characterized by ingestion of no greater than 5 ml diquat, no deaths occurred but gastrointestinal and renal tract damage was observed (USEPA, 1992a).

The acute oral toxicity of diquat in mammals is moderate. Reported acute toxicity values for diquat in mammals include an oral LD50 of 430 mg diquat ion/kg/day in the rat and >26 mg diquat ion/kg/day in the dog. These relatively high levels are attributed to the poor absorption of diquat through the gastrointestinal tract (USEPA, 1992a).

Rats exposed to 100-200 mg/kg diquat ion/kg had minor histopathological changes in the gastrointestinal tract, kidney and liver. An oral Lowest Observed Adverse Effect Level (LOAEL) was determined to be 18.4 mg diquat ion/kg for a single dose of diquat (based on an increase in water content in the gastrointestinal tract) (USEPA, 1992a).

Monkeys that died after being exposed to 100-400 mg of diquat ion/kg showed distinct exfoliation of the gastrointestinal tract epithelium and distinct pathological changes in kidneys (USEPA, 1992a).

Rats that were administered an LD50 dose of 166 mg diquat ion/kg were lethargic, showed signs of piloerection and weight loss, uncharacteristic, off-color feces, gross abdominal swelling, muscular twitching, erratic gait and, the most notable effect, an increase in gastrointestinal water content and hemoconcentration (USEPA, 1992a).

At LD50 doses of 100-200 mg diquat ion/kg in dogs and 100 mg diquat ion/kg in rabbits, perforation of the stomach wall was noted (USEPA, 1992a).

A single oral dose of 99 mg diquat ion/kg produced a marked decrease in renal excretory function. At 166 mg ion/kg, hemoconcentration and a significant reduction in renal plasma flow were observed. At LD50 levels, minimal pathological changes in the kidney were observed in rats at LD50 dose levels. Researchers have concluded that effects on kidney function observed after exposure to diquat are mainly due to body fluid redistribution. Pathological changes were observed in kidneys of monkeys receiving single oral doses of 100-400 mg diquat ion/kg (USEPA, 1992a).

In rats receiving acute lethal doses of diquat intraperitoneally and in monkeys receiving oral doses of diquat, minimal effects on the liver were noted. An increase in liver glycogen and blood glucose appeared to be mediated by altered adrenal secretion. Selenium-deficient rats, given 3.6 mg/kg diquat via intraperitoneal exposure were characterized by rapid and massive liver necrosis accompanied by a marked increase in hepatic liver peroxidation (USEPA, 1992a). A series of other acute toxicity studies conducted with various species yielded the toxicity values summarized in Table III 2-3.

Subchronic:

In a 4-week dietary study, a No Observed Adverse Effect Level (NOAEL) of 6.7 mg diquat ion/kg/day was identified in Charles River CD female rats (USEPA, 1992a).

Oral exposure of rats with either 2.1 or 4.3 mg/kg/day of diquat for four and one-half months produced lung damage characterized by apparently dose-related papillomatous proliferations of the bronchial and bronchiolar epithelia. In addition, moderate to severe alveolar damage was produced in mice exposed either intratracheally or intraperitoneally (USEPA, 1992a).

Table III.2-3. Acute Toxicity Studies With Diquat

SPECIES	TYPE	RESULTS	REFERENCE
Rabbit	dermal LD50	>750 mg/kg	Hartley and Kidd, 1983 as cited in HSDB, 1994
Cattle	oral LD50	30 mg/kg	Clark and Hurst, 1970 as cited in HSDB, 1994
guinea pig	oral LD50	100 mg/kg	Clark and Hurst, 1970 as cited in HSDB, 1994
Mouse	oral LD50	106-146 mg/kg	Clark and Hurst, 1970 as cited in HSDB, 1994
Rabbit	oral LD50	72-138 mg/kg	Clark and Hurst, 1970 as cited in HSDB, 1994
Rat	oral LD50	194-274 mg/kg	Clark and Hurst, 1970 as cited in HSDB, 1994

In rats exposed to 500 and 1,000 mg/l diquat in drinking water for 20 and 8 days respectively and in rabbits exposed to 100 and 500 mg/l for 6 and 10 days respectively, no irritation of the digestive mucosa was noted (USEPA, 1992a).

Chronic:

Chronic feeding studies conducted in dogs, guinea pigs and rats resulted in the formation of cataracts. Cataract formation is cited as the most sensitive toxic indicator of diquat exposure. Diquat-induced formation of cataracts was found to be both dose and time-dependent in laboratory animals. In rats exposed for two years or longer to doses as low as 1.8 mg diquat ion/kg/day, a high frequency of cataract formation was noted. The minimal effective dose in rats was 2 mg/kg/day in drinking water. In a two-year study conducted with rats, cataracts were noted in animals exposed to 3.28 and 17.16 mg diquat ion/kg/day. A NOAEL of 0.22 mg/kg/day was identified for rats in this study. In another study in rats exposed to concentrations up to 36 mg diquat ion/kg/day, an extensive examination of hematology, urinalysis and gross and microscopic pathological examination showed no effects (other than in the eye) at any treatment level. Animals exposed to higher doses experienced more serious effects sooner. No effects were noted in rats exposed to 0.36 mg diquat ion/kg/day. No cataracts were noted in dogs exposed to 1.2 mg/kg/day for 4 years or at a dose level of 0.58 mg diquat ion/kg/day for 3 years. A LOAEL of 3.6 mg diquat ion/kg/day for dogs was identified from this study . A NOAEL for guinea pigs was identified in another study as 0.1 mg diquat ion/kg/day (USEPA, 1992a).

Developmental/Reproductive Effects:

No reproductive or teratogenic effects were observed in mice, or rats after oral diquat administration. In a mouse study in which animals received five daily oral doses of 10 mg diquat ion/kg as well as in a three-generation rat study in which animals were given 25 mg diquat ion/kg, no reproductive effects were reported in the parental, F_1 or F_2 generations. No significant teratogenic effects were observed in mice, rats or rabbits. However, teratogenic effects were produced with diquat administered intraperitoneally or intravenously. In rats administered a single intravenous dose of 8 mg diquat ion/kg, an increase in the number of dead and resorbed fetuses was observed. In addition, skeletal abnormalities were found in the embryos of mice exposed to 1.4 and 5.9 mg diquat ion/kg and rats exposed to 7.5 mg diquat ion/kg after treatment of dams with single intraperitoneal doses (USEPA, 1992a).

Mutagenicity:

The potential mutagenicity of diquat was tested in a number of bacterial and eukaryotic systems with contradictory results. Both positive and negative results were found in *Salmonella* assay, unscheduled DNA synthesis and mitotic gene conversion assay. Diquat induced recessive lethal damage in *Aspergillus* but not in *Drosophila* (USEPA, 1992a).

Carcinogenicity:

In four feeding studies conducted in rats and one in mice (in which only doses of up to 75 mg diquat ion/kg were given for periods of up to two years) no tumors were detected. However, two of these studies had insufficient data upon which to base any final conclusions. Under the old EPA carcinogen classification system, the U.S. EPA OPP determined that diquat was an E carcinogen (i.e., having evidence of noncarcinogenicity in humans) based on a lack of tumor production in rats and mice. Under EPA's current classification system involving the designation of descriptors for summarizing weight-of-evidence, the old E designation corresponds to the descriptor, "not likely to be carcinogenic to humans".

Available Toxicity Criteria:

The Environmental Protection Agency (EPA) Carcinogen Risk Assessment Verification Endeavor (CRAVE) RfD/RfC Workgroup has developed an oral Reference Dose (RfD) of 0.0022 mg/kg/day for diquat based upon a 1985 2-year dietary rat study. The RfD is an estimate, (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime (USEPA, 1992b). The World Health Organization (WHO) has also developed an RfD of 0.002008 mg/kg/day. The EPA Office of Pesticide Programs (OPP) has developed an RfD of 0.005 mg/kg/day based upon a 1-year feeding study in dogs. (USEPA, 1995).

In addition, the EPA has also developed a Maximum Contaminant Level Goal (MCLG) of 0.02 mg/l for drinking water and has promulgated this value as a Maximum Contaminant Level (MCL) standard (USEPA, 1992b; USEPA, 1995b). Massachusetts has adopted this value as a drinking water standard, known as a Massachusetts Maximum Contaminant Level (MMCL).

ECOLOGICAL TOXICITY

Aquatic Organisms :

Acute flow-through type bioassays have been conducted with a variety of freshwater and marine fish and invertebrates. Because dissipation of diquat is very rapid, a comparison of toxicity data generated in the laboratory to expected diquat concentrations following application and dissipation in the field, indicates that acute effects on organisms in the field are unlikely at rates used for vegetation control (Hamer, 1994; MacKenzie, 1971 as cited in Aquatic Plants Management Program for Washington State, 1992).

Invertebrates:

LC50 toxicity values for invertebrates show a range of sensitivities to diquat. The most sensitive organisms tested were *Daphni*a and *Hyalella* with 24-hour LC50 values of 1-2 ppm and 0.6 ppm, respectively (Hamer, 1994). Studies of estuarine organisms in Florida, showed no adverse effects on oysters, shrimp or fish (Wilson and Bond, 1969 as cited in Aquatic Plants Management Program for Washington State, 1992). In a pond study, diquat had no direct effect on aquatic insects but a decrease in pond weeds after treatment did result in migration of some species to shoreline vegetation (Hilsenhoff, 1966 as cited in Aquatic Plants Management Program for Washington State, 1992). An application with 0.5 ppm diquat in another pond led to loss of aquatic vegetation. The decaying vegetation appeared to benefit certain organisms such as Oligochaetes, indicated by an increased number (Tatum and Blackburn, 1962 as cited in Aquatic Plants Management Program for Washington State, 1992).

Dragonflies, damselflies and tendipedids exposed to diquat concentrations 40 times the maximum field application rate, survived. *Hyalella* was very sensitive to diquat as was *Cladocera* although *Cladocera* populations returned to normal levels after diquat concentrations disappeared from the water (Gilderhus, 1967 as cited in Aquatic Plants Management Program for Washington State, 1992.)

The species discussed above are all water column or epibenthic organisms (with the exception of the Oligochaetes). Because diquat is very persistent in sediments, it would seem that infauna or deposit-feeding organisms would have the highest potential for exposure to this compound. No specific studies pertinent to this issue were available.

Vertebrates:

The toxicity of diquat varies with the size and type of fish as well as the softness or hardness of the water. Reported LC50 values from one source ranged from 12-90 mg/l for 24-hour exposures, 6-44 mg/l for 48-hour exposures and 4-36 mg/l for 96-hour exposures (Calderbank, 1972 as cited in State of Washington, 1984). Another source reports acute toxicity values for specific fish ranging from a 96-hour LC50 value of 5 mg/l for rainbow trout to a 96-hour LC50 value of 140 mg/l for bluegill sunfish (Aquatic Plant Identification and Herbicide Use Guide, 1988). The EPA AQUIRE database contains the results of acute toxicity tests ranging from a 24-hour acute LC50 value of 1.0 mg/l in striped bass (an anadromous fish) to a 24-hour acute LC50 value of 5967 mg/l in grass carp (AQUIRE, 1995). In a survey of the results of diquat toxicity tests, the manufacturer has identified a range in toxicity of diquat to fish, with 96 hour LC50 values of 0.5-245 mg/l (Hamer, 1994).

The results of 13 experiments conducted with diquat indicate that diquat did not cause direct mortality to any fish species at 1.0 ppm and below. (MacKenzie, 1971 as cited in Aquatic Plants Management Program for Washington State, 1992). The highest concentration of diquat allowed by the manufacturer's label would equal an initial in-water diquat concentration of 1.5 ppm (Aquatic Plants Management Program for Washington State, 1992).

Studies conducted with fish exposed to solutions of diquat indicate that diquat concentrations in fish do not accumulate above the concentration of diquat in the surrounding water. In addition, when water concentrations decrease, fish diquat residues also decrease. In salmon, trout and goldfish kept in water containing a 1 µg/ml diquat concentration, diquat residues in fish were less than external water concentrations and were mostly found in the nonedible portion of the fish including skin and viscera (Valent U.S.A. Corporation, 1989 as cited in Aquatic Plants Management Program for Washington State, 1992).

Following 24-hour exposure to diquat, changes in rheotaxis and swimming speeds were noted in rainbow trout (Dodson and Mayfield, 1979 as cited in HSDB, 1994).

Trout immersed in water containing 0.5 ppm and 1.0 ppm diquat for 16 days had diquat residue levels of 0.4 and 0.6 ppm, respectively. When fish were returned to non-contaminated water, these levels slowly returned to non-detectable levels. Similar results were obtained with goldfish. (Aquatic Plants Management Program for Washington State, 1992).

Diquat is used to treat disease in fish at hatcheries and for the species tested did not affect the breeding rate in bluegills or cause mortality in young fish. 1 ppm diquat applied up to 3 times and 3 ppm applied once or twice, with 8-week intervals between applications did not affect hatching and growth rates of bluegills in seven different pools. Channel catfish fry were not affected at 10 ppm and bluegill fry were not affected at 4 ppm diquat. Largemouth black bass fry were affected at 22.5°C at levels greater than 1.0 ppm and at 26.0°C at levels greater than 0.5 ppm (Jones, 1965 as cited in Aquatic Plants Management Program for Washington State, 1992).

Decaying vegetation caused by treatment with diquat may deplete oxygen content in the water. For this reason, it is recommended that only 1/3 to 1/2 of an area containing dense vegetation be treated with diquat at a time with a 14-day waiting period in between (Aquatic Plants Management Program for Washington State, 1992).

Plants:

Since diquat is effective in treating a large range of plants, it may have a widespread effect on non-target plants. In addition to direct toxic effects of the herbicide, treatment of a pond with diquat may also cause indirect impacts including dissolved oxygen depletion and habitat loss. These impacts may cause general weakening and/or death of plants on a large scale (Aquatic Plants Management Program for Washington State, 1992).

Microorganisms :

Incubation with diquat caused rapid loss of potassium and phosphate from *Aspergillus niger*, *Penicillium frequentans*, *Mucor hiemalis* and *Zygorrhynchus heterogamus*. At higher concentrations of diquat, the rate of loss is greater, especially with *Zynchorrhynchus* and *Mucor*. Short-term incubation with diquat is followed by sustained loss of potassium when colonies of the above four species are transferred to water (Sahid *et al.*, 1981).

A 50% decrease in O_2 evolution was noted in the following algae organisms: *Chlorococcum sp*, *Dunaliella tertiolecta*, *Isochrysis galbana* and *Phaedactylum tricornutum* in water containing >500 ppm, >500 ppm, 15 ppm and 15 ppm of diquat dibromide, respectively. A 50% decrease in growth was noted in *Chlorococcum sp*, *Dunaliella tertiolecta*, *Isochrysis galbana* and *Phaedactylum tricornutum* in water containing 200 ppm, 30 ppm, 15 ppm and 15 ppm of diquat dibromide, respectively (Verschueren, 1983 as cited in HSDB, 1994).

Table III.2-4. Properties of Diquat

CAS #:	85-00-7
Synonyms	Dipyrido(1,2-a:2',1-c)pyrazinediium, 6,7-dihydro-dibromide; Deiquat; Diquat; Ethylene dipyridylium dibromide; 1,1-Ethylene 2,2-dipyridylium dibromide; 5,6-Dihydro-dipyrido(1,2a:2,1c)pyraziniu m dibromide; 6,7-Dihydropyrido(1,2-a:2',1'-c)pyrazinedium dibromide 9,10-Dihydro-8A,10A-diazoniaphenanthrene dibromide
Molecular formula (salt)	$C_{12}H_{12}N_2Br_2$
Molecular weight (salt)	344.07
Physical properties	yellow solid (pure salt monohydrate); aqueous solution is dark reddish-brown.
Melting point	salts decompose at high temperatures, charring rather than melting; decomposition temperature is >300°C
Density	1.20-1.27 g/ml @20°C/20°C
Vapor Pressure	nonvolatile
Photolysis half-life	2-11 days
Hydrolysis half-life	insignificant
Biodegradation half-life	32 days
K_{ow}	603
K_{oc}	205-691 ml/g
BCF	<1-62
Water solubility	568 mg/l

(HSDB, 1994; Aquatic Plants Identification and Herbicide Use Guide, 1988; Herbicide Handbook, 1983)

Diquat References

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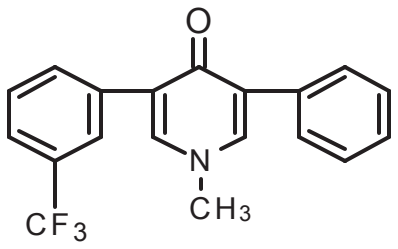
III.5 FLURIDONE



FLURIDONE

SUMMARY

Fluridone (1-methyl-3-phenyl-5-[3-(trifluoromethyl)phenyl]-4(1H)-pyridinone) is a selective systemic aquatic herbicide used to control primarily broad-leaved, submerged aquatic macrophyte species including Eurasian watermilfoil, curly-leaf pondweed as well as native pondweeds (McLaren/Hart, 1995). It is used to treat ponds, lakes, reservoirs, canals and rivers. Fluridone is stable to oxidation and hydrolysis (McCowen *et al.*, 1979 as cited in Aquatic Plant Identification and Herbicide Use Guide, 1988). Volatilization of fluridone is insignificant (Muir and Grift, 1982 as cited in Aquatic Plant Identification Guide, 1988). Breakdown of fluridone in the aquatic environment occurs mostly through photolysis. Other fate processes include plant uptake and adsorption to soil and suspended colloids (Joyce and Ramey, 1986). Some microbial degradation of fluridone has also been reported (Muir and Grift, 1982 as cited in McLaren/Hart, 1995). Fluridone is taken up in fish but studies demonstrate that fish tissue concentrations generally reflect water concentrations and that fish concentrations rapidly clear when fluridone residues are removed from the water (West *et al.*, 1983 and Muir and Grift, 1982 as cited in McLaren/Hart, 1995). There are no restrictions on the use of fluridone to treat water used for swimming or domestic purposes. Care should be taken when applying Fluridone within one-fourth mile of any potable water intake (WSDOE, 1992).

The U.S. Environmental Protection Agency (USEPA) approved the label for Sonar on March 31, 1986 (McLaren/Hart, 1995).

REGISTERED PRODUCTS IN MASSACHUSETTS

The current list of aquatic herbicides containing fluridone that are registered in Massachusetts can be accessed at http://www.state.ma.us/dfa/pesticides/water/Aquatic/Herbicides.htm on the Massachusetts Department of Agricultural Resources (DAR) Aquatic Pesticide Website. The DAR updates this list regularly with changes. In addition, the DAR can be contacted directly at (617) 626-1700 for more specific questions regarding these products.

FLURIDONE USES AND APPLICATION

Fluridone is used to manage aquatic vegetation in fresh water ponds, lakes, reservoirs, canals and rivers (Cockreham, pers. comm., 1996). It is absorbed from the water by the shoots of submerged plants and from the hydrosoil by the roots of aquatic vascular plants. The effectiveness of fluridone depends on the degree to which the herbicide maintains contact with plants. Rapid water movement or any dilution of this herbicide in water will reduce its effectiveness (Dow Elanco, 1992; Aquatic Plant Identification and Herbicide Use Guide, 1988; WSDOE, 1992).

Application of fluridone may be made in several ways depending on the formulation used. The liquid suspension may be applied as a spray to the water surface, subsurface or along the bottom of the water body using specialized equipment. The pellet can be spread on the water surface (WSSA, 1983). Water should be used as a carrier during application of the liquid fluridone suspension. No surfactant is specified for use during application.

When treating ponds, application should be made to the entire water body. When treating lakes and reservoirs, plots no smaller than ten surface acres should be treated. In addition, areas with a large linear aspect (such as boat lanes and narrow shorelines) should not be treated (Aquatic Plant Identification and Herbicide Use Guide, 1988).

Application of fluridone may be made prior to active growth of aquatic weeds or any time during the spring or summer when weeds are visible (WSSA, 1983; Aquatic Plant Identification and Herbicide Use Guide, 1988).

Caution should be used when applying fluridone within one-fourth mile of any functioning potable water intake.

The plant selectivity of fluridone is dependent upon dose, application timing and formulation used. For specific information on recommended application rates for a particular product, the product label should be consulted. The USEPA Office of Pesticide Programs (OPP) has a link to a database of product pesticide labels at http://www.epa.gov/pesticides/pestlabels/. A list of the weeds that these products control, which has been compiled from the Environmental Protection Agency (EPA) registration labels for these products, is contained in Table III.5-1.

MECHANISM OF ACTION

Fluridone produces its toxic effect in plants by inhibiting synthesis of carotenes (pigments that protect chlorophyll molecules from photodegradation). The absence of carotenes causes degradation or "bleaching" of chlorophyll by sunlight from plants. Plants become whitish-pink or chlorotic at growing points and die slowly. This slow dying-off of plants (i.e., 30-90 days) (Cockreham, pers. comm., 1996) reduces the instantaneous oxygen demand caused by plants dying off and decomposing all at once (Joyce and Ramey, 1986). The herbicidal effects of fluridone usually appear within 7-10 days. Species susceptibility to fluridone may vary depending on time of year, stage of growth and water movement (McLaren/Hart, 1995).

Table III.5-1. List of Aquatic Plants Controlled by Fluridone

Common Name	Scientific Name
American Lotus	*Nelumbo lutea*
Bladderwort	*Utricularia* spp.
Common Coontail	*Ceratophyllum demersum*
Common Duckweed	*Lemna minor*
Common Elodea	*Elodea canadensis*
Egeria, Brazilian Elodea	*Egeria densa*
Fanwort	*Cabomba caroliniana*
Hydrilla	*Hydrilla verticillata*
Naiad	*Najas* spp.
Pondweed (except Illinois)	*Potamogeton* spp.
Watermilfoil (including Eurasian Watermilfoil)	*Myriophyllum* spp. (including *M. spicatum)*
Spatterdock	*Nuphar* spp.
Waterlily	*Nymphaea* spp.
Waterprimrose (including Waterpurslane)	*Ludwigia* spp. (including *Ludwigia palustris*)
Watershield	*Brasenia schreberi*

(McLaren/Hart, 1995; SePRO, 1994)

ENVIRONMENTAL FATE/TRANSPORT

The major fate process affecting fluridone persistence in aqueous environments is photolysis. Thus any factors which affect sunlight intensity and/or penetration of light into the water column will affect the dissipation rate of fluridone (Joyce and Ramey, 1986). Other factors affecting dissipation include geographic location, date of application, water depth, turbidity, weather and weed cover (West *et al.*, 1983 as cited in McLaren/Hart, 1995). Microbial degradation is also reported to occur in laboratories, but photolysis generally occurs much more quickly (Muir and Grift, 1982 as cited in McLaren/Hart, 1995). Other secondary fate processes include adsorption to soil and suspended colloids and plant uptake (Joyce and Ramey, 1986).

Fluridone will adhere to sediment particles/organics in the sediment. Eventually, the fluridone will desorb and photodegrade into the water column from the hydrosoil (Elanco, 1981 as cited in McLaren/Hart, 1995). The pH of the water can affect this rate (with the lower the pH, the higher the adsorption rate (Malik and Drennan, 1990 as cited in McLaren/Hart, 1995).

Fluridone is taken up in fish tissue. Fluridone fish concentrations generally reflect the concentrations of fluridone in the water (McLaren/Hart, 1995). When fluridone residues are removed from the water

column, the fluridone concentration from fish tissue clears (West *et al.*, 1983; Muir *et al.*, 1983 as cited in McLaren/Hart). Based on a low bioaccumulation rate in fish and high levels of fluridone necessary to produce toxic responses in mammals and birds, it is not expected that fish-eating animals would be affected by fluridone used at recommended (registered) application rates (McLaren/Hart, 1995).

The primary metabolite of fluridone degradation in fish was identified as 1-methyl-3-(4-hydroxyphenol)-5-[3-trifluoromethyl)phenyl]-4[1H]-pyridone (West *et al.*, 1983 as cited in McLaren/Hart, 1995). This compound was also identified as a minor metabolite in water and hydrosoil (Muir and Grift, 1982 as cited in McLaren/Hart, 1995). 1,4-dihydro-1-methyl-4-oxo-5-[3-(trifluoromethyl)phenyl]-3-pyridone was also identified as the major hydrosoil metabolite in hydrosoil studies conducted in the laboratory; however, this compound has not been identified in the hydrosoil of small ponds under natural conditions (West *et al.*, 1983 as cited in McLaren/Hart, 1995). A number of other metabolites including benzaldehyde, 3-(trifluoromethyl)-benzaldehyde, benzoic acid and 3-(trifluoromethyl)-benzoic acid were produced as photolytic breakdown products in one laboratory study (Saunders and Mosier, 1983, as cited in McLaren/Hart, 1995). N-methylformamide (NMF) was produced in another study. However, NMF has not been identified as a breakdown product under natural conditions (Saunders and Mosier, 1983 as cited in McLaren/Hart, 1995).

The half-life of fluridone in water of small, artificial ponds ranged from 1-7 days. In hydrosoils, the compound persisted for 8 weeks to one year (Joyce and Ramey, 1986; WSDOE, 1992). Fluridone has a water solubility of 12 mg/l and an octanol-water partition coefficient (K_{ow}) of 74.1 (Elanco Products Company, 1985 as cited in Aquatic Plant Identification and Herbicide Use Guide, 1988). Fluridone is stable to oxidation and hydrolysis (McCowen *et al.*, 1979). Volatilization of fluridone is not expected to be a significant process, (Muir and Grift, 1982 as cited in Aquatic Plant Identification and Herbicide Use Guide, 1988).

PHARMACOKINETICS

Metabolism and distribution studies have shown that fluridone is absorbed and excreted in the feces within 72 hours of oral administration to rats (McLaren/Hart, 1995). No bioaccumulation of fluridone was noted. 90% of the absorbed fluridone was cleared in 96 hours (USEPA, 1988).

HEALTH EFFECTS

Avian:

Fluridone has very low toxicity to birds. A number of acute toxicity studies were conducted in various bird species. An oral LD50 value of >2,000 mg/kg was obtained for bobwhite quail. The EPA considers this value to represent slight toxicity (USEPA, 1986). An LD50 of >2,000 was identified for mallard ducks (WSDOE, 1992). Oral LC50 values of > 5,000 ppm were identified for bobwhite quail and mallard duck (USEPA, 1986). No impairment on reproduction for the above species was noted up to a dietary exposure concentration of 1,000 ppm (USEPA, 1986). In other studies, an LC50 value of about 10,000 ppm was identified for bobwhite quail and an LC50 value of >20,000 ppm was identified for mallard duck (WSDOE, 1992).

Mammalian:

Acute:

Most of the available information on the toxic effects of fluridone comes from studies conducted by the industry on various formulations of the product. Generally, the acute toxicity of fluridone is low. The LD_{50} for both rats and mice exposed through ingestion to technical grade fluridone is

greater than 10,000 mg/kg. The oral LD_{50}s for cats and dogs exposed to technical grade fluridone are 250 mg/kg and 500 mg/kg, respectively. The LD_{50} for rabbits exposed through the skin to technical grade fluridone is greater than 2,000 mg/kg (Elanco, 1981 as cited in McLaren/Hart, 1995).

Fluridone was found to produce eye irritation in rabbits with effects including redness, corneal dullness and conjunctivitis. Fluridone was found to be neither irritating nor a sensitizer to rabbit skin at 2,000 mg/kg (USEPA, 1988).

Subchronic/Chronic:

In a three-week study in which fluridone was applied to rabbit skin daily at doses ranging from 192-768 mg/kg/day, dose-dependent skin irritation was produced at all doses. No systemic effects were noted at any dose. An increase in organ weight was noted at 384 mg/kg/day (USEPA, 1988).

In a three-month subchronic feeding study with fluridone, no treatment-related effects were noted in rats administered doses of 62 mg/kg or in mice administered doses of 330 mg/kg (Elanco, 1981 as cited in McLaren/Hart, 1995). A dietary level of fluridone of 16.5 mg/kg/day administered to mice for three months resulted in a partial enlargement of livers. A dietary level of 166 mg/kg administered to rats for three months resulted in an increase in liver weights. A No Observed Effect Level (NOEL) of 30 mg/kg/day was identified in rats administered fluridone in the diet for three months (USEPA, 1988). A concentration of 0.033% of fluridone fed to mice for three months produced morphologic changes in the liver and an increase in absolute liver weights in male mice (USEPA, 1988). In a study conducted with dogs, daily dietary fluridone levels up to 200 mg/kg/day did not result in any treatment-related effects (Elanco, 1978 as cited in USEPA, 1990).

In a one-year chronic study in which dogs were administered fluridone by capsule in food, a number of effects including weight loss, an increase in liver weight and an increase in liver enzymes were noted at a dose level of 150 mg/kg/day. A NOEL of 75 mg/kg/day was identified (USEPA, 1988). In a two-year feeding study in which mice were administered fluridone concentrations in the diet of up to 330 ppm fluridone, there was an increase in liver enzymes in males exposed at 330 ppm. No other toxic effects or lesions were noted at any of the doses (USEPA, 1988). In another two-year study, rats were exposed to doses of 0, 8, 25 and 81 mg/kg/day. At 25 mg/kg/day, rats experienced inflammation in the kidney, atrophy of the testes, inflammation of the cornea, weight loss and decreased organ weights (USEPA, 1988; USEPA, 1990).

Developmental/Reproductive:

In a study in which rats were exposed to up to 200 mg/kg/day of fluridone, neither maternal nor fetotoxic effects were noted (USEPA, 1988). In a three-generation study conducted in rats exposed to fluridone at a dose of 100 mg/kg/day, no teratogenic or maternal effects were noted. However, a dose of 100 mg/kg/day was found to be toxic to rat pups (USEPA, 1988; USEPA 1990). In a teratology study in which rabbits were exposed to fluridone doses of up to 750 mg/kg/day, a level of 300 mg/kg resulted in maternal effects including a decrease in body weight gain and abortion. Fetal effects, also noted at this level, included resorptions (USEPA, 1988). No teratogenic effects were noted (USEPA, 1990). In a pilot study in which rabbits were exposed to fluridone at doses of 0, 250, 500, 750 and 1,000 ppm, a maternal NOEL of 500 mg/kg was identified. A level of 750 mg/kg produced a maternal loss in body weight. A NOEL of 250 mg/kg/day was identified for fetal effects. At 500 mg/kg/day, fetal resorptions occurred (USEPA 1988). In another study, rats were administered doses by oral gavage of 0, 100, 300 and 1,000 mg/kg/day. A maternal NOEL of 100 mg/kg/day was identified. At 300 mg/kg/day, there was a decrease in maternal body weight. The NOEL for developmental effects was identified as 300 mg/kg/day. At 1,000 mg/kg/day, fetal effects included a

decrease in fetal weight and delayed ossification. The NOEL for teratogenic effects was greater than 1,000 mg/kg/day (USEPA 1988).

Mutagenicity:

Fluridone was not found to be mutagenic in several test assays. Fluridone produced negative results in the Ames assay and did not induce sister chromatid exchange in Chinese hamster bone marrow cells. In addition, fluridone did not promote unscheduled DNA synthesis in rat hepatocytes (USEPA, 1988).

Carcinogenicity:

Based on negative cancer findings in the two chronic toxicity studies discussed above, there is no evidence indicating that fluridone is carcinogenic. The EPA Health Effects Division has designated fluridone as a Group E carcinogen (i.e., having evidence of noncarcinogenicity for humans) by the old EPA classification system. Under the new cancer classification system (USEPA, 1995), an E classification would correspond to a weight-of-evidence descriptor of "not likely to be carcinogenic to humans"..

Available Toxicity Criteria:

The EPA Carcinogen Risk Assessment Verification Endeavor (CRAVE) (RfD/RfC) workgroup has developed an oral Reference Dose (RfD) of 0.08 mg/kg/day for fluridone based on one of the two-year rat feeding studies conducted by Elanco cited earlier (USEPA, 1990). The EPA Office of Pesticide Programs (OPP) has calculated the same RfD value based on the same study (USEPA, 1995). The RfD is an estimate, (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime (USEPA, 1990).

The EPA has designated an acceptable residue level for fluridone in potable water of 0.15 ppm. This level is based on the maximum application rate for fluridone as registered under FIFRA (Federal Insecticide, Fungicide and Rodenticide Act) (USEPA, 1986 as cited in McLaren/Hart, 1995). The EPA has also established a tolerance of 0.5 ppm for residues of fluridone and its primary metabolites in fish and crayfish. In addition, EPA has established tolerances for crops irrigated with water containing fluridone residue concentrations at 0.15 ppm as well as for a number of raw, agricultural commodities (USEPA, 1986 as cited in McLaren/Hart, 1995).

ECOLOGICAL TOXICITY

Aquatic Organisms :

A number of studies have been conducted with fluridone to determine the LD50 or LC50 values for a variety of organisms. The LD50 (or LC50) is the dose (or concentration) to which a particular species is exposed, which results in the death of 50% of the test population. The EPA has cited the results of a number of these studies. EPA considers these studies to demonstrate moderate toxicity. These studies are listed in the Table III 5-2.

In addition, a Maximum acceptable theoretical concentration (MATC) value for fathead minnow (second generation fry) was calculated to be between 0.48 mg/l and 0.96 mg/l, meaning no treatment-related effects were noted at or below 0.48 mg/l. Total length of 3-day old fry was reduced at 2 mg/l fluridone (USEPA, 1986).

No adverse effects were noted on crayfish, bass, bluegill, catfish, long-neck soft-shelled turtles, frogs, water snakes and waterfowl from the use of 0.1 to 1.0 ppm fluridone during field experiments (Arnold, 1979, McCowen et al., 1979 as cited in WSDOE, 1992). Application of 1.0 ppm fluridone to zooplankton caused a reduction in population, but the population quickly recovered. Application of 0.3 ppm did not cause a change in the total number of benthic organisms whereas application of 1.0 ppm did cause a change (Parka *et al.*, 1978 as cited in WSDOE, 1992). An aqueous solution of fluridone caused a reduction in population of the amphipod *Hyalella azteca* when applied at a rate of 1.0 ppm but not when applied at a rate of 0.3 ppm (Arnold, 1979 as cited in McLaren/Hart, 1995). Fish abundance and community structure remained unchanged in ponds exposed to a fluridone concentration level of 0.125 ppm (Struve *et al.* 1991 as cited in McLaren/Hart, 1995). LC50 values for a variety of microscopic crustaceans including *Diaptomus*, sp., *Eucyclops* sp, *Alonella* sp., and *Cypria* sp., ranged from 8.0 - 13.0 ppm (Naqvi and Hawkins, 1989 as cited in McLaren/Hart, 1995).

Table III.5-2. Acute Toxicity Tests

SPECIES	TEST TYPE	VALUE
Daphnia magna	48-hr LC50	6.3 mg/l
Bluegill	96-hr LC50	12 mg/l
Rainbow trout	96-hr LC50	11.7 mg/l
Sheepshead minnow	96-hr LC50	10.91 mg/l
Oyster embryo larvae	48-hr LC50	16.51 mg/l

(USEPA, 1986)

One group of investigators conducted extensive acute toxicity tests on a variety of aquatic invertebrates including amphipods, midges, daphnids, crayfish, blue crabs, eastern oysters and pink shrimp. The average 48-hour or 96-hour LC50 or EC50 (concentration at which 50% of the organisms exhibit an effect) was calculated as 4.3 $\pm$ 3.7 ppm (Hamelink *et al.*, 1986 as cited in McLaren/Hart, 1995). The same investigators also conducted studies with a variety of fish including rainbow trout, fathead minnows, channel catfish, bluegills and sheepshead minnows. A 96-hour LC50 value of 10.4$\pm$3.9 was calculated (Hamelink *et al.*, 1986 as cited in McLaren/Hart, 1995).

Daphnids, amphipods and midge larvae exposed chronically to fluridone concentrations of 0.2, 0.6 and 0.6 ppm as well as catfish fry exposed to fluridone concentrations of 0.5 ppm showed no treatment-related significant effects. Exposure to concentrations of 1 ppm produced a decreased growth rate of catfish fry and concentrations of 0.95 and 1.9 ppm produced a decreased survival rate of fathead minnows within 30 days after hatching (Hamelink *et al.*, 1986 as cited in McLaren/Hart, 1995).

Plants:

Fluridone selectively controls a number of broad-leaved submerged and floating aquatic macrophyte species as specified by its EPA label. In addition, the literature contains reports of fluridone's variable efficacy in controlling other species. The efficacy of fluridone is very dependent on contact time with plants. Thus, fluridone should be applied during periods of minimum water movement. Factors related to fluridone's variable efficacy include temperature, pH and light levels (Wells *et al.* 1986 as cited in WSDOE, 1992). In addition, one investigator found that in *Hydrilla* exposed to fluridone at various concentrations for 1, 3 and 5 weeks, plant recovery was directly related to the concentration of active iron (Fe^{2+}) in the plant at the time of treatment (Spencer and Ksander, 1989 as cited in WSDOE, 1992).

Fluridone did not appear to adversely affect desirable phytoplankton but some reduction in population of the less desirable species given as *Anabaena* and *Anacystis* occurred upon application of fluridone at levels of 0.3 and 0.1 ppm (Parka et al, 1978 as cited in WSDOE, 1992). A drastic reduction in phytoplankton population in Greek ponds including the disappearance within two months of a population of Cyanophyceae (Cyanobacteria) occurred after fluridone application. Diatom populations, a more desirable species, increased significantly, especially epiphytic and benthic species (Kamarianos *et al.*, 1989 as cited in WSDOE, 1992). No sufficient reduction in phytoplankton densities was noted when they were consistently exposed to a fluridone concentration of 0.125 ppm (Struve *et al.*, 1991 as cited in McLaren/Hart, 1995).

An aqueous solution of fluridone applied at a concentration of 1.0 ppm produced a significant reduction in a zooplankton population whereas a concentration of 0.3 ppm had no effect. The 1.0 ppm population returned to pretreatment levels within 43 days (Arnold, 1979 as cited in McLaren/Hart, 1995).

Table III.5-3. Properties of Fluridone

CAS #:	59756-60-4
Synonyms:	1-methyl-3-phenyl-5-[3-(trifluoromethyl)phenyl-4(1H)-pyridinone;
Molecular formula	$C_{19}H_{14}F_3NO$
Molecular weight	329.3
Physical properties	white, crystalline solid
Melting point	154-155°C
Vapor pressure	< 1 x 10^{-7} mm Hg at 25°C
Photolysis half-life	1-6 days
Hydrolysis half-life	stable
Biodegradation half-life	2-60 days (based on overall half-life)
K_{ow}	74.1 at 20° C
K_{oc}	~350-2460 ml/g
BCF	0.9-15.5
Water solubility	12 mg/l at 25° C and pH 7

(Reinert and Rodgers, 1987; WSSA, 1983; Aquatic Plant Identification and Herbicide UseGuide, 1988; WSSA, 1994)

Fluridone References

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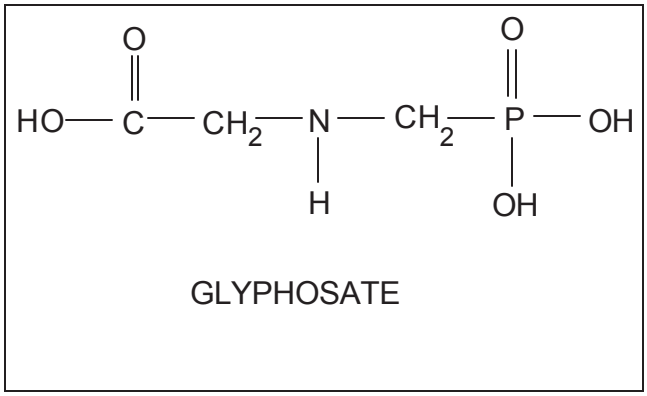
III.4 GLYPHOSATE



SUMMARY

Glyphosate ((N-phosphonomethyl)glycine) is a broad-spectrum herbicide used to control emersed aquatic grasses, broadleaf weeds and brush. It is not applied to submersed or mostly submersed vegetation. Glyphosate is not subject to hydrolysis or photolysis and is not expected to degrade by either route. It is not volatile. In natural waters, glyphosate dissipates in about 1.5-14 days. Breakdown of glyphosate in the aquatic environment occurs mostly through microbial degradation. Glyphosate is also rapidly inactivated by adsorption to soil. Its tendency to bioconcentrate in fish is very low. There are no restrictions on the use of glyphosate-treated water for irrigation, recreation, or domestic purposes. However, there are restrictions on the application of glyphosate within 0.5 mile upstream of potable water intakes and on the retreatment of an area within 24 hours (Monsanto, 1990). Available information indicates that glyphosate is of relatively low toxicity to mammals and aquatic organisms.

The Environmental Protection Agency (EPA) first registered glyphosate for use in 1974. The glyphosate registration was reviewed under EPA 1988 amendments to FIFRA (Federal Insecticide, Fungicide and Rodenticide Act). In 1993, the EPA issued a Reregistration Eligibility Decision (RED) on glyphosate along with a large number of products containing glyphosate as an active ingredient (USEPA, 1994).

REGISTERED PRODUCTS IN MASSACHUSETTS

The current list of aquatic herbicides containing glyphosate that are registered in Massachusetts can be accessed at http://www.state.ma.us/dfa/pesticides/water/Aquatic/Herbicides.htm on the Massachusetts Department of Agricultural Resources (DAR) Aquatic Pesticide Website. The DAR updates this list regularly with changes. In addition, the DAR can be contacted directly at (617) 626-1700 for more specific questions regarding these products.

GLYPHOSATE USES AND APPLICATION

Glyphosate can be used to control emergent aquatic weeds in freshwater lakes, ponds, reservoirs, canals, rivers, estuaries, seeps, irrigation and drainage ditches, wastewater treatment facilities and wildlife habitat restoration and management areas (McLaren/Hart, 1995).

Application of glyphosate may be made using a variety of methods. Broadcast sprays (either ground-rig or aerial) can be used for broad spectrum control over large areas. Handgun and backpack sprayers can be used for more localized application of the herbicide when the spray needs to be targeted away from desirable species. Wiper trunk injection, cut stem/cut stump and tree injection techniques can also be used for more localized control. The more selective methods are only practical for treating relatively small areas (McLaren/Hart, 1995).

The most effective time of application for most perennial and rhizome-bearing species (cattails, phragmites, etc.) is after the plant enters the reproductive stages of growth (ie., generally late August to October) (Kantrud, 1992 as cited in McLaren/Hart, 1995). In general, application should be made in times of low stress (e.g., drought, disease, nutrient depletion, infestation, etc.) and maximum translocation.

Glyphosate is effective for use on floating and emergent aquatic plants but not on submerged aquatic plants because it is diluted below an effective concentration in the treated water. In floating weeds, the effectiveness is reduced if wave action washes the product off before it can penetrate plant foliage (McLaren/Hart, 1995).

The application rate of glyphosate varies depending on the target species, the application method and the specific formulation used. The maximum rates are used for the most resistant target species or for high target weed infestations. Product labels should be consulted for recommended application rates and use restrictions (e.g., not to apply within specified distance from potable water sources).

The addition of a non-ionic surfactant is recommended to promote adhesion, spreading and penetration of the spray droplets through the plant cuticle on the leaves and to maximize absorption and effectiveness of treatment (WSDOE, 1992).

For specific information on recommended application rates for a particular product, the product label should be consulted. The USEPA Office of Pesticide Programs (OPP) has a link to a database of product pesticide labels at http://www.epa.gov/pesticides/pestlabels/.

MECHANISM OF ACTION

Glyphosate penetrates the plant leaf cuticle shortly after contact and begins a cell by cell migration to the phloem, from which it is transported throughout the plants. The herbicidal action usually occurs within 7 days and up to 30 for woody plants (McLaren/Hart, 1995; Monsanto, 1990.)

Glyphosate's primary herbicidal mode of action is to block the synthesis of aromatic amino acids and the metabolism of phenolic compounds by disrupting the plant's shikimic acid metabolic pathway, leading to the inability of the plant to synthesize protein and produce new plant tissue. This is the only herbicide known to interfere with this particular pathway (McLaren/Hart, 1995). A secondary mode of action affects the photosynthetic process, synthesis, respiration and synthesis of nucleic acids by interacting with a complex series of enzymes which control synthesis of important molecules such as chlorophyll. The results of these interactions are a decrease in the rate of photosynthesis, an increase in respiration rate and a series of cellular changes (i.e., formation of granular bodies, deterioration of oil bodies, the endoplasmic reticulum and ribosomes and the vacuolation of the cytoplasm) leading to death (McLaren/Hart, 1995).

Table III.4-1. List of Aquatic Plants Controlled by Glyphosate

Alder	*Alnus* spp.
Ash	*Fraxinus* spp.
Barnyardgrass	*Echinochloa crus-galli*
Birch	*Betula* spp.
Cattail	*Typha* spp.
Cordgrass	*Spartina* spp.
Dogwood	*Cornus* spp.
Elder	*Sambucus* spp.
Elm	*Ulmus* spp.
Flatsedge, Chufa	*Cyperus esculentus*
Fleabane	*Erigeron* spp.
Foxtail	*Setaria* spp.
Foxtail, Carolina	*Alopecurus carolinianus*
Hemlock, Poison	*Conium maculatum*
Honeysuckle	*Lonicera* spp.
Hornbeam, American	*Caprinus caroliniana*
Lettuce, prickly	*Lactuca serriola*
Maple, red	*Acer rubrum*
Milkweed	*Asclepias* spp.
Monkey-flower, Common	*Mimulus guttatus*
Nutgrass	*Cyperus rotundus*
Oak, pin	*Ouercus palustris*
Panicum	*Panicum* spp.
Phragmites	*Phragmites* spp.
Poison Ivy	*Rhus radicans*
Poplar	*Populus* spp.
Purple Loosestrife	*Lythrum salicaria*
Salt cedar	*Tamarix* spp.
Saltbush, sea myrtle	*Baccharis halimifolia*
Smartweed, Pennsylvania	*Polygonium pennsylvanicum*
Smartweed, swamp	*Polygonum coccineum*
Spikerush	*Eleocharis* spp.
Sumac, poison	*Rhus vernix*
Sycamore	*Platanus occidentalis*
Tules, common	*Scirpus acutus*
Willow	*Salix* spp.
Waterhyacinth	*Eichornia crassipes*
Water-lettuce	*Pistia stratiotes*

McLaren/Hart, 1995

ENVIRONMENTAL FATE/TRANSPORT

The major fate process affecting glyphosate persistence in aquatic environments is biodegradation. Microorganisms in soil, water and sediment biodegrade glyphosate under both aerobic and anaerobic conditions (Reinert and Rodgers, 1987; McLaren/Hart, 1995). The main biodegradation product in soil and sediments is aminomethylphosphonic acid (AMPA). Other minor metabolites, including N-

methylaminomethylphosphonic acid, N,N-dimethylaminomethylphosphonic acid, hydroxymethylphosphonic acid and two unidentified metabolites. Residue levels of glyphosate and AMPA in the aquatic environment are low and dissipate rapidly over time (McLaren/Hart, 1995).

Absorption to sediment is another major contributor to the aquatic dissipation of glyphosate. The average half-life of glyphosate in soil is 60 days. In natural waters, dissipation half-lives of glyphosate range from 1.5-14 days. The dissipation half-life of glyphosate in waters not associated with sediments is much longer, (i.e., 7-10 weeks). In the presence of sediments, under either aerobic or anaerobic conditions, dissipation half-lives for glyphosate range from 6.5-21 days (McLaren/Hart, 1995; WSDOE, 1992; Reinert and Rodgers, 1987).

Glyphosate is an acid and bonds to soil with ionic interactions. It has a negligible vapor pressure and is nonvolatile. Glyphosate contains no photolyzable or hydrolyzable groups and is not expected to degrade in these ways (WSSA, 1983 as cited in Reinert and Rodgers, 1987).

The bioconcentration factor (BCF) for glyphosate in fish is low (Westerdahl and Getsinger, 1988 as cited in WSDOE, 1992). Glyphosate residuals are not typically found in fish because there is no affinity between the glyphosate molecule and (the typically lipophilic) fish tissue. Any glyphosate will pass unchanged through the mouth or gills of the fish, remaining either in solution or adsorbed to suspended particulates (McLaren/Hart, 1995). Exposure of experimental fish for 10-14 days to glyphosate concentrations 3 to 4 times the recommended levels resulted in BCF values of 0.2-0.3, which are considered insignificant (Brandt, 1984 as cited in WSDOE, 1992). Information submitted by the manufacturer of this compound also supports the finding of BCF values no higher than 0.3 (Monsanto, 1990 as cited in McLaren/Hart, 1995).

PHARMACOKINETICS

Rat studies indicate that oral doses of glyphosate are rapidly but poorly absorbed by rats, with female rats absorbing more than males (McLaren/Hart, 1995; USEPA, 1992). The glyphosate that is absorbed is rapidly excreted as unmetabolized glyphosate, with 90% of the absorbed dose being excreted within 48 hours (McLaren/Hart, 1995). Peak levels of glyphosate in the blood and bone marrow of rats dosed intraperitoneally occurred within 30 minutes. The concentration of glyphosate in blood had a half-life of one hour but remained relatively constant in bone marrow, with a half-life of 7.6 hours for males and 4.2 hours for females. Following intravenous doses of glyphosate administered to mice, 30-36% of the compound was eliminated unchanged in the urine and the rest in the feces. Traces (0.04%) of aminomethylphosphonic acid (AMPA) were found to be the only metabolites in the feces. Studies conducted with glyphosate administered in feed to chickens, cows and swine suggest that glyphosate does not accumulate in animal tissues during periods of oral exposure (USEPA, 1992). A series of residue and metabolism studies have shown that glyphosate is poorly absorbed across the gastrointestinal tract and there is minimal tissue retention and rapid elimination of residues in birds and fish in addition to mammals (Monsanto, 1993).

HEALTH EFFECTS

Avian:

A number of acute toxicity studies of technical grade glyphosate were conducted on ducks and quail. Five-day LC50 values were >3,850 mg/l for each or, practically nontoxic (Monsanto, 1988 and USEPA, 1986 as cited in WSDOE, 1992; AQUIRE, 1995).

Mammalian:

Acute:

There is very little information in the published literature on the acute toxic health effects of glyphosate. Glyphosate has very low mammalian acute oral or dermal toxicity (McLaren/Hart, 1995). Acute toxicity studies for a commercial formulation of glyphosate have produced oral LD50 values for Rodeo of 4,873 and 5,600 mg/kg in rats and 1,568 mg/kg in mice (USEPA, 1992). A dermal LD50 value of greater than 5,000 mg/kg (i.e., practically nontoxic) was reported for rabbits (USEPA, 1992). For technical glyphosate, an oral LD50 in the rat and a dermal LD50 in the rabbit were found to be greater than 5,000 mg/kg. The most prominent effect following glyphosate poisoning was reported to be hyperemia (i.e., an excess of blood) of the lungs, with severe stress, accelerated breathing, elevated temperature, occasional convulsive movements and rigor preceding death. A commercial formulation of glyphosate was found to be practically nonirritating to rabbit eye and skin whereas technical glyphosate was severely irritating to rabbit eye but practically nonirritating to rabbit skin (McLaren/Hart, 1995). Glyphosate was found to be a cumulative irritant in guinea pigs (USEPA, 1992). The EPA concluded that glyphosate is slightly irritating to skin and is not a dermal sensitizer (USEPA, 1993a).

Subchronic/Chronic:

Results of subchronic and chronic laboratory studies also indicate that glyphosate is not very toxic. In 90-day feeding studies conducted with rats at doses up to 1,000 mg/kg, no changes as compared with controls in body weight, behavior, mortality, hematology, blood chemistry, or urinalysis were noted. In dogs administered up to 60 mg/kg, a similar lack of changes was noted (USEPA, 1992). A 26-month chronic feeding study in which rats were administered doses of up to 31.5 mg/kg/day (males) and 34 mg/kg/day (females) produced no significant effects on body weight, organ weight, organ/body weight ratios or hematologic and clinical chemistry parameters (USEPA, 1992). In a 24-month chronic study in which rats were administered glyphosate at 2,000, 8,000 and 20,000 ppm for 24 months, a significant decrease in body weight in high-dose females was noted. The No Observed Adverse Effect Level (NOAEL) for glyphosate in this study is 8,000 ppm (McLaren/Hart, 1995). In a one-year dog feeding study, there was an apparent decrease in absolute and relative pituitary weights with no accompanying histopathologic changes. A NOAEL of greater than 500 was reported from this study (Monsanto, 1985 as cited in USEPA, 1992).

Developmental/Reproductive:

In a three generation reproductive study in which male and female rats were administered dietary concentrations of glyphosate corresponding to 0, 3, 10 and 30 mg/kg/day, there were no treatment-related systemic or reproductive effects noted in adults. One group of third generation male pups whose parents were exposed to the highest dose (30 mg/kg/day) showed an increase in the incidence of unilateral renal tubular dilation. The No Observed Adverse Effect Level (NOAEL) for glyphosate in this study is 10 mg/kg/day and the Low Observed Adverse Effect Level (LOAEL) is 30 mg/kg/day (Bio/dynamics, Inc., 1981a as cited in USEPA, 1992). In a subsequent two-generation reproductive study in rats, rats were administered glyphosate in the diet at levels up to 30,000 ppm (about 1,500 mg/kg/day). The only effects noted were very frequent soft stools in the F_0 and F_1 males and females, decreased food consumption and body weight gain of the F_0 and F_1 males and females during the growth (premating) period and decreased body weight gain of the F_{1a}, F_{2a} and F_{2b} male and female pups during the second and third weeks of lactation. Focal tubular dilation of the kidneys, observed in the previous study, was not observed in this study at any level. As a result, the EPA concluded that the presence of this effect in the three-generation study was a spurious rather than glyphosate-related

effect (USEPA, 1993a). Rabbits treated with 350 mg/kg/day during days 6-27 of gestation produced signs of maternal toxicity but did not exhibit developmental toxicity.

Mutagenicity:

Glyphosate was not found to be mutagenic in eight strains of bacteria and yeast evaluated in microbial test systems and in Chinese hamster ovary cells (USEPA, 1988; USEPA, 1993b). In addition, glyphosate also produced negative results for chromosomal aberrations in mouse dominant lethal test, the *in vivo* cytogenetics assay, the *Bacillus subtilis* rec assay and in the rat hepatocyte DNA repair assay. High concentrations of glyphosate have produced sister chromatid exchange in human lymphocytes *in vitro* (USEPA, 1992). However, the information from this study has been shown to be possibly erroneous (Slapikoff, 1983; Brusick, 1983).

Carcinogenicity:

No clear-cut dose-response relationship has been established between glyphosate exposure and tumor formation. In one study, male and female rats were administered glyphosate in the diet at doses up to 31.5 and 34.0 mg/kg/day, respectively, for 26 months. No increase in tumor formation was noted (Bio/dynamics, Inc., 1981b as cited in USEPA, 1992). In a 24-month chronic feeding study in mice exposed to levels up to 30,000 ppm glyphosate, no excess of tumors was noted. However, the EPA has classified this study as a chronic toxicity study rather than a cancer study because the study does not meet the specific guidelines for a cancer study established by EPA (USEPA, 1986 as cited in USEPA, 1992). Another cancer study, in which rats were fed glyphosate at concentrations of 2,000, 8,000 and 20,000 ppm for 24 months revealed an increased incidence of adenomas (i.e., benign tumors) of the pancreas, thyroid and liver. Although no dose-response relationship was established and the tumors did not progress from adenomas to carcinomas (malignant tumors), the EPA has recommended that the carcinogenic effects of glyphosate be addressed by a peer review committee (USEPA, 1992). In an 18-month carcinogenicity study, mice were fed diets containing 1, 150, 750 or 4500 mg/kg/day of glyphosate. No effects were observed in the low and mid-dose groups. Effects noted in the high-dose group included decreased body weight gain in males and females, various liver and kidney effects as well as slightly increased incidence of renal tubular adenomas, a rare tumor, in males. The EPA concluded that occurrence of these adenomas was spontaneous rather than compound-induced because the incidence of renal tubular adenomas in males was not statistically significant when compared with the concurrent controls. After extensive evaluation, an independent group of pathologists and biometricians concurred with this conclusion. Therefore, glyphosate was not considered to be carcinogenic in this study.

In 1988, an EPA Science Advisory Panel labeled glyphosate as a D carcinogen under the old EPA cancer classification system, indicating that it is “not classifiable as to human carcinogenicity” based on a lack of statistical significance and uncertainty as to a treatment-related effect (Doyle, 1996; USEPA, 1993b). Under the new EPA cancer classification system using descriptors, a designation of D corresponds to the descriptor, “Data are inadequate for an assessment of human carcinogenic potential”. On June 26, 1991, the EPA Office of Pesticide Programs (OPP) labeled glyphosate an E carcinogen (again, based on the old EPA cancer classification system) based on a lack of convincing evidence of carcinogenicity in adequate studies with two animal species, rat and mouse. An E classification is EPA's most favorable category and is given to compounds for which there is "evidence of noncarcinogenicity in humans" (McLaren/Hart, 1995). The EPA Integrated Risk Information System (IRIS) database still lists the 1988 D cancer classification. However, the most recent EPA classification is the OPP 1991 designation of E. Under the new EPA cancer classification system, a designation of E corresponds to the descriptor, “not likely to be carcinogenic to humans”.

Available Toxicity Criteria:

The EPA has developed several Drinking Water Health Advisories for glyphosate. Health Advisories are defined as concentrations of a substance in drinking water estimated to have negligible deleterious effects in humans, when ingested for a specified period of time. These values include a ten-day health advisory for a child of 20 mg/l as well as a lifetime health advisory of 1 mg/l for a child and 4 mg/l for a 70-kg adult (USEPA, 1988).

The EPA has also developed a Maximum Contaminant Level Goal (MCLG) for drinking water and has promulgated this value as a Maximum Contaminant Level (MCL) standard (USEPA, 1993b; USEPA, 1995). Massachusetts has adopted this value as a drinking water standard, known as a Massachusetts Maximum Contaminant Level (MMCL).

In addition, the EPA Carcinogen Risk Assessment Verification Endeavor (CRAVE) RfD/RfC workgroup has developed an oral Reference Dose (RfD) of 0.1 mg/kg/day for glyphosate based on the three-generation rat reproduction study conducted by Monsanto cited earlier. The RfD is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime (USEPA, 1993b). The EPA Office of Pesticide Programs (OPP) has developed an RfD of 2.0 mg/kg/day. The World Health Organization (WHO) has developed an RfD of 1.75 mg/kg/day (USEPA, 1995b).

ECOLOGICAL TOXICITY

Aquatic Organisms :

Glyphosate has very low toxicity in aquatic fish and invertebrates. A range of 96-hr LC50 values identified for fish exposed to a formulation of glyphosate were reported to be greater than 1,000 mg/l for a number of species including carp, rainbow trout, bluegill, sunfish and harlequin fish (WSDOE, 1992 as cited in McLaren/Hart, 1995). Another source cites an LC50 greater than 10,000 mg/l for carp. Values over 1,000 mg/l are considered an insignificant hazard (Christensen, 1976 as cited in McLaren/Hart, 1995). Reported 96-hour LC50s for technical grade glyphosate include values ranging from 86 mg/l for rainbow trout to 168 mg/l for harlequin fish. Reported LC50s for technical glyphosate for other invertebrate species include values ranging from >10 mg/l for American oyster larvae to 934 mg/l for a fiddler crab, with the LC50s for *Daphnia magna*, honeybee, shrimp and *Chironomus plumosus* falling in between (WSDOE, 1992; McKee, pers. comm., 1996). A value greater than 10 is considered only slightly toxic (Christensen, 1976 as cited in McLaren/Hart, 1995). The EPA AQUIRE database lists reported LC50s for unspecified forms of "glyphosate" ranging from a 4-hr LC50 value of 1.3 mg/l for rainbow trout to a 4-hr LC50 value of 25,605 mg/l for goldfish (EPA, 1995).

Plants:

Since glyphosate is a broad spectrum herbicide, it is effective on a large number of annual and perennial grasses, broadleaf weeds, sedges, rushes and woody plants as well as ditchbank or shoreline aquatic weeds. Glyphosate is not effective on plants that are completely submerged or which have most of their foliage under water (Monsanto, 1981 as cited in WSDOE, 1992). Because of its widespread effects, glyphosate may affect non-target plants. As with all herbicides, use of glyphosate should be coordinated as part of an overall management plan to control vegetation in an organized manner. Such a plan is particularly important when the objective is the control of large areas of vegetation such as phragmites, cattails or purple loosestrife due to the potential for simultaneous die-off. This die-off could result in oxygen depletion due to rapid decomposition of organic matter, resulting in widespread

nonspecific destruction of plant life in addition to fish kills and the proliferation of microfauna and flora which are harmful to waterfowl (WSDOE, 1992 as cited in McLaren/Hart, 1995).

Table III.4-2. Properties of Glyphosate

CAS #:	1071-83-6
Synonyms	isopropylamine salt; n-(phosphonomethyl)glycine
Molecular formula	$C_3H_8NO_5P$
Molecular weight	169.1
Physical properties	solid, white, odorless
Melting point	200^oC
Density	0.5 gm/cc for pure chemical
Vapor pressure	negligible
Photolysis half-life	stable
Hydrolysis half-life	stable
Biodegradation half-life	60 days (soil)
Dissipation half-life	1.5-14 days
K_{ow}	5.6×10^{-4}
K_{oc}	High
BCF	Low
Water Solubility	1.2×10^4

(WSSA, 1983; Aquatic Plant Identification and Herbicide Use Guide, 1988)

Glyphosate References

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