SŌLITUDE
LAKE MANAGEMENT

Annual Report

2019 Post-Treatment Management Program
Westford Ponds – Keyes, Long Sought For, Nabnasset
Westford, MA

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Submitted on: October 25, 2019

Introduction

In accordance with the aquatic management program contract between SŌLitude Lake Management and the Town of Westford for Keyes Pond, Long Sought For Pond, and Nabnasset Pond, the following document serves to provide this year's treatment and monitoring results, as well as recommendations for the 2020 management season. As proposed, ESS Group, Inc. (ESS) conducted all monitoring work.

All management activities were conducted in compliance with the current Orders of Conditions issued by the Westford Conservation Commission and the Licenses to Apply Chemicals (#19124 – Keyes, 19126 – Long Sought For, 19128 - Nabnasset) issued by the MA DEP Office of Watershed Management.

Consistent with management in previous years, the main objective of the 2019 program was to achieve control of non-native aquatic vegetation in three Westford ponds, specifically variable watermilfoil (*Myriophyllum heterophyllum*), curlyleaf pondweed (*Potamogeton crispus*), and Eurasian watermilfoil (*Myriophyllum spicatum*) in their respective locations.

Herbicide Treatments

Treatment of Keyes Pond, Long Sought For Pond and Nabnasset Pond were performed on May 30 to control respective aquatic invasive species growth around select areas of the shoreline. Prior to both treatment events, notification was posted on the Town's website and Facebook page, as well as water-use restriction signs that were posted along the shoreline of each pond.

All three ponds were treated utilizing diquat herbicide; approximately 2.5 acres in Keyes, 12.5 acres in Long Sought For, and 25 acres in Nabnasset were treated. Based on seasonal growth timing, ESS had surveyed these three ponds earlier than the remaining four in anticipation of appropriately timed treatments.

Nabnasset and Keyes were also treated with copper sulfate to mitigate algal blooms at later dates, July 1 and September 6, respectively.

Post-Treatment Assessment
The final post-treatment plant mapping and WQ sampling at all three ponds was conducted by ESS on September 12.

Overall, the herbicide treatments at each of the ponds was successful in controlling the target species present. ESS did not observe the target species in Keyes Pond during the post-treatment mapping. Nabnasset Lake did not have any curlyleaf pondweed growth present at the time of the survey but had brittle naiad growth in some areas; additionally, it is understood that variable milfoil still persists in Shipley Swamp. Curlyleaf pondweed was also observed within Long Sought For, but this was anticipated as curlyleaf pondweed can begin to regrow that late in the season. Overall, all three ponds continued to maintain a diverse and significant native aquatic plant community post-treatment events. The detailed results of the interim sampling and post-treatment mapping work are included in the attached report by ESS; the other four Westford Ponds were also surveyed this fall and are included in the same report.

Ongoing Management Recommendations
Consistent with prior years, we recommend continuing annual monitoring and treatment, if warranted, at each pond in 2020. We strongly recommend initiating monitoring and management of all ponds in early spring to sufficiently allow for scheduling and appropriate treatment timing for the various target species. This year's differently timed surveying based on target species worked well. For monitoring, ESS recommends early season vegetation mapping, water quality sampling, as well as the required permit compliance monitoring to correspond with what has been done this and in previous years. More information on the recommendations from ESS are included in their attached report.

Regarding vegetation management, we anticipate regrowth of variable watermilfoil and curlyleaf pondweed in each of the ponds where it was observed this season. Treatment of these ponds should be considered using diquat herbicide again as it has proven to be effective in controlling the target species there. Due to the significant increase in thin-leaf pondweed observed at Long Sought For Pond by residents this season, we recommend diligently monitoring the pond for growth through the season and conducting a diquat treatment, if necessary, to manage the growth. For all of the ponds that were not managed this season, we recommend continuing diligent monitoring at each to be aware of any shifts in vegetation compositions and/or new invasive species infestations. Of the unmanaged ponds this year, if the Town wants to begin managing any of them in 2020 or future years, we are happy to provide management recommendations and strategies as necessary to align with the Town's goals.

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October 22, 2019

Kara Sliwoski
SOLitude Lake Management
590 Lake Street
Shrewsbury, Massachusetts 01545

Re: ***Lake and Pond Monitoring and Reporting, Post-treatment/ Late Season – 2019***
Westford, Massachusetts
ESS Project No. S469-004

Dear Ms. Sliwoski,

ESS Group, Inc. (ESS) was contracted by SOLitude Lake Management (SOLitude) to complete a post-treatment monitoring program at three lakes and ponds located within the Town of Westford (Town), as follows: Keyes Pond, Long Sought-for Pond, and Nabnasset Lake. In addition, a late season monitoring event was completed at four additional ponds, as follows: Old Mill/Graniteville Ponds, Burge's Pond, Kennedy Pond, and Forge Pond. The post-treatment/late season monitoring program was completed to complement pre-treatment/early season monitoring completed by ESS in late spring 2019.

This report provides the findings of the monitoring program, builds on the findings of prior monitoring efforts, and makes recommendations for management of these water bodies in 2020.

Post-treatment and Late-Season Monitoring 2019

The 2019 post-treatment/late season monitoring program consisted of aquatic vegetation mapping and water quality sampling and was completed at each of the seven ponds on the following dates:

- September 11 (Late season mapping of Burge's Pond, Kennedy Pond and Old Mill/Graniteville Ponds)
- September 12 (Post-treatment mapping of Nabnasset Lake, Long-Sought for Pond and Keyes Pond)
- September 17 (Late season mapping of Forge Pond)

Aquatic Vegetation Monitoring

Aquatic plants were surveyed using comparable methods to recent monitoring events, including the 2019 pre-treatment/early season monitoring effort. Plant rakes were used to help assess aquatic invasive plant densities. Data were collected using a combination of field notes and a Trimble Geo7x DGPS receiver capable of sub-meter accuracy. Aquatic plants observed during the post-treatment/ late season monitoring are presented in Table 1.

Additional details on the results of the aquatic plant surveys are presented, by pond, on subsequent pages.

Table 1. Aquatic Plants Observed at Westford Ponds during 2019 Post-treatment/ Late Season Surveys.

Common Name	Scientific Name	Native or Exotic	Keyes Pond	Long Sought-for Pond	Nabnasset Lake	Old Mill/Graniteville Ponds	Burge's Pond	Kennedy Pond	Forge Pond
Bigleaf Pondweed	*Potamogeton amplifolius*	Native			X				
Brittle Naiad	***Najas minor***	**Exotic**			**X**				
Bushy Naiad	*Najas flexilis*	Native		X	X				
Canadian Waterweed	*Elodea canadensis*	Native							X
Clasping-leaf Pondweed	*Potamogeton perfoliatus*	Native						X	
Common Bladderwort	*Utricularia macrorhiza*	Native				X			
Coontail	*Ceratophyllum demersum*	Native				X			X
Curly-leaf Pondweed	***Potamogeton crispus***	**Exotic**		**X**					
Duckweed	*Lemna* sp.	Native				X			
Eurasian Milfoil	***Myriophyllum spicatum***	**Exotic**							**X**
Fanwort	***Cabomba caroliniana***	**Exotic**				**X**			**X**
Floating-leaf Pondweed	*Potamogeton epihydrus*	Native		X		X			X
Golden Hedge-hyssop	*Gratiola aurea*	Native						X	
Humped Bladderwort	*Utricularia gibba*	Native	X						X
Little Floating Bladderwort	*Utricularia radiata*	Native					X		
Low Milfoil	*Myriophyllum humile*	Native					X		
Marsh Seedbox	*Ludwigia palustris*	Native				X			
Purple Bladderwort	*Utricularia purpurea*	Native	X		X				
Robbins' Pondweed	*Potamogeton robbinsii*	Native							X
Spikerush	*Eleocharis* sp.	Native				X		X	
Stonewort	*Nitella* sp.	Native		X					
Thinleaf Pondweeds	*Potamogeton spp.*	Native		X	X			X	
Variable-leaf Milfoil	***Myriophyllum heterophyllum***	**Exotic**				**X**			**X**
Water Celery (Tapegrass)	*Vallisneria americana*	Native			X	X			X
Watershield	*Brasenia schreberi*	Native	X		X		X		
White Water Lily	*Nymphaea odorata*	Native	X		X	X	X		X
Yellow Water Lily	*Nuphar lutea variegata*	Native	X		X		X	X	X
Total			**5**	**5**	**9**	**10**	**5**	**5**	**11**

Keyes Pond

Five species of native plants were observed in Keyes pond during the 2019 post-treatment survey, including one exotic invasive species. Curly-leaf pondweed (*Potamogeton crispus*), which covered approximately one acre of the pond during the pre-treatment survey (Figure 1), was not observed during post-treatment monitoring (Figure 2). Aquatic invasive variable-leaf milfoil (*Myriophyllum heterophyllum*) was not observed during pre- or post-treatment mapping efforts in 2019, which is consistent with results of the 2017 and 2018 post-treatment surveys. A pond resident did report an area of suspected variable-leaf milfoil growth near the outlet of Keyes Pond; however, this was not confirmed with photographs or a physical specimen.

In late August, the Westford Health Department collected a sample of surface water and sent it to ESS, in response to community reports of color and cloudiness in surface waters of the pond. ESS confirmed the presence of cyanobacteria in the sample (*Anabaena* sp.), as well as detritus and other non-harmful algal species. Given the presence of potentially toxigenic cyanobacteria, the sample was also tested for cyanotoxins, which were not detected by laboratory analysis.

Long Sought-for Pond

Four species of aquatic plants and one species of macroalgae were observed in Long Sought-for Pond during the 2019 post-treatment survey. This included one exotic invasive species. As was the case during early season monitoring (Figure 3), curly-leaf pondweed was the only exotic vascular plant observed during the late season survey, and covered approximately 6.2 acres of Long Sought-for Pond (Figure 4). This species predominantly occurred near the shore along the northern side of the pond, including an area of sparse growth within a cove. Only sparse growth of curly-leaf pondweed was observed during the 2019 pre-treatment survey. While curly-leaf pondweed was observed primarily as dormant turions (winter buds) during the post-treatment survey, some dense standing patches of this species were also noted. Typically, the active season of curly-leaf pondweed growth ends in June or early July. This suggests that a second summer flush of curly-leaf pondweed growth occurred over a limited portion of Long Sought-for Pond in 2019.

Dense patches of native thinleaf pondweed were observed at Long Sought-for Pond on September 12, 2019.

Dense patches of native thinleaf pondweeds (*Potamogeton spp.*) were also observed in the central portion of the northern shoreline in 2019 (Figure 5). These beds were not observed in the pre-treatment surveys and ESS is unaware of thinleaf pondweeds growing to nuisance levels prior to 2019. However, nearly four acres of growth was observed by ESS during this year's post-treatment survey. During our survey, the plants appeared to be in decline, which leaves open the possibility that beds were even more extensive or denser at some point over the summer.

Nabnasset Lake

Nine species of aquatic plants were observed at Nabnasset Lake during the 2019 post-treatment survey, including one exotic invasive species. Aquatic invasive curly-leaf pondweed was observed in Nabnasset Lake during the 2019 pre-treatment survey (Figure 6), but was not seen during the post-treatment survey (Figure 7). This is a notable reduction compared to the 2019 pre-treatment survey, when patchy to sparse growth of curly-leaf pondweed was found to cover approximately 4.4 acres of Nabnasset Lake, primarily within a few coves along the northern and eastern shorelines. As with Long Sought-for Pond, a second summer flush of curly-leaf pondweed growth was reported by residents in Nabnasset Lake during summer 2019. However, this growth appeared to have declined by the time ESS conducted the post-treatment mapping in September.

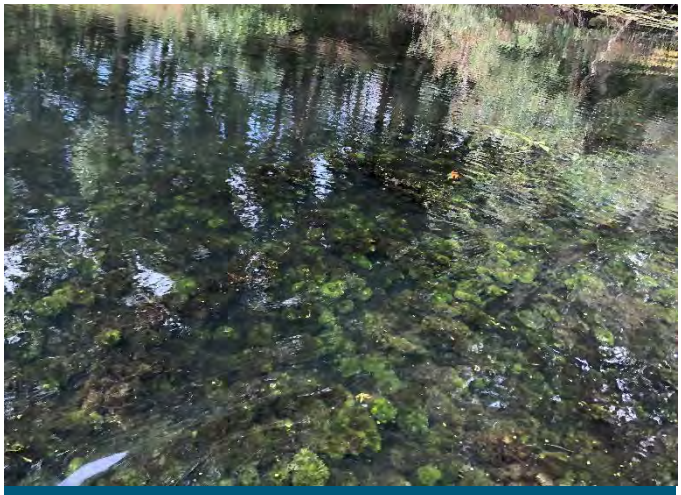
Brittle naiad collected at Nabnasset Lake on September 12, 2019. The occurrence of this species in the lake dramatically increased between the 2019 pre-treatment and post-treatment surveys.

Invasive brittle naiad (*Najas minor*), which was not observed during the pre-treatment site visit, was found to occupy approximately 13.6 acres of the northern shoreline of the pond, occurring as sparse to patchy growth (Figure 8). This species was also observed forming dense beds covering approximately 0.6 acres of the lake bottom in coves along the eastern shoreline, and near Shipley Swamp on the western side of the pond. Consistent with the 2019 pre-treatment survey, variable-leaf milfoil was not observed during 2019 post-treatment monitoring. However, it is known to persist in parts of adjacent Shipley Swamp.

Old Mill/Graniteville Ponds

Ten species of aquatic plants were observed at the Old Mill/Graniteville Ponds during the 2019 late season survey, including two exotic invasive species. Aquatic invasive fanwort (*Cabomba caroliniana*), and variable-leaf milfoil were observed during the late season mapping.

Fanwort was found growing in sparse to dense stands in both basins of the pond, covering approximately 7.0 acres (Figure 12). This represents an increase from the early season survey, when fanwort was observed in approximately 1.9 acres of the ponds (Figure 9). However, due to the timing of the early season survey, fanwort cover was likely underestimated at that time.



Dense growth of fanwort observed at the Old Mill/ Graniteville Ponds on September 11, 2019.

Variable-leaf milfoil cover decreased from approximately 7.8 acres during the 2019 early season survey (Figure 10) to approximately 3.5 acres during the late season survey (Figure 13). However, this decrease in cover appears to largely coincide with the accelerated growth of fanwort, which tends to reach maximum growth levels later in the season than variable-leaf milfoil.

Curly-leaf pondweed, which was observed forming extensive beds in Old Mill/Graniteville Ponds during the early season survey (Figure 11), was not observed during late season monitoring (Figure 14). This seasonal decline in curly-leaf pondweed is expected, as the plant typically completes its life cycle in early summer.

Burge's Pond

Five species of aquatic plants were found in Burge's Pond during the late season survey. No aquatic invasive plant species were observed in Burge's Pond during the 2019 early or late season surveys (Figure 15). The control of variable-leaf milfoil previously achieved in 2016 appears to have persisted, based on the survey results. However, a Westford resident reported having observed some stems of variable-leaf milfoil in the pond in 2019. This observation was not confirmed with photographs or a physical specimen.

Kennedy Pond

Five species of aquatic plants were observed in Kennedy Pond during the late season survey. No aquatic invasive plant species were found within Kennedy Pond during the 2019 early or late season surveys (Figure 16), although the exotic invasive common reed (*Phragmites australis*) was observed growing along portions of the shoreline, as it has in prior years.

Forge Pond

Eleven species of aquatic plants were observed during the late season survey of Forge Pond, including three exotic invasive species.

Although curly-leaf pondweed was observed to cover approximately 6.1 acres as sparse to patchy growth during the early season survey (Figure 17), this species was not observed during the late season survey (Figure 21).

Variable-leaf milfoil covered approximately 10.5 acres of the pond in patchy to dense growth during the early season survey, predominantly along the northwestern shoreline and within the eastern cove (Figure 18). The overall coverage of variable-leaf milfoil increased to 15.6 acres during the late season survey, although growth of this species appears to be less dense than observed during early season monitoring (Figure 22). This reduction in apparent density is likely due to the increased growth of fanwort, which reaches maximum development later in the season than variable-leaf milfoil.

Dense fanwort observed at Forge Pond on September 17, 2019.

Eurasian milfoil exhibited a pattern similar to variable-leaf milfoil; although the total coverage of this species increased from 11.9 acres during the early season survey (Figure 19) to 13.7 acres during the late season survey (Figure 23), the density of Eurasian milfoil growth appears to have decreased between the monitoring visits.

In contrast, fanwort cover notably increased between the 2019 early and late season surveys. This species was only observed as sparse growth covering 1.4 acres in a cove along the northwestern shoreline during early season monitoring (Figure 20). However, during the late season survey, dense beds of this species were observed to cover approximately 17.2 acres, and sparse growth covered an additional 8.6 acres, of Forge Pond (Figure 24).

Water Quality Monitoring

As in 2018 and the 2019 pre-treatment/early season monitoring event, ESS conducted water quality sampling at three stations within each waterbody, including at least one location in the deepest portion of each waterbody. During the water quality monitoring event, ESS measured the following parameters in the field: dissolved oxygen, temperature, turbidity, pH, and water clarity (Secchi disk). ESS also collected water samples for laboratory analysis of the following analytes: hardness, nitrate nitrogen, alkalinity, total phosphorus, total Kjeldahl nitrogen, and ammonia nitrogen. Notable water quality results are summarized in the following sections.

Dissolved Oxygen

Each pond exhibited dissolved oxygen concentrations suitable for aquatic life near the surface, although surface water at the outlet of Keyes Pond was below the state numerical criterion of 5.0 mg/L for warmwater fisheries. However, post-treatment/late season water quality results indicate low (hypoxia) to very low (anoxia) dissolved oxygen levels in the deeper waters of all the ponds sampled. This pattern was most extensive in Keyes Pond, Old Mill/Graniteville Ponds, and Forge Pond. Extensive areas of persistently low dissolved oxygen concentrations are typically considered unsupportive of most aquatic life. Additionally, they may increase the likelihood of internal phosphorus release from pond sediments, which can compound management issues associated with eutrophication (nutrient enrichment).

Turbidity

Turbidity varied somewhat within each of the water bodies but did not appear to be abnormally elevated in any of the locations sampled during post-treatment/late season monitoring. Mostly minor variations were observed among sampling locations within a pond and between waterbodies.

Secchi Depth (Transparency)

Secchi depth is a measure of water transparency and may be reduced by suspended sediments, algal growth, or the presence of other organic matter in the water column. Reduced Secchi depths are typically associated with nutrient-enriched ponds. During post-treatment/late season monitoring, the shallowest Secchi depth was measured in Keyes Pond, where water transparency extended only 1.25 meters. The

deepest Secchi depths (i.e., clearest water) were measured at Burge's Pond and Long Sought-for Pond, where transparency extended to 3.5 meters.

pH, Hardness, and Alkalinity

In alignment with pre-treatment/early season sampling, most of the locations sampled during post-treatment/late season monitoring were circumneutral (i.e., pH near 7.0). The most acidic pH was measured in Burges Pond, and the most basic pH measurements were collected in Long Sought-for Pond.

Hardness and alkalinity tend to be naturally higher in the Merrimack River valley than adjacent parts of eastern Massachusetts, although they can also be influenced by human activity in the watershed as well as atmospheric acid deposition. These parameters varied substantially between ponds, but generally demonstrated similar patterns in variation with lower hardness values corresponding to lower alkalinity. This is not unexpected, as harder waters tend to have a higher alkalinity (also known as acid neutralizing capacity). Increased alkalinity suggests greater buffering capacity of the water (i.e., resistance to pH change). As was noted during pre-treatment/early season sampling, the alkalinity results from post-treatment monitoring indicate that Old Mill/Graniteville Ponds, Forge Pond, and Nabnasset Lake are relatively well-buffered, while Kennedy Pond has distinctly less buffering capacity, and Burge's Pond has almost no measurable buffering capacity. Ponds with low buffering capacity may be susceptible to more abrupt swings in pH than those with higher alkalinity.

Phosphorus and Nitrogen

Phosphorus and nitrogen are both major nutrients fueling plant and algal growth. Of the two, phosphorus tends to be limiting nutrient in most New England freshwater systems. However, nitrogen levels can also impact the overall productivity of the system and type of algal growth favored, and may even influence the production of toxins in some cyanobacteria. In general, high nutrient levels in the water column can contribute to algal blooms and excessive floating plant growth. High availability of nutrients in the sediments can contribute to excessive rooted plant growth.

During post-treatment/late season monitoring, total phosphorus concentrations were generally highest at Keyes Pond and Old Mill/ Graniteville Ponds, and lowest at Long Sought-for Pond. Concentrations in excess of 0.020 mg/L were recorded from at least one of the three sampling locations in each of the ponds sampled except for Long Sought-for Pond. Algal blooms may occur even where total phosphorus levels are very low. However, they tend to be more frequent and are more likely to become problematic where concentrations regularly exceed 0.020 mg/L. Sediment release of phosphorus is apparent when bottom (hypolimnetic) concentrations are much higher than surface (epilimnetic) concentrations during the time of the year when the water body is stratified (warm surface water overlaying cold bottom water). This pattern is most apparent at Keyes Pond, Old Mill/Graniteville Ponds, Nabnasset Lake, and Forge Pond. As indicated previously, release of sediment phosphorus may be aggravated by low dissolved oxygen concentrations at depth.

Overall nitrogen levels were highest at Keyes Pond, and nitrate nitrogen levels were greatest at Old Mill/ Graniteville Ponds and Nabnasset Lake. High levels of nitrate nitrogen may be an indication of septic loading or stormwater runoff. Post-treatment/late season samples from Nabnasset Lake and Forge Pond contained the highest levels of ammonia nitrogen, which may be associated with direct septic loading or persistent anoxic or hypoxic conditions.

Table 2. Dissolved Oxygen Profiles at Deep Hole Locations during 2019 Post-treatment/Late Season Monitoring

Depth	Keyes Pond		Old Mill/Graniteville Ponds		Burge's Pond		Kennedy Pond		Long-Sought-for Pond		Nabnasset Lake		Forge Pond	
m	%	mg/L	%	mg/L	%	mg/L	%	mg/L	%	mg/L	%	mg/L	%	mg/L
0.5	96	8.5	80	7.1	72	6.4	100	8.6	95	8.4	88	7.7	87	7.8
1.0	81	7.6	74	6.7	68	6.0	98	8.5	97	8.4	87	7.6	87	7.8
1.5	72	6.6	74	6.7	66	5.9	97	8.5	96	8.4	87	7.7	87	7.9
2.0	47	4.3	13	1.3	67	5.9	99	8.6	95	8.3	85	7.5	86	7.8
2.5	14	1.6	7	0.7	67	5.8	98	8.6	95	8.3	83	7.3	84	7.6
3.0	4	0.4	15	1.4	60	5.4	90	7.9	95	8.3	85	7.5	85	7.7
3.5	2	0.2	10	1.0	58	5.1	94	8.3	94	8.2	84	7.4	75	6.8
4.0	2	0.2	3	0.3	47	4.2	94	8.2	93	8.2	84	7.4	69	6.3
4.5	1	0.2			12	1.1	96	8.4	88	7.8	86	7.6	63	5.8
5.0	1	0.1			4	0.4	89	7.8	85	7.5	86	7.5	54	4.9
5.5							36	3.7	79	7.1	86	7.6	13	1.3
6.0							7	0.6	61	5.5	12	1.2	4	0.4
6.5							2	0.2	17	1.6	5	0.4	3	0.3
7.0							1	0.1	7	0.7	3	0.3	2	0.3
7.5									2	0.2			2	0.2
8.0									2	0.2			2	0.2
Total depth (m)	5.8		4.7		5.6		7.6		8.8		7.6		8.0	

Table 3. Temperature Profiles at Deep Hole Locations during 2019 Post-treatment/Late Season Monitoring

Depth (m)	Keyes Pond	Old Mill/Graniteville Ponds	Burge's Pond	Kennedy Pond	Long-Sought-for Pond	Nabnasset Lake	Forge Pond
0.5	21.4	20.7	21.4	22.3	22.2	21.9	20.6
1.0	21.2	20.4	21.3	22.2	22.2	21.9	20.5
1.5	20.7	20.3	21.3	22.2	22.2	21.9	20.4
2.0	20.3	18.3	21.3	22.2	22.2	21.9	20.3
2.5	18.9	18.1	21.2	22.2	22.2	21.9	20.3
3.0	16.6	17.9	21.2	22.1	22.0	21.9	20.3
3.5	14.9	17.8	21.2	22.1	22.0	21.9	20.2
4.0	12.5	17.5	20.9	22.1	21.9	21.9	20.1
4.5	11.2		20.5	22.0	21.7	21.9	20.1
5.0	10.2		19.0	21.9	21.7	21.9	19.9
5.5				21.2	21.5	21.9	18.5
6.0				20.1	20.9	20.2	17.1
6.5				19.2	19.4	17.2	15.0
7.0				18.9	16.8	15.5	12.8
7.5					14.3		11.9
8.0					14.3		11.6
Total depth (m)	**5.8**	**4.7**	**5.6**	**7.6**	**8.8**	**7.6**	**8.0**

Table 4. Water Quality Parameters Collected During 2019 Post-treatment/Late Season Monitoring

Parameter	Units	Keyes Pond			Old Mill/Graniteville Ponds			Burge's Pond			Kennedy Pond			Long Sought-for Pond			Nabnasset Lake			Forge Pond		
Station ID		KEY-A	KEY-B	KEY-C	OLD-A	OLD-B	OLD-C	BUR-A	BUR-B	BUR-C	KEN-A	KEN-B	KEN-C	LSF-A	LSF-B	LSF-C	NAB-A	NAB-B	NAB-C	FOR-A	FOR-B	FOR-C
Location		Deep hole	Inlet	Outlet	Deep Hole		Inlet	Deep Hole		In-pond	Deep Hole		In-pond	Deep Hole		Inlet	Deep Hole		Outlet	Deep Hole		Inlet
		mid-depth			Surface	Bottom		Surface	Bottom		Surface	Bottom		Surface	Bottom		Surface	Bottom		Surface	Bottom	
Total depth	m	5.8	1.2	0.6	5.2		1.5	5.6		4.7	7.6		1.5	8.8		0.3	7.2		2.9	8.0		3.3
Sample depth	m	3	0.5	0.5	0.5	4.0	0.5	0.5	4.5	0.5	0.5	6.5	0.5	0.5	7.5	0.2	0.5	6.5	0.5	0.5	7.0	0.5
Temperature	C	16.6	21.1	20.9	20.7	17.5	20.1	21.4	20.5	21.3	22.3	19.2	22.3	22.2	14.3	22.1	21.9	17.2	22.4	17.7	12.8	17.8
Dissolved oxygen	%	4	70	52	80	3	63	72	12	61	100	2	95	95	2	93	88	5	85	86	2	92
	mg/L	0.4	6.2	4.7	7.1	0.3	5.7	6.4	1.1	5.4	8.6	0.2	8.3	8.4	0.2	8.1	7.7	0.4	7.4	8.1	0.3	8.2
Turbidity	NTU	2.43	2.23	1.70	2.12	3.98	1.67	1.30	1.33	1.32	1.09	1.43	1.26	1.57	1.55	1.55	2.21	2.43	1.70	2.53	2.80	2.55
pH	SU	6.6	6.8	6.8	7.0	6.9	6.7	6.8	5.9	5.5	6.3	7.3	7.0	7.5	7.4	7.0	7.3	7.0	7.0	6.0	6.9	7.0
Secchi Depth	m	1.25	NS	NS	2.5		bottom (1.5)	3.5		3.5	3.0		bottom (1.5)	3.5		NS	2.5		bottom (2.9)	2.3		2.0
Hardness	mg/L	33.3	32.0	30.5	74.9	79.5	75.0	1.9	1.9	2.0	35.5	38.4	36.9	34.9	33.0	35.0	50.8	54.1	49.3	75.5	73.0	73.0
Alkalinity	mg/L	25.0	21.9	22.6	49.2	52.7	53.3	<5.00	<5.00	<5.00	11.4	14.0	12.2	22.3	24.1	23.2	44.1	41.3	25.8	47.3	58.1	47.2
Total phosphorus	mg/L	0.032	0.043	0.029	0.031	0.046	0.028	0.022	0.028	0.021	0.015	0.026	0.022	0.015	0.014	0.017	0.017	0.033	0.020	0.023	0.035	0.031
Nitrate nitrogen	mg/L	<0.02	<0.02	<0.02	0.09	0.08	0.10	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	< 0.02	0.03	< 0.02	0.05	0.03	0.04	< 0.02	< 0.02	< 0.02
Total Kjeldahl nitrogen	mg/L	0.97	0.97	0.92	0.51	0.66	0.65	0.47	0.55	0.59	0.54	0.76	0.56	0.49	0.45	0.60	0.59	0.79	0.50	0.55	1.07	0.68
Ammonia nitrogen	mg/L	0.11	0.08	0.09	0.07	0.08	0.09	0.07	0.10	0.07	0.14	0.25	0.10	0.11	0.06	0.12	0.18	0.38	0.16	0.14	0.54	0.12

Management Recommendations for 2020

The vegetation management program at Keyes Pond, Long Sought-for Pond, and Nabnasset Lake appears to have been very successful in controlling most of the targeted perennial exotic species (including exotic milfoils), However, variable-leaf milfoil should be closely monitored for regrowth in Keyes Pond, given a potential observation of this species by a pond resident, as well as Nabnasset Lake, where the plant is known to persist in adjacent waters of Shipley Swamp.

Curly-leaf pondweed, which has an annual life cycle, continues to be a challenge in these ponds, which may be exacerbated when management efforts are incomplete or management timing allows the plants to mature. This plant is typically problematic from spring through early summer and management efforts are usually targeted for this period to prevent plant maturation and the release of seeds and turions. However, as witnessed in 2019, curly-leaf pond weed occasionally reaches nuisance levels later in the year, locally persisting into late-summer. Therefore, ESS recommends that the timing of management actions for curly-leaf pondweed remain flexible, where possible, to account for this possibility.

Aquatic invasive species were not observed by ESS in either Burge's or Kennedy Ponds in 2019, although a Westford resident reported an unconfirmed observation of variable-leaf milfoil at Burge's Pond. Old Mill/ Graniteville Ponds and Forge Pond were not treated in 2019, and exotic milfoils, curly-leaf pondweed, and fanwort were present over some period of the year in these waterbodies.

Recommendations for the 2020 management program at the Westford Ponds are presented in the following sections.

Chemical Controls

The Order of Conditions issued by the Town Conservation Commission for Keyes Pond, Old Mill/Graniteville Ponds, and Burge's Pond allows herbicide treatment with fluridone (trade name Sonar) and diquat dibromide (also known as Reward or simply Diquat). Similarly, Long Sought-for Pond's Order of Conditions allows for treatment of aquatic vegetation with fluridone and diquat dibromide. Nabnasset Lake's Order of Conditions permits treatment of aquatic vegetation with diquat dibromide and a copper-based herbicide sold under the trade name Nautique. ESS is not aware of other herbicides currently authorized for use in any of the seven ponds included in this study.

Diquat dibromide (diquat) is recommended for the control of curly-leaf pondweed at Keyes Pond, Long Sought-for Pond, and Nabnasset Lake. Infestations of curly-leaf pondweed are expected to return at all of these waterbodies in spring 2020. If possible, the timing of this treatment should be prior to the plants topping out in the water column (i.e., before June) to avoid seed and turion maturation, which would otherwise perpetuate curly-leaf pondweed growth into future years. The Town may also wish to consider the option for a second round of spot treatments, should curly-leaf pondweed regrow later in the season, as was observed at Long Sought-for Pond and Nabnasset Lake in 2019.

Additionally, diquat may also be used for the treatment of exotic milfoils in Keyes Pond and Burge's Pond, should substantial regrowth develop in 2020. Though milfoils were not observed by ESS personnel in 2019, residents have reported the presence of invasive milfoil at Keyes Pond and Burges Pond, as well as in adjacent waters of Shipley Swamp at Nabnasset Lake. If either of these species are observed in 2020, diquat (or diver harvesting, if the infestation is localized and limited in extent) could be used to manage infestations.

Diquat is also effective on brittle naiad, which formed fairly extensive beds at Nabnasset Lake in 2019. Should brittle naiad be targeted for treatment in 2020, ESS recommends confirming the extent of active beds first, as populations of this species are known to vacillate considerably from year to year.

Finally, diquat would be effective in controlling nuisance beds of native thinleaf pondweeds, should they return to Long Sought-for Pond in 2020. The Town would need to seek clarification on whether diquat can be applied to nuisance beds of native species under the existing Order of Conditions for Long Sought-for Pond. If not permitted under the current Order of Conditions, an amendment may be required to allow the use of diquat for the control of the native aquatic plants that occur at nuisance levels.

Fluridone is not currently recommended for use in 2020, as each of the actively managed lakes and ponds included in this report lack widespread beds of the target species that would be impacted by fluridone (e.g. fanwort and Eurasian milfoil).

Should the Town elect to move forward with active management of Old Mill/ Graniteville Ponds and/or Forge Pond, fluridone may be an appropriate chemical control for the dense and widespread beds of fanwort and exotic milfoils in those water bodies. Fluridone requires a long contact time to be effective on most target species and should therefore ideally be applied starting in spring.

ESS is not aware of fluridone being approved for use under a valid Order of Conditions at Forge Pond. Therefore, additional permitting may be required before moving forward with a fluridone treatment there.

Nautique was not applied in 2019, but is recommended for spot or partial-lake control of nuisance beds of water celery (tapegrass) at Nabnasset Lake in 2020, if permitted and desired by the Town.

Other copper-based algaecide formulations (selected by contractor for effectiveness on the species present) may also be helpful for the control of nuisance algal growths or blooms in any of the ponds, should they develop in 2020. Copper-based algaecide was used to control a nuisance bloom at Keyes Pond in 2019 and has also been used to control excessive growth of filamentous green algae in Nabnasset Lake in prior years.

Depending on the actual development of plant beds and algal blooms in 2020, more than one treatment may be needed to effectively address the seasonality of different target species. The specific chemical controls currently recommended for consideration in 2020 are summarized in Table 5.

Table 5. Recommended Herbicides for Aquatic Invasive Vegetation Treatment in 2020

Herbicide	Keyes Pond	Burge's Pond	Long Sought-for Pond	Nabnasset Lake
Diquat dibromide (Reward/Diquat)	X	X[a]	X	X
Copper Ethylenediamine and Triethanolamine Complexes (Nautique)				X[b]

[a] Only if needed for exotic milfoil control, based on early-season vegetation mapping results in 2020
[b]Recommended for use with diquat in controlling nuisance beds of water celery (*Vallisneria sp.*)

Water Level Controls (Drawdown)

Winter drawdown has been an effective management option for the control of variable-leaf milfoil at Nabnasset Lake in the past. However, this species was not observed in the lake during either the 2019 pre-treatment or post-treatment survey and appears to remain confined to Shipley Swamp. ESS does not believe a full six-foot drawdown would provide significant advantages for the control of exotic plants in Nabnasset Lake, and such action is not anticipated for the winter of 2019-2020.

Low-dose Alum

A low-dose alum treatment was approved under the Order of Conditions for Burge's, Keyes, and Old Mill/Graniteville Ponds (DEP File # 334-1635) and may be an option for implementation in 2020, if needed. Cyanobacteria were observed coincident with low water clarity and elevated total phosphorus concentration at Keyes Pond in August 2019. Additionally, the low dissolved oxygen concentrations in Keyes Pond are likely to enhance the introduction of phosphorus into the system from the sediments, particularly in mid- to late summer, when dissolved oxygen levels typically become most depleted. Alum acts as a flocculent and binds phosphorus, while also settling out particulates from the water column.

Prior nutrient budgets developed by ESS in 2017 suggest that low-dose alum could be effective at stripping phosphorus, algae, and particulates from incoming flows and the pond water column while also gradually reducing internal recycling of phosphorus from the sediments. Therefore, it may be useful for providing rapid improvement of water quality conditions, particularly in Keyes Pond, where low water transparency and dissolved oxygen concentrations tend to be more persistent.

Observed post-treatment/late season water quality results from 2019 suggest that Old Mill/Graniteville Ponds, Nabnasset Lake, and Forge Pond may also experience a combination of reduced water transparency, low dissolved oxygen concentrations, and elevated phosphorus concentrations (at least at depth) at times. Although the observed water quality parameters at these ponds currently do not appear to indicate issues that are as persistent or acute as those experienced at Keyes Pond, the Town may wish to consider the use of alum as a future option in these locations, as well.

Monitoring

The 2019 monitoring program was useful in identifying newly emerging management issues and better measuring change at each of the ponds of interest. Therefore, ESS recommends pre-treatment/early season and post-treatment/late season water quality and aquatic vegetation monitoring at each pond in 2020, with a priority on water bodies where active management has recently been undertaken or is likely to be advanced in 2020. As always, continuing to monitor each of the ponds will allow for the detection of pioneer infestations of invasive species before they spread, thereby allow the Town the opportunity to respond quickly and avoid or minimize more costly large-scale management activities in the future.

We appreciate the opportunity to work with you on this project. Please contact Matt Ladewig at (401) 330-1204 if you have any questions.

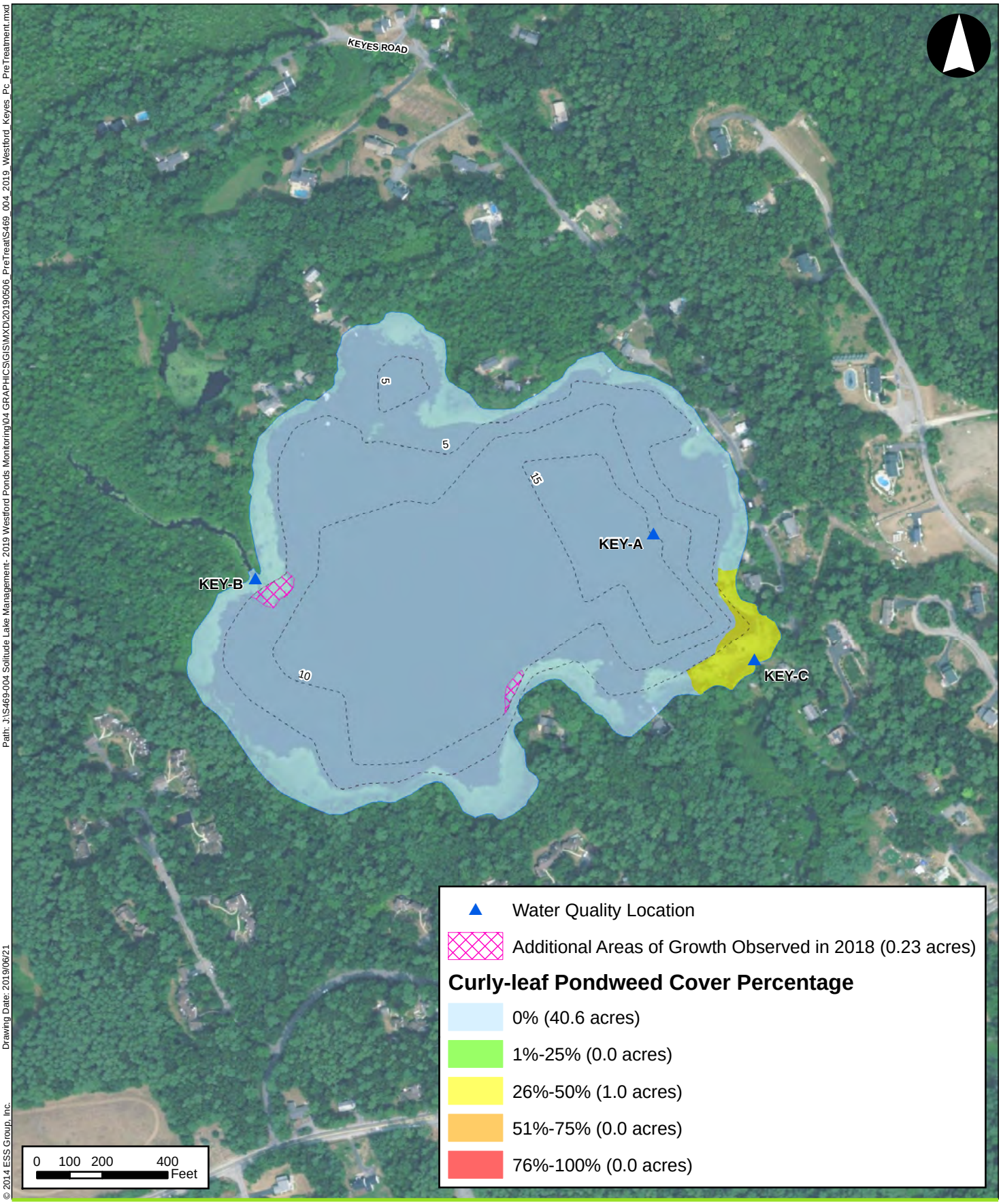
Sincerely,

ESS GROUP, INC.

Matt Ladewig, CLM
Senior Scientist

Anna Chase
Environmental Scientist

Attachments: Figures



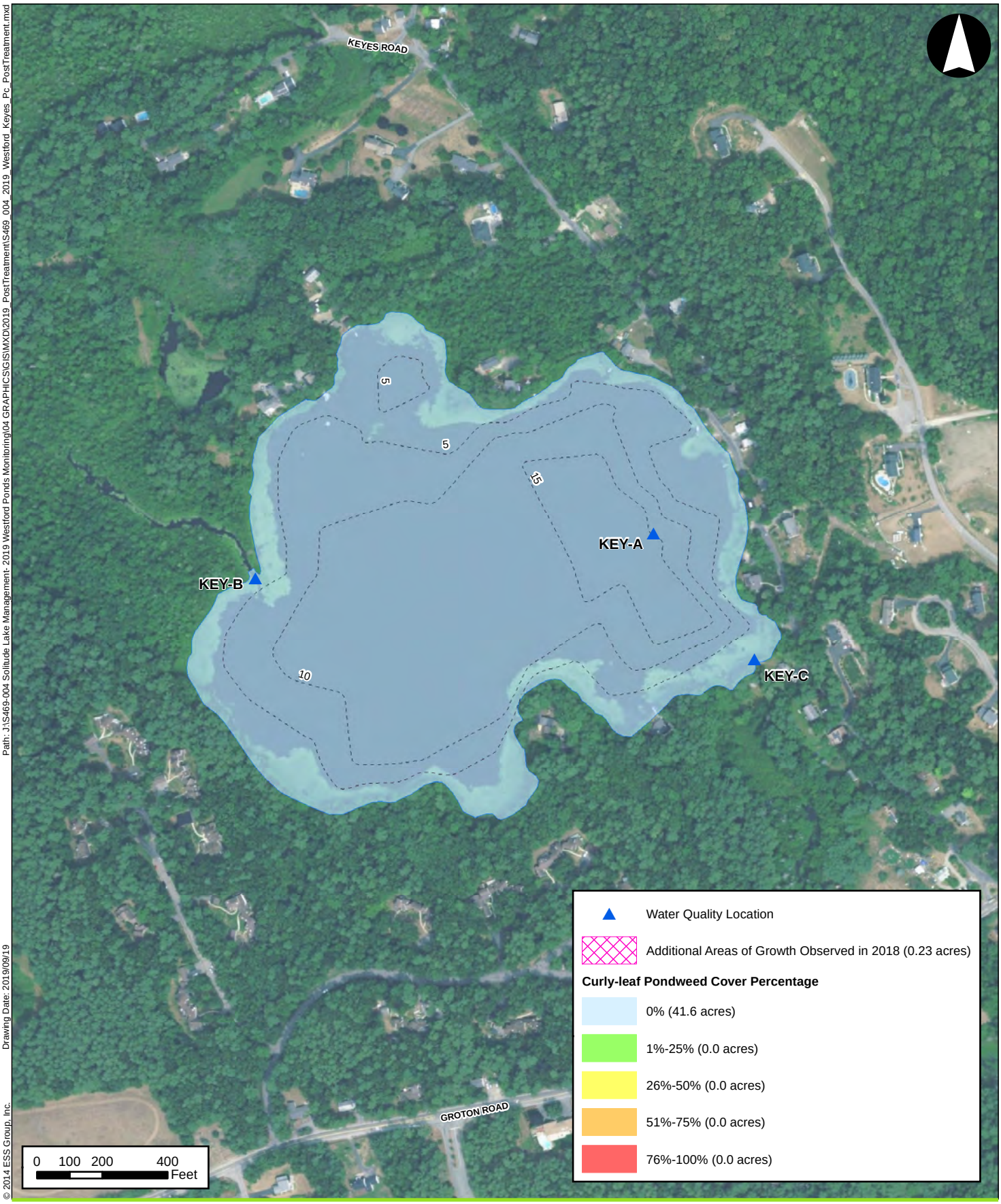
Solitude Lake Management LLC
Westford, Massachusetts

1 inch = 400 feet

Source: 1) USDA, NAIP Imagery, 2016
2) MassGIS, Major Roads, 2003
3) ESS, Bathymetry, 2015 4) ESS, GPS Data, 2019

Keyes Pond
Curly-leaf Pondweed
Pre-treatment (May 2019)

Figure 1



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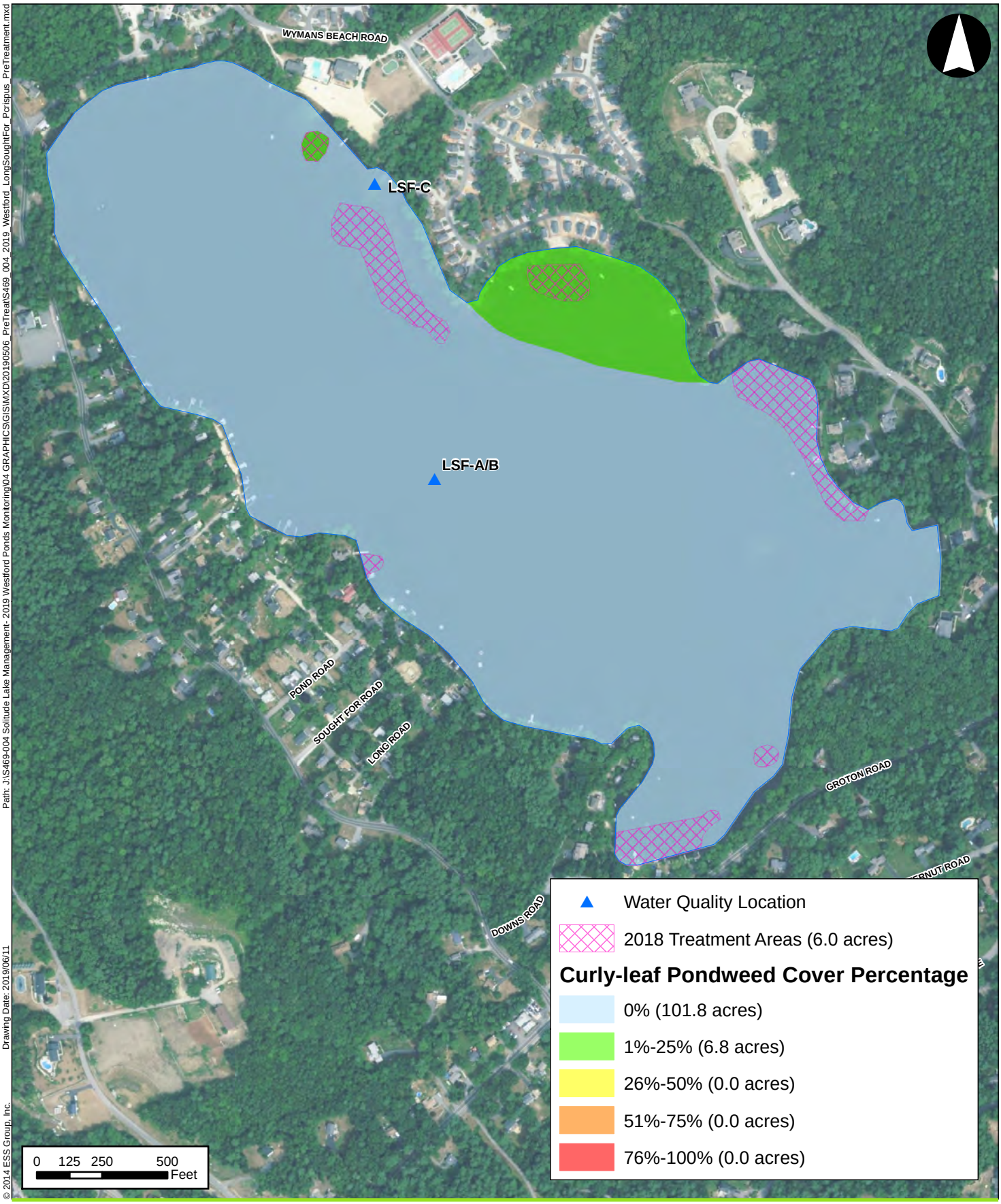
Solitude Lake Management LLC
Westford, Massachusetts

1 inch = 400 feet

Source: 1) USDA, NAIP Imagery, 2016
2) MassGIS, Major Roads, 2003
3) ESS, Bathymetry, 2015 4) ESS, GPS Data, 2019

Keyes Pond
Curly-leaf Pondweed
Post-treatment (September 2019)

Figure 2



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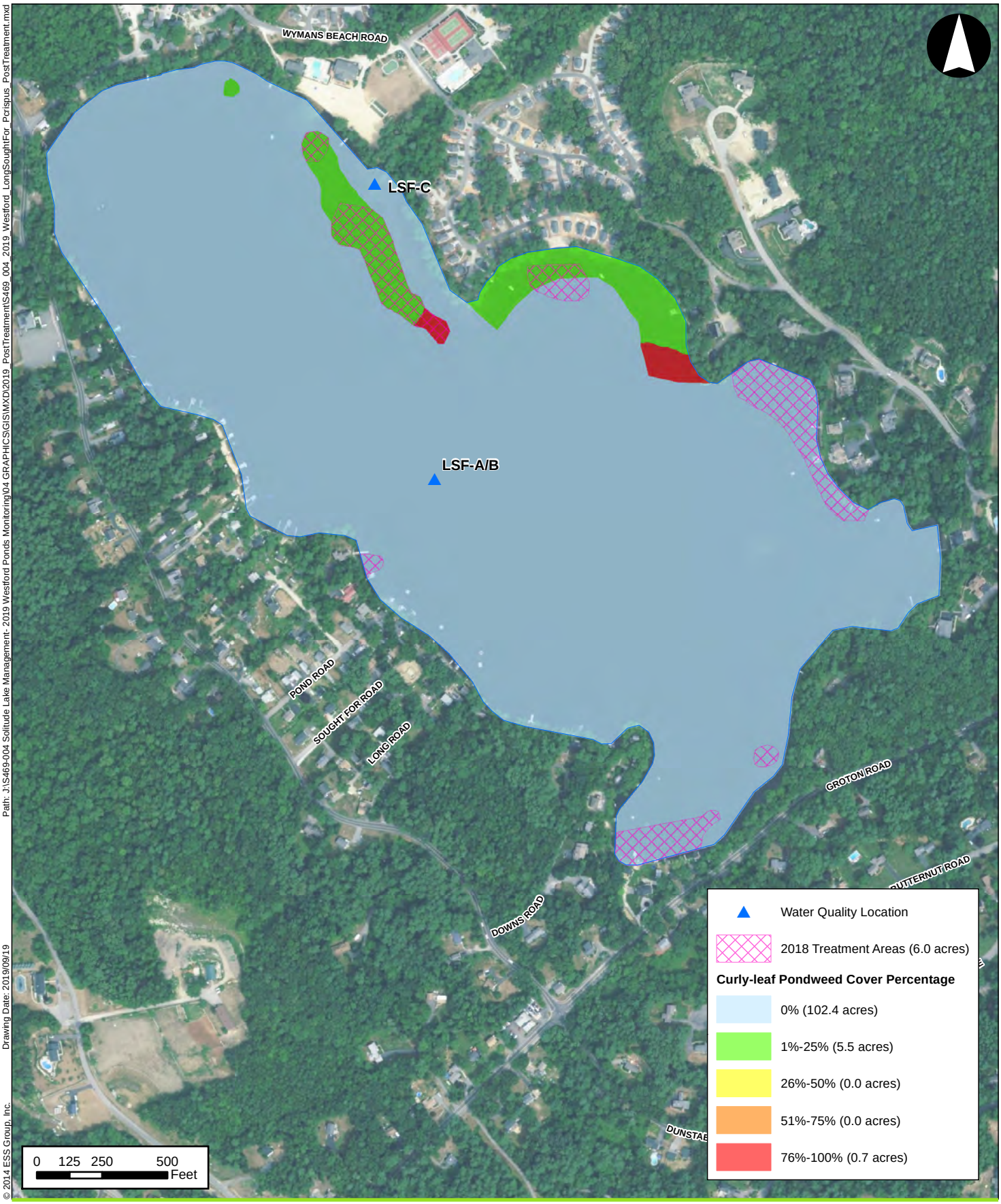
Solitude Lake Management LLC
Westford, Massachusetts

1 inch = 500 feet

Source: 1) USDA, NAIP Imagery, 2016
2) MassGIS, Major Roads, 2003
3) ESS, GPS Data, 2019

Long Sought For Pond
Curly-leaf Pondweed
Pre-treatment (May 2019)

Figure 3



ess group
environmental consulting & engineering services

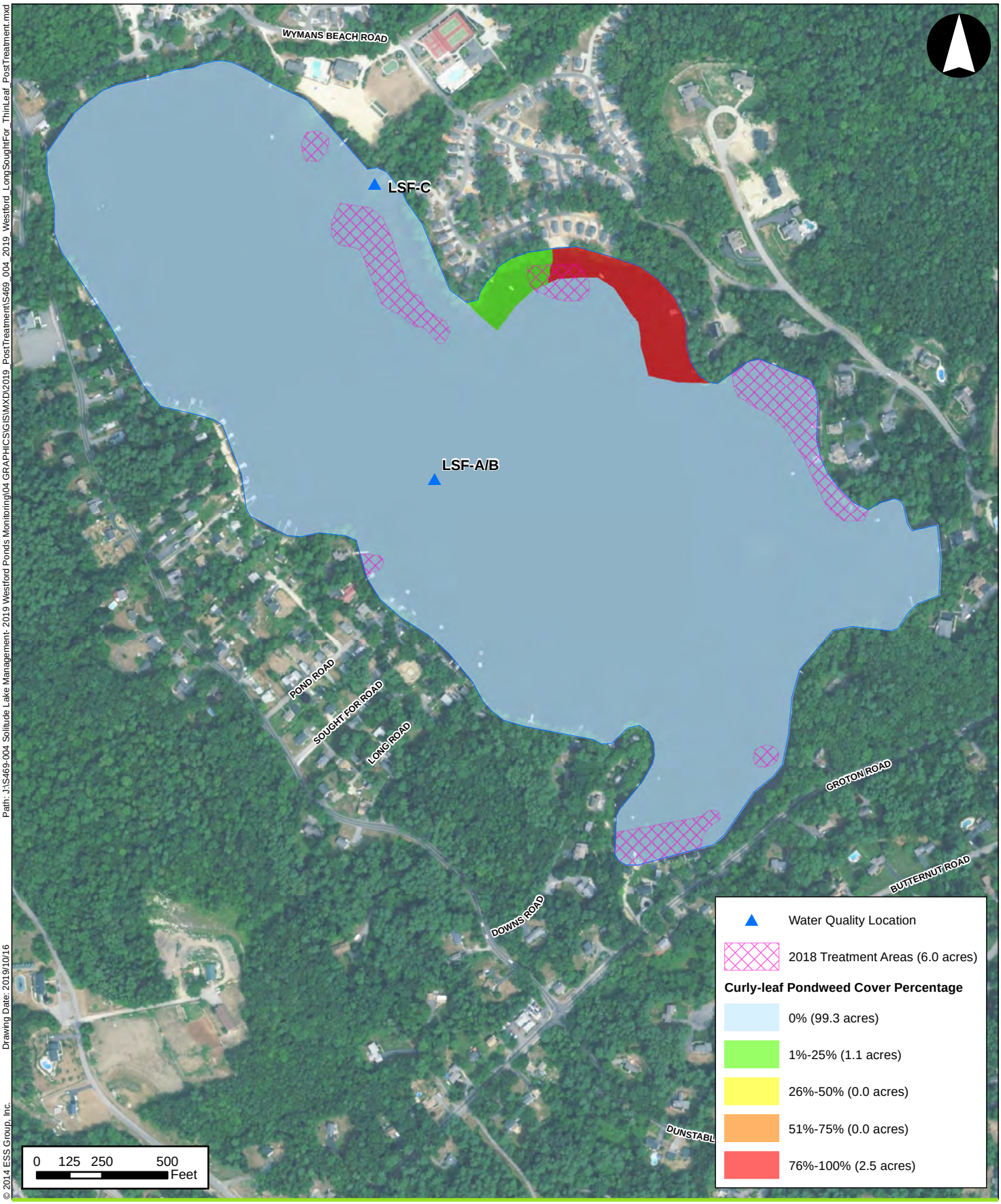
Solitude Lake Management LLC
Westford, Massachusetts

1 inch = 500 feet

Source: 1) USDA, NAIP Imagery, 2016
2) MassGIS, Major Roads, 2003
3) ESS, GPS Data, 2019

Long Sought For Pond
Curly-leaf Pondweed
Post-treatment (September 2019)

Figure 4



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ess group
environmental consulting & engineering services

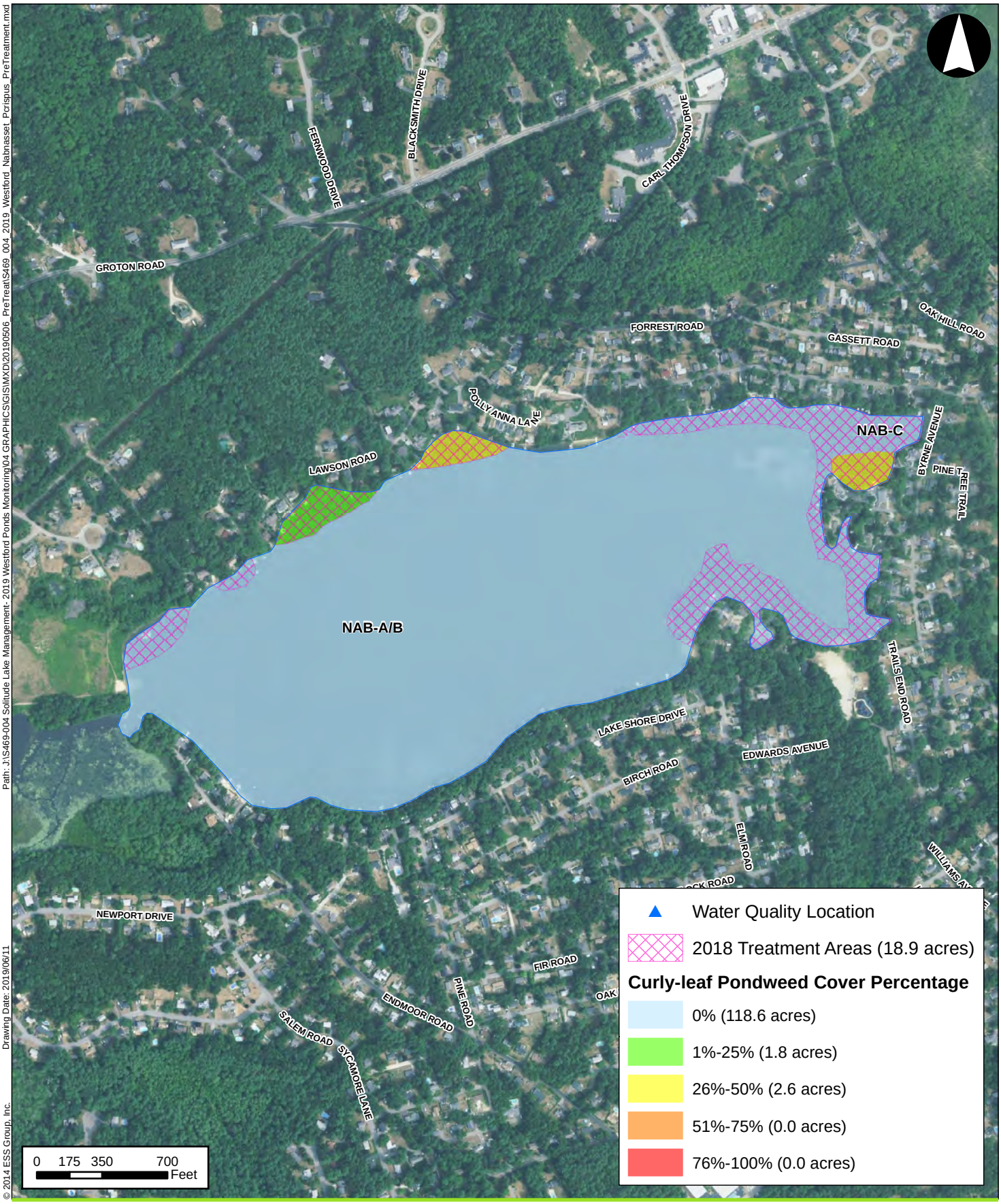
Solitude Lake Management LLC
Westford, Massachusetts

1 inch = 500 feet

Source: 1) USDA, NAIP Imagery, 2016
2) MassGIS, Major Roads, 2003
3) ESS, GPS Data, 2019

Long Sought For Pond
Thin-leaf Pondweed
Post-treatment (September 2019)

Figure 5



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Drawing Date: 2019/06/11

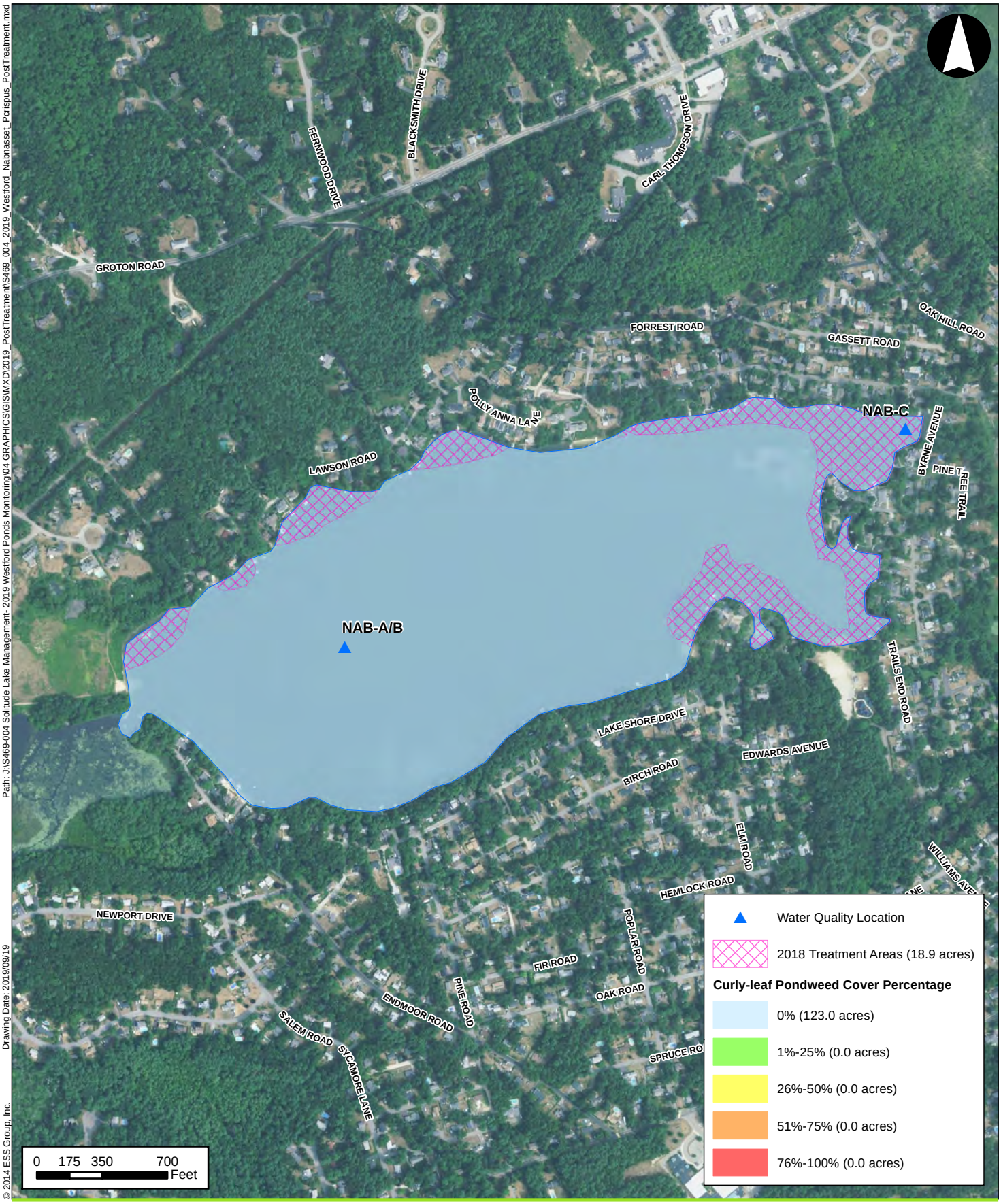
Solitude Lake Management LLC
Westford, Massachusetts

1 inch = 700 feet

Source: 1) USDA, NAIP Imagery, 2016
2) MassGIS, Major Roads, 2003
3) ESS, GPS Data, 2019

Nabnasset Lake
Curly-leaf Pondweed
Pre-treatment (May 2019)

Figure 6



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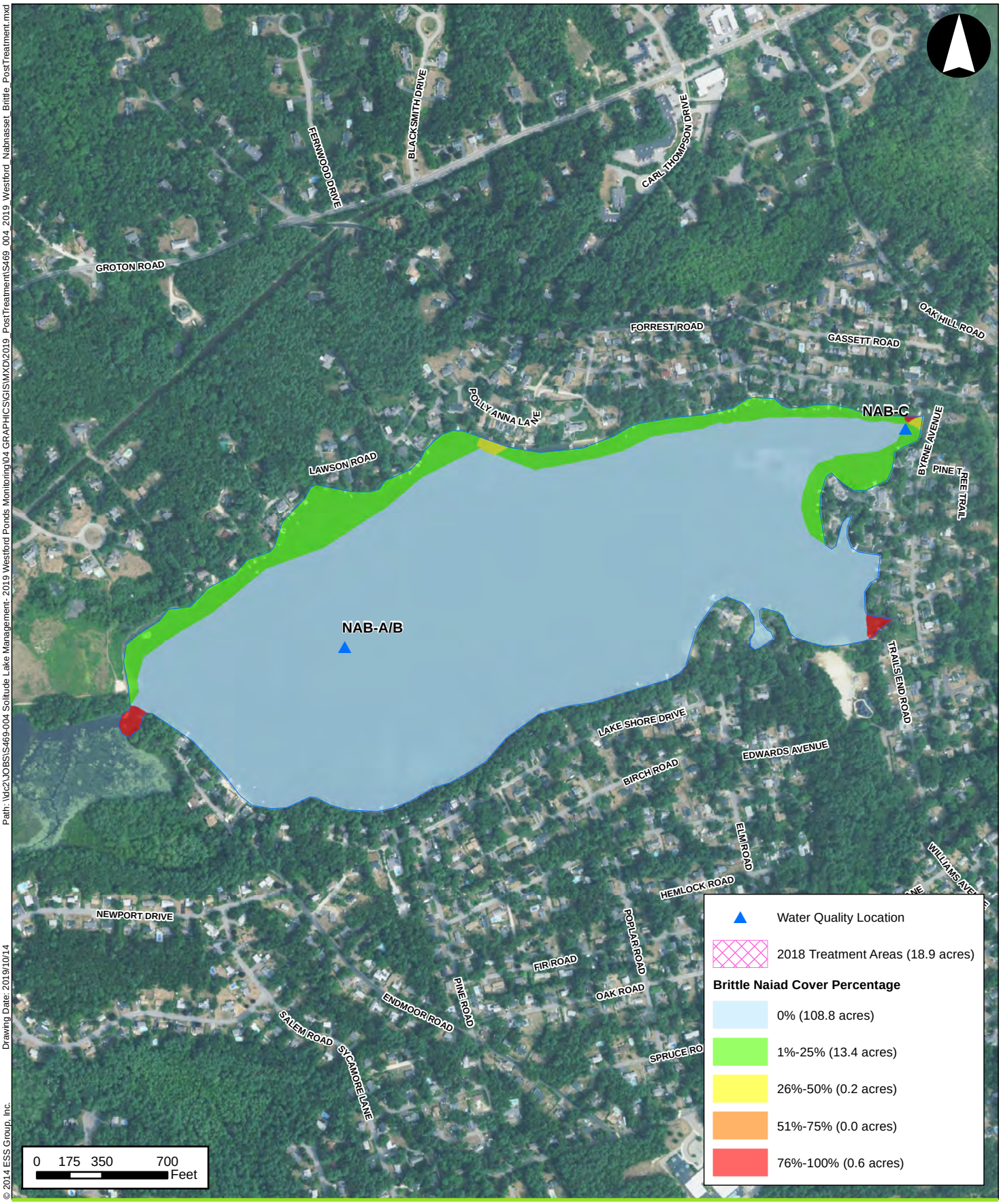
Solitude Lake Management LLC
Westford, Massachusetts

1 inch = 700 feet

Source: 1) USDA, NAIP Imagery, 2016
2) MassGIS, Major Roads, 2003
3) ESS, GPS Data, 2019

Nabnasset Lake
Curly-leaf Pondweed
Post-treatment (September 2019)

Figure 7



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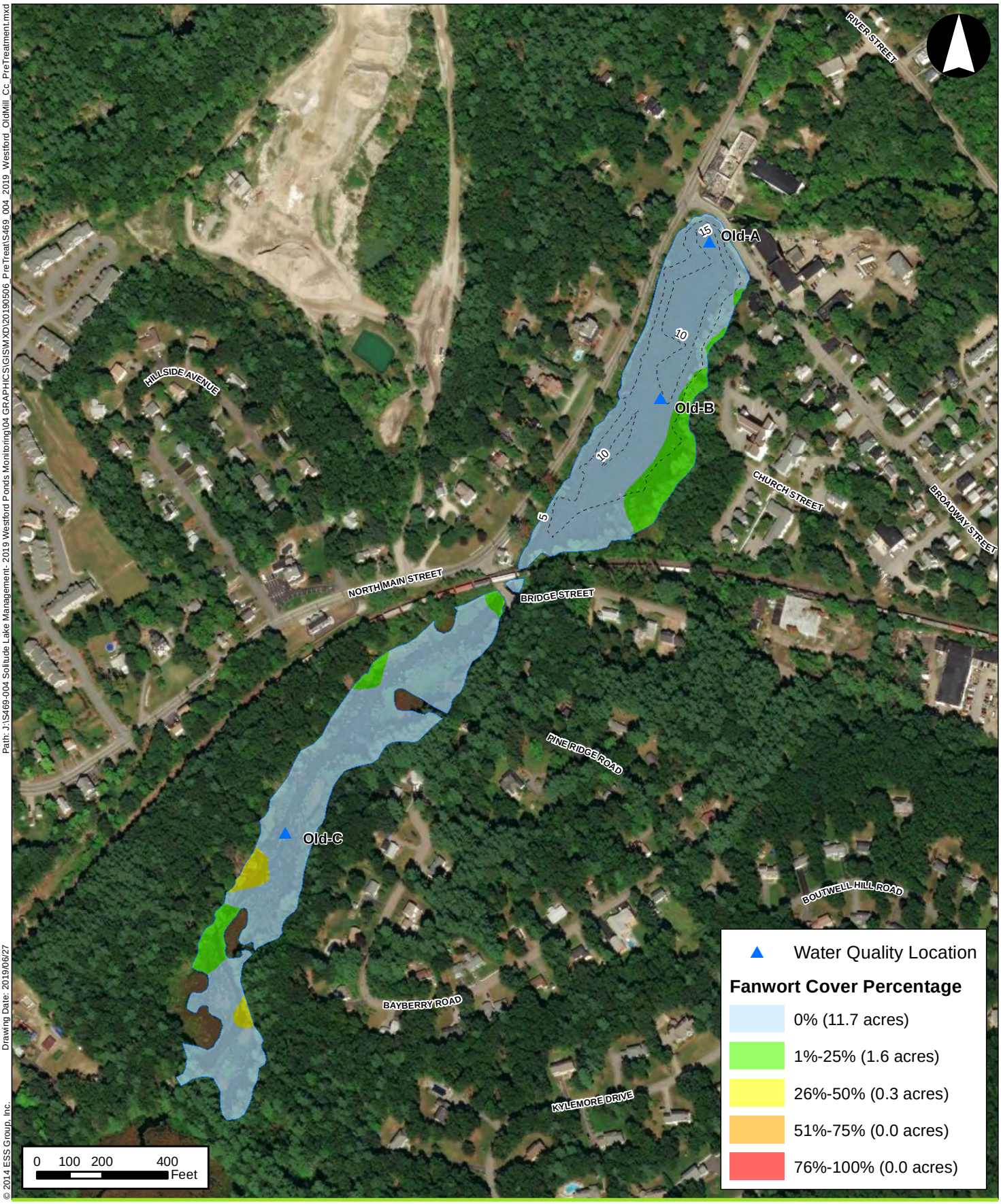
Solitude Lake Management LLC
Westford, Massachusetts

1 inch = 700 feet

Source: 1) USDA, NAIP Imagery, 2016
2) MassGIS, Major Roads, 2003
3) ESS, GPS Data, 2019

Nabnasset Lake
Brittle Naiad
Post-treatment (September 2019)

Figure 8



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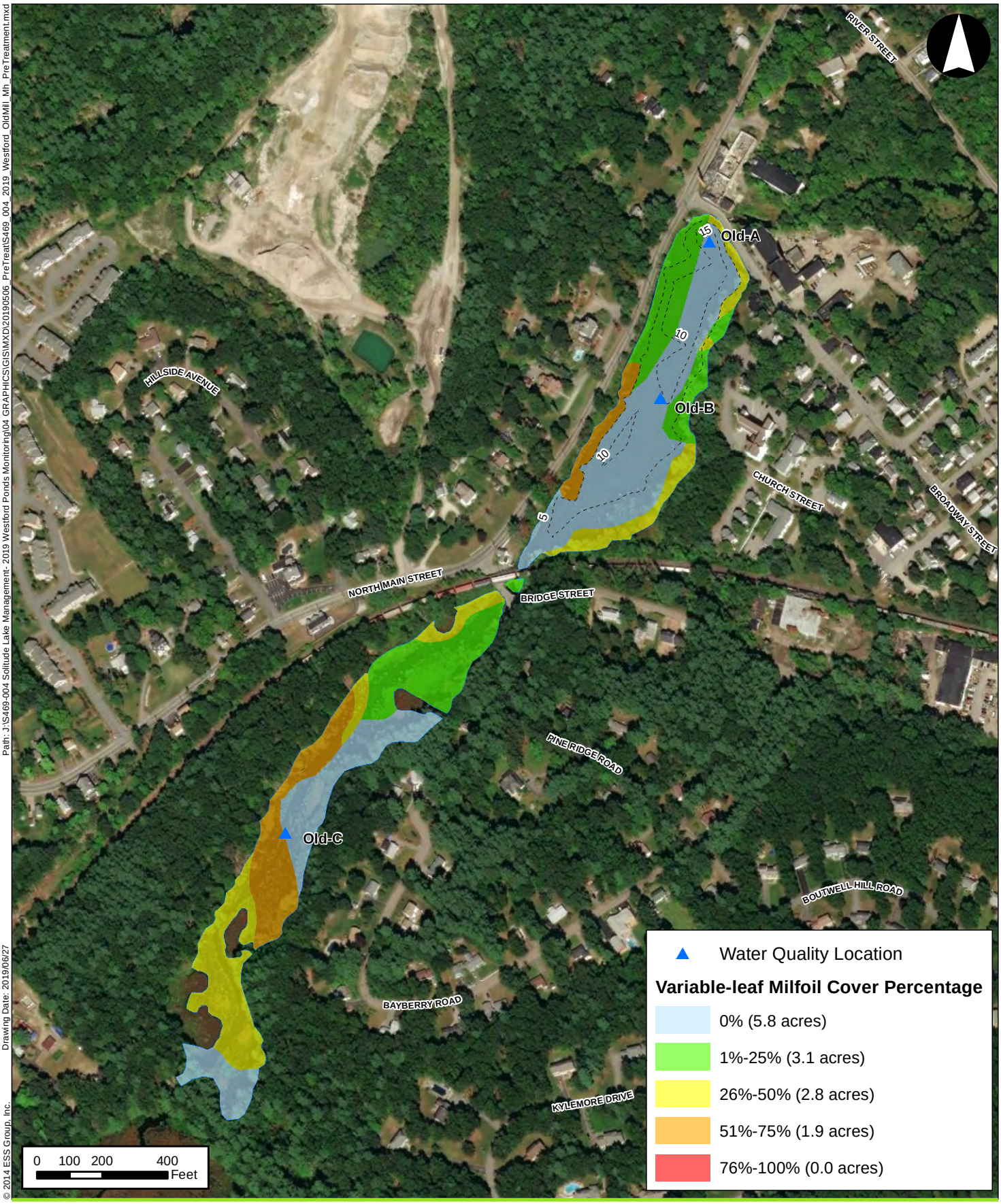
Solitude Lake Management LLC
Westford, Massachusetts

1 inch = 400 feet

Source: 1) USDA, NAIP Imagery, 2016
2) MassGIS, Major Roads, 2003
3) ESS, Bathymetry, 2015 4) ESS, GPS Data, 2019

Old Mill/Graniteville Pond
Fanwort
Early Season (May 2019)

Figure 9



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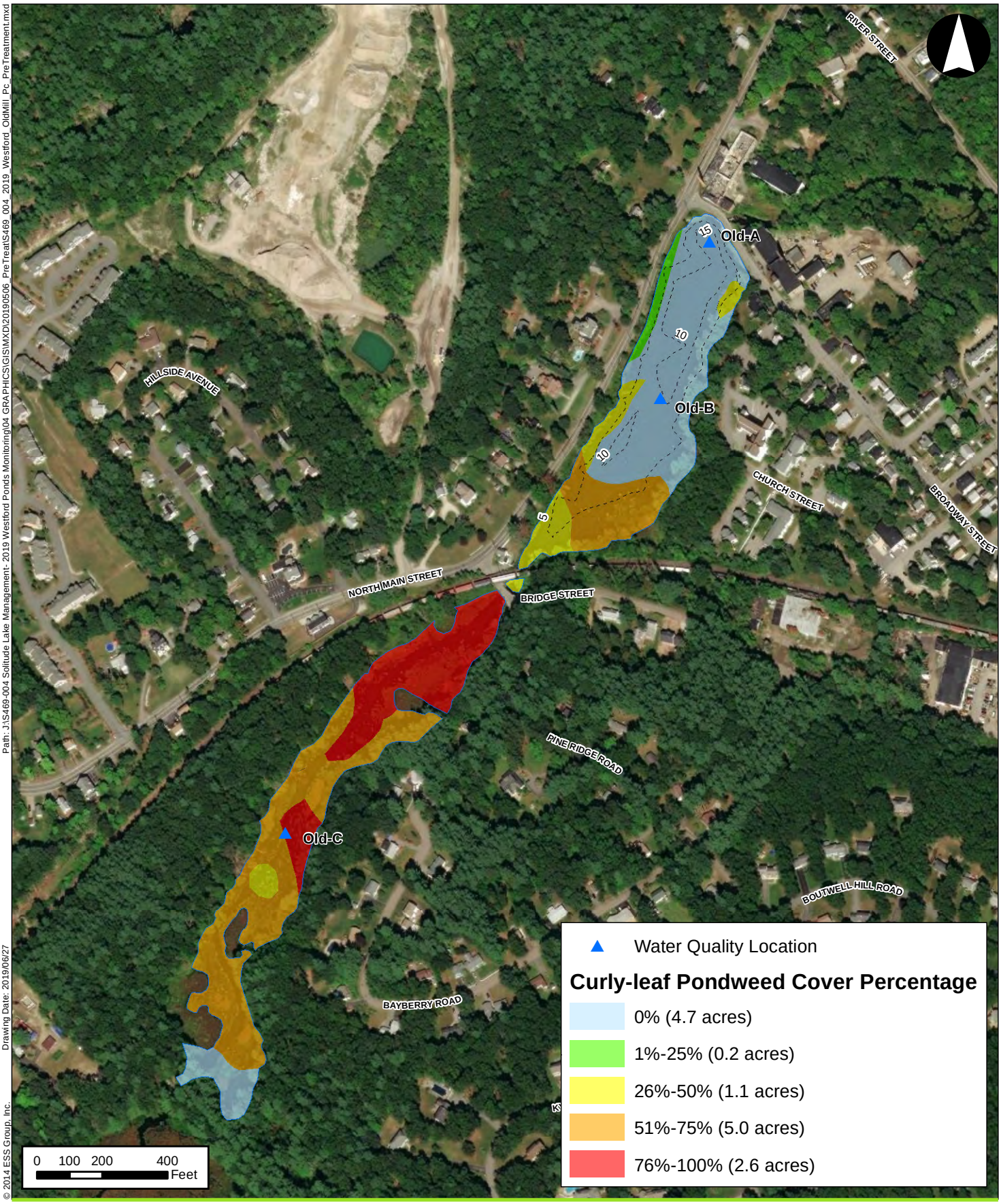
Solitude Lake Management LLC
Westford, Massachusetts

1 inch = 400 feet

Source: 1) USDA, NAIP Imagery, 2016
2) MassGIS, Major Roads, 2003
3) ESS, Bathymetry, 2015 4) ESS, GPS Data, 2019

Old Mill/Graniteville Pond
Variable-leaf Milfoil
Early Season (May 2019)

Figure 10



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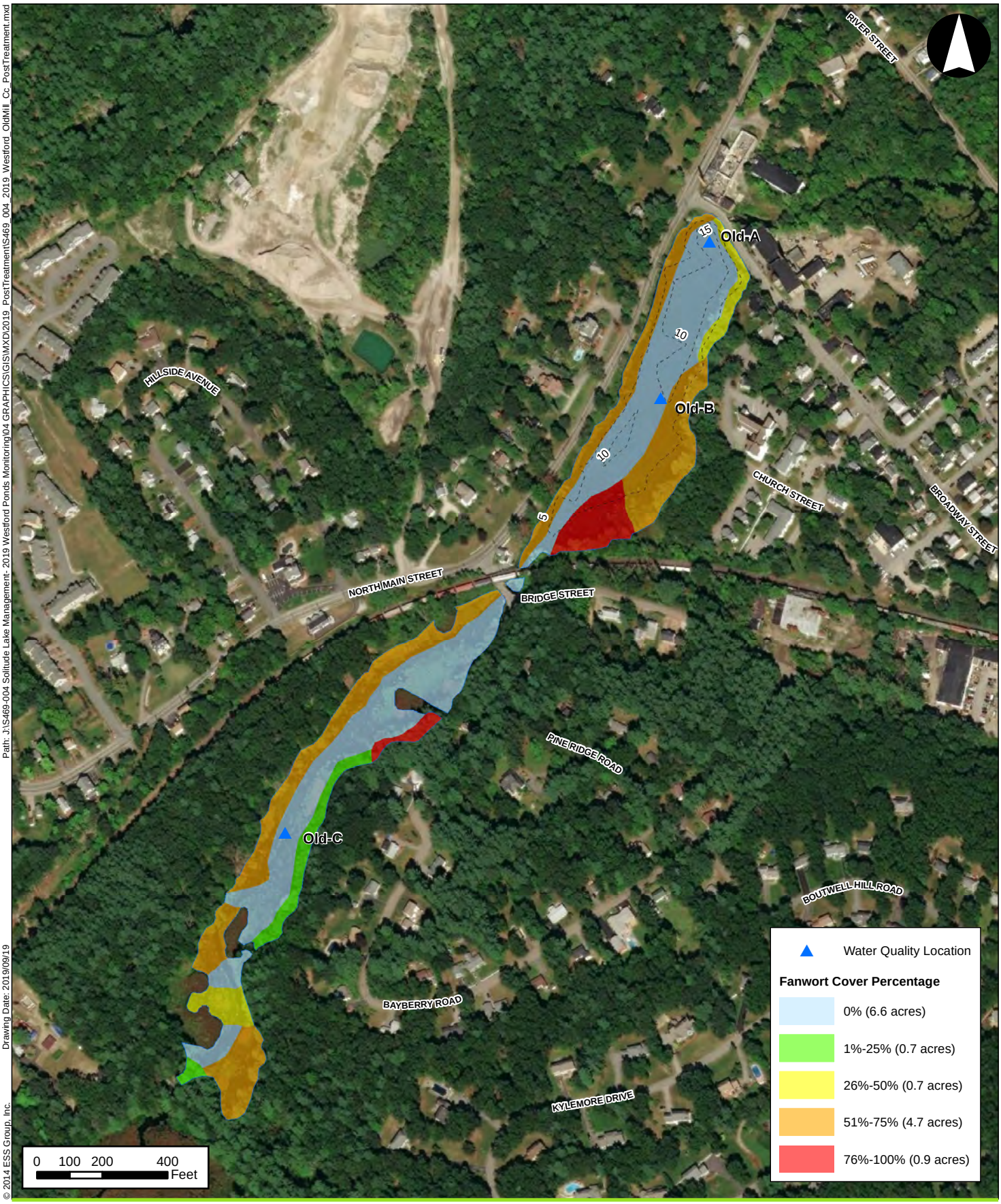
Solitude Lake Management LLC
Westford, Massachusetts

1 inch = 400 feet

Source: 1) USDA, NAIP Imagery, 2016
2) MassGIS, Major Roads, 2003
3) ESS, Bathymetry, 2015 4) ESS, GPS Data, 2019

Old Mill/Graniteville Pond
Curly-leaf Pondweed
Early Season (May 2019)

Figure 11



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Drawing Date: 2019/09/19

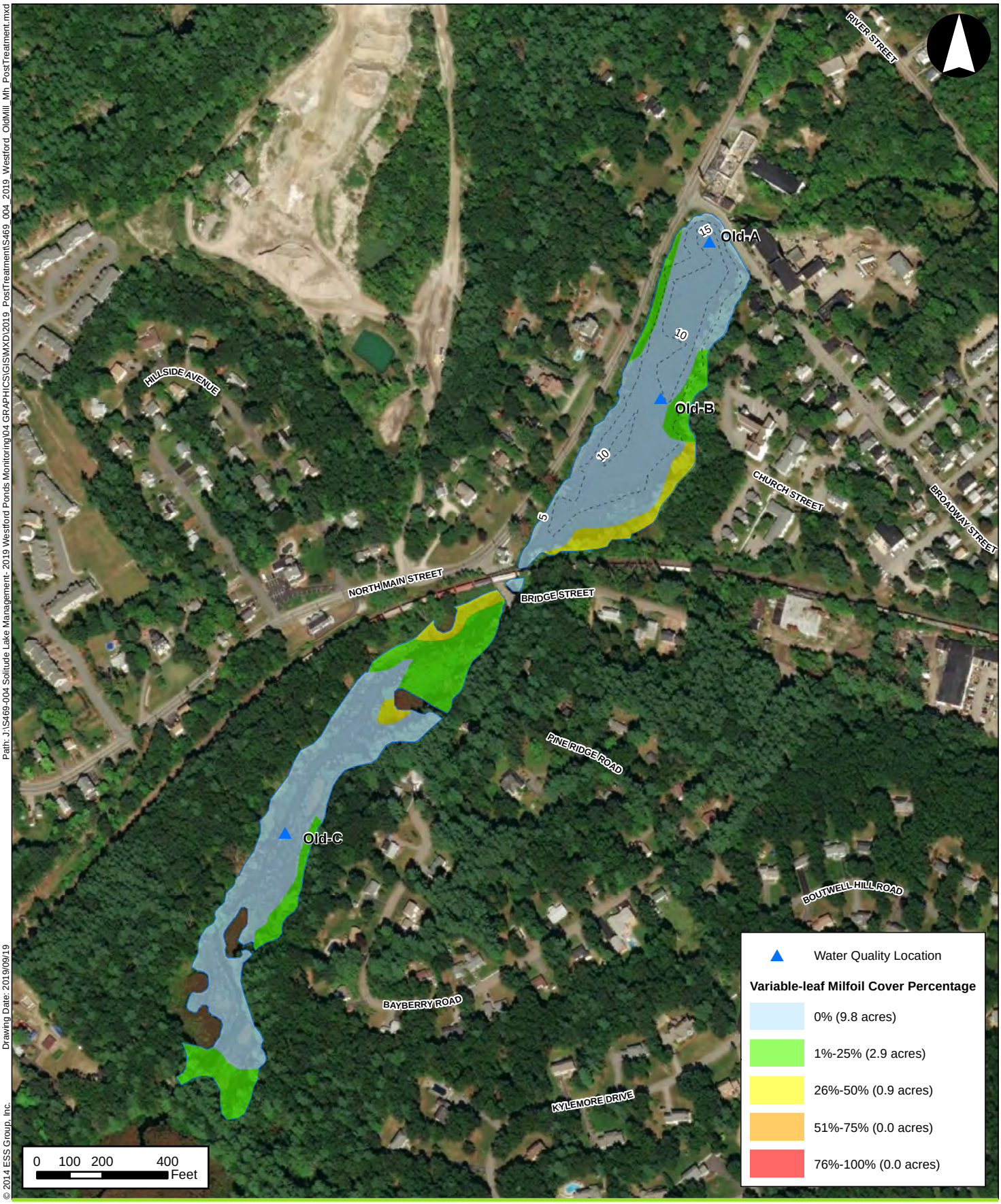
Solitude Lake Management LLC
Westford, Massachusetts

1 inch = 400 feet

Source: 1) USDA, NAIP Imagery, 2016
2) MassGIS, Major Roads, 2003
3) ESS, Bathymetry, 2015 4) ESS, GPS Data, 2019

Old Mill/Graniteville Pond
Fanwort
Late Season (September 2019)

Figure 12



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Drawing Date: 2019/09/19

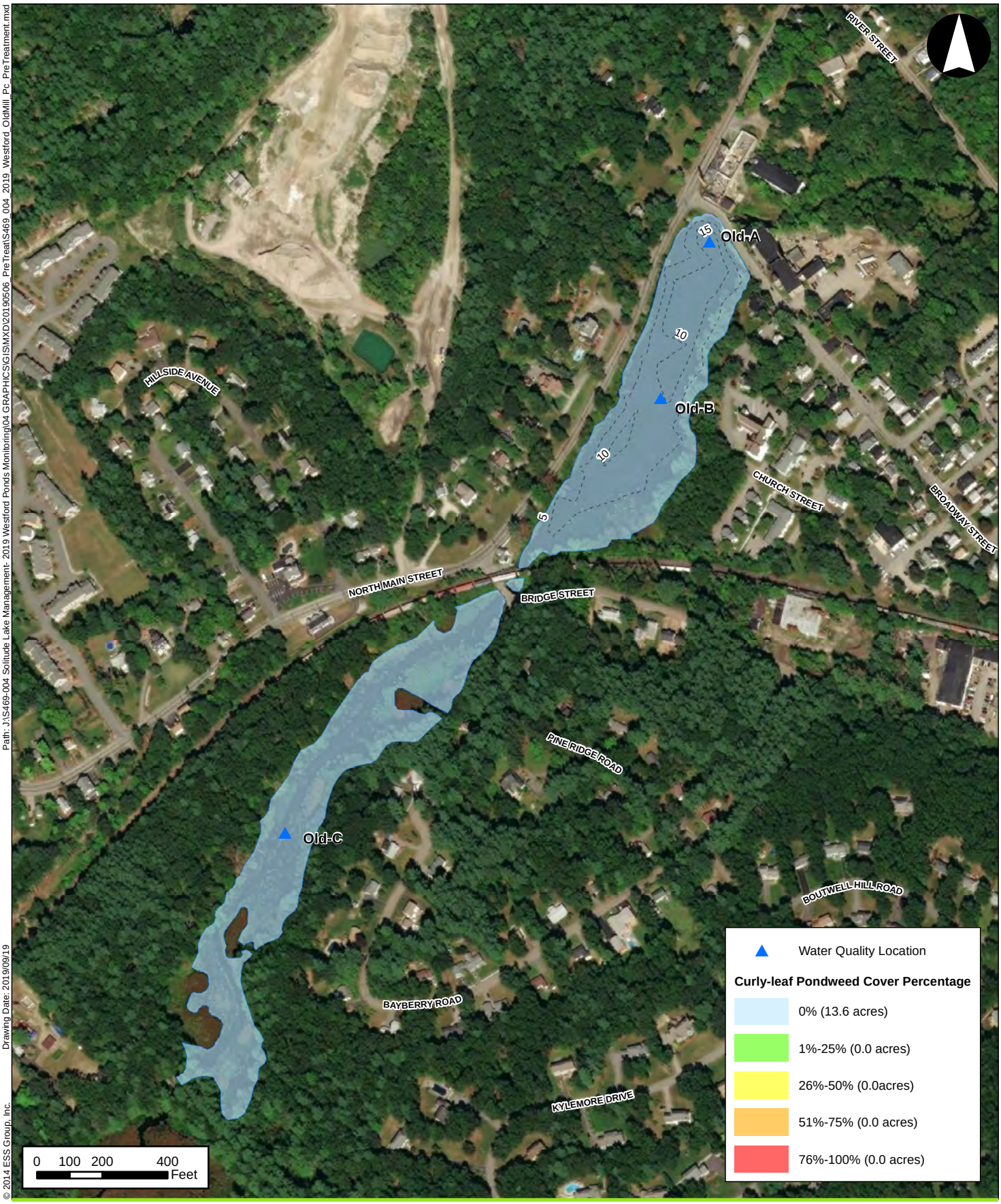
Solitude Lake Management LLC
Westford, Massachusetts

1 inch = 400 feet

Source: 1) USDA, NAIP Imagery, 2016
2) MassGIS, Major Roads, 2003
3) ESS, Bathymetry, 2015 4) ESS, GPS Data, 2019

Old Mill/Graniteville Pond
Variable-leaf Milfoil
Late Season (September 2019)

Figure 13



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Drawing Date: 2019/09/19

Solitude Lake Management LLC
Westford, Massachusetts

1 inch = 400 feet

Source: 1) USDA, NAIP Imagery, 2016
2) MassGIS, Major Roads, 2003
3) ESS, Bathymetry, 2015 4) ESS, GPS Data, 2019

Old Mill/Graniteville Pond
Curly-leaf Pondweed
Late Season (September 2019)

Figure 14

Drawing Date: 2019/06/10

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Solitude Lake Management LLC
Westford, Massachusetts

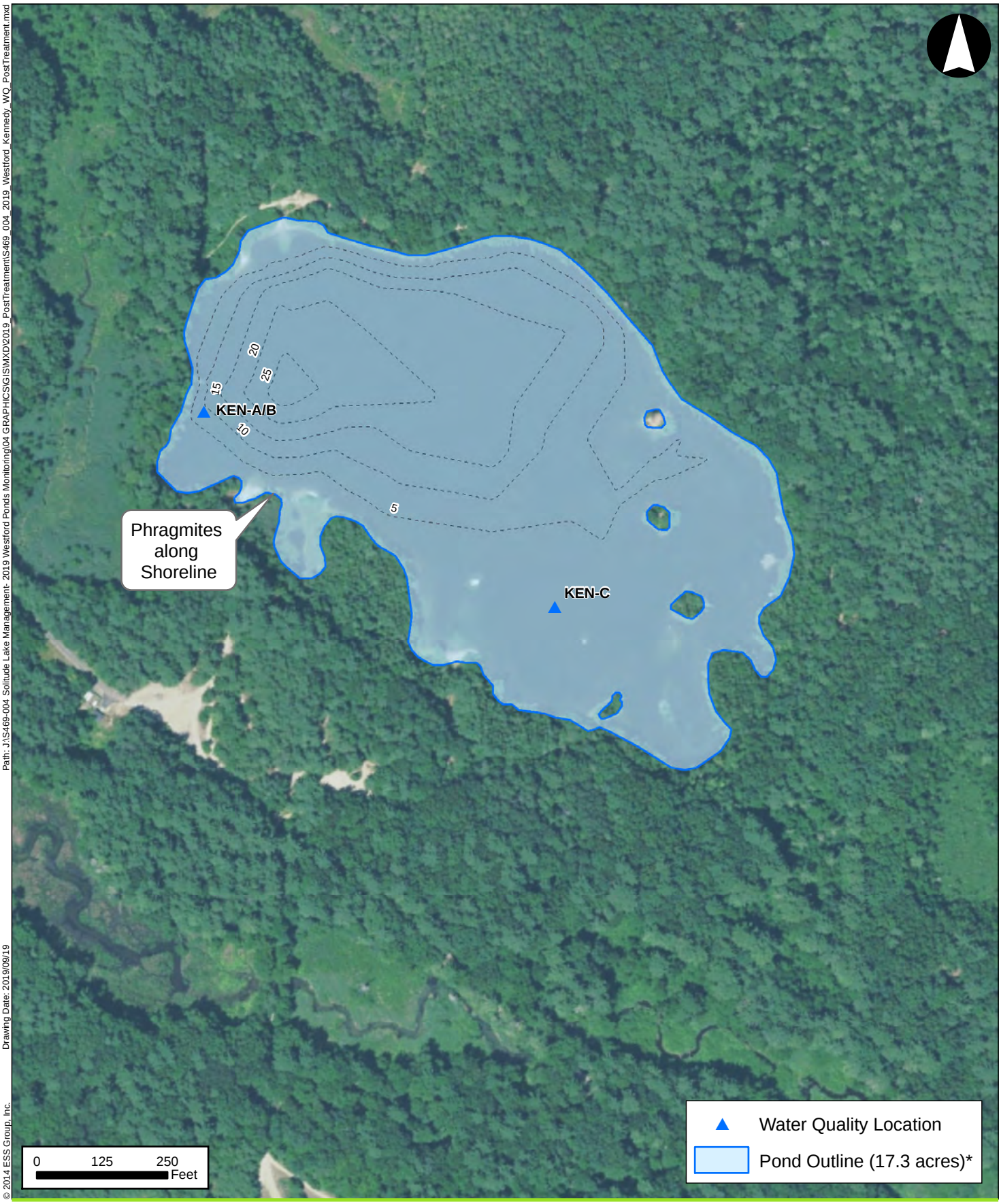
1 inch = 400 feet

Source: 1) USDA, NAIP Imagery, 2016
2) MassGIS, Major Roads, 2003
3) ESS, GPS Data, 2019

***No invasive species found.**

Burges Pond
Early Season and Late Season
(May and September 2019)

Figure 15



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Solitude Lake Management LLC
Westford, Massachusetts

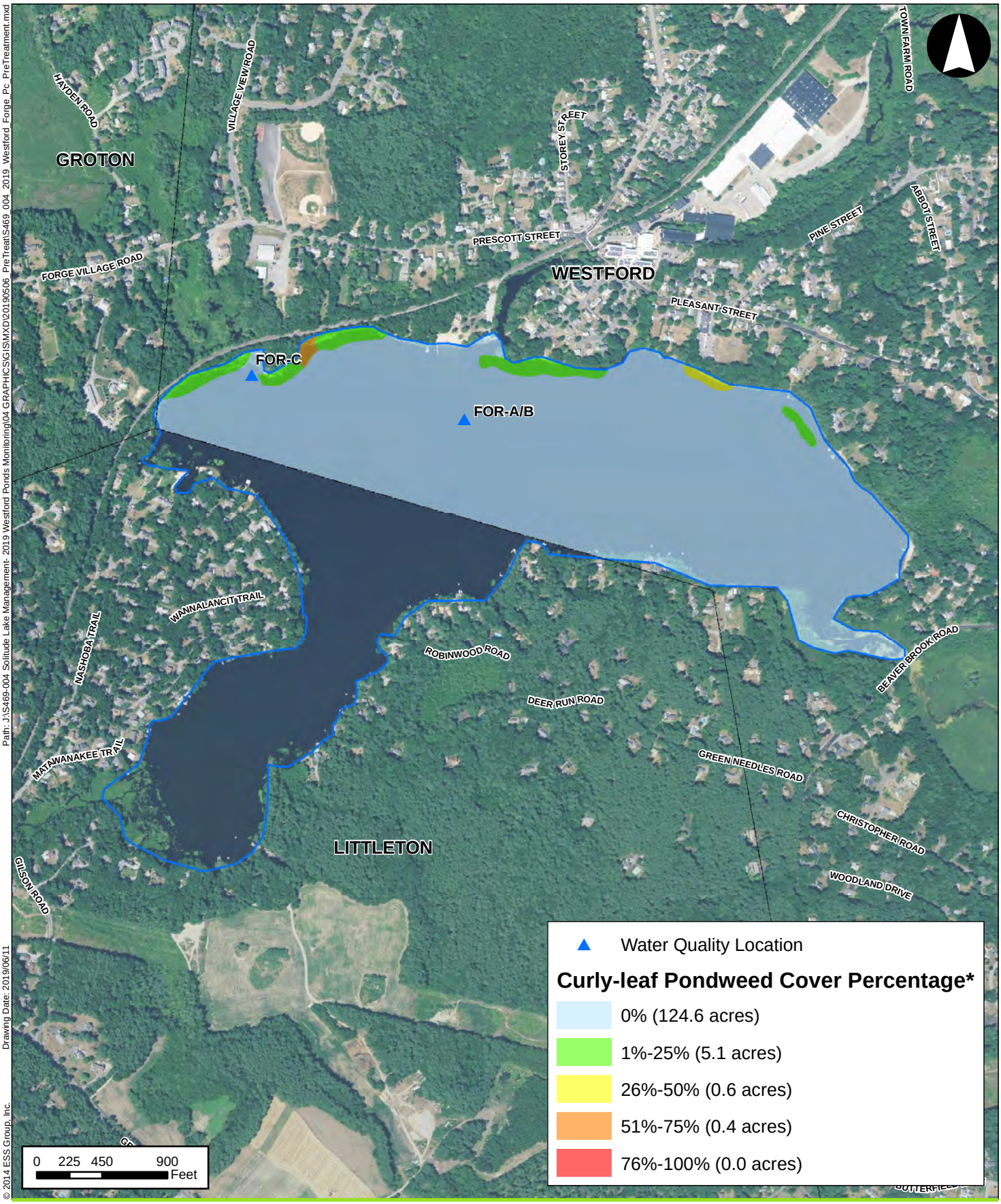
1 inch = 250 feet

Source: 1) USDA, NAIP Imagery, 2016
2) MassGIS, Major Roads, 2003
3) ESS, GPS Data, 2019

Kennedy Pond
Early Season and Late Season
(May and September 2019)

***No invasive species found.**

Figure 16



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Solitude Lake Management LLC
Westford, Massachusetts

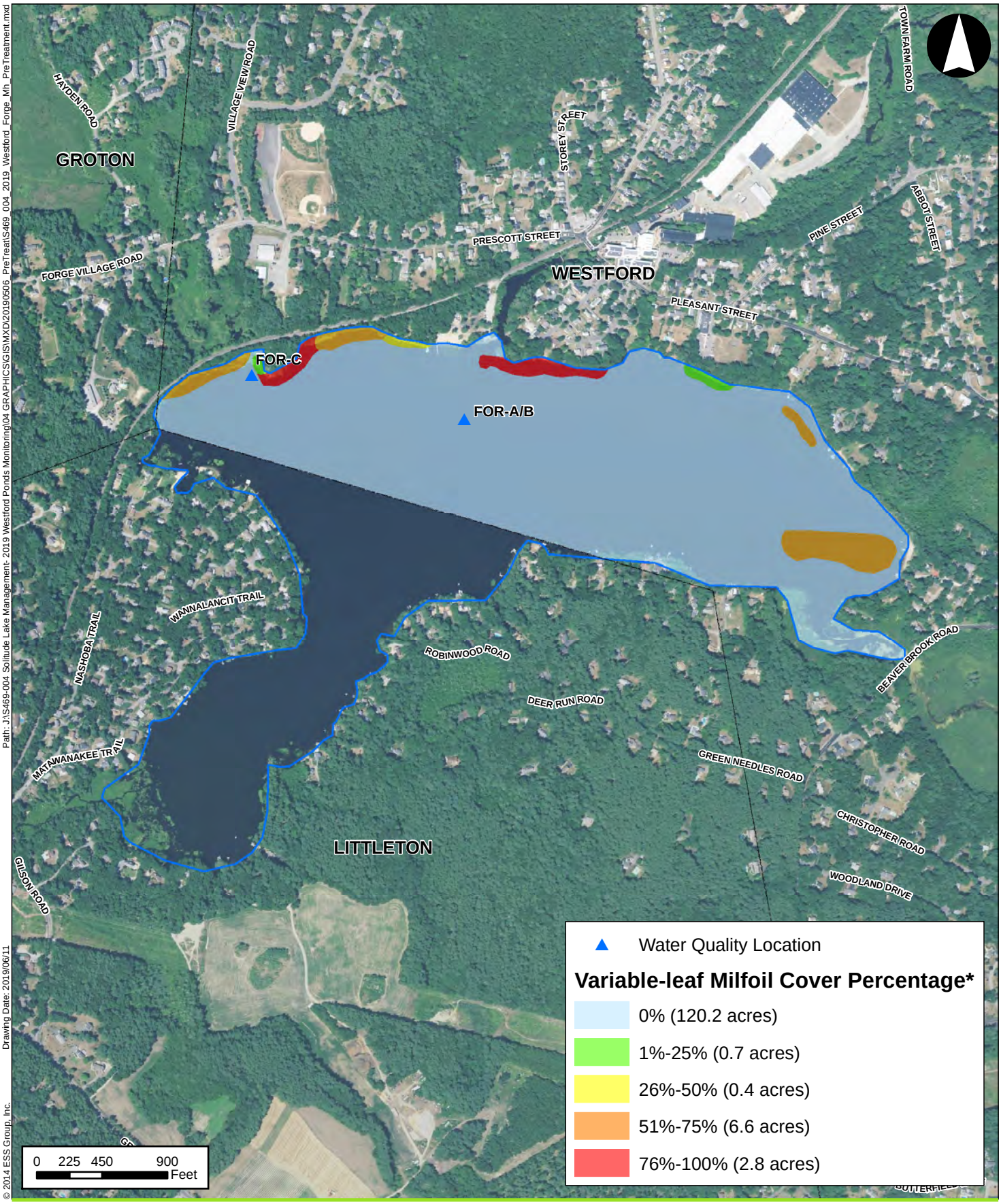
1 inch = 900 feet

Source: 1) USDA, NAIP Imagery, 2016
2) MassGIS, Major Roads, 2003
3) ESS, GPS Data, 2019

***Survey area limited to Westford.**

Forge Pond
Curly-leaf Pondweed
Early Season (May 2019)

Figure 17



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Solitude Lake Management LLC
Westford, Massachusetts

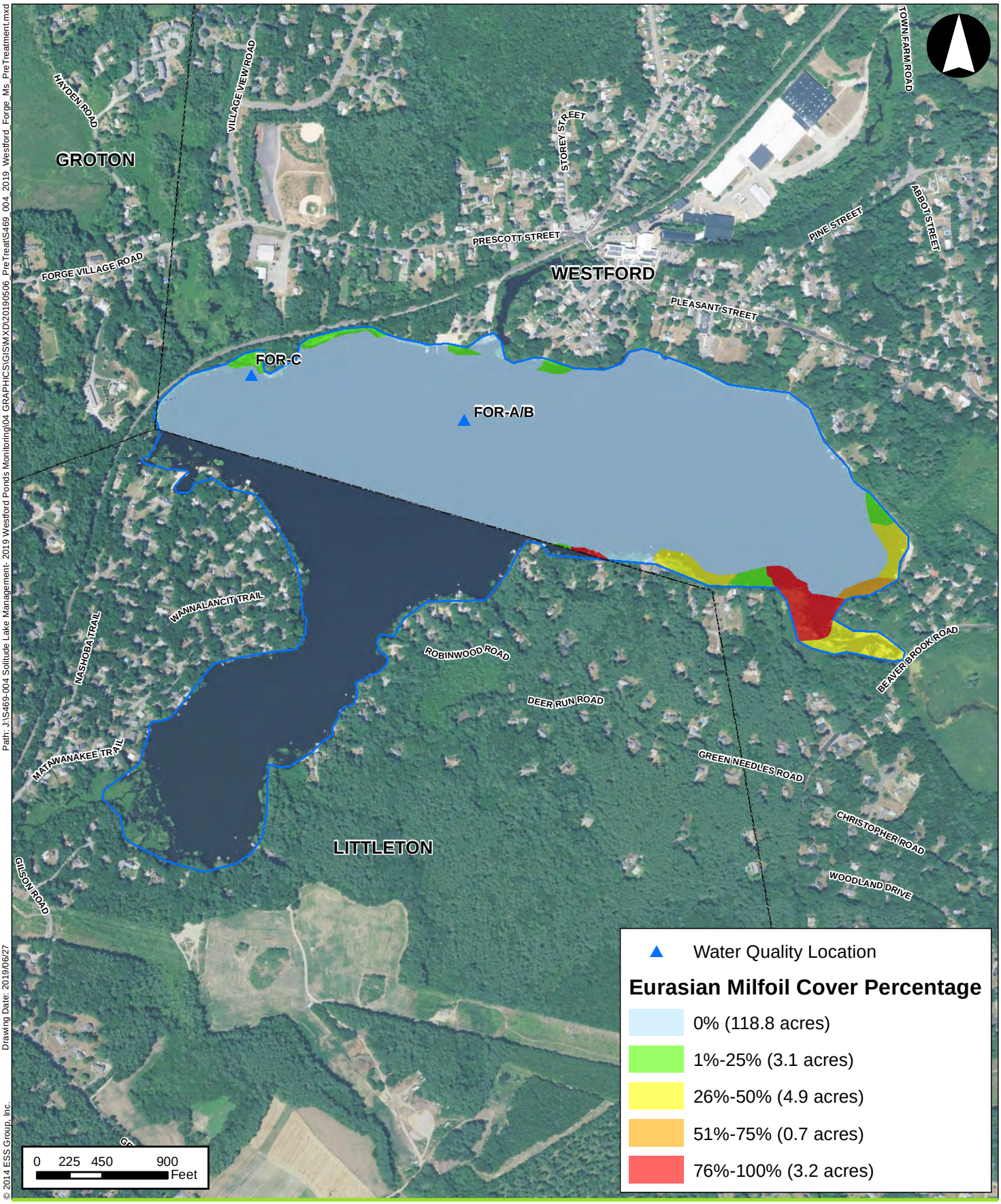
1 inch = 900 feet

Source: 1) USDA, NAIP Imagery, 2016
2) MassGIS, Major Roads, 2003
3) ESS, GPS Data, 2019

***Survey area limited to Westford.**

Forge Pond
Variable-leaf Milfoil
Early Season (May 2019)

Figure 18



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Solitude Lake Management LLC
Westford, Massachusetts

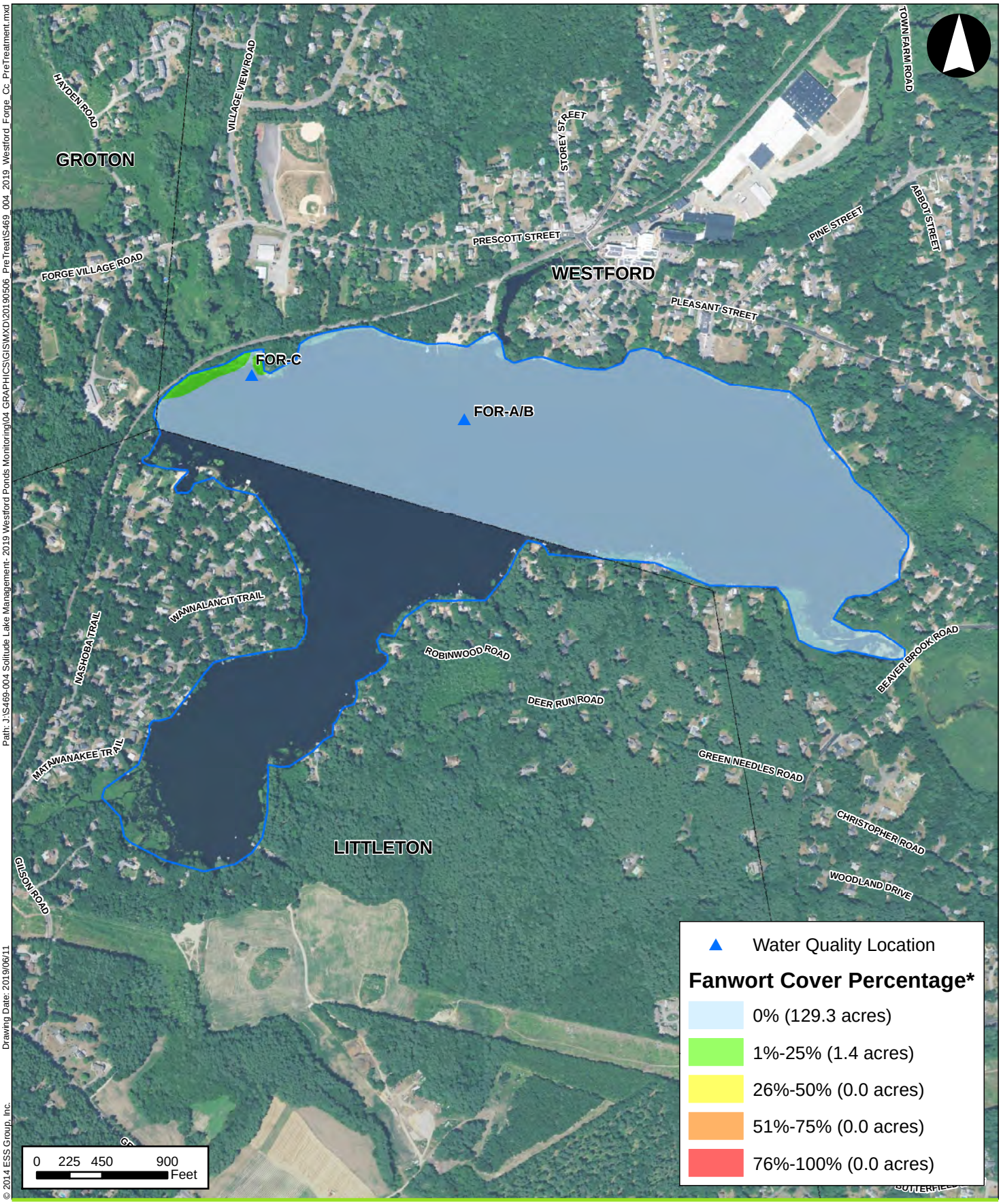
1 inch = 900 feet

Source: 1) USDA, NAIP Imagery, 2016
2) MassGIS, Major Roads, 2003
3) ESS, GPS Data, 2019

***Survey area limited to Westford.**

Forge Pond
Eurasian Milfoil
Early Season (May 2019)

Figure 19



Drawing Date: 2019/06/11

Path: J:\S469-004 Solitude Lake Management- 2019 Westford Ponds Monitoring\04 GRAPHICS\GIS\MXD\20190506_PreTreatS469_004_2019_Westford_Forge_Cc_PreTreatment.mxd

Solitude Lake Management LLC
Westford, Massachusetts

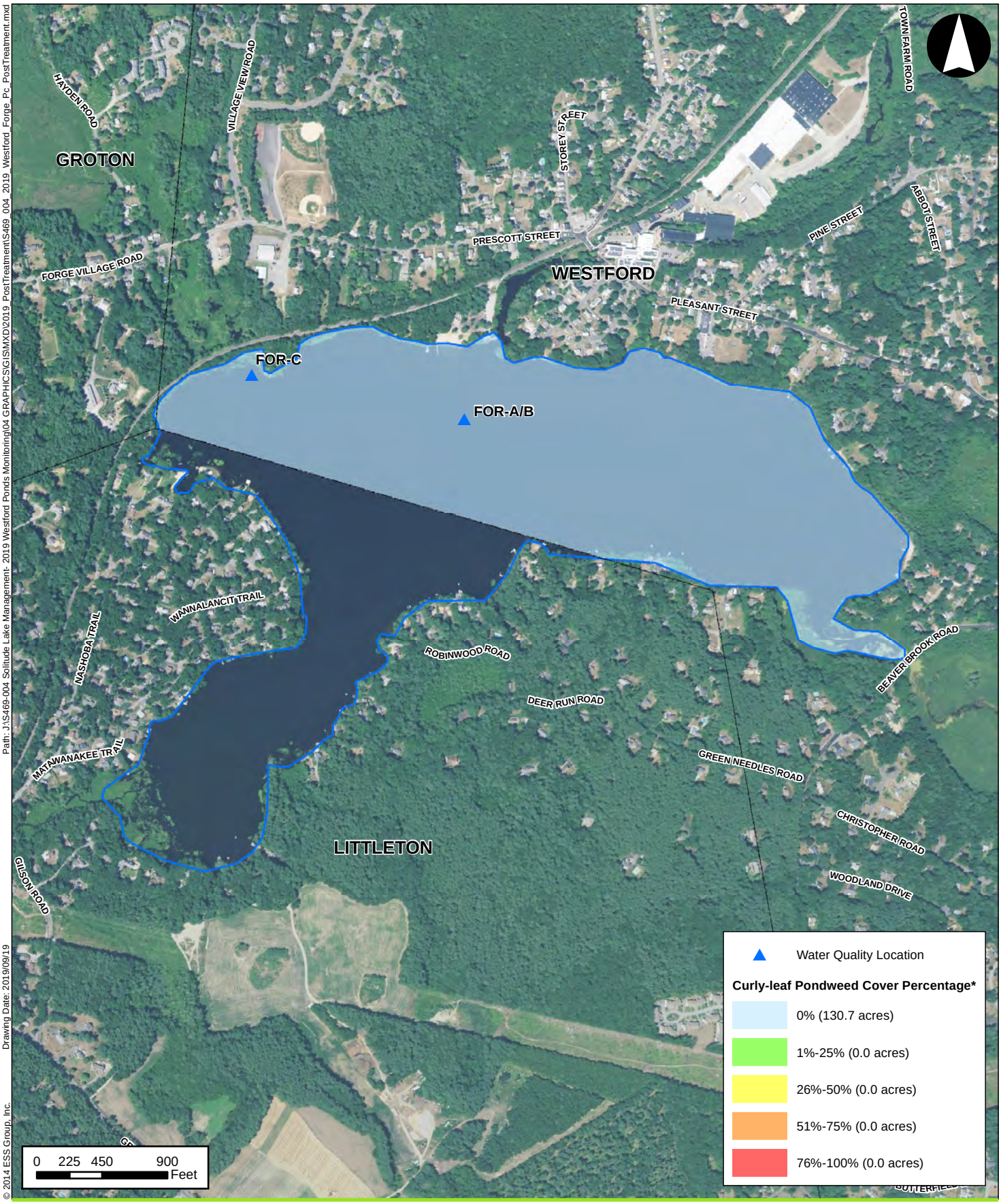
1 inch = 900 feet

Source: 1) USDA, NAIP Imagery, 2016
2) MassGIS, Major Roads, 2003
3) ESS, GPS Data, 2019

Forge Pond
Fanwort
Early Season (May 2019)

***Survey area limited to Westford.**

Figure 20



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Drawing Date: 2019/09/19

Solitude Lake Management LLC
Westford, Massachusetts

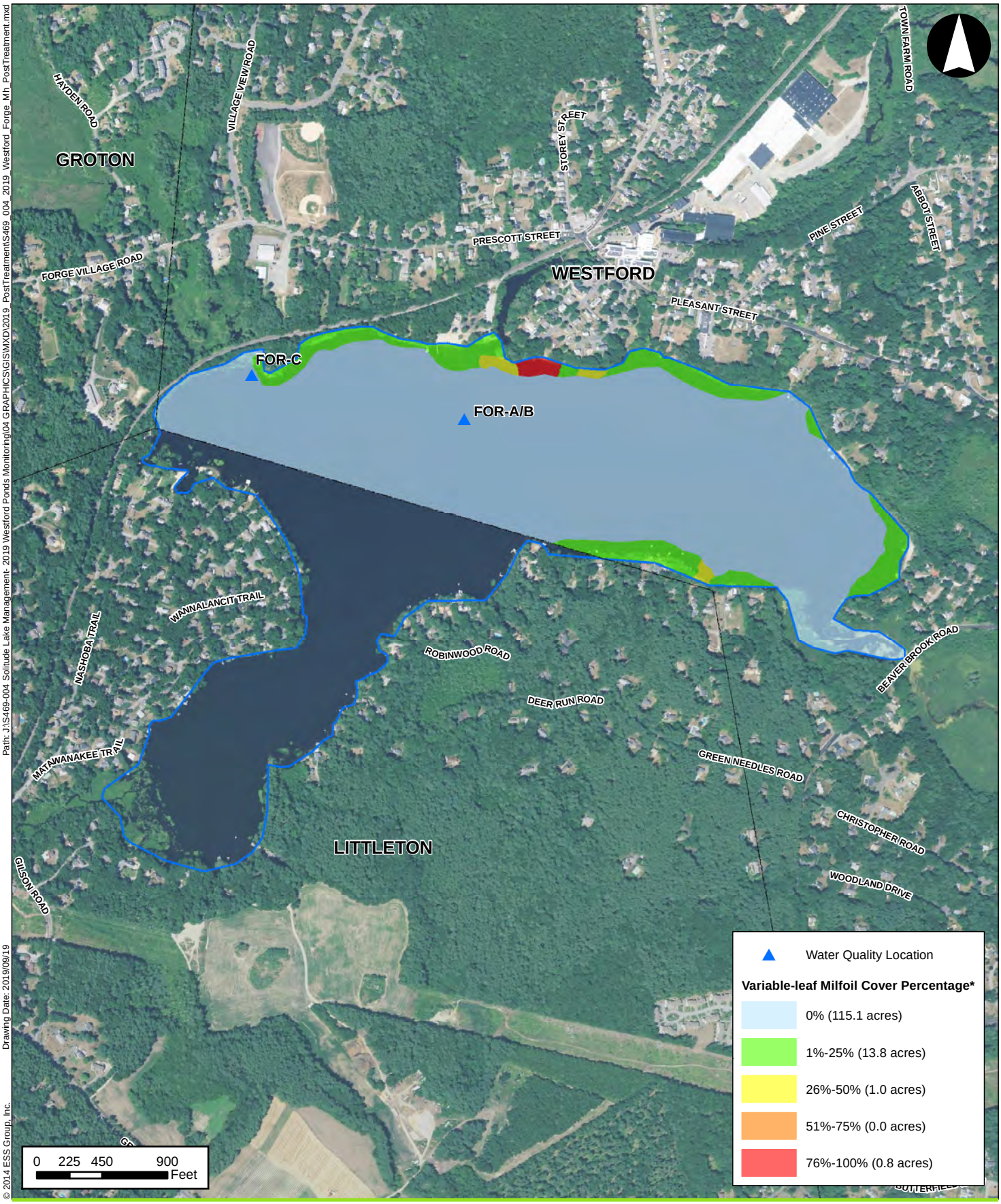
1 inch = 900 feet

Source: 1) USDA, NAIP Imagery, 2016
2) MassGIS, Major Roads, 2003
3) ESS, GPS Data, 2019

Forge Pond
Curly-leaf Pondweed
Late Season (September 2019)

***Survey area limited to Westford.**

Figure 21



Drawing Date: 2019/09/19

Path: J:\S469-004 Solitude Lake Management- 2019 Westford Ponds Monitoring\04 GRAPHICS\GIS\MXD\2019_PostTreatment\S469_004_2019_Westford_Forge_Mh_PostTreatment.mxd

Solitude Lake Management LLC
Westford, Massachusetts

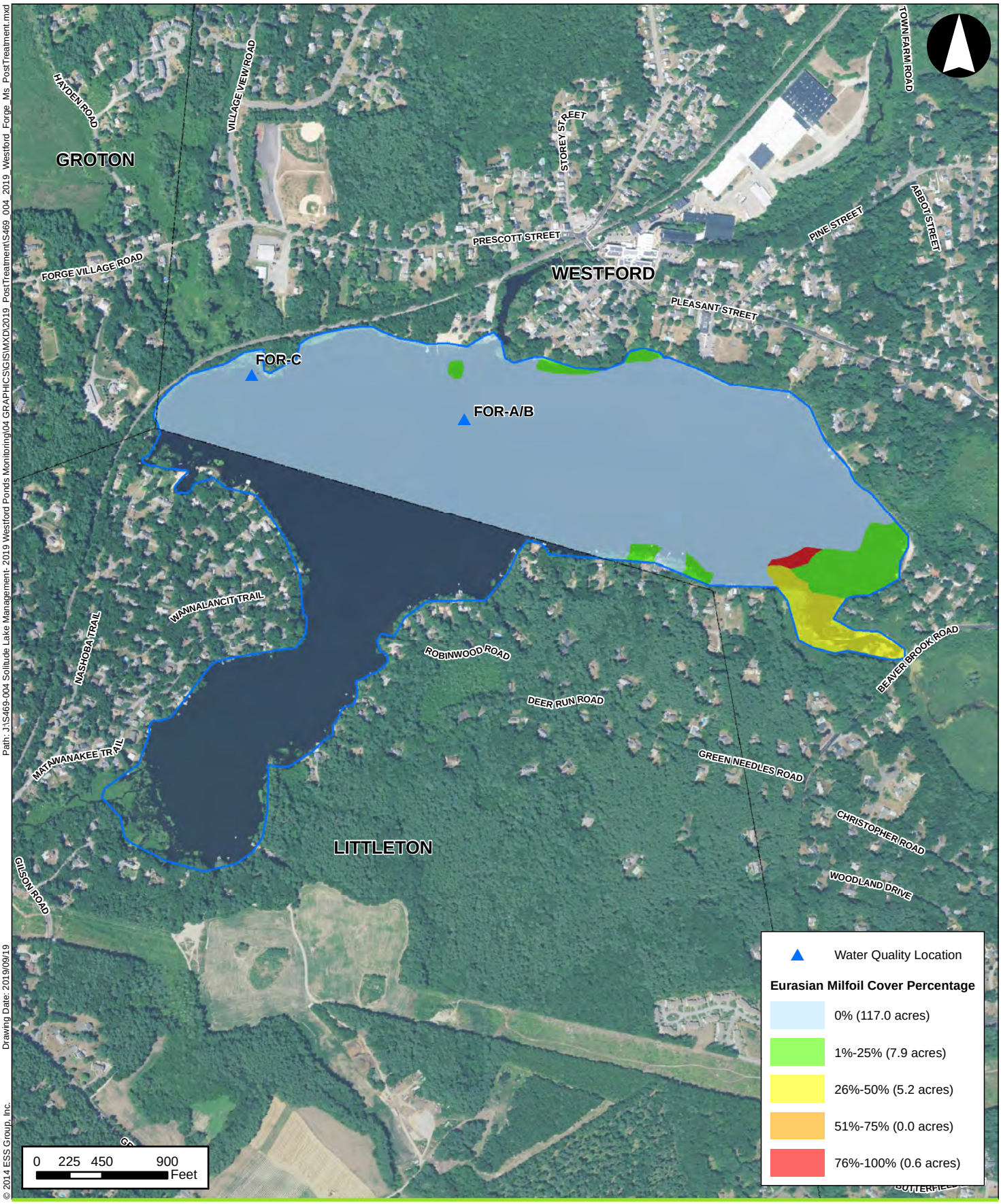
1 inch = 900 feet

Source: 1) USDA, NAIP Imagery, 2016
2) MassGIS, Major Roads, 2003
3) ESS, GPS Data, 2019

Forge Pond
Variable-leaf Milfoil
Late Season (September 2019)

***Survey area limited to Westford.**

Figure 22



Drawing Date: 2019/09/19

Path: J:\S469-004 Solitude Lake Management- 2019 Westford Ponds Monitoring\04 GRAPHICS\GIS\MXD\2019_PostTreatment\S469_004_2019_Westford_Forge_Ms_PostTreatment.mxd

Solitude Lake Management LLC
Westford, Massachusetts

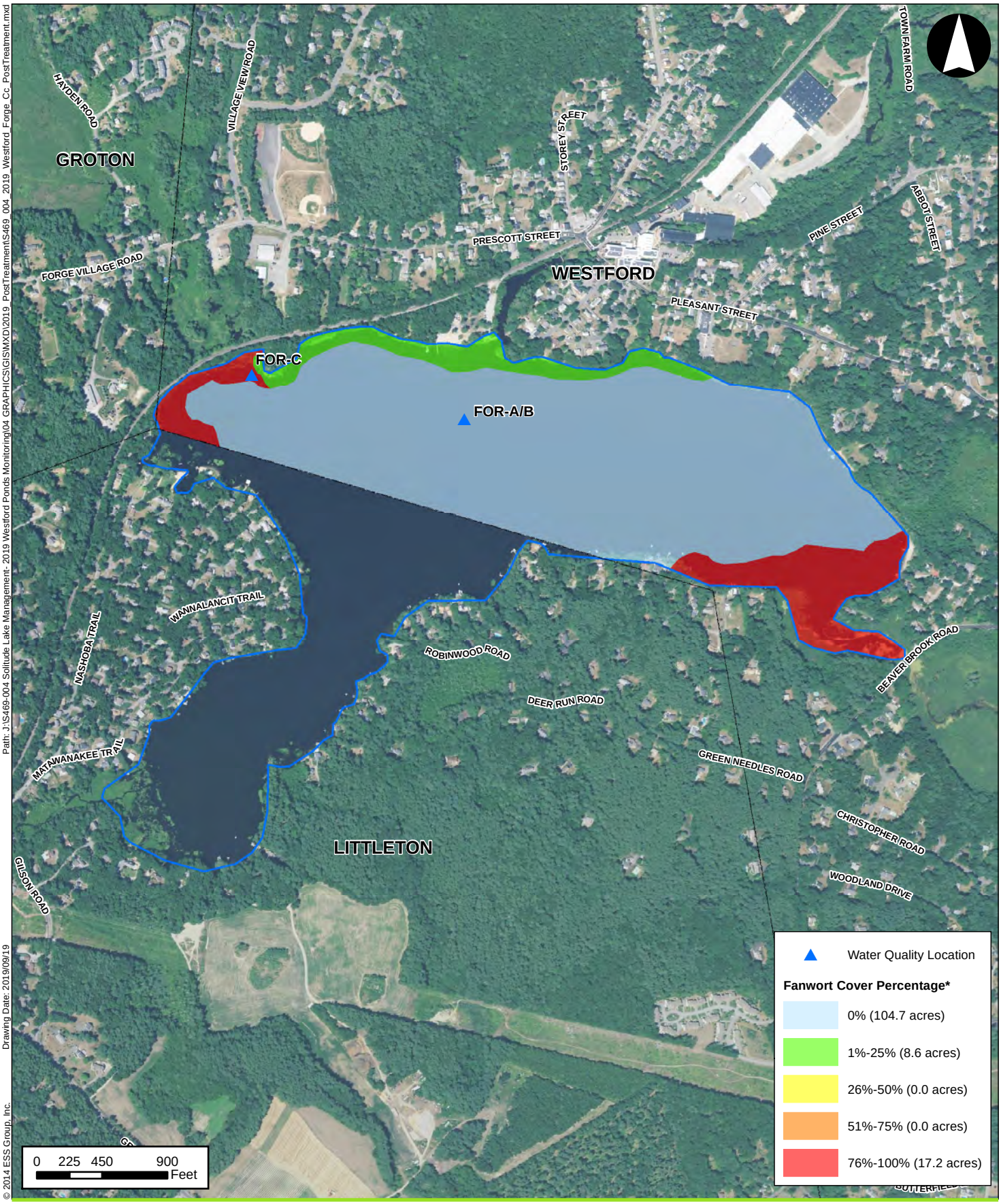
1 inch = 900 feet

Source: 1) USDA, NAIP Imagery, 2016
2) MassGIS, Major Roads, 2003
3) ESS, GPS Data, 2019

***Survey area limited to Westford.**

Forge Pond
Eurasian Milfoil
Late Season (September 2019)

Figure 23



Drawing Date: 2019/09/19

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Solitude Lake Management LLC
Westford, Massachusetts

1 inch = 900 feet

Source: 1) USDA, NAIP Imagery, 2016
2) MassGIS, Major Roads, 2003
3) ESS, GPS Data, 2019

Forge Pond
Fanwort
Late Season (September 2019)

***Survey area limited to Westford.**

Figure 24