

The Effect of the Accumulation of Heavy Metals in Soil on the Growth of Vegetation in the Long Island Solar Farm

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The construction of the Long Island Solar Farm (LISF) at Brookhaven National Laboratory is a step towards our nation's goal of a renewable energy future. The LISF will be built on what is currently two hundred acres comprised of a variety of habitat types. Before clear cutting these habitats, it is necessary to do an assessment of the vegetation, soil, and wildlife to gain baseline data to discover effects of acid rain in a more concentrated area under the solar panels. In relation to soil, the aim of this project was to explore the connection between soil composition and the vegetation growing within the LISF. Specifically, the study focused on the effect of metals, such as aluminum, calcium, magnesium, and mercury, on vegetation growth. In order to find metals present in soil, samples were taken in each habitat location within the solar field perimeters. Each location had two samples at depths of 0-6 inches and 10-16 inches. Using an auger and following a composite sampling procedure, soil was extracted at each depth. A total of ten locations and six control locations were visited and the soil samples were sent to TestAmerica labs to be analyzed for TAL metals, pH, and mercury. In addition, the vegetation in the overstory and the understory were observed and recorded to analyze later in the study. After discovering the concentration of metals in each soil sample, it was evident that aluminum, calcium, and magnesium impact vegetation growth. A common cause of accumulation of some metals and increased acidity in soil is acid rain. For example, each sample showed high concentrations of aluminum, which is normal for Pine Barrens soil. However, too much soluble aluminum, caused by increased acidity in soil, damages plant roots. Due to the porous, sandy Pine Barrens soil, metals and nutrients leach down even faster and prevent plants from taking in other important nutrients, like calcium and magnesium. It is evident that metals effect soil composition, but future research will indicate what amounts are the most harmful to vegetation and organisms in the micro-habitats under the solar panels.

Introduction

Brookhaven National Laboratory, which is located in the Long Island Pine Barrens Region, was chosen as the site to build a two hundred acre solar farm. The power generated will be distributed to homes in the surrounding area. However, in order to install the solar panels, approximately one hundred and fifty acres of forest will be removed. The plan is to use a method of clear cutting, which removes the overstory and tall plants in the understory. However, before clear cutting it is necessary to do an assessment of the soil, flora, and fauna in order to gain baseline data to use as a comparison with future research.

The focus of my project is to do an assessment of the concentration of metals found in soil. The baseline soil data will help researchers further understand the effects of acid rain in soil. The solar panels will act as a pathway for water to flow down into the soil. The area directly below the bottom end of the solar panel, “the drip line,” will be the most concentrated area of moisture. It will be useful to study the drip line area and analyze the potential increase in concentration of metals and type of vegetation able to grow in the micro-habitat. The unique acidic, sandy characteristics of Pine Barrens soil and role that soil plays in plant growth, makes this chosen site extremely beneficial to research.

Long Island is home to one of the largest areas of Pine Barrens forest. The type of forest earned its name by early settlers who referred to the areas as “barren” because they were unable to produce a substantial crop yield (Boyd 1). Typical Pine Barrens soil is very acidic and sandy; two characteristics that hinder plant growth. However, the native vegetation is well adapted to this unique soil. Forms of overstory plant life able to grow in the Pine Barrens include trees from the Pine family, Maple family, and Beech family. Typical trees include pitch pine, white oak, scarlet oak, and red maple. Understory plants are mainly from the heath family and include

huckleberry, blueberry, and cranberry.

Soil of the Pine Barrens originated from glacial deposits thousands of years ago. The glaciers left behind sandy, sedimentary deposits. Sandy soil is characteristically very porous and acidic. The soil is so porous in fact that any water drains down through them very quickly. As a result, the surface soil is dry and nutrients are easily washed through the soil. Leaching of nutrients through the soil prevents plants from absorbing their essential nutrients, such as potassium, calcium, magnesium, and nitrates. Also, the top soil layer is very thin in Pine Barrens soil. The lack of a thick humus layer subjects the soil underneath to acid rain and runoff.

There are different types of sandy loam soil in the pine barrens, such as Riverhead, Plymouth, Sudbury, Deerfield, Walpole, and Atsion, to name a few. Each soil series has different characteristics. For example, the Riverhead sandy loam series is the most common soil of the Pine Barrens and is very well drained (“Riverhead Series” 2). The pH is commonly very acidic and the color ranges along different hues of yellow-red. The soil texture is loamy coarse/fine sand. On the other hand, soil of the Sudbury series is poorly drained and is moderately acidic. The soil texture is moderately fine grained (Sudbury 2). The hue ranges from yellow-red to a more distinct yellow-olive color. Each soil series varies slightly, but the variation plays a large role in what vegetation is able to grow. Typically, in Riverhead soil, pines and some oaks flourish. Plants in the Pine Barrens are adapted to the acidic soil, but in some areas the pH is extremely acidic, between 3.5-4.0 and only specific plants can survive. Pines are among the adapted vegetation types.

Permeability also plays an important role in the type of flora able to flourish. Research indicates that the varied grain size impacts plant growth (“Soil: Effects Plant Growth” 2). Some

plants need soils that are medium-well sorted sands with good drainage. Without proper drainage around the roots, growth of the plant is stunted or the plant is outcompeted. For example, clay soil has very poor drainage. Water cannot permeate down to the farthest points near the roots. Soil that is well-drained does not retain enough moisture for food vegetative development (Boyd 6). Water is essential for plant survival as well as the nutrients, which aide in the process of photosynthesis and growth.

Plants rely on a combination of nutrients from the air and mineral nutrients from the soil. Photosynthesis is a process by which plants use light energy to change carbon dioxide and water into starches and sugars (“Plant Nutrients” 1). Mineral nutrients in the soil dissolve in water and are absorbed through the roots of the plants. The major nutrients include nitrogen, potassium and phosphorous and aide in the processes of growth. Other essential nutrients include calcium, magnesium, iron, zinc, and sulfur. These micro-nutrients aide in growth processes, as well as regulate certain functions for plants, like reproduction or formation of proteins.

Specifically for this project, calcium, magnesium, and aluminum were analyzed to discover metals trends in different forest habitat types. Calcium is an important part of the cell wall structure of plants (“Plant Nutrients” 4). It strengthens plants and is used in processes that transport sugars and water from the roots to the leaves (“Plant Nutrients” 4). Magnesium is also used in processes of photosynthesis. It is part of the chlorophyll and helps to activate enzymes needed for plant growth. Aluminum is naturally found in soil and in large amounts. However, too much aluminum can harm vegetation growth. An increase of aluminum can damage plants and prevent roots from taking in calcium, which slows the growth of plants. It is important for the soil to contain the right concentrations of metals in order for plants to grow and thrive.

A cause of change in the concentration of metals in soil is acid rain. The northeastern United States is heavily affected by acid rain. Acid rain contains harmful metals such as mercury, lead, aluminum, and cadmium. Pine Barrens soil is especially vulnerable to acid because of its already acidic nature and sandy loam texture. The soil lacks calcium ions and is very porous, which allows for quicker leaching of nutrients and harmful metals through the soil (“Effects of Acid Rain” 1). The lack of top soil buffer layer in Pine Barrens makes the soil more susceptible to metals and the chemical effects of acid rain.

Acid rain damages both the overstory and understory of forests. Trees, both coniferous and deciduous, are affected. There is nutrient loss from trees, reduced resistance to disease and insects, and increased mortality of seedlings (“Effects of Acid Rain” 2). The physical damage to tree leaves results in reduced canopy cover and low growth rate. Eventually the trees can no longer endure the stress and they perish. Moreover, beneath the forest floor, different types of damages occur. The roots are harmed by changes in metal concentration. Aluminum, for example, becomes soluble in soils with a pH of 4.0. This harmful metal is able to leach down and damage plant roots and slow the growth of soil bacteria, algae and fungi (Francis 1). As a result of increased aluminum, nutrient uptake is reduced and the plants cannot survive. Major signs of acid rain damage and heavy metal accumulation include, damage to the root hairs, stunted growth of trees, and slow decomposition of leaf litter. The dying out of trees creates holes in the canopy and allows for more light to reach the forest floor. With just a slight change in soil composition, an area of forest can be affected. Different plants will grow in the area of increased light and eventually out compete the native plants. The accumulation of metals in soils and devastation to trees and shrubs decreases the health of a forest.

Methods and Materials

Soil Samples were collected using a composite sampling method. An auger was used to dig down to the desired depths of 0-6 inches and 10-16 inches. The procedure began with discarding the top layer of soil. Included in the top layer is the organic and leaf layer. These layers were measured to determine depth and potential to act as a buffer to acid rain. Next, the first depth of 0-6 inches was removed and poured into a plastic bag. A meter stick was used to check accuracy of digging depth. The next layer 6-10 inches was extracted and put to the side. This layer was not used for analysis. The final layer of 10-16 inches was removed and poured into a second plastic bag. According to the composite sampling procedure (Brookhaven National Laboratory Environmental Monitoring Procedure 7), a few samples were taken for each location. The three small samples from each depth were mixed in their respective bags. Only 125mL of mixed soil from each depth were needed to be sent out for analysis at TestAmerica Lab. The samples were analyzed for TAL metals, pH, and mercury concentration.

A total of 16 locations were visited in order to include all habitats in the southern property of Brookhaven National Laboratory. Each location point was recorded by a global positioning unit (GPS). Ten locations were “samples” and were chosen by their habitat type within the 200 acres of land to be used for the solar farm. A variety of habitat types were selected, including pine forest, oak-pine mix, maple-scarlet oak. Six “control” locations were also chosen outside of the 200 acre perimeters. Each point can be seen on Figure 6. Each site was predetermined by the environmental assessment team and main sites used in this study were 26, 19, 13, 14, and 4. In addition to collecting soil samples, the vegetation was observed and noted. Since each location was different, it was necessary to do an assessment on the vegetation and form hypotheses on why only certain trees were growing or why the understory was so

dense.

Furthermore, to test the hypothesis that the majority of soil in the Pine Barrens is of the Riverhead Soil series, it was necessary to collect small samples at each depth. The soil in this region is characteristically very acidic and red or yellow in color. Using Munsell Soil Color Charts, each soil sample was compared to range of colors. Acidity was obtained by using a pH meter and testing the top six inches of soil.

Results

The TAL metals analysis results gave a wide scope of the concentration of metals in the soil sample locations. The main metals I focused on were aluminum, calcium, magnesium, and mercury. It was predicted that trends would show correlation between magnesium, calcium, and aluminum. Aluminum characteristically increases with depth and calcium and magnesium decrease. In each location, except in the Biofields, these trends were true (Figure 1). The Biofields showed opposite results due to nutrient treatment of the soil in the past. There were also very high levels of aluminum, calcium, and magnesium seen in several control samples (Figure 5). Also, the concentrations found for each metal were at normal levels. According to the Suffolk County soil standards, a normal level for aluminum is 33,000mg/kg (see Figure 3). Any concentration above that level is considered hazardous and may be subject to clean up. The levels in this study did not exceed 33,000mg/kg, in fact the highest level found was 20,200mg/kg. Levels of mercury were also of normal concentrations (Figure 2). In the Biofields, however, sample 10 showed a high concentration (Figure 4). This is thought to be due to effects of the Sewage Recharge Project.

In addition to concentrations of metals, the samples and control samples were tested for

pH. The results were more accurate from TestAmerica than the pH meter. It was predicted that the soil would be very acidic since the samples were taken in the Pine Barrens. Each location, except for the Biofields, had a pH between 4.5-5.5 (Figure 7). The Biofields soil had pHs between 6.0-6.8 due to treatment in the past. The vegetation also varied with relation to pH. There was a higher pH where grass was growing, whereas there was a lower pH where pines and oaks were growing.

Furthermore, the soil characteristics matched the typical soil found in the Pine Barrens. The soil series found were Riverhead sandy loam (RdA, RdB), Sudbury (Su), Plymouth (PIA, PIB, PsA), and Deerfield (De). The majority of soil was of the Riverhead sandy loam series (See Figure 6). The soil texture for each sample was porous sand with fine grains and few coarse grains. Particle size was consistent throughout each sample. The soil color also changed with depth. Lighter, more yellow in hue soil was found at the 10-16 inch depth. Using the Munsell Soil Color Charts it was evident that most soil was yellow-red with values between 4-6 and chromas of 3-6. The top soil layer, if organic material was present, was a very dark reddish brown. However, Pine Barrens soil characteristically lacks a thick organic layer. Each location with a dense understory, such as oak-pine mix and maple-scarlet oak, had a noticeable organic layer. But in locations without an understory, the layer was very thin or non-existent. The grass fields completely lacked an organic layer.

Discussion/Conclusions

After discovering the concentration of metals in each soil sample, it was evident that aluminum, calcium, and magnesium impact vegetation growth. Soils with high levels of aluminum do not provide the best growing environment for plants. Vegetation needs calcium

and magnesium to grow, as well as potassium, nitrogen, and phosphorous. In this study, only calcium and magnesium were tested and their concentrations in the soil were normal. This supported the idea that the soil in the Pine Barrens is not completely barren and can support life.

However, the accumulation of acid rain changes metal concentrations and directly effects vegetation growth. For example, each sample showed high concentrations of aluminum, which is normal for Pine Barrens soil. But, too much soluble aluminum, caused by increased acidity in soil, damages plant roots. The acidity from acid rain changes some harmful metals, like aluminum, from an insoluble state to a soluble state (Mannings and Smith 3). As a result, soluble metals leach down into the soil at a faster rate and prevent other important nutrients from being taken up by the plant roots.

The vegetation growth at each sample location varied due to soil composition and texture. The pine forests lacked an understory and did not have a dense canopy. The oak-pine mix forest, however, had a very dense understory and canopy. These differences in plant growth and type of tree growing can partially be explained by the composition of the soil. Although there was not a huge difference in soil composition, it was evident that in some areas the soil was sandier than others. The pine forests had very sandy soil, which is the natural habitat for pine trees.

Observing the overstory and understory, I was able to conclude that the flora was natural to the area and so far not significantly affected by acid rain. The main vegetation differences were in the sandy texture of soil. Pines grew in sandy soil and maples grew in darker, clay like soil.

Moreover, future studies will show if there is a significant change in forest when the soil composition changes due to acid rain. A change in pH of soil will affect the growth of plants.

An increase in acidity will result in stunted growth of trees and dieback. The pine forests that are not being cut down for the solar farm could have an even sparser canopy and fewer saplings.

Also, the Biofields yielded varied results due to the treatment of soil in past projects. The fields were used for growing crops and were fertilized and limed every third year up until about 2007. Liming lowers the acidity and increases the concentrations of calcium and magnesium in soil. The liming technique also makes toxic metals change to a solid form, which cannot be used by plants. Another section of the fields was treated with sewage as a part of the Upland Recharge Project. This would support the results of high concentrations of metals such as arsenic, mercury, and silver. Furthermore, the soil in the Biofields was turned over every three years, which changed the soil at certain depths. The different concentrations found may have been higher or lower if the soil was not plowed. The lack of a top soil layer can also be explained by the fact that the soil was plowed.

Due to the porous, sandy Pine Barrens soil, metals and nutrients leach down even faster and prevent them from taking in other important nutrients, like calcium and magnesium. Future studies in the Long Island Solar farm will indicate changes in heavy metal concentrations in soil. The drip line will be analyzed for potentially higher concentrations of metals due to acid rain. It will also be useful to design a similar study that uses depths greater than sixteen inches. The largest changes in my study took place at the 10-16 inch depth. It would be beneficial to see if there is a higher concentration of metals deep in the soil. It is evident that metals effect soil composition, but future research will indicate what amounts are the most harmful to vegetation and organisms in the micro-habitats under the solar panels.

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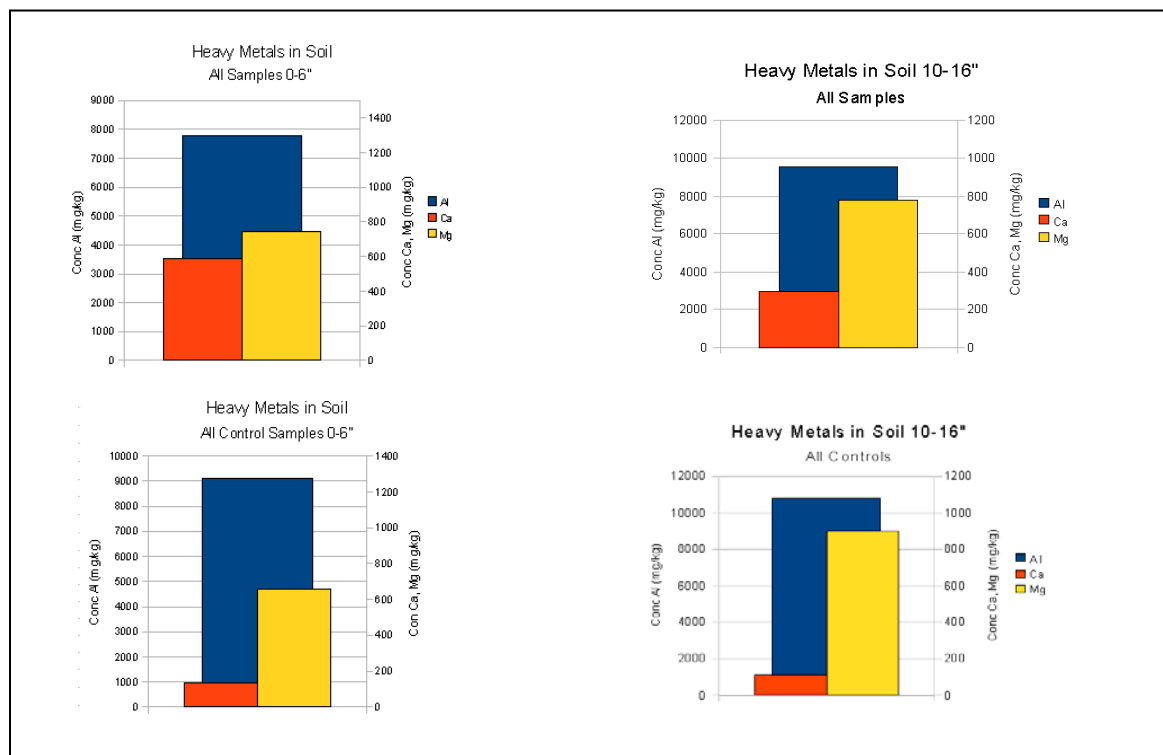


Figure 1: Concentration of Al, Ca, Mg in Soil Samples and Controls

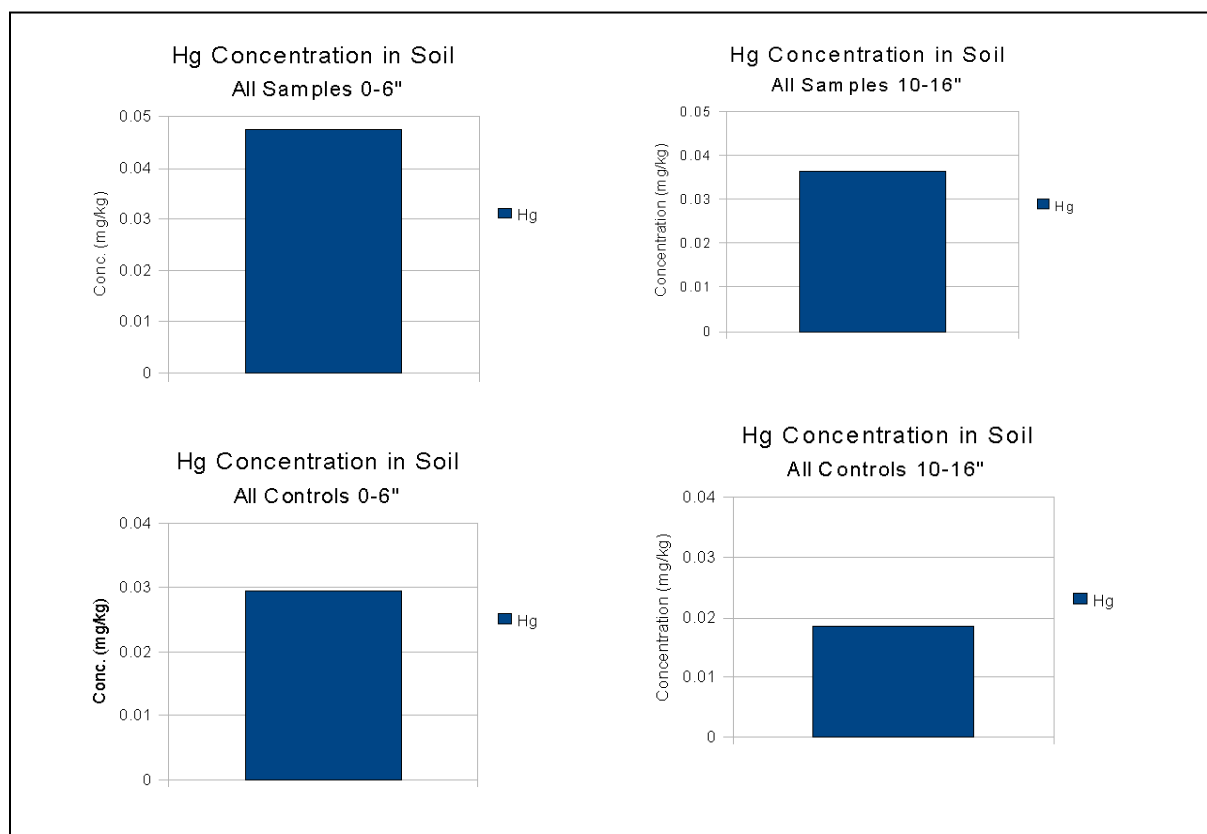


Figure 2: Concentration of Mercury in Soil Samples and Controls

Heavy Metal	Concentration before Cleanup (mg/kg)
Aluminum (Al)	33,000
Calcium (Ca)	130-35,000
Magnesium (Mg)	100-5,000
Mercury (Hg)	0.001-0.20
Iron (Fe)	2000-550,000

Figure 3: Concentrations of heavy metals in Soil before clean up, Eastern USA Background

Sample #	pH	Hg (mg/kg)	Al (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Soil Type
1	4.6	0.023	8790	62.70	572	RdA
3	4.6	0.048	9340	52.00	482	RdA
5	4.8	0.029	9420	81.40	557	RdA
7	4.8	0.031	8160	100.00	534	RdA
9	4.9	0.040	8180	78.30	295	Su
11	4.5	0.019	8910	111.00	659	RdA
13	4.9	0.056	9880	109.00	766	PIA
15	6.1	0.026	7120	594.00	665	RdA
17	5.8	0.045	1100	102.00	103	RdA
19	6.7	0.160	6880	4610.00	2800	RdA, RdB
Average (0-6)	5.170	0.05	7778	590.04	743.3	
Sample #	pH	Hg (mg/kg)	Al (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Soil Type
2	4.6	0.011	9780	65.10	670	RdA
4	4.7	0.021	10800	48.40	699	RdA
6	4.7	0.021	12100	56.20	892	RdA
8	4.6	0.028	11300	60.90	690	RdA
10	5.4	0.030	8280	69.10	522	Su
12	4.7	0.012	12800	84.80	1030	RdA
14	4.8	0.030	10200	85.30	957	PIA
16	5.9	0.032	6380	440.00	589	RdA
18	6	0.038	5800	578.00	520	RdA
20	6.9	0.140	8260	1500.00	1220	RdA, RdB
Average 10 -16	5.23	0.04	9570	298.78	778.9	

Figure 4: Heavy metal (Hg, Al, Ca, Mg) concentrations for soil samples in the LISF

C Sample #	pH	Hg (mg/kg)	Al (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Soil Type
21	4.8	0.031	9960	60.60	603	RdB
23	4.8	0.027	10600	217.00	746	RdA
25	4.7	0.056	16600	133.00	1570	PIB
27	4.4	0.016	1920	26.90	94.3	De
29	4.5	0.031	9680	59.20	557	RdA
31	5.4	0.015	6110	297.00	368	PsA
Average C (0-6)	4.77	0.03	9128.33	132.28	656.38	

C Sample #	pH	Hg (mg/kg)	Al (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Soil Type
22	4.6	0.020	10700	54.20	855	RdB
24	4.9	0.023	14200	114.00	1110	RdA
26	4.5	0.029	20200	69.80	2130	PIB
28	4.8	0.008	1780	21.00	59	De
30	5.2	0.017	11600	55.30	883	RdA
32	5.6	0.014	6430	342.00	376	PsA
Average C 10 -16	4.93	0.02	10818.33	109.38	902.17	

Figure 5: Heavy metal (Hg, Al, Ca, Mg) concentrations for soil controls in the LISF

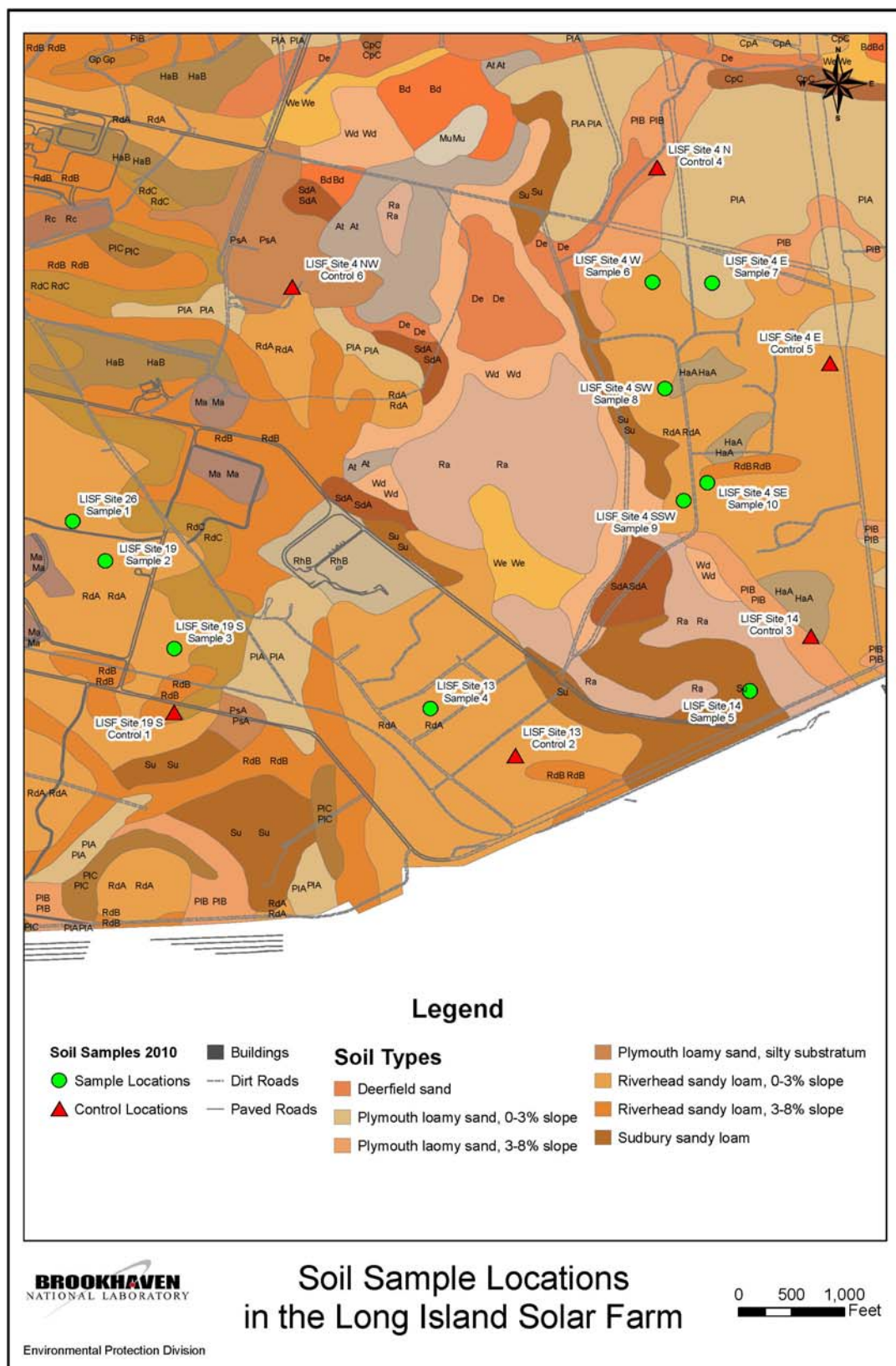


Figure 6: Soil series type and sample locations

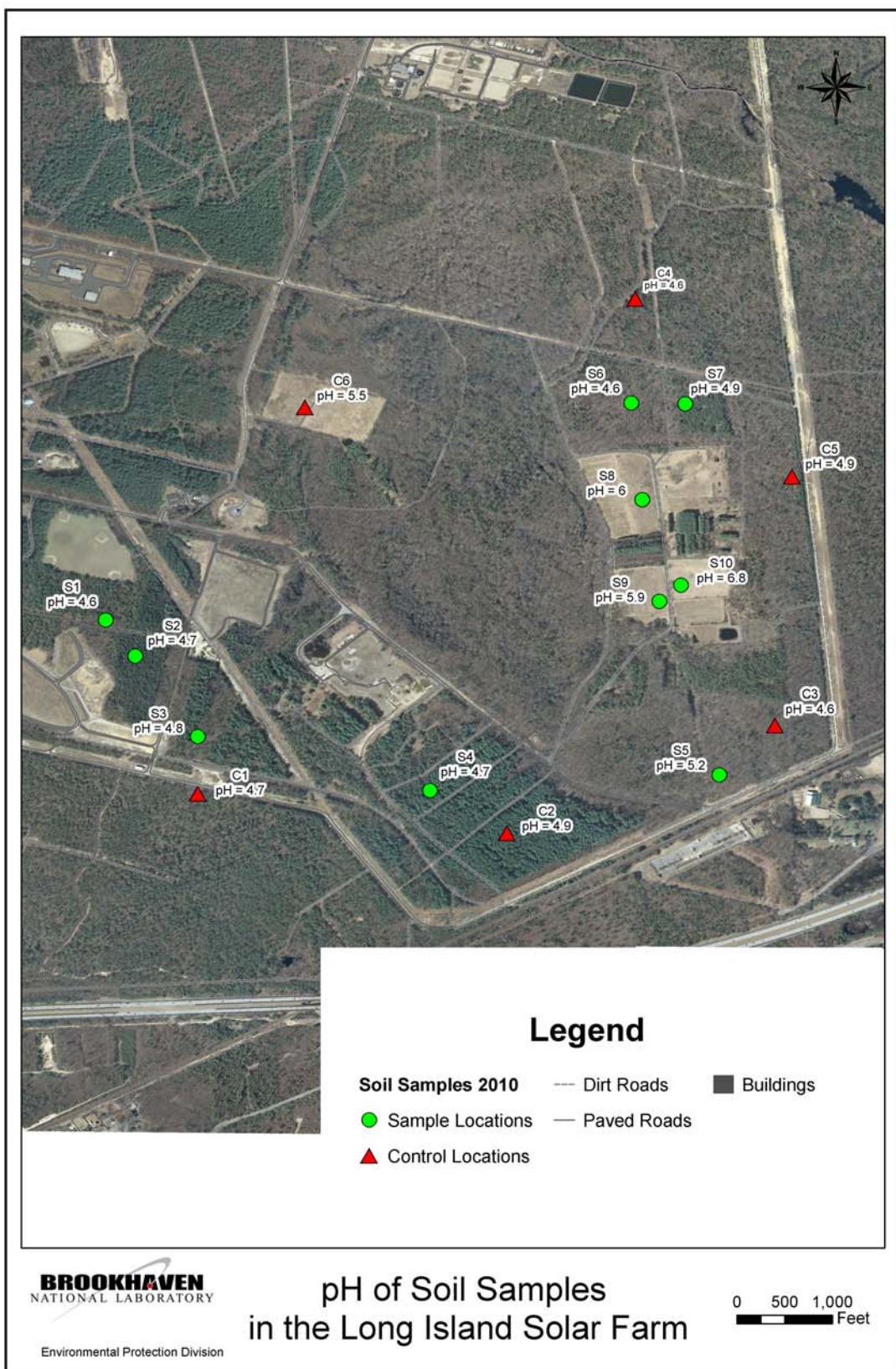


Figure 7: pH of soil samples and controls

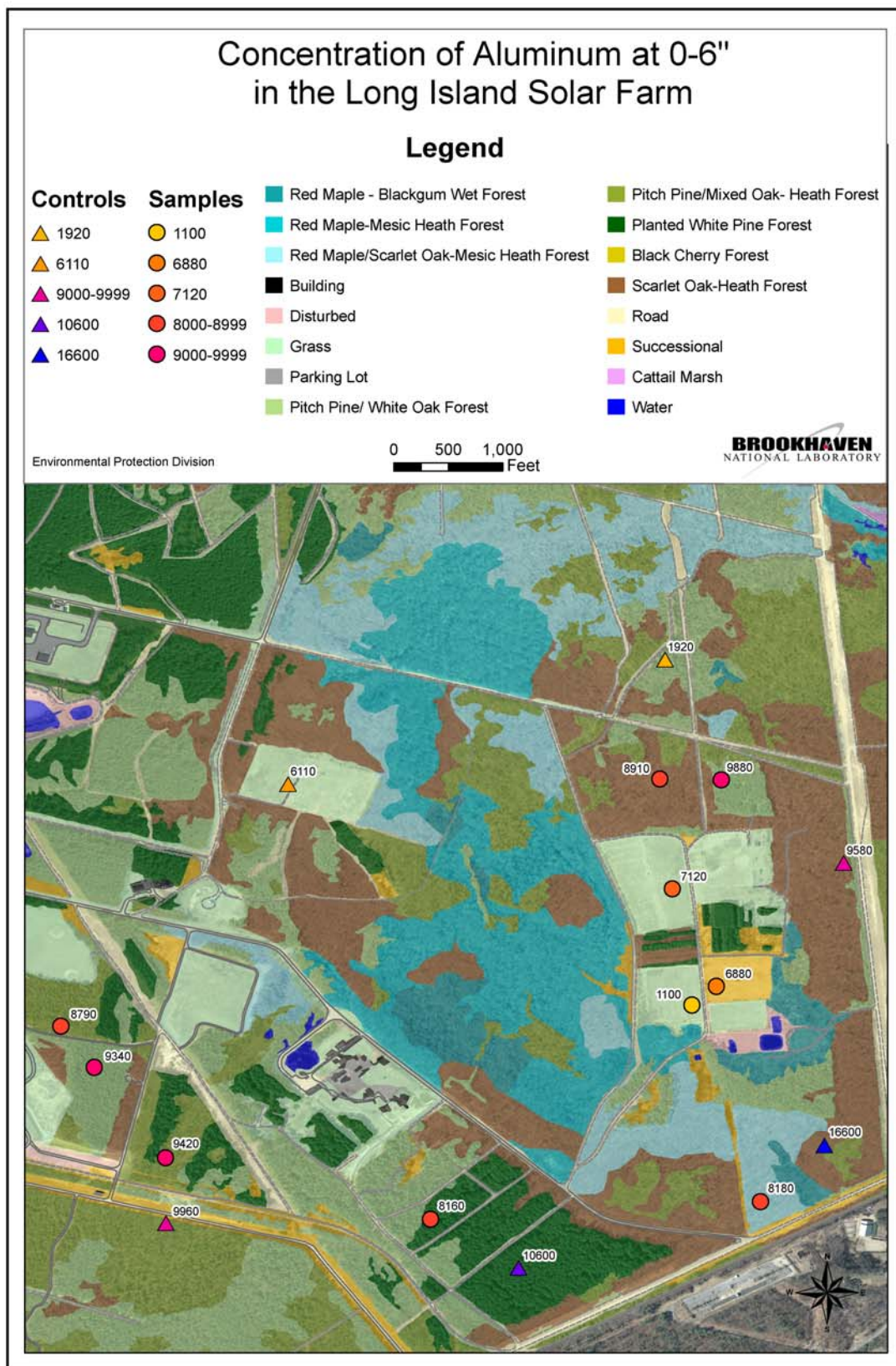


Figure 8: Concentration of Aluminum at 0-6"

Concentration of Aluminum at 10-16" in the Long Island Solar Farm

Legend

Controls	Samples	Red Maple - Blackgum Wet Forest	Pitch Pine/Mixed Oak- Heath Forest
▲ 1780	● 5800	Red Maple-Mesic Heath Forest	Planted White Pine Forest
▲ 6430	● 6380	Red Maple/Scarlet Oak-Mesic Heath Forest	Black Cherry Forest
▲ 10700	● 8000-8999	■ Building	Scarlet Oak-Heath Forest
▲ 11600	● 9780	■ Disturbed	■ Road
▲ 14200	● 10000-10999	■ Grass	■ Successional
▲ 20200	● 11300	■ Parking Lot	■ Cattail Marsh
	● 12000-12999	■ Pitch Pine/ White Oak Forest	■ Water

Environmental Protection Division

0 500 1,000
Feet

BROOKHAVEN
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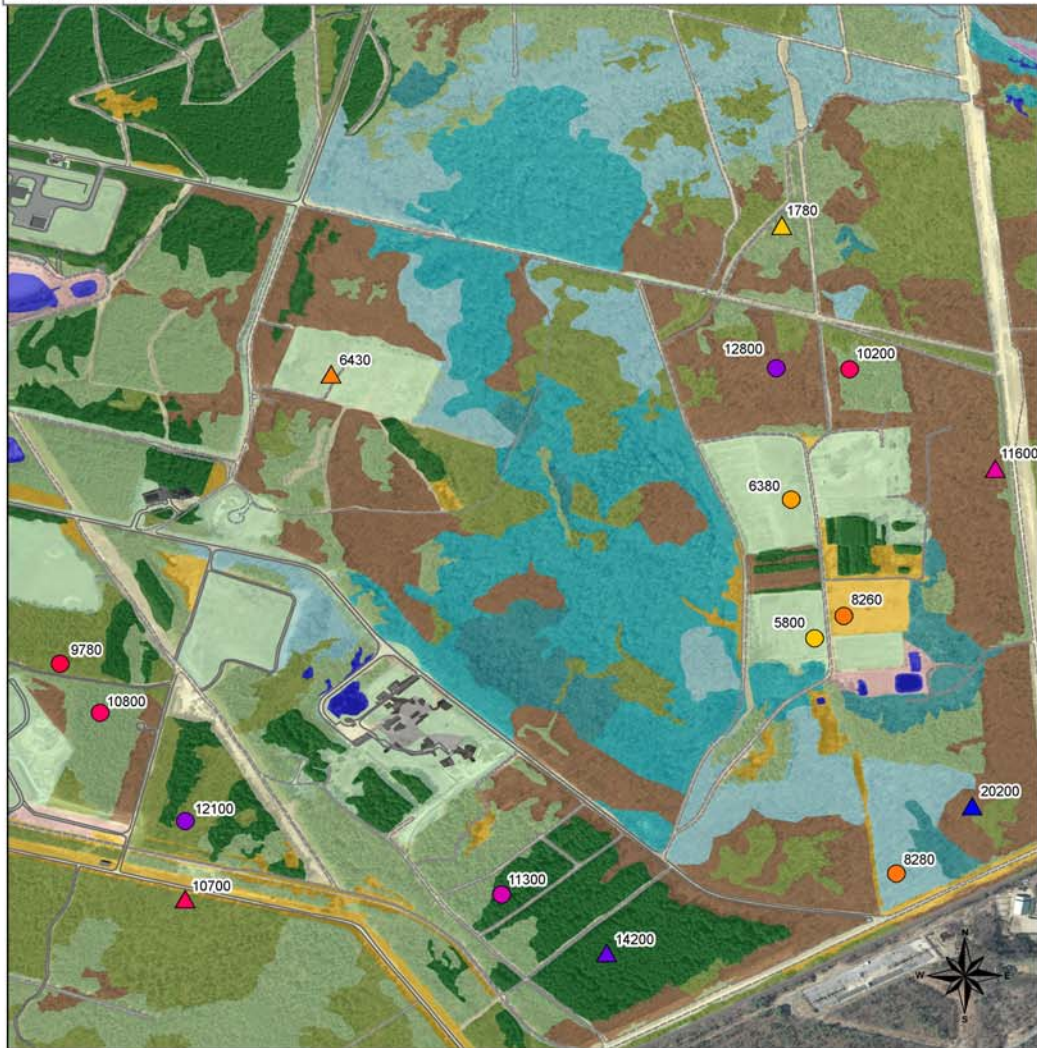


Figure 9: Concentration of Aluminum at 10-16"

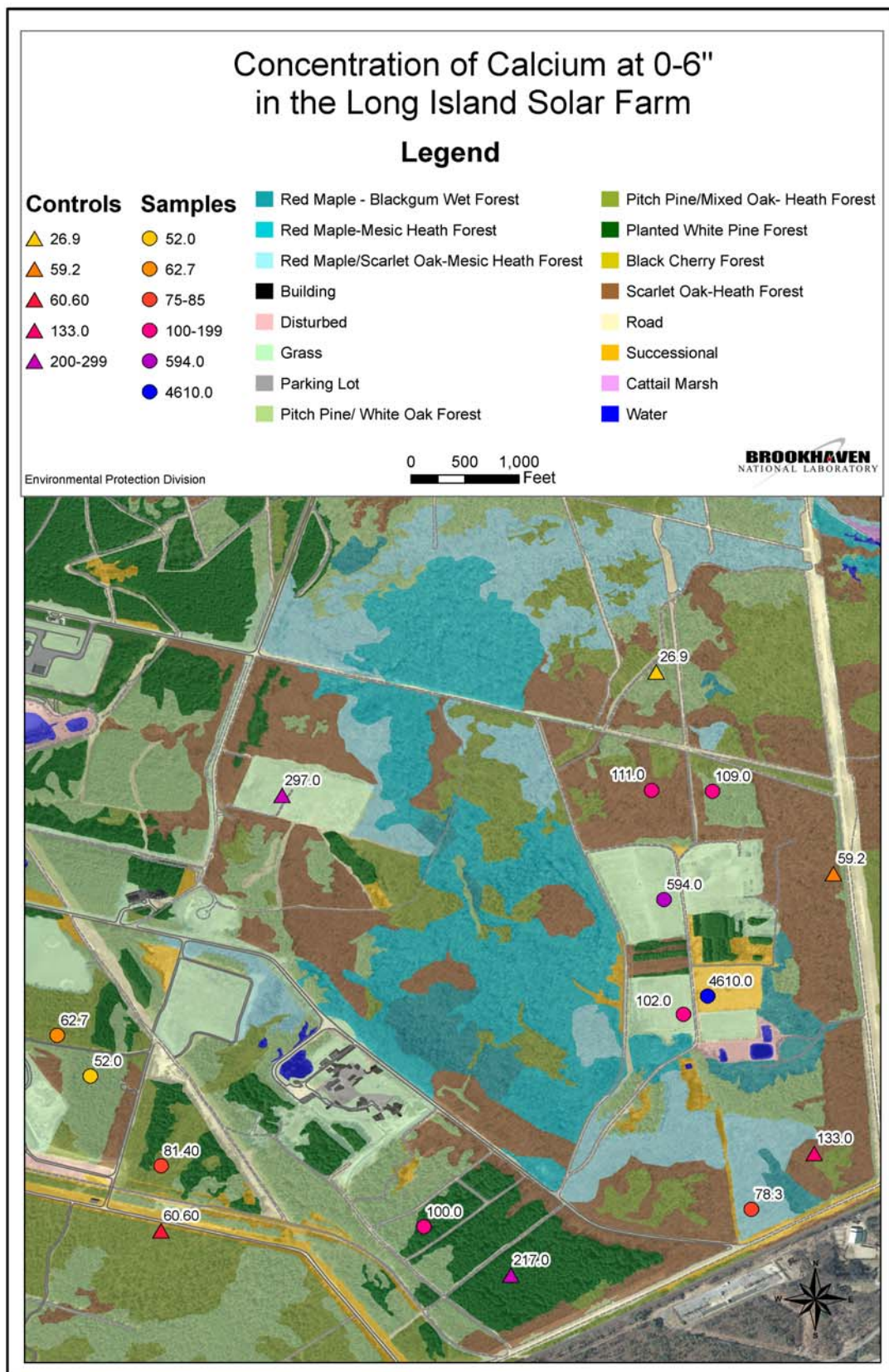


Figure 10: Concentration of Calcium at 0-6"

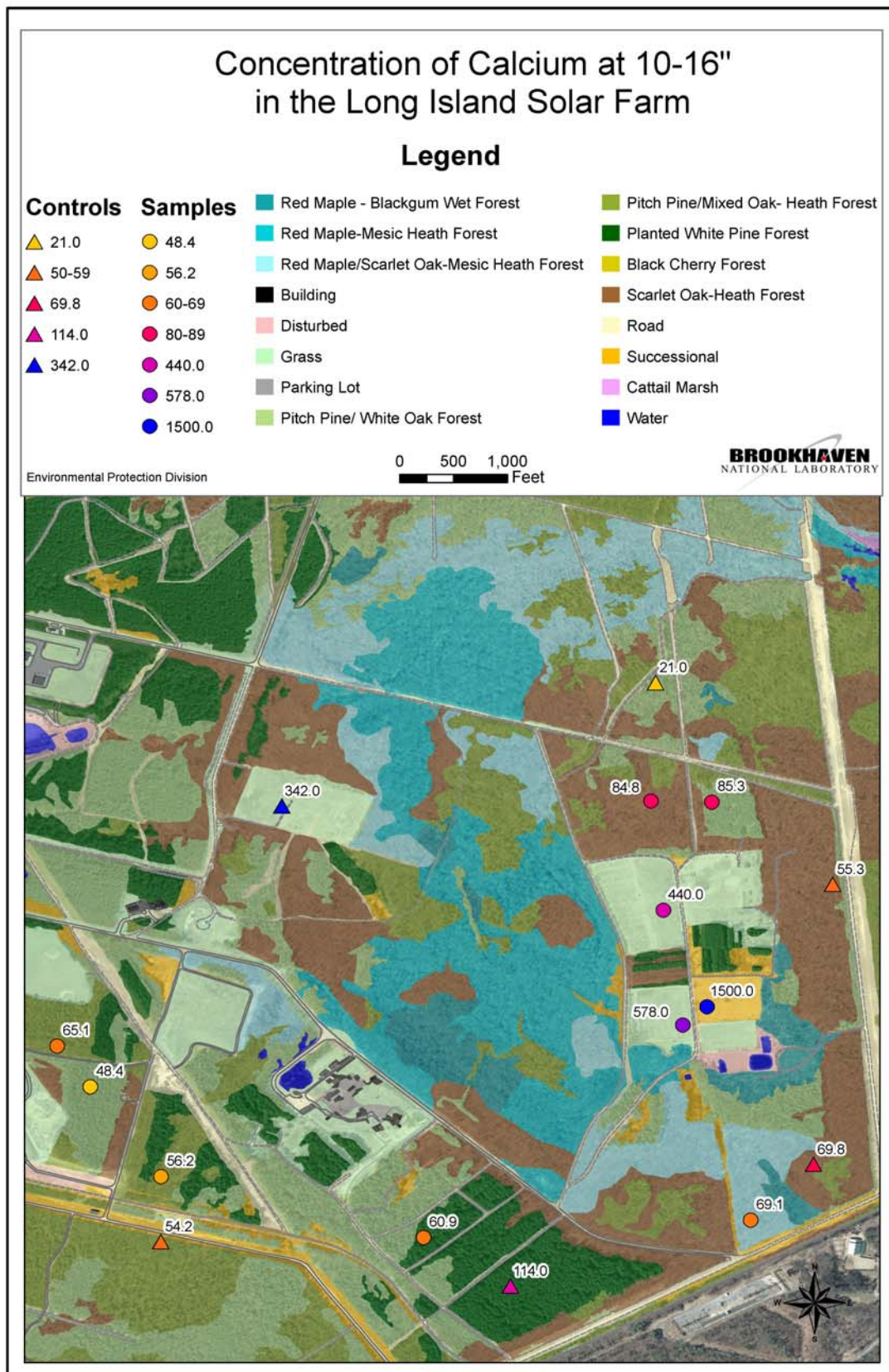


Figure 11: Concentration of calcium at 10-16"

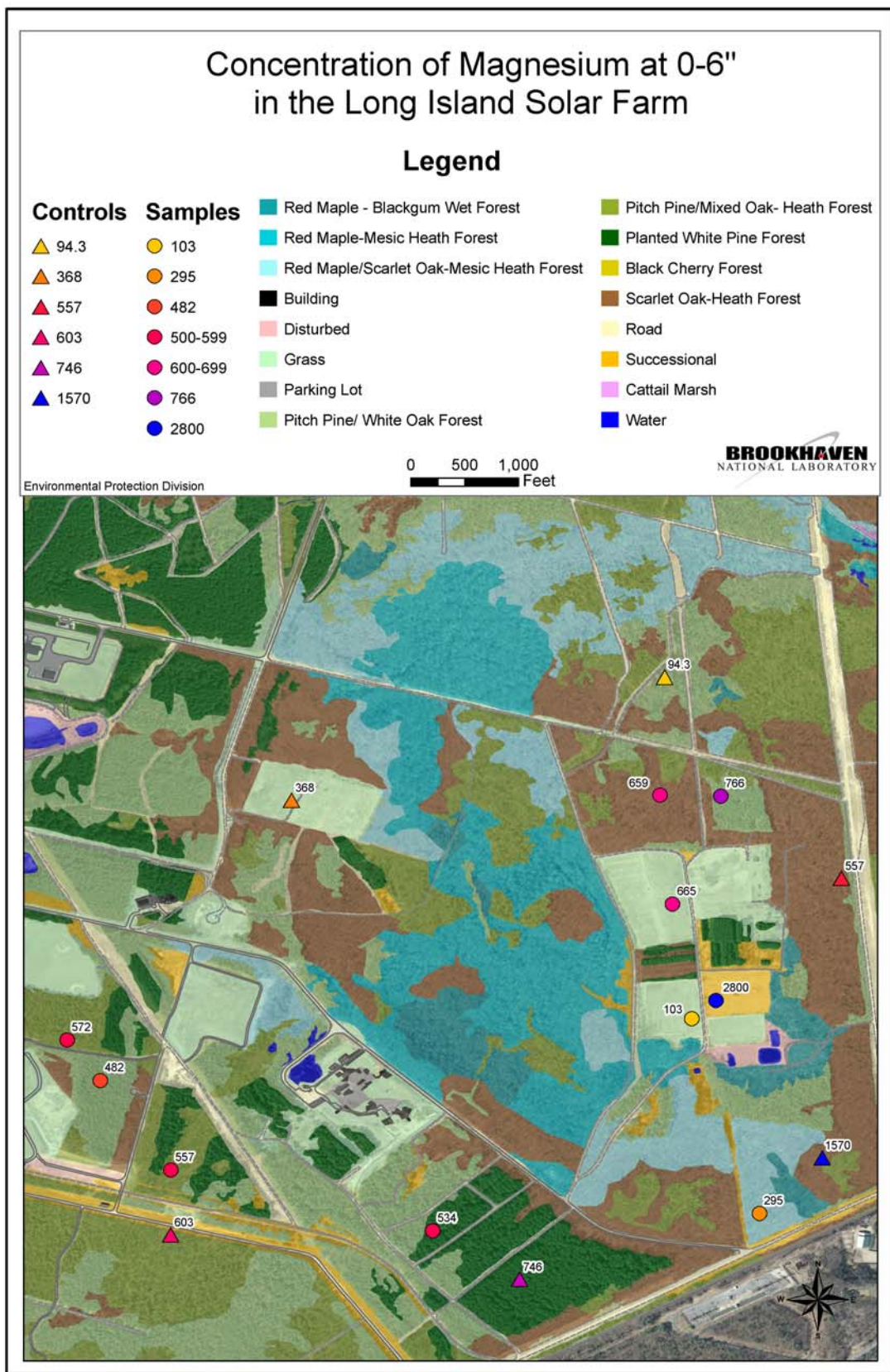


Figure 12: Concentration of Magnesium at 0-6"

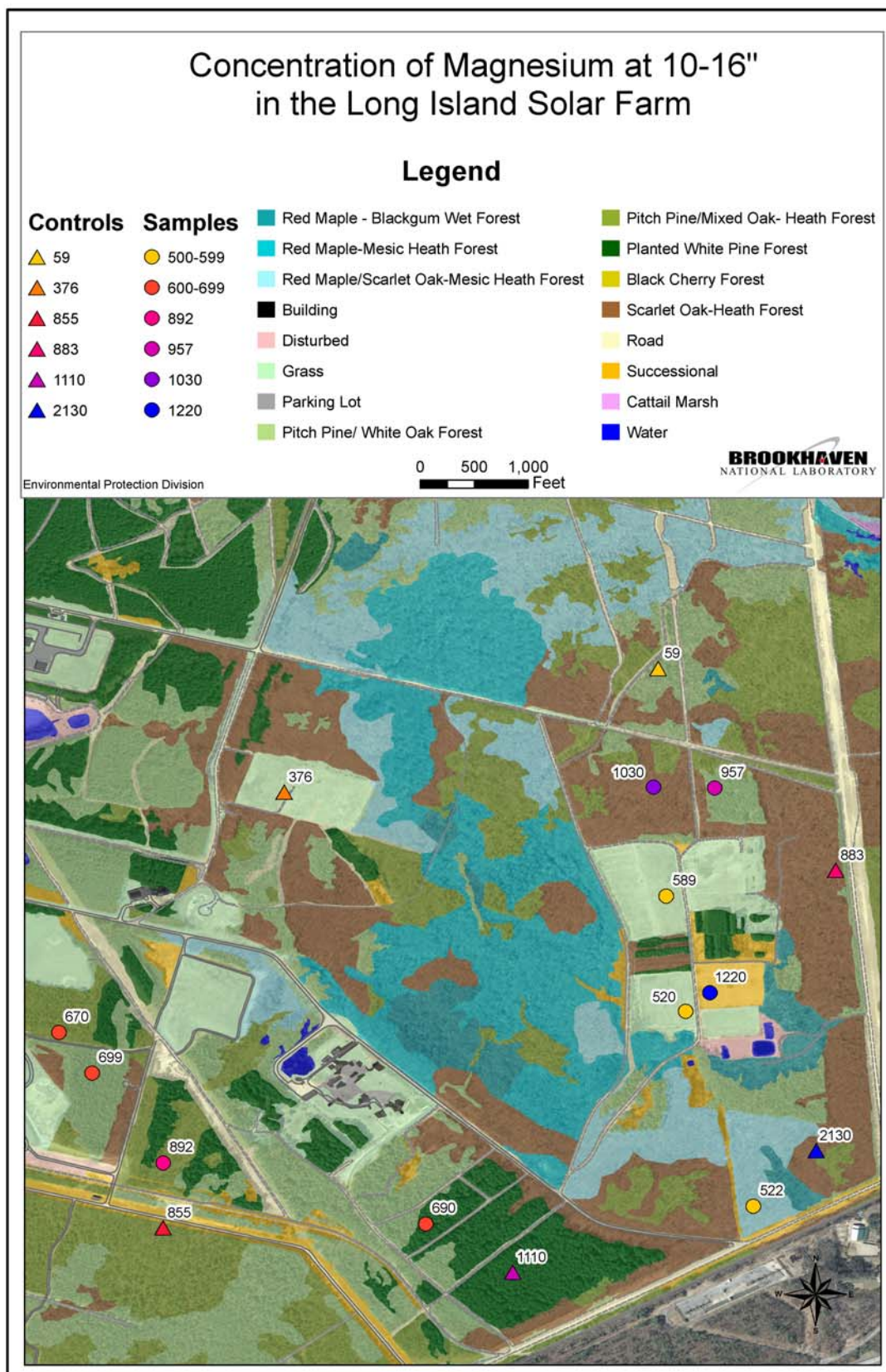


Figure 13: Concentration of Magnesium at 10-16"

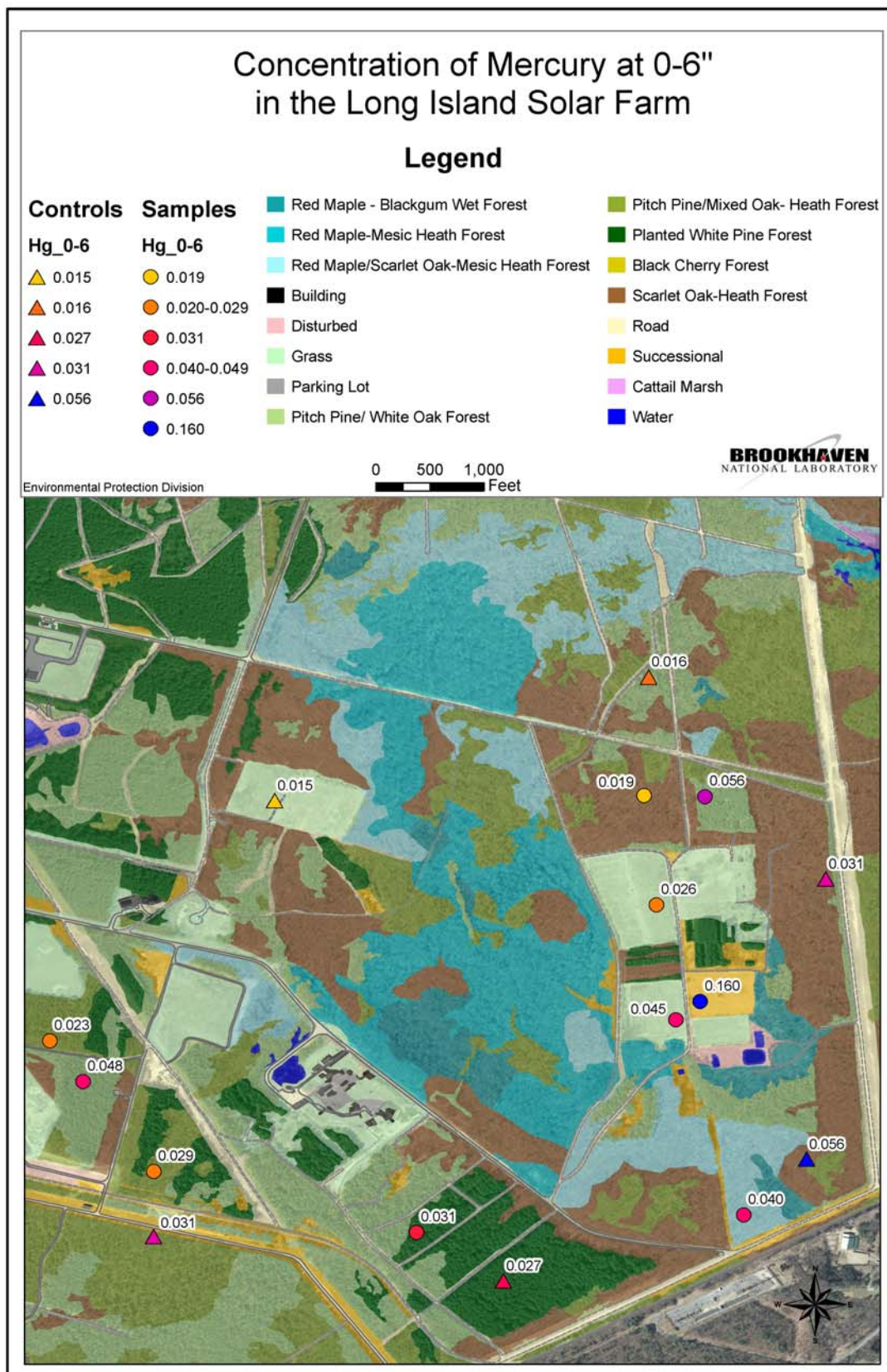


Figure 14: Concentration of Mercury at 0-6"

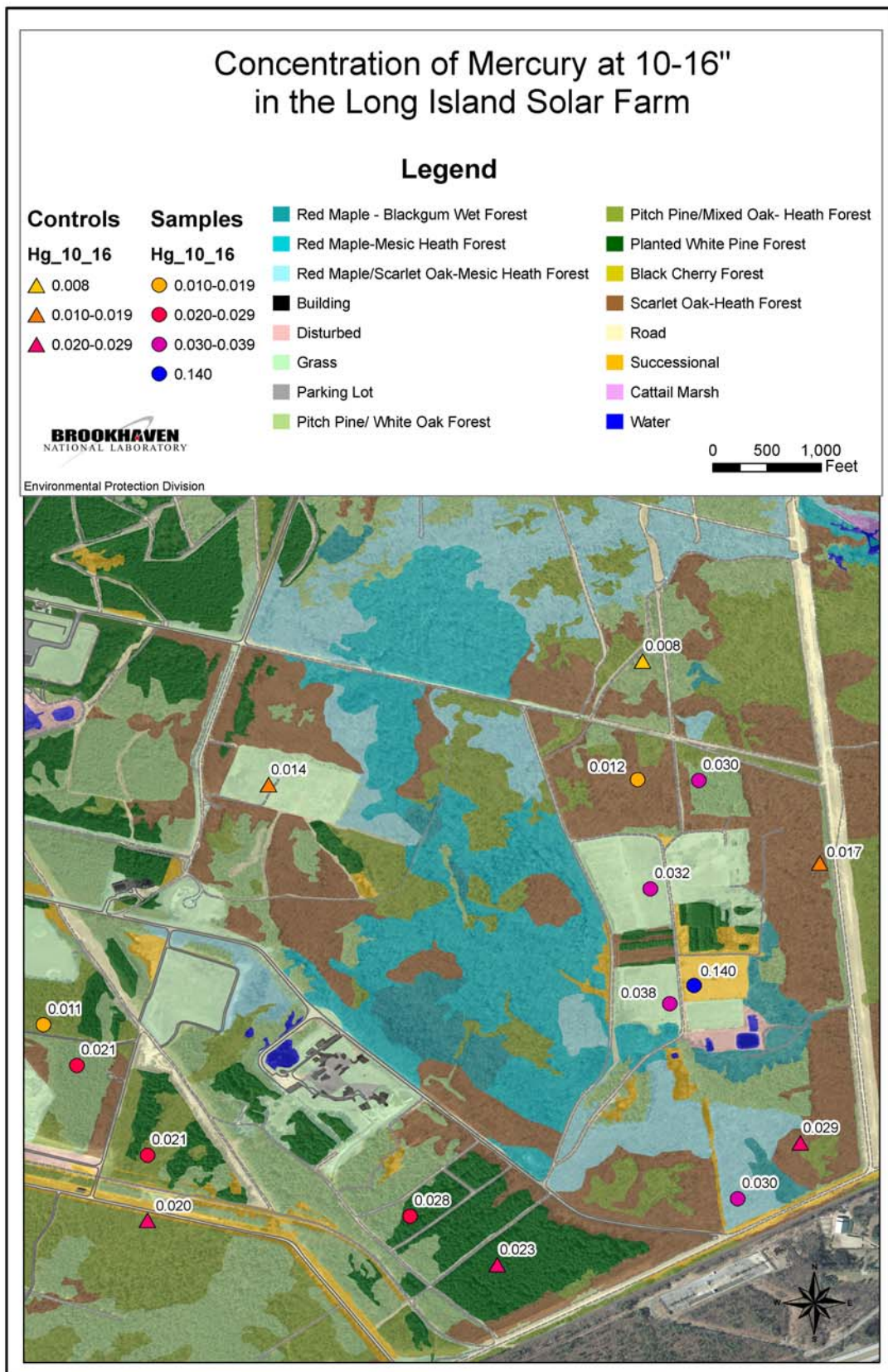


Figure 15: Concentration of Mercury at 10-16"