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A Diagnostic Feasibility Study of Moodus Reservoir, East Haddam, CT:

Water chemistry, aquatic vegetation survey and management options 2002

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INTRODUCTION

Connecticut's lakes and ponds are important natural resources. These bodies of fresh water provide drinking supplies, wildlife habitat, and a multitude of recreational opportunities. Because people desire to live near lakes and ponds, watersheds become developed, and forests are replaced with homes and businesses. This increases the runoff of nutrients and accelerates the natural process of nutrient buildup called eutrophication. Nutrient runoff from developed land is often the combined effect of many diffuse sources and is called nonpoint pollution. Sources of nonpoint pollution are usually difficult to locate (Duggan et al.,1997), and prevention requires proper land use guidelines and enforcement of land use regulations by government agencies. Eutrophication increases the chances of problems with nuisance aquatic weeds and algae.

Overabundance of aquatic plants is of great concern to lake mangers and residents. When these plants overpopulate a lake, they can make most forms of recreation difficult and reduce the value of nearby homes. The introduction to Connecticut of the invasive non-native weeds, Eurasian milfoil (*Myriophyllum spicatum*), variable milfoil (*Myriophyllum heterophyllum)* and fanwort (*Cabomba Caroliniana)*, has drastically changed many of our lake's ecosystems. Populations of native plants are replaced by invasive plants (Madsen et al., 1991). Once invasive non-native weeds are established, their elimination is nearly impossible. Past efforts to study lake water chemistry were based on the premise that increases in key nutrients such as phosphorus (P) and nitrogen (N) lead to the growth of algae that degrades lakes. Algae are limited mainly by the amount of phosphorus in the water (Vallentyne, 1974). Past concerns over increases in algal blooms have largely been replaced by worries over the spread of invasive rooted aquatic vegetation. Unlike algae, the growth of aquatic weeds has not been well correlated with concentrations of nutrients in water. Aquatic weeds obtain a large proportion of their nutrients from the sediment and can flourish in nutrient poor water. Work by Bristow and Whitcombe (1971) found Eurasian milfoil obtained 60 – 90 percent of its phosphorus from the sediment. Recent work on controlling variable milfoil in Bashan Lake, East Haddam, CT, has found high densities of the weed growing in water containing extremely low P (Bugbee and White, 2001). Reducing nutrient inputs into the lake by watershed management is important and may limit algae, but may not reduce aquatic weeds. Efforts to prevent problems with lakes becoming choked with non-native weeds entail public education programs. There is also a need to prevent

Figure 1. Bathymetric map of Moodus Reservoir and sampling sites.

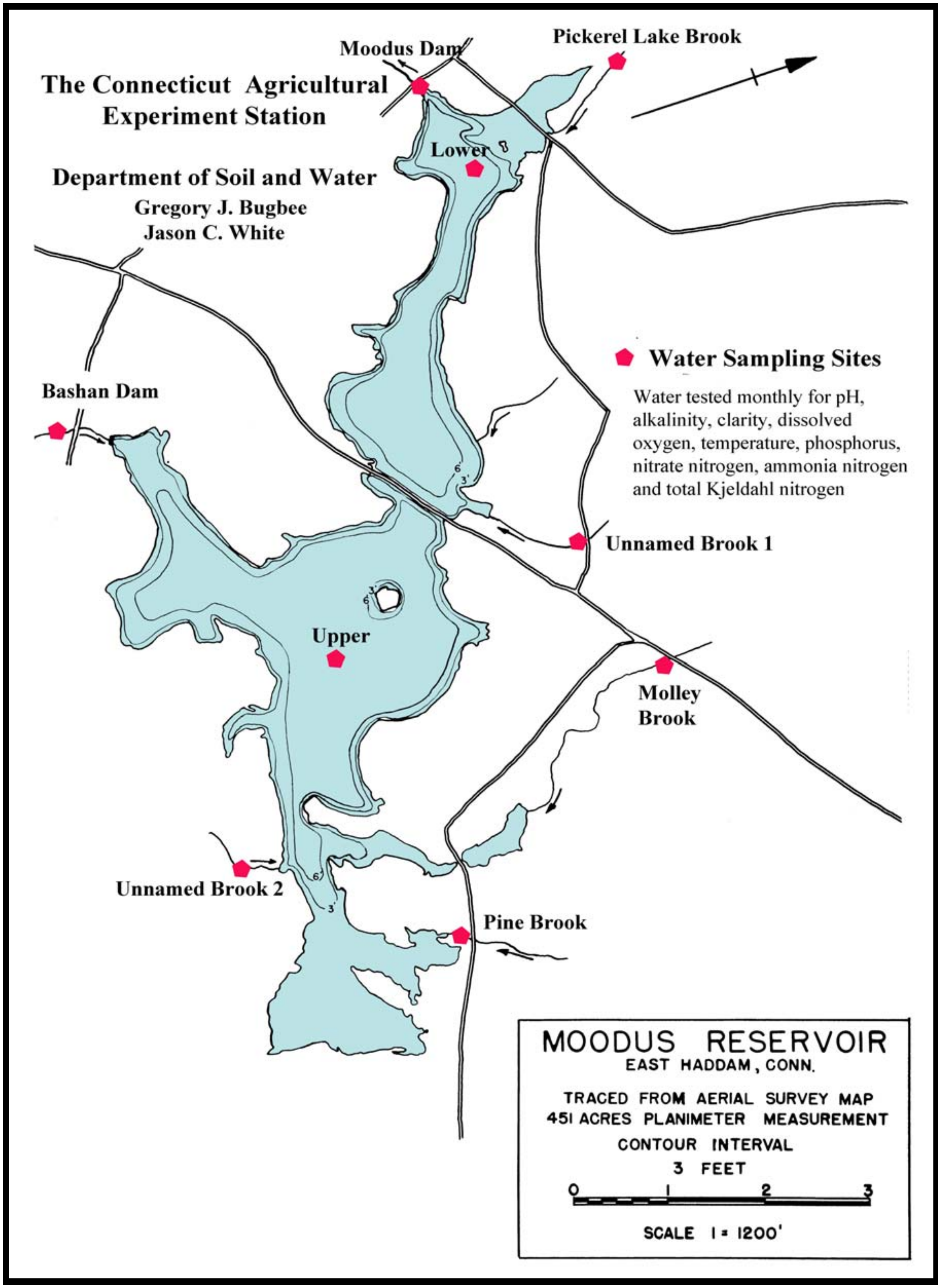
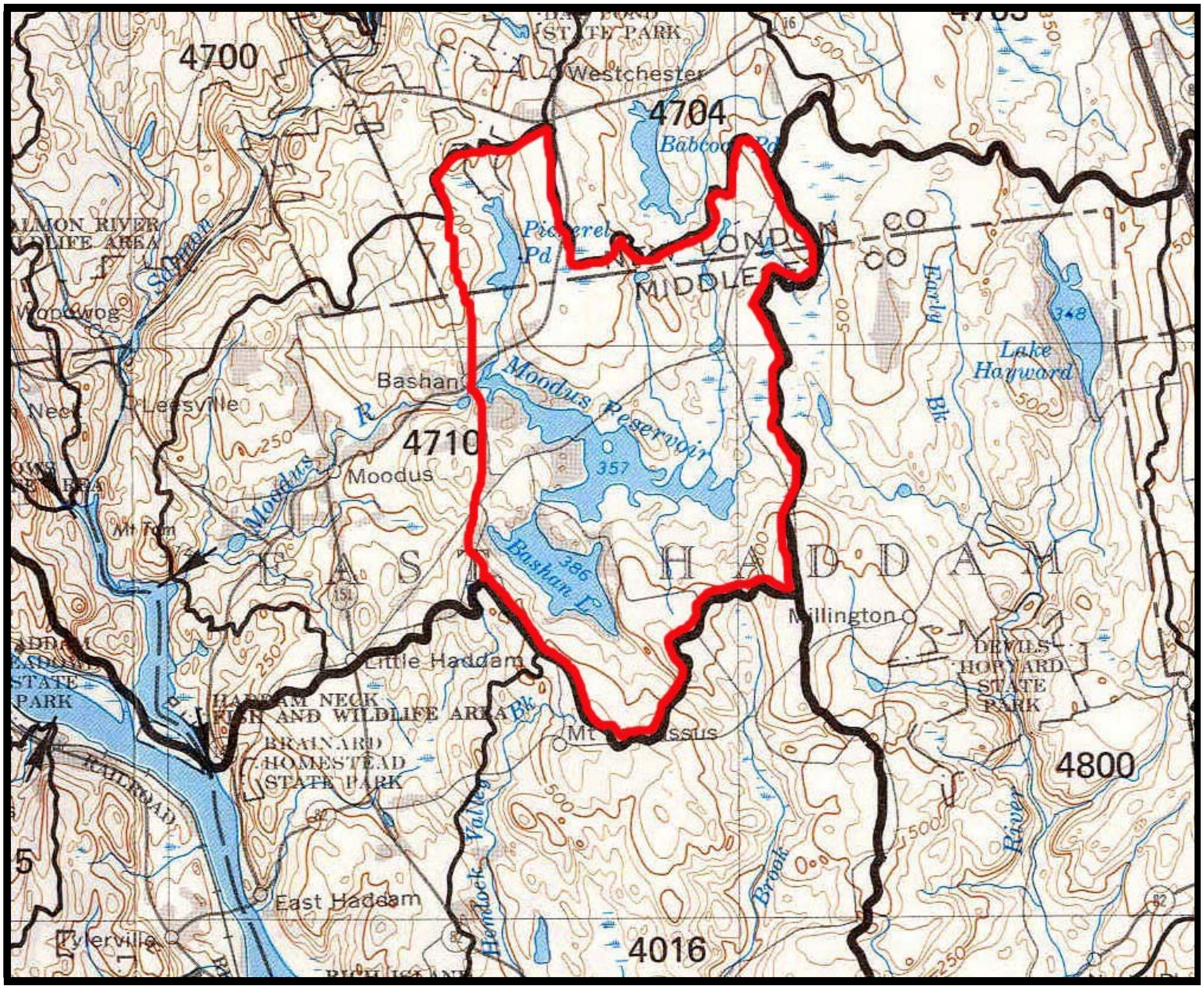


Figure 2. Topographic map of the Moodus Reservoir watershed (borders in red).



and eliminate pioneer infestations and to find new weed control methods. The purpose of this study is to determine the current condition of Moodus Reservoir, compare it to historical data and provide guidance for future management.

REVIEW OF AVAILABLE DATA

Moodus Reservoir is a 451 acre lake located in Middlesex County. The lake has an upper and a lower basin separated by a causeway. It is a man-made impoundment formed by the construction of a dam in the southwest portion of the lower basin. This dam has an outlet gate at its base that allows the lake to be drained. In recent years partial winter drawdown has been practiced to protect docks, reduce the risk of flooding, allow homeowners to work on their lake frontage and possibly offer some weed control. Because it is a state-owned dam, the drawdown has been managed by the Connecticut Department of Environmental Protection (CTDEP) and has been limited to about three feet. Moodus Reservoir has a maximum depth of 10 feet and an average depth of about six feet. The lake is accessible to state residents by boat launch ramps in each basin and to local residents via a town beach. Edward Deevey Jr. (1940) performed the first study on the water quality of Moodus Reservoir in the 1930's. This study found a maximum depth of 9.5 feet, a mean transparency of 6.2 feet and water with a “brown humus-like color.” Work by the Connecticut State Board of Fisheries and Game (1942) found the shoreline to be “almost entirely weedy with dense beds of submerged vegetation.” The species of aquatic “weeds” were not identified. The water was described as “brown in color from peat extractives.” Moodus Reservoir was reported as being stocked with many species of fish including yellow perch *(Perca flavescens)*, chain pickerel *(Esox niger)*, common bullhead *(Ameiurus nebulosus)*, largemouth bass *(Micropterus salmoides)*, calico bass *(Pomoxis nigromaculatus)*, rock bass *(Ambloplites rupestris)*, and sunfish *(Lepomis macrochirus)*. A similar study in the 1950’s (Connecticut State Board of Fisheries and Game, 1959) described the lake as being “almost completely choked with submerged vegetation.” As in the 1940 study, the water is described as brown in color. The mean transparency was four feet. The Connecticut Agricultural Experiment Station (CAES) performed a detailed study of the chemical and physical properties of Moodus Reservoir in 1980 (Frink and Norvell, 1984). The mean transparency was 6.2 feet and concentrations of phosphorus and nitrogen were in the mid-range for Connecticut lakes. Although the main goal of this work was to determine water chemistry, a rudimentary aquatic plant survey was performed and the existence of fanwort was documented. Moodus Reservoir has been a CTDEP Bass Management Lake since 1989 when the bass minimum length limit was changed from 12 to 15 inches. During the years following the implementation of this length limit the number of bass between 12 and 15 inches increased significantly (Jacobs et al., 1995).

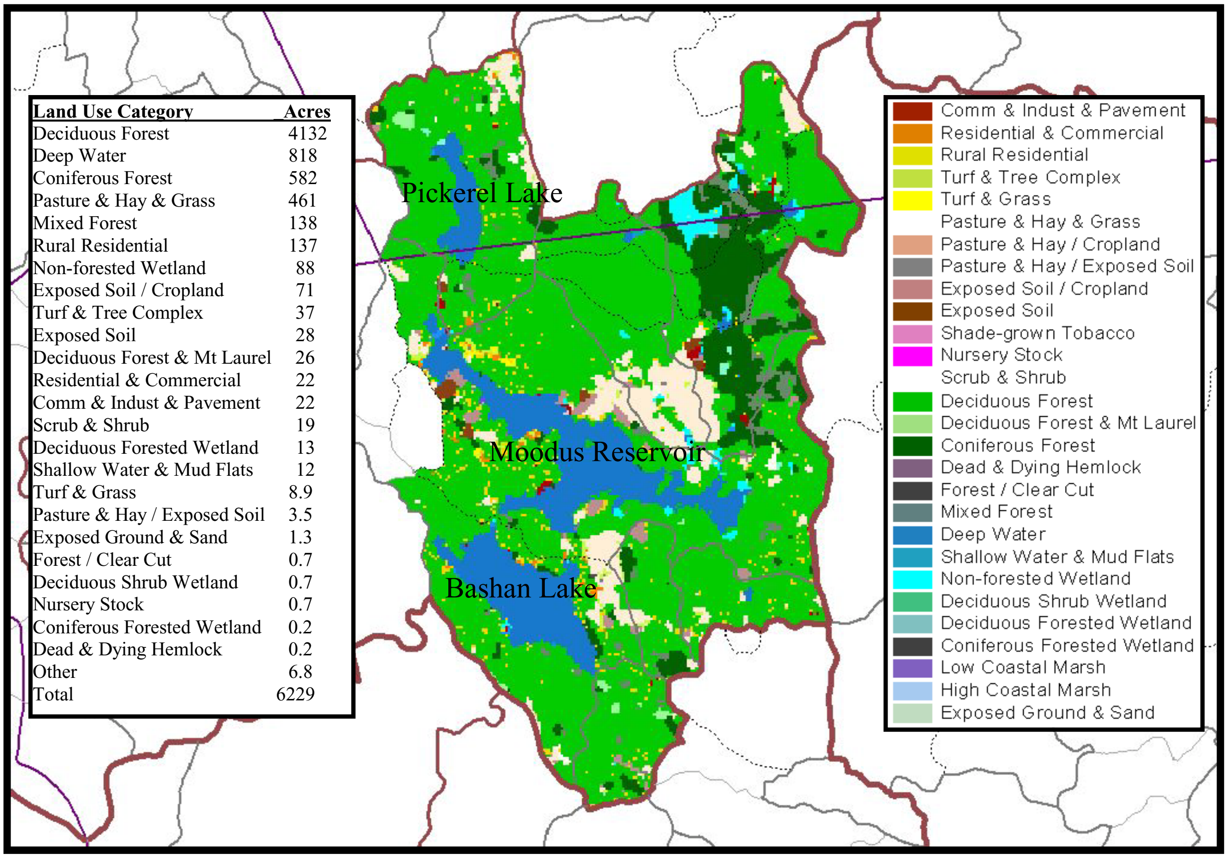
MATERIALS AND METHODS

Mapping:

The bathymetric map of Moodus Reservoir (Figure 1) was obtained from the Fishery Survey of Lakes and Ponds of Connecticut (Connecticut State Board of Fisheries and Game, 1959). The topographic map of the watershed (Figure 2) is from the map of Natural Drainage Basins in Connecticut (CTDEP, USGS, 1981). Land cover was mapped (Figure 3) using a statewide datalayer of landuse and landcover information for Connecticut, based on LANDSAT Thematic Mapper Satellite Imagery for 1994 and 1995 and SPOT Panchromatic Satellite Imagery. The datalayer resolution is 30 meters. The minimum mapping unit is one hectare (2.4 acres). Compiled by the University of Connecticut in raster format (ERDAS), the inventory was later converted from raster to vector (polygon) format by the Environmental and Geographic Information Center, CTDEP. General comparison to the 1990 landuse and landcover information may be possible but detailed comparison is not appropriate due, in part, to differences in classification techniques.

The percent impervious surface in the watershed was mapped (Figure 4) using a statewide datalayer based on LANDSAT Thematic Mapper Satellite Imagery information for 1994 and 1995 and SPOT Panchromatic Satellite Imagery from 1994 -1996. The datalayer resolution is 30 meters. This is an evaluation product compiled by the University of Connecticut in raster format (ERDAS). The inventory was later converted from raster to polygon feature (vector) format by the CTDEP Environmental and Geographic Information Center.

Figure 3. Land Use in Moodus Reservoir watershed.

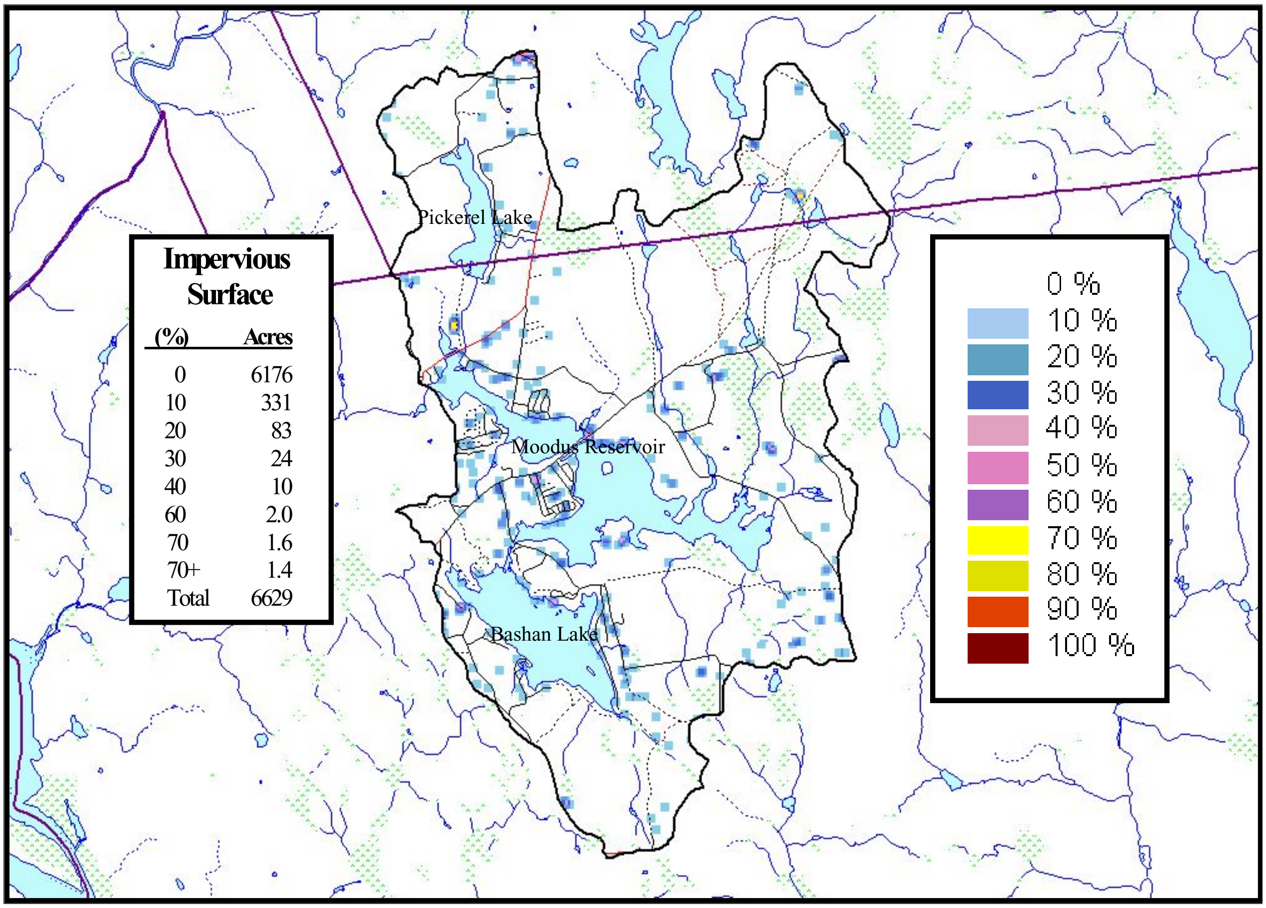


Land Use Category	Acres
Deciduous Forest	4132
Deep Water	818
Coniferous Forest	582
Pasture & Hay & Grass	461
Mixed Forest	138
Rural Residential	137
Non-forested Wetland	88
Exposed Soil / Cropland	71
Turf & Tree Complex	37
Exposed Soil	28
Deciduous Forest & Mt Laurel	26
Residential & Commercial	22
Comm & Indust & Pavement	22
Scrub & Shrub	19
Deciduous Forested Wetland	13
Shallow Water & Mud Flats	12
Turf & Grass	8.9
Pasture & Hay / Exposed Soil	3.5
Exposed Ground & Sand	1.3
Forest / Clear Cut	0.7
Deciduous Shrub Wetland	0.7
Nursery Stock	0.7
Coniferous Forested Wetland	0.2
Dead & Dying Hemlock	0.2
Other	6.8
Total	6229

Water sampling:

Water was sampled at one-month intervals from May through October. Sampling sites (Figure 1) included the inlets: Bashan Dam, Molly Brook, Pickerel Lake Brook, Pine Brook, and unnamed brooks 1 and 2. Water from the outlet at the Moodus Reservoir dam was also sampled. Lake water was obtained in the upper and lower basins at the surface (1 foot deep) and near the bottom (6 feet deep). Surface samples were obtained by hand, while bottom water was sampled with a battery-powered pump attached to a hose. Sample size was 250-mL, and all samples were placed in a cooler prior to testing. A Fisher AR20 meter was used to determine pH and conductivity. Alkalinity was quantified using a Hach digital titrator and is expressed as mg/l $CaCO_3$. The titrant was 0.16 N H_2SO_4 and the titration end point was pH 4.5. Total phosphorus was determined using the ascorbic acid method preceded by digestion with potassium persulfate (APHA, 1995). Phosphorus was quantified using a Milton Roy Spectronic 20D spectrometer with a light path of 2 cm and a wave length of 880 nm. Nitrate nitrogen (NO_3-N), ammonia nitrogen (NH_4-N), and total Kjeldahl nitrogen (TKN) were determined by the South Central Regional Water Authority water testing laboratory in New Haven, CT. Water was tested for temperature and dissolved oxygen by lowering a probe from a YSI 58 meter. Sampling depths were 0.5,1, and 2 meters in the lake and at a mid depth point in the inlets and outlet. Transparency (water clarity) was measured by lowering a six inch diameter black and white Secchi disk into the water and determining to what depth it could be viewed.

Figure 4. Impervious surfaces in Moodus Reservoir watershed.



Impervious Surface

(%)	Acres
0	6176
10	331
20	83
30	24
40	10
60	2.0
70	1.6
70+	1.4
Total	6629

Flow measurements:

Flow measurements were made on all inlets and the outlet at the Moodus dam. Flow over the Bashan dam inlet and the Moodus dam outlet was determined by collecting water in a square, nine inch wide 14 L bucket, at six intervals on Bashan dam and nine intervals on Moodus dam. The time necessary to fill the bucket was recorded and averaged for each dam. The flow rate was then calculated by extrapolating the flow to the entire length of the dam. The flow of Molley brook was measured directly by catching and measuring water flowing out of a culvert running under Mott Lane. Water flowing in the other brooks, except Pickerel Lake Brook, was measured by timing a float passing through the culvert and multiplying by the cross-sectional area of the water. Flow at Pine Brook and Pickerel Lake Brook was particularly difficult to measure, and the data were prone to error. Pine Brook enters Moodus Reservoir via an extended wetland. The only place to measure flow was in a culvert under Beebe Road. This culvert is 8 feet in diameter with sediment filling the bottom 1.5 feet. Because this culvert is at lake level, wind blowing from the lake could create back currents and affect the timing of the float. Pickerel Lake Brook is a small stream flowing over a rocky irregular bottom, and accurate flow measurements were difficult.

Aquatic plant survey and identification of planktonic algae:

Moodus Reservoir was surveyed for aquatic vegetation on August 14 and 15. A spotter, a note taker and a driver accomplished the survey from a motorized boat.

In the shallows ,where the bottom was visible or plants were at the surface, visual observation was the basis for obtaining the data. In deeper water, the lake was transected on intervals of approximately 100 feet. A drop line with hook was placed approximately every 100 feet and retrieved. Plants attached to the hook were identified and locations were marked on the bathymetric map. Resources for plant identification included: *Aquatic and Wetland Plants of Northeastern North America: Volumes 1 and 2* (Crow and Hellquist, 2000) and *Aquatic Plants of the United States* (Muenscher, 1944).

Blooms of planktonic algae, if any, were assessed visually during each visit to the lake. A more detailed study of the phytoplankton population was performed on August 21. This sampling involved collecting one liter surface-water samples from the upper and lower basins, centrifuging the samples and placing the concentrated algae under a microscope. Resources for identifying the organisms included: *Freshwater Algae of the United States* (Smith,1950) and color plates in *Standard Methods for the Examination of Water and Waste Water* (APHA, AWWA, WEF, 1995).

WATERSHED AND POLLUTION SOURCE INVESTIGATION

The Moodus Reservoir watershed comprises approximately 6629 acres in the towns of East Haddam and Colchester, CT. Topography within the watershed is hilly with moderate slopes to the lake (Figure 2). The primary tributaries of the lake are the Bashan Lake outflow, Pickerel Lake Brook, Molley Brook and Pine Brook (Figure1). Forests comprise 73 percent (4882 acres) of the watershed (Figure 3) with 4132 acres classified as deciduous, 582 acres as coniferous, 138 acres as mixed and 30 acres as other. Areas of pasture and hay on the north side of both Moodus and Bashan Lake make up 7 percent (461 acres) of the watershed. Because pasture and hay usually receive minimal fertilizer and protect the soil from erosion, this land use would not be expected to be a significant source of nutrients to the lake. Livestock rearing on farmland on the northwest shore of the upper basin often created a manure odor on the lake during this study. Improper manure management in such close proximity to the lake could result in movement of nutrients to the water. Residential and commercial land use covers only 0.3 percent (22 acres), but because most is clustered near the lakeshore, its impacts on the lake probably are greater than other more distant land uses. Commercial, industrial and paved areas constitute another 0.3 percent (22 acres).

Frink and Norvell (1979) estimated that developed land exported 1.5 pounds of P per acre per year to the watershed compared to 0.1 pounds per year for forests. Figure 4 provides a more detailed view of the impervious surfaces and the clustering of most of these surfaces near the lake. The road system throughout the watershed is a combination of paved primary roads and paved and unpaved secondary roads. Most roads have no drainage systems, and pollution from road runoff is probably minimal.

Table 1. Temperature in inlets, outlet and lake.

Site	23-May	19-Jun	24-Jul	21-Aug	30-Sep	29-Oct
Inlets			**Temperature (°F)**			
Unnamed Brook 1	54	60	67	-	-	45
Molley Brook	-	64	69	-	-	46
Pine Brook	62	72	76	-	-	44
Unnamed Brook 2	56	62	-	-	-	41
Bashan Dam	62	74	-	-	-	53
Pickerel Lake Brook	*	*	*	*	*	47
Outlet						
Moodus Dam	62	74	-	-	-	50
Lake						
Upper Basin (Surface, 1ft.)	64	72	80	74	69	49
Upper Basin (Mid, 3 ft.)	63	71	80	75	68	49
Upper Basin (Bottom, 6 ft.)	60	72	79	74	68	49
Lower Basin (Surface1 ft.)	64	71	82	76	69	50
Lower Basin (Mid, 3 ft)	64	71	81	76	69	50
Lower Basin (Bottom,6 ft.)	60	67	80	75	68	50

- No water

* Pickerel Lake Brook was sampled only on 29-Oct.

Table 2. Dissolved oxygen in inlets, outlet and lake.

Site	23-May	19-Jun	24-Jul	21-Aug	30-Sep	29-Oct
Inlets			**Dissolved Oxygen (mg/l)**			
Unnamed Brook 1	11	9.8	8.6	-	-	11
Molley Brook	-	9.7	7.9	-	-	10
Pine Brook	7.8	5.8	3.4	-	-	7.6
Unnamed Brook 2	9.5	8.8	-	-	-	13
Bashan Dam	10	9.3	-	-	-	9.9
Pickerel Lake Brook	*	*	*	*	*	11.8
Outlet						
Moodus Dam	9.8	8.8	-	-	-	11
Lake						
Upper Basin (Surface, 1 ft.)	10	9.5	7.0	7.8	8.3	10
Upper Basin (Mid, 3 ft)	11	9.7	7.5	8.1	8.3	11
Upper Basin (Bottom, 6 ft.)	11	9.1	4.1	3.4	7.9	10
Lower Basin (Surface1 ft.)	10	9.8	7.0	7.5	8.3	10
Lower Basin (Mid, 3 ft)	10	9.8	7.4	7.6	8.2	11
Lower Basin (Bottom,6 ft	11	8.2	7.1	6.5	8.0	10

- No water

* Pickerel Lake Brook was sampled only on 29-Oct.

Table 3. Alkalinity, pH and conductivity in inlets, outlet and lake.

Site	23-May	19-Jun	24-Jul	21-Aug	30-Sep	29-Oct
Inlets			**Alkalinity($CaCO_3$ mg/l)**			
Unnamed Brook 1	0.0	4.9	0.7	-	-	0.3
Molley Brook	0.0	5.2	3.2	-	-	2.0
Pine Brook	2.6	5.3	6.1	-	-	2.1
Unnamed Brook 2	1.7	5.7	-	-	-	2.2
Bashan Dam	2.9	6.1	-	-	-	4.5
Pickerel Lake Brook	*	*	*	*	*	7.9
Outlet						
Moodus Dam	6.8	6.1	-	-	9.7	8.0
Lake						
Upper Basin (surface)	6.7	6.8	8.1	12.0	8.3	5.9
Upper Basin (bottom)	5.4	8.3	7.7	9.1	8.2	6.8
Lower Basin (surface)	6.9	6.7	7.2	9.0	8.6	7.5
Lower Basin (bottom)	7.2	7.1	7.3	9.1	9.4	8.6
Inlets			**pH**			
Unnamed Brook 1	4.5	4.9	4.8	-	-	4.6
Molley Brook	4.5	5.2	6.0	-	-	5.3
Pine Brook	5.2	5.3	5.9	-	-	5.0
Unnamed Brook 2	5.4	5.7	-	-	-	5.5
Bashan Dam	5.9	6.1	-	-	-	6.1
Pickerel Lake Brook	*	*	*	*	*	6.3
Outlet						
Moodus Dam	6.1	6.1	-	-	6.3	6.4
Lake						
Upper Basin (surface)	6.2	6.0	6.6	6.7	6.6	6.7
Upper Basin (bottom)	6.2	5.7	6.8	6.4	6.3	6.5
Lower Basin (surface)	6.2	6.2	6.6	6.5	6.3	6.6
Lower Basin (bottom)	6.2	6.0	6.7	5.9	6.3	6.5
Inlets			**Conductivity (*us*/cm)**			
Unnamed Brook 1	28	29	35	-	-	32
Molley Brook	23	24	27	-	-	25
Pine Brook	39	37	44	-	-	35
Unnamed Brook 2	34	39	-	-	-	46
Bashan Dam	50	57	-	-	-	45
Pickerel Lake Brook	*	*	*	*	*	45
Outlet						
Moodus Dam	58	57	-	-	59	46
Lake						
Upper Basin (Surface)	45	52	53	52	46	37
Upper Basin (Bottom)	45	52	53	59	53	40
Lower Basin (surface)	52	56	60	58	59	45
Lower Basin (bottom)	50	57	59	53	58	47

- No water

* Pickerel Lake Brook was sampled only on 29-Oct.

Table 4. Total phosphorus in inlets, outlet and lake.

Site	23-May	19-Jun	24-Jul	21-Aug	30-Sep	29-Oct
Inflow			**Total Phosphorus (ppb)**			
Unnamed Brook 1	19	14	11	-	-	1
Molley Brook	35	15	12	-	-	10
Pine Brook	26	23	29	-	-	11
Unnamed Brook 2	27	14	-	-	-	16
Bashan Dam	28	17	-	-	-	7
Pickerel Lake Brook	*	*	*	*	*	7
Outlet						
Moodus Dam	38	23	-	-	13	18
Lake						
Upper Basin (surface)	35.0	28.0	13.7	24.9	16.2	13.7
Upper Basin (bottom)	27.1	26.2	18.0	38.5	37.3	25.5
Lower Basin (surface)	24.5	28.0	13.7	24.9	16.2	13.7
Lower Basin (bottom)	22.7	26.2	18.0	38.5	37.3	25.5

- No water
* Pickerel Lake Brook was sampled only on 29-Oct.

Table 5. Rate of total phosphorus additions in inflow and subtraction in outflow.

Site	23-May	19-Jun	24-Jul	21-Aug	30-Sep	29-Oct
Inflow			**Total Phosphorus (g/day)**			
Unnamed Brook 1	109	2.7	0.3	0.0	0.0-	0.0
Molley Brook	174	45	0.0	0.0	0.0	10.6
Pine Brook	150	332	0.0	0.0	0.0	80
Unnamed Brook 2	8.6	13	0.0	0.0	0.0	1.1
Bashan Dam	348	198	0.0	0.0	0.0	71
Pickerel Lake Brook	*	*	*	*	*	78
Total	***790***	***591***	***0.3***			***241***
Outflow						
Moodus Dam	1929	799	0.0	0.0	0.0	351

Pickerel Lake Brook was sampled only on 29-Oct.

Table 6. Total nitrogen in inlets, outlet and lake.

Site	23-May	19-Jun	24-Jul	21-Aug	30-Sep	29-Oct
Inlets			**Total Nitrogen (ppb)**			
Unnamed Brook 1	101	196	211	-	-	141
Molley Brook	<100	343	639	-	-	261
Pine Brook	211	581	471	-	-	421
Unnamed Brook 2	191	236	-	-	-	211
Bashan Dam	135	251	-	-	-	281
Pickerel Lake Brook	*	*	*	*	*	325
Outlet						
Moodus Dam	321	725	-	-	-	392
Lake						
Upper Basin (Surface)	331	641	501	501	501	344
Upper Basin (Bottom)	321	796	591	541	381	373
Lower Basin (Surface)	301	575	491	581	421	364
Lower Basin (Bottom)	381	884	821	581	441	373

- No water

* Pickerel Lake Brook was sampled only on 29-Oct.

Table 7. Rate of total nitrogen additions in inflow and subtraction in outflow.

Site	23-May	19-Jun	24-Jul	21-Aug	30-Sep	29-Oct
Inflow			**Total Nitrogen (g/day)**			
Unnamed Brook 1	571	38	5.1	0.0	0.0-	6.9
Molley Brook	247	983	0.0	0.0	0.0	262
Pine Brook	1204	8169	0.0	0.0	0.0	2836
Unnamed Brook 2	61	225	0.0	0.0	0.0	15.5
Bashan Dam	1680	2847	0.0	0.0	0.0	2691
Pickerel Lake Brook	*	*	*	*	*	3660
Total	***3764***	***12262***	***5.1***			***9472***
Outflow						
Moodus Dam	16071	24542	0.0	0.0	0.0	7374

Pickerel Lake Brook was sampled only on 29-Oct.

Table 8. TKN, Nitrate- N and Ammonium-N in inlets and outlet.

Site	23-May	19-Jun	24-Jul	21-Aug	30-Sep	29-Oct
Inlets			**TKN (ppb)**			
Unnamed Brook 1	100	190	210	-	-	140
Molley Brook	<100	320	550	-	-	250
Pine Brook	210	580	470	-	-	420
Unnamed Brook 2	190	210	-	-	-	210
Bashan Dam	110	250	-	-	-	260
Pickerel Lake Brook	*	*	*	*	*	320
Outlet						
Moodus Dam	320	720	-	-	-	390
Lake						
Upper Basin (surface)	330	640	500	500	630	340
Upper Basin (bottom)	320	790	590	540	380	370
Lower Basin (surface)	300	570	490	580	420	360
Lower Basin (bottom)	380	880	820	580	440	370
Inlets			**Nitrate Nitrogen (ppb)**			
Unnamed Brook 1	<2	6	<2	-	-	<2
Molley Brook	<2	23	89	-	-	11
Pine Brook	<2	<2	<2	-	-	<2
Unnamed Brook 2	<2	26	-	-	-	11
Bashan Dam	25	<2	-	-	-	21
Pickerel Lake Brook	*	*	*	*	*	5
Outlet						
Moodus Dam	<2	5	-	-	-	2
Lake						
Upper Basin (surface)	<2	<2	<2	<2	<2	4
Upper Basin (bottom)	<2	6	<2	<2	<2	3
Lower Basin (surface)	<2	5	<2	<2	<2	4
Lower Basin (bottom)	<2	4	<2	<2	<2	3
Inlets			**Ammonium Nitrogen (ppb)**			
Unnamed Brook 1	<20	<20	30	-	-	<20
Molley Brook	<20	30	100	-	-	<20
Pine Brook	<20	<20	30	-	-	<20
Unnamed Brook 2	<20	26	-	-	-	<20
Bashan Dam	<20	20	-	-	-	<20
Pickerel Lake Brook	*	*	*	*	*	<20
Outlet						
Moodus Dam	20	20	-	-	-	<20
Lake						
Upper Basin (Surface)	<20	<20	20	<20	<20	<20
Upper Basin (Bottom)	<20	10	20	<20	<20	<20
Lower Basin (surface)	<20	30	30	<20	<20	<20
Lower Basin (bottom)	30	40	20	<20	<20	<20

- No water

* Pickerel Lake Brook was sampled only on 29-Oct.

Table 9. Approximate flow rates of inlets and outlet.

Site	23-May	19-Jun	24-Jul	21-Aug	30-Sep	29-Oct
Inlets			**Flow (cfs)**			
Unnamed Brook 1	2.31	.08	0.01	-	-	0.02
Molley Brook	1.98	1.17	-	-	-	0.41
Pine Brook	2.33	5.74	-	-	-	2.75
Unnamed Brook 2	0.13	0.39	-	-	-	0.03
Bashan Dam	5.08	4.63	-	-	-	3.91
Pickerel Lake Brook	*	*	*	*	*	4.67
Total Inflow	***11.83***	***12.01***	***0.01***			***11.79***
Outlet						
Moodus Dam	20.44	13.82	-	-	7.35	7.68

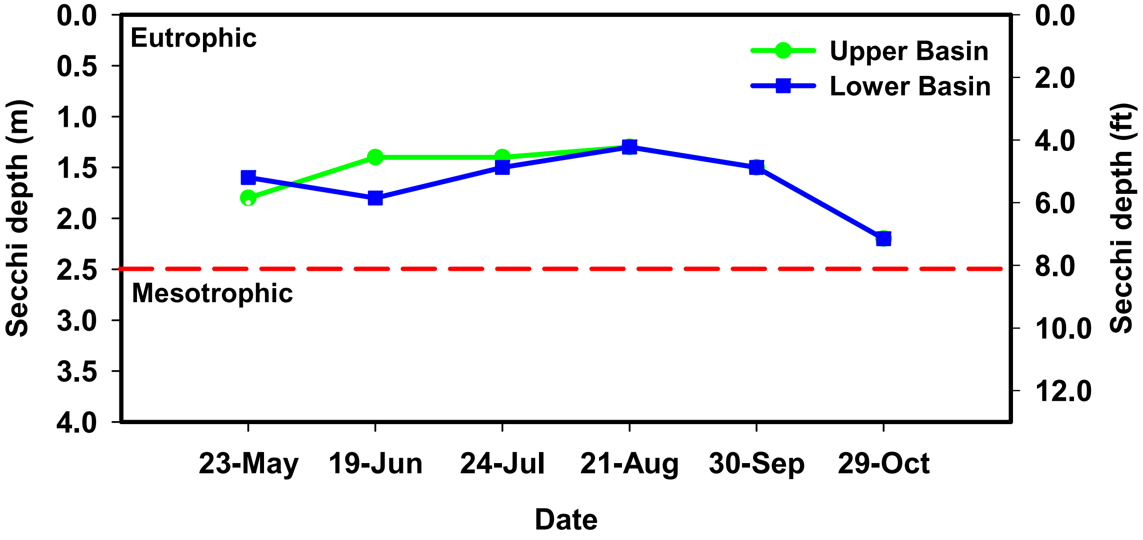
- No water
* Pickerel Lake Brook was sampled only on 29-Oct.

Flow rates for the inlets and the Moodus dam outlet are shown in Table 9. Dry weather caused a cessation of all inflow during the June 19 – September 30 sampling periods. Because frequent rains had caused all inlets to resume flow by October 29, this date represents a reasonable estimate of the contribution of each tributary to the lake. Pickerel Lake Brook, Bashan Lake Brook and Pine Brook are the greatest source of inflow. Flow in these tributaries was 4.7, 3.9 and 2.8 cubic feet per second (cfs) respectively. This represented 97 % of the total inflow of 11.8 cfs. Total outflow at this time was only 7.7 cfs. This probably indicates the lake was refilling from low levels experienced during the summer. The inlet water was generally cooler than the water in Moodus Reservoir (Table 1). All inlets contained abundant dissolved oxygen (Table 2). Except for the water entering the lake from the Bashan Lake outlet, which undoubtedly has the characteristic of the surface water of Bashan Lake, the alkalinity and pH of water entering Moodus Reservoir was generally lower than that in the lake (Table 3). This probably reflects the influence of the soil acidity on rainfall as it moves to the inlets.

Highest concentrations of phosphorus (P) in the inlets occurred in the spring (Table 4). The highest concentration of P was 36 ppb in Molley Brook on May 23. This is similar to the 35 ppb found in the upper basin's surface water and could be wind-induced movement of lake water back up the culvert where the sample was obtained. Frink and Norvell (1984) classified water with P levels between 15–25 ppb as mesotrophic, 25-30 as mesoeutrophic, and 30-50 ppb as eutrophic. P levels in all inlets were generally less than those in the lake on a given sampling date. This indicates that the inlets are not a major source of P enrichment for the lake. Because differences in flow (Table 9) were far greater than differences in concentration (Table 4), the rate of P added to the lake from each inlet (Table 5) was most dependent on flow. Pickerel Lake Brook was not sampled until October 29 and, therefore, a greater rate of total inflow of P than reported here is likely during the May and June samplings. On October 29, P concentration and rate in the outlet was slightly greater than in the inlets indicating that other sources of P were entering the lake. These sources could be internal release from sediments and decaying organic matter, inputs from land use and septic systems directly along the lakeshore.

The concentration of total nitrogen, in the streams entering the lake, was generally lower than in the lake water (Table 6). Concentrations of total N range from 101 to 639 ppb in the inlets, with the greatest amounts in Pine and Molley Brook. The highest level of 639 ppb, found in Molley Brook on July 24, was when no flow was occurring. Therefore, any threat to the lake

Figure 5. Transparency of water in Moodus Reservoir.



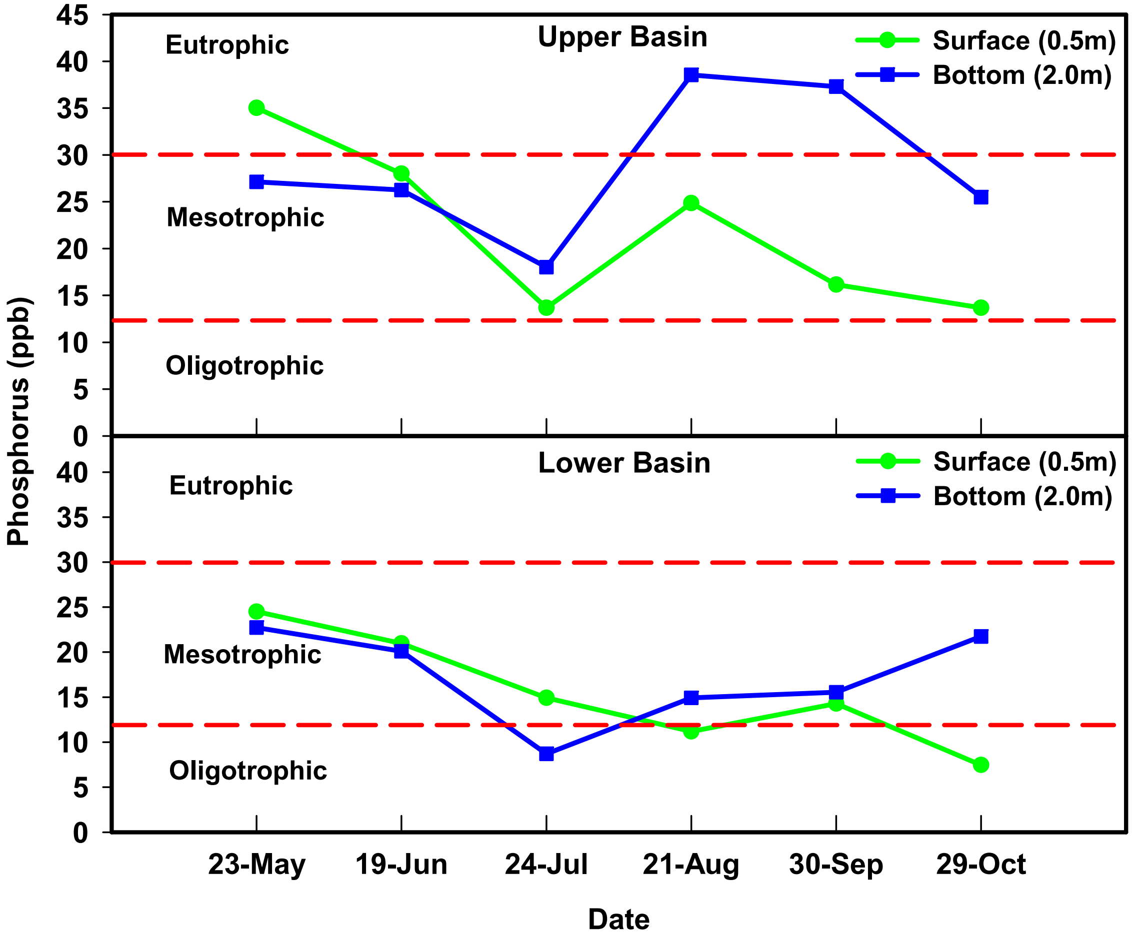
is low. Nitrate and ammonium forms of N were only occasionally detected and most N was in TKN (organic) form (Table 8). The rate of N entering the lake from the inlets may best be illustrated by the October 29 data shown in Table 7. A total of 9472 g of N per day was introduced into the lake via the inlet streams with 3660 g/day added by Pickerel Lake Brook, 2836 g/day by Pine Brook and 2691 g/day by the stream flowing over Bashan Dam. During this sampling, less N was leaving the lake (7374 g/day) than was coming into the lake via the inlet streams. This was probably because the lake inflow of water (Table 9) exceeded the outflow (11.79 vs. 7.68cfs) water at this time. As with P, the rate of P added to the lake from each inlet (Table 7) was most dependent on flow and not concentration.

IN-LAKE WATER QUALITY MONITORING AND ANALYSES

Water testing revealed that transparency in Moodus Reservoir has changed little since the 1940's (Figure 5). Secchi measurements were between four and seven feet with little difference between the upper and lower basins. This compares to 6.2 feet in the 1930's (Deevey Jr. 1940), 4.0 feet in 1950's (Connecticut State Board of Fisheries and Game ,1959) and 6.2 in 1980 (Frink and Norvell,1983). Much of the limitation in transparency is because of the brown coloration of the water. This is caused by organic decay and not by algae. The brown coloration has been a component of the lake water in all the previously mentioned studies and, therefore, is not new. Temperatures in the lake peaked near 80 °F on July 24 (Table 1). Little stratification was evident during any of the sampling dates. This was probably because of the mixing action of wind over the lake's large surface area and the lakes shallow nature.

The alkalinity, pH and conductivity for Connecticut lakes averages near 22 mg/l $CaCO_3$, 7.0 and 95 *u*s/cm respectively (Canavan et al., 1995). Alkalinity in Moodus Reservoir ranged between 4 and 10 mg/l $CaCO_3$. Tests on Moodus Reservoir in 1980 (Frink and Norvell,1984) found alkalinities between 5 and 11 mg/l $CaCO_3$. Work by Deevey (1940) in the late 1930's found a summer alkalinity of 14.6 mg/l HCO_3, which corresponds to an alkalinity of 12.0 mg/L $CaCO_3$. This may indicate that the alkalinity of the lake has decreased slightly over the last century. Lakes with low alkalinities tend to be more prone to acidification because of a low buffering capacity or low pH. Little difference between the alkalinity of the surface and bottom water were evident. The pH of the surface water ranged between 6.0 and 7.0 while the bottom water exhibited

Figure 6. Total phosphorus in Moodus Reservoir.

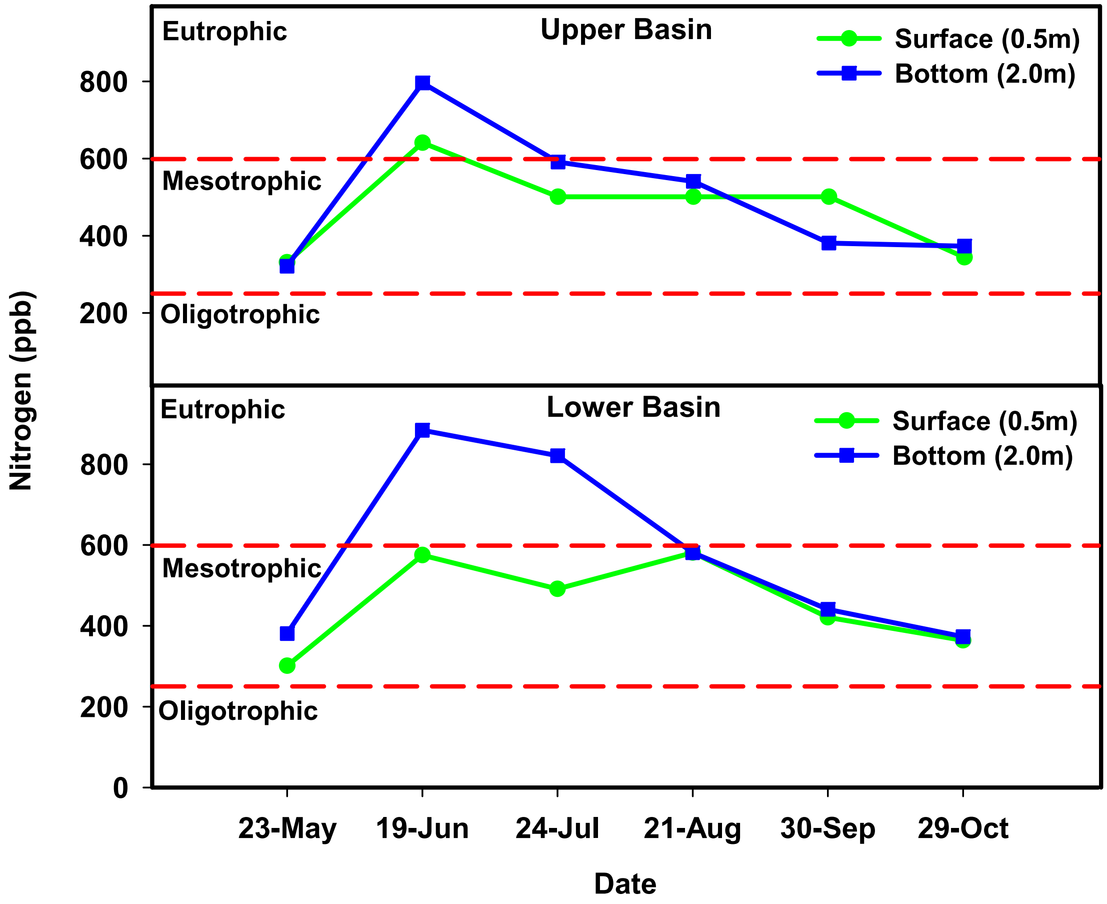


more variability particularly in the upper basin (Table 3). The conductivity of Moodus Reservoir ranged from 37 – 60 *u*g/cm with the values decreasing slightly from spring to fall (Table 3). Because the range is considerably below the state average, this indicates little influence of outside sources of salt such as that used in road deicing. No previous data on conductivity in the lake are available.

Phosphorus concentrations were considerably higher in the upper basin compared to the lower basin (Figure 6). Surface water was generally higher in P than bottom water during May and June. During the remaining sampling periods, this situation reversed. P in the upper basin generally fell within the category of mesotrophic to eutrophic, while P in the lower basin was mesotrophic to oligotrophic (Frink and Norvell, 1984). The biggest differences between the basins occurred during August and September when the lake was influenced by the low flow that occurred previously in July and August (Table 1). Causes for the difference in P between the basins are unclear but may be related to bioaccumulation of P as it moves to the outlet. P levels were 12 ppb in the 1930's, 22 - 33 ppb in 1980 and 14 - 39 in this study. A trend toward increased P enrichment appears likely, however, the variability in the 1980 and 2002 data and the relatively few years of measurements could be misleading.

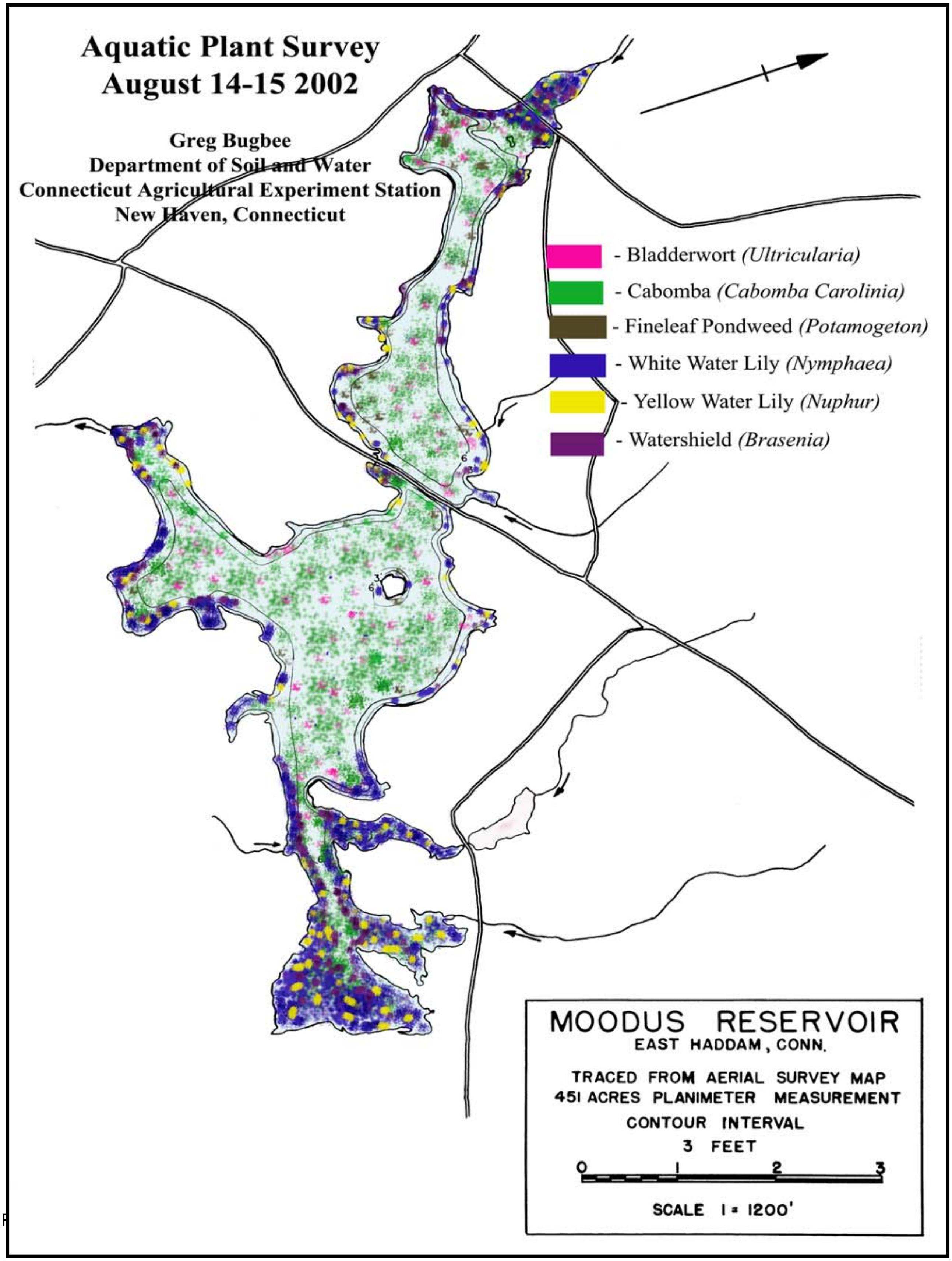
Levels of total nitrogen in the lake were similar in the upper and lower basins (Figure 7). Unlike phosphorus, N levels were greater in the bottom water in the

Figure 7. Total nitrogen in Moodus Reservoir.



spring and lower thereafter. Total N levels peaked at 600 - 800 ppb in June. These N levels would classify the lake as eutrophic. During the remainder of the testing period, N levels were 250 - 600 ppb. Under these conditions, the lake would be considered mesotrophic. Historically, total N was measured only in 1980 (Frink and Norvell, 1984) and ranged between 345 - 519 ppb. Compared to data in this study, any trend in N enrichment would be highly speculative. Breakdowns of the forms of N found are shown in Table 8. Nitrate and ammonium N made up a small part of the total N. Most N was found with Kjeldahl digestion (TKN). Because TKN measures organic forms of N, it can be implied that most N was in an organic complex and the result of plant and algal decay. In addition, planktonic algae and aquatic macrophytes quickly metabolize ammonium and nitrate to organic forms of N in well oxygenated lakes. Algal populations found on August 27 were surprisingly few and contained a mix of diatoms, flagellates and amoeba. No algae considered to be associated with water pollution were present (APHA, AWWA, WEF, 1995).

Figure 8. Aquatic plant survey of Moodus Reservoir.



AQUATIC PLANT SURVEY

Moodus Reservoir supports a vibrant plant community. Species of plants found in the lake in this study are shown in Figure 8. In the shallow coves, white water lily (*Nymphaea odorata*), yellow water lily (*Nuphur variegata*), and water shield (*Brasenia schreberi*) formed dense patches. In shoreline areas, patches of these plants were sporadic. Where the emersed plants were not present submersed fanwort *(Cabomba caroliniana)* was prevalent. Fineleaf pondweed (*Potamogeton* sp.), bladderwort (*Ultricularia* spp.), Nitella *(Nitella sp.)*, and aquatic moss *(Fontinalis sp.)* were occasional. Variable milfoil *(Myriophyllum heterophyllum)* was sparse. Along the shore, patches of burr reed (*Sparganium sp*) were common, and areas with pickerel weed *(Pontederia cordata)* and cattails (*Typha sp.*) were sporadic. Investigations of the plant life in the large areas of wetlands in the northeast part of the upper basin were beyond the scope of this study. It is likely that a diverse array of plant life occurs here and plants not documented by this survey are present. In addition to the plants documented here, recent CTDEP surveys (Nancy Murray, CTDEP, personnel communication, November 21, 2002) have found water starwort *(Callitriche heterphylla)*, hedge-hyssop *(Gratiola aurea)*, and quillwort *(Isotes sp.)*. The CTDEP surveys did not find any endangered, threatened or protected plant species. In areas of the lake greater than three feet deep, fanwort was the primary plant. Because the brownish water color caused limited visibility of the bottom, the fanwort was usually not seen from the surface and appeared to have no negative impact on the lake. In shallower areas, fanwort often reached the surface and emerged flowers were present. These areas were often dense and boating and other recreational uses would be limited. Previous work on Bashan Lake found the primary invasive aquatic plant to be variable milfoil. Because Moodus Reservoir is downstream, it would be expected that this plant would also be in abundance. Although occasional pieces of variable milfoil were seen floating, particularly in the upper boat launch, no large or dense areas of this plant were found in the lake. Sporadic areas of fineleaf pondweed and bladderwort were identified. In shoreline areas of both basins, patches of white water lily, yellow water lily, and water shield were common. These patches were generally not large or dense enough to be considered a problem and probably contributed to diverse aquatic life and an improved fishery.

DIAGNOSTIC ASSESSMENT

Moodus reservoir is a shallow lake with abundant plant life. Large numbers of residents utilize the lake for recreational activities, particularly fishing, boating and swimming. Evidence from past studies suggests an over abundance of aquatic vegetation has occurred since the 1940's. Fanwort currently exists over most of the lake bottom, but only gets near enough to the surface to be a problem in some shallow areas. The fanwort is more of a nuisance than a major problem. Because the maximum depth in the lake is only six feet, a change in water level, nutrient status or water clarity could allow the fanwort to reach the surface in most of the lake. This would drastically deteriorate the recreation value of the lake and might cause surrounding property values to fall. Whether this is likely in the near future is difficult to predict but in the event it does occur, control options must be considered. Controlling aquatic weeds in large heavily infested lakes is neither a precise science nor easy at this time. Options include: deepening the lake by dredging, water level drawdown, harvesting, biological controls, bottom barriers and herbicides (Cooke et al., 1986).

Dredging removes nutrients in the sediment, positions the lake bottom below where low light deters plant growth and returns the lake to conditions similar to those at it's inception. It can be an excellent long-term solution but is impractical for most large lakes. Wet dredging removes sediment by cranes from shore or on a barge. Usually nearby drying beds are necessary and this requires suitable land. Dry dredging requires draining part or all of the lake and excavating the overburden. Because Moodus Reservoir has a dam that allows the lake to be drained, dry dredging would be an option. If the material in the lake bottom is sand, gravel or other marketable material, the cost of the dredging can be significantly offset by its sale. Both types of dredging are disruptive to lake ecology.

Dry dredging is particularly so because the lake may be without water for years. The permitting process for dredging through the CTDEP, the United States Army Corp of Engineers and the town is lengthy, expensive and often unsuccessful. Partial dredging or removal of sediment to an insufficient depth often yields disappointing results. Approximately 60 acres of 960-acre Bantam Lake, in Litchfield, CT, were dredged from 1982 to 1990. About 370,000 cubic yards of sediment were removed at a cost of 1.7 million dollars (Baystate Environmental Consultants, Inc., 1992). Although some weed control was achieved, many areas of weeds remained in undredged areas and locations not dredged sufficiently deep.

Water level drawdown can be effective if weeds are allowed to freeze or dry, but this has adverse effects on non-target aquatic organisms. Weed control by winter drawdown can be affected by weather. Some weeds, like milfoil, have seeds or other plant parts that can survive substantial drying (Standifer and Madsen, 1997) and best control can be expected if the bottom sediment is allowed to freeze. Drawdown is possible in Moodus Reservoir because the dam has a functioning gate valve and the water can be drained to expose most of the bottom. Because drawdowns in Moodus Reservoir are controlled by CTDEP, and the Inland Fisheries Division has determined that the drawdown will negatively affect the largemouth bass fishery, great difficulty in getting approval for a deep drawdown is likely.

Harvesting or mechanical removal has the benefit of providing immediate control but problems include rapid regrowth, finding suitable disposal sites and spreading of weeds by fragmentation (Cooke et al., 1986). Weeds like milfoil (Madsen, et al, 1988) and fanwort spread by the rooting of broken pieces. Harvesting practices can distribute the weed throughout a lake. These weeds also have strong root systems that will cause regrowth. Usually, harvesting needs to be done each year.

Herbicides can be effective in controlling unwanted aquatic vegetation. The most widely used aquatic herbicides in Connecticut are fluridone (Sonar, Avast), diquat (Reward), 2,4-D (Navigate, AquaKlean) and Glyphosate (Rodeo, Eagre). Fluridone, 2,4-D and glyphosate are translocated throughout the entire plant, causing dieback of the roots and shoots. Diquat destroys only foliage, and regrowth from the roots is likely. Fluridone is the only herbicide that currently is considered effective against fanwort. Because it is commonly applied as a liquid to lakes and weeds must be exposed to adequate concentrations of this herbicide for many weeks, whole lake treatments are customary. This technique has limited use in Moodus Reservoir because the lake is large, areas of nontarget plants could be adversely affected and the large quantity of herbicide needed would probably be cost prohibitive. A pelletized form of fluridone is labeled for spot treatments. By utilizing spot treatments, herbicide usage is reduced, areas containing desirable plants are avoided and exposure to humans and wildlife is minimized. Spot treatments can also eliminate troublesome vegetation near boat launch ramps where weeds become attached to boat trailers and get transported to other lakes. Glyphosate is sprayed directly on plants and is effective only on weeds like water lily and water shield that have large areas of foliage above the surface.

CAES has recently completed a study on controlling fanwort in Lake Quonnipaug, Guilford, CT with spot treatments of Sonar SRP. Sonar SRP was applied in four weekly applications of 15 lbs/A, starting in late May, to a two-acre cove adjacent to the boat launch ramp. The goal was to maintain fluridone concentrations of 5-10 ppb for several weeks. The Sonar treatments initially yielded disappointing results, with only some minor yellowing, and decline in plant vigor noted in late July. Water tests found fluridone levels were below the desired range of 5-10 ppb. By mid-August, fluridone concentrations unexpectedly began to increase to just over 5 ppb and the decline of the fanwort accelerated. By mid-September, the fanwort in the boat area was nearly gone. In 2002, some minor hand pulling of fanwort was employed, and the treated area remained nearly free of fanwort. This technique may hold promise for localized areas in Moodus Reservoir particularly if they are in small coves where herbicide movement is partially restricted.

Considerable efforts are underway to find biological controls for lake weeds. Plant eating fish, called grass carp *(Ctenopharyngodon idella)*, can effectively reduce the populations of certain aquatic weeds. The introduction of grass carp into Connecticut lakes requires approval by the CTDEP. Often these fish are considered inappropriate because their feeding is not selective and desirable plants can be eliminated. In addition, if the fish begin to breed, they could move to other lakes and harm desirable native plants. In Connecticut, only sterile grass carp (triploid) are permitted. They are usually 10-12 inches in length when purchased and can grow to over 30 inches. All lake inlets and outlets must be screened to prevent movement of the fish. These screens must be CTDEP approved and cannot interfere with the flow of water or the integrity of the dam. The screen must be kept free of debris to prevent flooding. Written approval by all lakefront landowners is necessary. Introducing grass carp in Moodus Reservoir could cause damage to nontarget plants necessary to maintain the current fishery. Attempts to find plant pathogens and insects that control nuisance aquatic plants are ongoing. Some appear promising, but there is little likelihood they will play a major role in the reduction of aquatic weeds in Moodus Reservoir in the near future.

CONCLUSIONS

Moodus Reservoir has a unique combination of large shallow areas with emergent vegetation and large areas of open water suitable for boating, fishing, swimming and other recreational opportunities. Extensive growth of aquatic vegetation has been part of the lake since records began in the 1930's. The shallows are often adjacent to large areas of wooded undeveloped shoreline that make excellent wildlife habitat. The lake is located in a watershed composed primarily of forests but development, particularly near the lake, continues at a moderate pace. During the past century, water quality has changed little with only slight increase in P and a small decrease in alkalinity. The brown water coloration caused by organic compounds has been a part of the lake since the first water tests in the 1930's and is not a sign of pollution. Of greatest concern is the nearly complete coverage of the bottom with the nonnative aquatic plant called fanwort. Fortunately, the fanwort does reach the surface in most of the lake and recreational uses are usually not impaired. This may be because the water color limits light penetration. If conditions change and the fanwort begins to reach the surface, the lake will be seriously impacted. Temporary control of fanwort in coves or other highly utilized areas might be accomplished with spot applications of granular fluridone. The practice of partial winter drawdown has the benefit of reducing ice damage to shoreline structures and may help reduce the chances of flooding but probably does little to control aquatic weeds. This practice could reduce the largemouth bass fishery. To help protect Moodus Reservoir, a yearly monitoring program for aquatic vegetation, transparency and some rudimentary chemistry such as dissolved oxygen, alkalinity and pH should be conducted.

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