BANTAM LAKE SEDIMENTS:

Physical and Chemical Properties Relevant to Dredging and Spoils Disposal

By Wendell A. Norvell

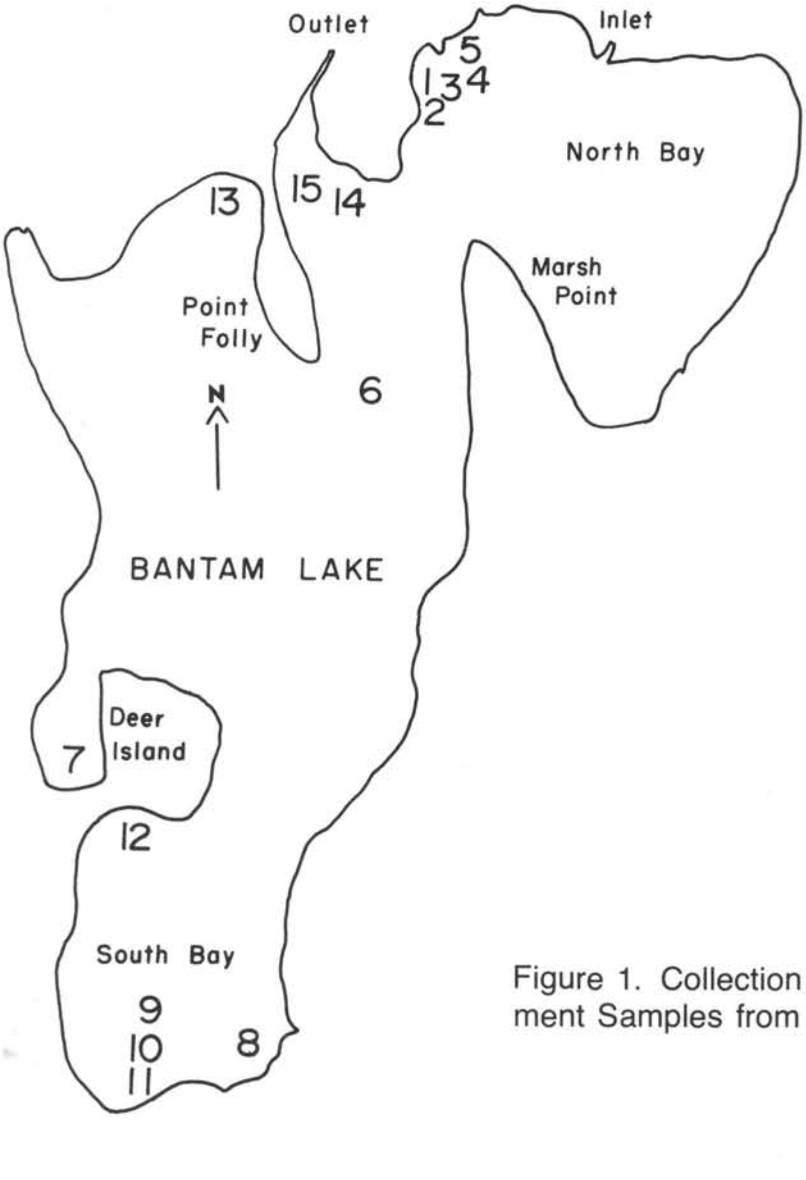

Figure 1. Collection sites for Sediment Samples from Bantam Lake.

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By W. A. Norvell

Sediment samples from Bantam Lake were collected and analyzed to determine physical and chemical properties influencing dredging, disposal, and establishing vegetation on spoils. The first phase of the study was a survey of sediment characteristics in six areas of the lake where dredging has been proposed (Academy of Natural Sciences of Philadelphia, 1975).

Sediment from 15 locations was studied in the laboratory, and corn seedlings were grown as a test crop on five of the samples. The second phase was a study of a bulk sample of sediment that was spread on an agricultural soil and left exposed to the weather for 10 months. The purpose of the second phase was to observe in the field changes in the physical and chemical properties of sediments that might restrict the growth of plants or alter the underlying soil or ground water. Because the two parts of this investigation involved different experimental techniques and were carried out over different periods of time, they are reported separately, as Parts I and II. Although these investigations were confined to sediments from Bantam Lake, the findings should apply to sediments from similar eutrophic lakes in the Northeast.

PART I: SURVEY OF SEDIMENT CHARACTERISTICS IN AREAS PROPOSED FOR DREDGING

Sediment samples were collected from 15 locations within areas proposed for dredging in Bantam Lake. These locations are indicated by number in Fig. 1. One set was collected on October 8, 1975, and additional samples were collected on September 25, 1976. Samples of the upper 5 to 8 inches of sediment were taken with either an Eckman dredge or a 2-inch diameter core tube. Sample bottles were filled completely with sediment and closed tightly to prevent oxidation by air during transport to the laboratory.

PHYSICAL CHARACTERISTICS

Methods:

Sediments were classified by observation as sand, mud (firm, fine-textured), gyttja (soft or fluid, fine-textured), peat (medium to coarse fragments of organic matter), or combinations of these categories.

The bulk density, i.e. weight per unit volume in grams/cubic centimeter (g/cc), was measured on selected samples of fresh sediment and on most dried samples. Bulk

Table 1. Physical Characteristics of Bantam Lake Sediments.

			Bulk Density				Consistence		
			Fresh		Dry		Dry	Rewetted	
Sediment Site	Water Depth	Sediment Type	Total	Solids	Solids	Shrinkage		Moist	Wet
	ft		------g/cc		------	%			
1	3	sand	--	--	1.60	--	soft	loose	nonsticky & nonplastic
2	4	sand	1.68	1.12	1.24	10	soft	very friable	
3	6	sandy mud	--	--	1.28	--	soft	very friable	"
4	6	sand	--	--	1.26	--	slightly hard	very friable	"
5	3	sand	--	--	1.25	--	soft	very friable	"
6	20	gyttja	1.04	0.093	0.88	89	extremely hard	very firm	"
7	8	gyttja	--	--	0.89	--	extremely hard	very firm	"
8	6	sand, peat, mud	1.69	1.08	1.15	6	slightly hard	very friable	"
9	8	mud, gyttja	1.12	0.22	0.96	77	very hard	friable	"
10	7	mud, peat	--	--	0.95	--	very hard	firm	"
11a	6	upper mud layer	1.13	0.23	1.09	79	very hard	firm	"
11b	6	lower peat layer	1.05	0.12	0.54	78	very hard	firm	"
12	6	peat	--	--	0.62	--	hard	friable	"
13	5	mud, sand	1.78	1.23	1.37	10	soft	very friable	"
14	5	sand, peat	--	--	1.21	--	slightly hard	very friable	"
15	4	sand, peat	1.68	1.02	1.17	13	slightly hard	very friable	"

densities of fresh samples were obtained by weighing known volumes of sediment, drying, and weighing again. Results were expressed in two ways: weight of solids plus liquid per unit volume of fresh sediment and the weight of solids per unit volume of fresh sediment. Bulk densities of dried samples were obtained from the weight and volume of dry chunks; these results are expressed as weight of solids per unit volume of dry sediment. The change in volume on drying was calculated as the % shrinkage:

$$100 \times \frac{\text{Bulk density dry - Bulk density fresh}}{\text{Bulk density dry}}$$

Consistence of dried samples and of rewetted samples was estimated by the procedures of the Soil Survey Manual of the Soil Conservation Service (Soil Survey Staff, 1951). The terms used to describe consistence are defined in the Soil Survey Manual but are adequately self-descriptive for use here.

Results and Discussion:

Sediment samples ranged from nearly pure sands near the Litchfield Town Beach in North Bay to soupy gyttja in Nicks Cove and to reasonably pure peat in South Bay (Table 1). Sandy sediments were quite dense, even when wet, and did not shrink much in volume when dried. In the dry state they were soft or, at most, slightly hard. When rewetted they were loose or very friable in the moist state and were neither sticky nor plastic when completely wetted. Samples of mud, gyttja, and peat were low in bulk density when fresh having only 0.1 to 0.25 g of solids per cc. Extensive shrinkage occurred upon drying, ranging from 77 to 89%. Shrinkage of this magnitude causes very extensive cracking during drying of sediment. In contrast to the softer sandy sediments, the mud, peat and gyttja samples were hard to extremely hard when dry. The gyttja sediments were extremely hard when dry and chunks could be broken only by striking with a hammer or other heavy object. When rewetted the gyttja was very firm but the muds and peats were more friable. None was sticky or plastic.

CHEMICAL CHARACTERISTICS

Methods:

The pH of sediments was measured on the day of collection (fresh pH) and then again after four cycles of drying and re-wetting (final pH). The organic matter content was estimated by the % loss on ignition (L.O.I.) of dried sediments ignited for 4 hours at 450 C. Total N was measured by Kjeldahl

Table 2. Chemical Characteristics of Selected Sediment Samples from Bantam Lake: Sediment pH and Composition.

Sediment Site	Sediment Type	pH						
		Fresh	Final	L.O.I.	N	P	Cu	Zn
				--------%----------			---µg/g----	
2	sand	6.3	5.6	1.5	0.07	0.04	12	10
6	gyttja	6.6	5.3	24.6	1.50	0.16	242	54
7	gyttja	6.4	5.3	--	--	--	293	40
8	sand, peat, mud	6.4	4.9	1.8	0.07	0.04	10	18
9	mud, gyttja	6.6	5.0	15.0	0.71	0.10	116	188
10	mud, peat	--	--	31.7	1.21	0.06	75	106
11a	mud	6.5	4.9	13.9	0.72	0.09	88	181
11b	peat	6.7	5.0	50.4	1.72	0.04	45	46
12	peat	--	--	34.6	1.08	0.06	40	54
13	mud, sand	6.4	4.6	1.4	0.07	0.05	12	12
15	sand, peat	6.6	5.9	14.7	0.08	0.06	16	15

digestion using HgO as catalyst. Total P was determined after nitric-perchloric acid digestion (Jackson, 1958). Phosphorus was measured by the ascorbic acid method (Murphy and Riley, 1962). Total Cu, Zn, and Pb were measured by atomic absorption spectrophotometry (Perkin-Elmer Corp., 1968) after destruction of organic matter by ignition and extraction of metals from the residue by hydrochloric acid.

Water soluble constituents were measured in extracts obtained by procedures similar to the "Standard Elutriate Test" (Keeley and Engler, 1974). Procedures for Bantam Lake sediments differed in that one portion of sediment was extracted by air-saturated water for release of nutrients, as is usual, but a second was extracted with oxygen-free, nitrogen-saturated water to estimate the maximum release of heavy metals to water. Extracts were centrifuged to remove debris and acidified. Filtration of extracts was omitted in order to provide maximum estimates of nutrient and metal release. Total P in extracts was measured by the ascorbic acid reductant method following persulfate digestion (Gales et al., 1966; Harwood et al., 1969). Concentrations of ammonium and nitrate were measured by the phenol-hypochlorite-nitroprusside and chromotropic acid methods respectively (West and Ramachandran, 1966; Wetherburn, 1967).

Metals potentially available to plants were estimated by extraction with ammonium acetate and the chelating agent DTPA (diethylene-triaminepentaacetic acid). Sediments were first extracted with 1 N ammonium acetate at pH 7 to remove exchangeable metals and then with 0.005 M DTPA in 1 N ammonium acetate with 1 N ammonium acetate at pH 7.

Results and Discussion:

Sediment pH and Composition (Table 2). The pH values of freshly collected sediments were slightly acid ranging from a low of pH 6.3 for one of the sands to a high of pH 6.7 for one of the peats. Sediment pH usually decreases upon drying and oxidation. An estimate of the final pH that might be reached by sediment spoils after drying and weathering was obtained from the pH of samples subjected to four cycles of drying and rewetting over a period of 3 to 4 weeks. This treatment reduced the pH of all samples by 0.7 to 1.8 pH units, making all samples strongly or very strongly acid. Although these pH values are too low for good crop production, they are within the normal range for undisturbed wooded soils in the surrounding watershed (Gonick, Shearin, and Hill, 1970).

The organic matter content was widely variable ranging from less than 2% loss on ignition (L.O.I.) for some of the sandy sediments to more than 50% for one of the peats. Nitrogen (N) content was well correlated with the organic matter content; most N was undoubtably contained within organic compounds. Both the N content and

Table 3. Chemical Characteristics of Selected Sediment Samples from Bantam Lake: Water Extractable Nutrients and Heavy Metals from Leachate Tests.

Sediment Site	Sediment Type	P	K	NH_4-N	NO_3-N	Cu	Zn	Mn	Fe
		----------------µg/ml in leachate-------------------							
2	sand	.07	3.0	2.1	0.8	N.D.*	N.D.*	N.D.*	1.5
6	gyttja	.21	3.6	1.9	0.9	"	"	"	2.0
7	gyttja	.16	--	2.0	0.9	"	"	--	--
8	sand, peat, mud	.07	3.1	0.3	0.9	"	"	N.D.	1.9
9	mud, gyttja	.42	2.2	2.4	2.2	"	"	0.1	3.9
10	mud, peat	.54	--	1.4	2.3	"	"	--	--
11	mixed mud, peat	.11	2.7	0.9	1.6	"	"	0.1	1.8
12	peat	.11	--	0.6	1.1	"	"	--	--
13	mud, sand	.11	4.9	0.4	1.3	"	"	N.D.	N.D.
15	sand, peat	.07	11.6	1.1	0.7	"	"	"	2.3

* N.D. = Not Detected

the organic matter content were greater in sediment samples than in soils of this region. Phosphorus contents, however, were generally lower than in soils. In addition, phosphorus contents were much less variable than N or organic matter although the deep water gyttja sample was appreciably higher in P than were other sediments. These relationships among N, P, and organic matter in Bantam Lake sediments were observed also in an earlier study by Frink (1969).

The Zn contents of the samples were not unusual in any respect. Normal soils range from about 10 to 300 ppm with an average of 50 to 100 ppm (Bowen, H.J.M. 1966). The sediment samples ranged from 10 to 188 ppm with the finer textured muds tending to be highest as would also be true with soils.

The Cu contents of many samples were somewhat elevated as would be expected for a lake that has received numerous treatments with copper sulfate for control of algae. The gyttja samples, representing the type of fine sediment that settles out in deeper water, were the highest in Cu. Even here, the Cu content was not unexpectedly high, considering that each copper sulfate treatment adds 10 to 20 ppm of Cu to the sediment. Except for the gyttja-rich samples at sites 6, 7, and 9, the range in concentration of Cu was only 12-88 ppm. Normal soils range from 2 to 100 ppm in Cu (Bowen, H.J.M. 1966).

Water extractable constituents (Table 3). These results provide an estimate of the extent to which the backflow from spoils disposal areas would refertilize or pollute the lake. This measure is similar to that of the "standard elutriate test" and applies to constituents deemed critical to the disposal area, taking into account other known or probable sources (Keeley and Engler, 1974). For soluble constituents, the "standard elutriate test" arbitrarily uses an increase of 50% as the dividing point between non-polluting and potentially polluting concentrations. A more reasonable approach is simply to consider the results in light of what we already know about the chemistry and fertility of Bantam Lake.

During most of the growing season, the algae in Bantam Lake are limited in their growth by phosphorus supplies. Total P in surface waters of the lake is typically in the range of 0.02 to 0.04 ppm P (Norvell and Frink, 1975). Comparing this range with Table 3 suggests that the backflow from disposal areas would increase phosphorus supplies in discharge areas. However, much of this returned phosphorus would be as fine particulate matter which would settle back to the bottom again and cause little problem. In addition, the volume of this discharge is small relative to the volume of the lake and to other sources of inflow. Consequently any problems arising from phosphorus refertiliztion should be both small and temporary.

Potassium supplies in the lake are more than adequate. Thus, no effects on the lake should be expected from the small amounts of potassium in the backflow.

Table 4. Chemical Characteristics of Selected Sediment Samples from Bantam Lake: Heavy Metals Extracted by the Chelating Agent DTPA (diethylenetriaminepenta-acetic acid).

Sediment Site	Sediment Type	Cu	Zu	Mn	Fe
		--µg/g in dry solids--			
2	sand	1.0	0.5	27	40
6	gyttja	11.0	12.0	334	2860
8	sand, peat, mud	0.6	1.0	51	165
9	mud, gyttja	5.0	14.0	331	1850
11a	mud	7.0	5.0	228	700
11b	peat	7.0	0.1	123	48
13	mud, sand	0.2	0.3	21	63
15	sand, peat	0.6	0.1	25	71

Nitrogen concentrations in the water extracts are higher than in the surface waters of the lake by a factor of 2 to 4. In addition, the nitrogen in sediment extracts was essentially all as inorganic nitrogen, i.e. as ammonium and nitrate. This nitrogen should be readily available to both algae and rooted weeds. Growth of the rooted weeds in backflow discharge would in all likelihood be increased during periods of discharge. Stimulation of algae growth should be minor because the algae are limited primarily by the low phosphorus supply.

Neither Cu nor Zn were detected in water extracts of the sediments. Small amounts of Mn were occasionally found as would be expected because these sediments exist, as do most sediments from eutrophic lakes, under largely anaerobic conditions. For similar reasons, small amounts of ferrous iron were also found. No difficulties from these constituents are anticipated. Indeed, the eventual oxidation of ferrous iron to ferric iron in the backflow or lake would precipitate inorganic phosphorus and thus aid in phosphorus removal from the water.

In conclusion, no serious problem should arise from discharge to the lake of a relatively small volume of backflow from spoils disposal areas. Small but temporary increases in algal growth from phosphorus discharge and in rooted weed growth from nitrogen discharge are possible and should be expected.

Heavy metals extracted by DTPA (Table 4). Chelating agents are often used to estimate the amounts of micronutrient metals and heavy metals in soils that are available to plants. The chelating agent DTPA is especially effective for this purpose (Lindsay and Norvell, 1978). Extractable Zn and Cu were within normal ranges for agricultural soils. However, sediments 6 and 9 were fairly high in extractable Zn, and sediments 6, 9 and 11 were fairly high in extractable Cu considering that the pH of the fresh sediments was near 6.5 where Zn and Cu solubility is low. Under acid conditions, high Zn and Cu solubility could be a problem for plants growing in some spoils disposal areas.

Compared to soils, extractable Fe and Mn in the fresh sediments were very high as expected. Under reducing conditions in sediments, Fe and Mn are present largely as very soluble divalent cations. During drying of the sediment and exposure to air, most of the Fe and some of the Mn will oxidize and precipitate as insoluble oxides. These reactions are an important source of acidity and contribute to the pH decreases observed with time (Table 2). As the pH falls, Mn toxicity could be a problem at least temporarily. Application of ground limestone may be needed on some spoils to raise pH and reduce the possibility of toxicity to plants from Mn and, perhaps, from Zn or Cu.

ESTABLISHING VEGETATION ON FRESH SPOILS

Methods:

Fertility. Estimates of the fertility of dried sediment samples were made by the Soil Testing Laboratory of The Connecticut Agricultural Experiment Station using standard procedures (Lunt, Jacobson, and Swanson, 1950).

Growth Tests. Samples of sediment from sites 2, 6, 8, 9, and 10 were dried, crushed to pass a 3 mm mesh stainless steel screen, and placed in 4.5 inch plastic pots. Over a period of 2 weeks, the pots were leached intermittently with about five volumes of tap water to remove excess salts. Pots were dried and stored until planting.

Four corn seeds (Agway 595S) were planted in each pot. The corn germinated in 7 days and each pot was thinned to three

Table 5. Estimation of Fertility of Dried Sediment by Soil Testing Lab of Connecticut Agricultural Experiment Station.

Sediment Site	Sediment Type	Nitrate	Ammonia	Phosphorus	Potassium	Calcium	Magnesium
2	sand	med. low	low	med. low	low	very low	med. high
6	gyttja	very low	high	med. high	med. low	med. high	high
8	sand, peat, mud	very low	medium	med. high	low	low	med. high
9	mud, gyttja	very low	high	medium	low	high	high
10	mud, peat	very low	medium	med. high	low	high	high
11a	mud	med. high	high	med. high	low	high	high
12	peat	medium	med. low	med. high	med. low	med. high	high
13	mud, sand	very low	med. high	medium	low	low	med. high
15	sand, peat	med. low	med. low	med. high	low	low	med. high

Table 6. Yield and Composition of Young Corn Plants Grown in Soil and Five Sediments without Fertilization.

	Yield	N	P	K	Ca	Mg	Fe	Mn	Cu	Zn	Soil pH After Harvest
	g	%					ppm				
Soil	2.05	1.43^{ℓ}	0.32	2.9	0.42	0.42	68	25	8	79	6.50
Sediments											
2	0.63	1.03^{ℓ}	0.21	1.7	0.64	0.69	67	15	12	28	7.20
6	0.91	3.42	0.20	2.9	0.61	0.61	126	6^{ℓ}	32^{h}	126	5.20
8	0.32	1.84^{ℓ}	0.27	0.5^{ℓ}	1.1^{h}	0.75	141	2500^{v}	5	177	4.20
9	0.64	2.45	0.34	0.7^{ℓ}	1.1^{h}	0.63	128	2500^{v}	57^{v}	1100^{v}	4.30
10	0.27	2.56	0.16	0.6^{ℓ}	1.2^{h}	0.45	160	1300^{v}	28^{h}	590^{h}	3.60

$^{\ell}$ Low, possibly deficient

^{h} High

^{v} Very high, probably injurious

plants which were grown for 26 days in a lighted growth room at 20 to 25 C. No fertilizer was added. Water was added as needed. A pot of fertile soil was included in this growth test for comparison with the five sediments. Yield of corn tops per pot was measured at harvest and tissue samples were analyzed for N, P, K, Ca, Mg, Mn, Zn, Cu, and Fe. Appearance of corn was compared to visual symptoms described by Chapman (1966).

Results and Discussion

Sediment Fertility (Table 5). Very sandy sediments, like very sandy soils, tend to have low nutrient fertility, and the sediments from Bantam were no exception. Site 2, especially, was very sandy and low in all nutrients tested, except magnesium. Sediments with more organic matter and finer texture were generally more fertile. Potassium was low in all samples as is usually true also for unfertilized soil in Connecticut.

Growth Test with Corn (Table 6). Corn grew well on the unfertilized soil and had good color until the last week when leaves became a paler green probably because available soil N was becoming depleted.

Growth of corn on all five sediments was very poor compared to growth on the soil. On sediment 10, almost no growth occurred following emergence and only about one quarter of a gram of dry matter was harvested. Visual deficiency symptoms were not particularly distinct except on the corn grown on sediment 2 which showed symptoms of both N and P deficiencies. On sediments 8 and 9, corn leaves showed irregular necrotic striping that appeared to be a Mg deficiency but was more likely a complication of Mn toxicity.

Analysis of the corn suggests that N was low in the soil and in sandy sediments 8 and 2. Phosphorus levels in the tissue were within normal ranges. Potassium was low in corn from sediments 8, 9, and 10 but this was probably a side effect of high acidity and Mn toxicity rather than a result of inadequate available K. Very high and clearly toxic levels of Mn were found in corn grown on all three of these strongly acid sediments. Copper and Zn were present at toxic levels in corn from sediment 9 and high levels were present in corn from sediment 10.

Sediments in this growth test were subjected to more extensive oxidation and weathering reactions than the samples in Table 2. As a result, some additional pH decreases occurred in samples 8, 9, and especially 10. At these low pH levels many metals that are naturally present in soils and sediment can become toxic, especially Mn, Al, Fe(II), and the trace elements Zn and Cu. Dredged spoils from South Bay will undoubtedly require applications of ground limestone to neutralize acidity and suppress the solubility of metal ions.

CONCLUSIONS

The major problems with establishing vegetative cover on dredged spoils from Bantam Lake will probably be caused by poor physical characteristics, low pH, and toxicity from excess soluble metals, especially manganese. The sands will be droughty and structureless while the fine-textured sediments will drain slowly, dry slowly, shrink and crack badly during drying, and when dry many will be extraordinarily hard. Sandy dredged spoils will probably be deficient in nitrogen. Finer textured dredged spoils may be difficult to vegetate because of acidity released during drying and oxidation by air. Toxicity to plants from excessive solubility of metals is likely on spoils with pH values near 4 or lower. Application of limestone may be required to raise pH and alleviate metal toxicities.

Phosphorus and nitrogen in the backflow to the lake from soils disposal areas may increase growth of algae and rooted weeds, but the effect should be both small and temporary.

Part II: CHARACTERISTICS OF SEDIMENT AFTER WEATHERING IN THE FIELD

METHODS

Collection and treatment of sediment:

A bulk sample of sediment was collected from South Bay in Bantam Lake on July 1, 1977. A total of about 120 gallons of wet sediment was taken from five locations in the general area of site 8 (Fig. 1) in water 5 to 7 feet deep. The sediment was collected with a 2 gallon scoop and composited in 55 gallon drums.

After transport to the Experiment Station's Lockwood Farm in Mt. Carmel, Connecticut, the sediment was spread to a depth of about 28 cm on soil. The sediment was contained by two square frames, 0.7 m on a side, with a surface area of 0.5 square meter per frame. The frames were built of plywood and protected with waterproof epoxy paint. Frame walls extended 15 cm into the underlying Cheshire fine sandy loam to ensure containment of the sediment and to promote vertical infiltration of water draining from the sediment through the soil.

Prior to spreading the sediment, 350 g of ground agricultural limestone were applied to the surface of the soil in one frame. Another 350 g were applied to the surface of the sediment in this same frame after spreading. The total application of limestone was 700 g or the equivalent of about 6 tons per acre. No limestone was added to the sediment in the other frame.

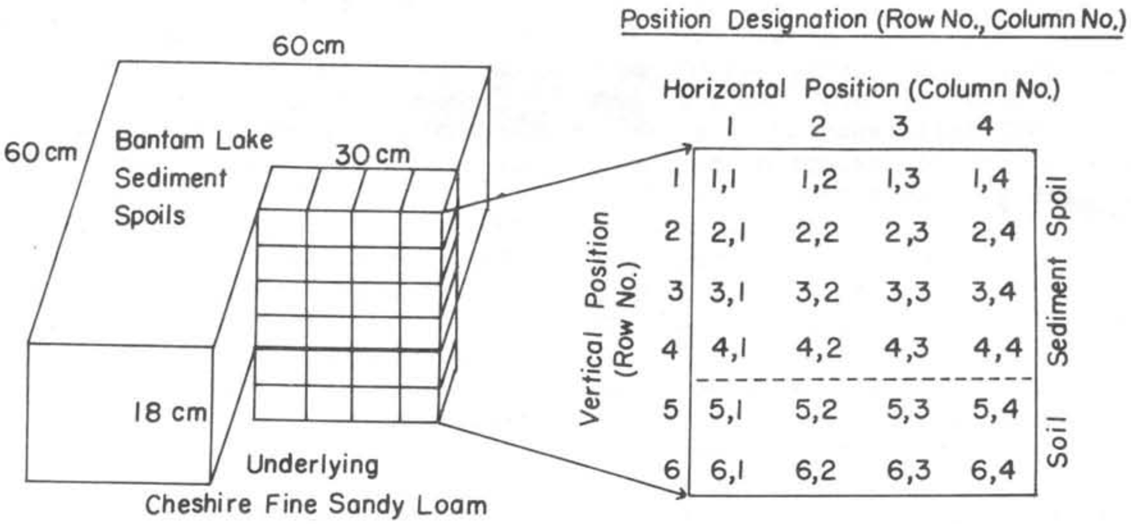

Figure 2. Diagramatic sketch of locations and position designations for the 16 samples of sediment spoils and 8 samples of underlying soil from each block of dredged sediment from Bantam Lake.

The sediment spoils were allowed to drain and dry during July. In early August, the surface 3-5 cm was loosened by cultivation (except at the edges which were left intact) and annual Rye grass was seeded. Seedling establishment was poor on both the untreated and limestone treated sides. Because of the hot dry weather and lateness of the season, no further attempts at seeding were made. Other than the cultivation of the surface, the sediment spoils remained undisturbed and exposed to the weather until the following May.

In May, 1978, the frames were dismantled and the sediment spoils were cut open to expose a vertical face running from the center of the block of spoils to the middle of one edge (Fig. 2). This vertical surface was divided vertically and horizontally into 16 sections and each section was sampled. In addition, 8 samples of the underlying soil were collected using a similar grid pattern extended below the soil surface. Each sample was identified by a pair of numbers representing the row and column locations from which it was taken (Fig. 2). For example, Sample (1,1) was taken from the surface layer of sediment spoils at the center of the block, while sample (4,4) was taken just above the soil surface at the outside edge of the block, and sample (5,4) was taken from the field soil directly beneath the sample (4,4). In addition, two samples of the field soil from outside the frames were collected to serve as controls for comparison with the samples of soil from beneath the sediment spoil.

A bulk sample of the spoil material from the untreated side was collected and stored for use in later studies of corn seedling growth.

Laboratory Procedures:

The 50 samples of sediment spoils and soils were dried, crushed, and sieved through a 1 mm mesh stainless steel screen to remove stones. The pH of each sample was measured with a pH electrode in a 1:1 soil:water suspension. A 5 g portion of each sample was extracted with 25 ml of the DTPA (diethylenetriamine pentaacetic acid) micronutrient soil testing solution of Lindsay and Norvell (1978). An extractant to sample ratio of 5 ml/g was chosen to ensure adequate DTPA chelating agent to complex all readily extracted heavy metals. The extracts were analyzed by atomic absorption spectrophotometry for Al, Fe, Mn, Zn, Cu, Ni, and Cd.

An estimate of the lime requirement of the bulk sample of untreated spoil was obtained by adding increasing amounts of calcium hydroxide to a series of spoil subsamples. After three cycles of wetting and drying, the final pH was measured and plotted against the calcium hydroxide added. From this plot, a rate of 3000 ppm of calcium hydroxide was estimated to raise the pH of the spoils to about pH 6.5. This rate of addition was used in the growth test described below.

Growth tests:

Two 4.5 inch plastic pots were filled with 500 g each of spoils from the untreated side. Two other pots were similarly filled, except that 1.5 g of calcium hydroxide was mixed with the spoils in each pot to neutralize acidity. Corn seeds (Agway 724) were planted in all pots and one plant per pot was grown in a well lighted growth room with day cycle temperatures of 28-32 C. Pots were watered daily with distilled water as needed. All pots were fertilized with N and K by occasional watering with solutions of calcium and potassium nitrates. After 5 weeks of growth, the plants were harvested, washed, dried and analyzed for Fe, Mn, Zn, Cu, Ni, and Cd.

RESULTS AND DISCUSSION

Physical Characteristics:

Free water drained from the sediment spoils within a day or two following placement in the frames. As the spoils drained and dried, they shrank but retained the block-like shape imposed initially by the square frames. Almost no cracks appeared and the block-like shape remained stable for the 10 months of the study. The blocks shrank a total of about 50% in volume from initial dimensions of 70x70x28 cm to approximately 60x60x18 cm.

On a field scale, lateral shrinkage would probably produce sizable cracks, splitting the drying spoils into large irregular blocks. Surface cultivation for seeding or for incorporation of limestone would, of course, help to fill cracks and produce a more uniform surface. Cultivation of these sandy spoils would not be difficult.

Particle size analysis of the bulk sample of spoils showed that it was a very fine sandy loam in texture, and contained 10% clay-size, 18% silt-size, and 72% sand-size particles on a dry weight basis.

Chemical Characteristics:

Results for the 16 spoil samples and 8 soil samples from the untreated and lime-treated spoil blocks are given in Tables 7 and 8 respectively. Results for pH and for extractable Al, Fe, Mn, Zn and Cu are presented as a function of position in the sediment spoil block or underlying soil. Data for Ni and Cd are not included because these metals were released in only small amounts. Results for extractable metals are expressed as ppm (parts per million) of each metal in air dry sediment or soil sample.

The pH of the spoils after weathering (Table 7 and 8) was much lower than the near neutral pH of 6.6 in the freshly collected spoils. Most of the 2 to 3 pH unit decrease occurred within the first month. Samples taken from the interior of the untreated block in early August ranged in pH from 3.9 to 4.1. Comparison with Table 7 shows that virtually all of the decrease in pH occurred soon after dredging, suggesting that rapid reactions, such as oxidation of reduced metals and precipitation of metal oxides, were the only major sources of acidity.

The pH varied considerably as a function of position within the blocks of spoil. Although some variation was apparently random, the pH of the spoils tended to be lowest at the base of the block (row 4) and at the exposed sides of the block (column 4) as shown in Tables 7 and 8. Presumably, leaching of acids or acid-forming metals downward in the spoils accounted for the greater acidity near the base. Increased acidity near the outer edges of the spoils may be explained by enhanced oxidation and accumulation of acid-forming metals from evaporating water. A similar effect would reasonably have been expected over the entire upper surface of the untreated block but was obliterated by cultivation during the attempt at seeding. In the lime-treated spoils, the pH of the surface was maintained near 7 by the added limestone, except at the

Table 7. Extractable metals and pH in untreated sediment spoil and underlying soil after 10 months exposure to weather. Sample positions correspond to Figure 2.

Sample pH

	Horizontal Position (Column #)			
Vertical Position (Row #)	1	2	3	4
1	4.60	4.35	4.32	3.77
2	4.51	4.31	4.16	3.78
3	4.14	4.31	4.37	3.92
4	3.77	3.90	4.08	4.00
5	4.50	4.48	4.60	4.78
6	5.22	5.22	5.26	5.27
	(pH 5.31 in control soil)			

Extractable Al, ppm

	Horizontal Position (Column #)			
Vertical Position (Row #)	1	2	3	4
1	53	47	45	77
2	46	46	46	76
3	41	64	64	87
4	83	97	100	93
5	53	56	48	40
6	31	31	28	29
	(26 ppm Al in control soil)			

Extractable Fe, ppm

	Horizontal Position (Column #)			
Vertical Position (Row #)	1	2	3	4
1	504	480	484	684
2	516	562	566	576
3	498	534	491	544
4	590	554	533	588
5	48	44	37	36
6	29	28	31	28
	(25 ppm Fe in control soil)			

Extractable Mn, ppm

	Horizontal Position (Column #)			
Vertical Position (Row #)	1	2	3	4
1	10	7.7	8.6	25
2	11	11	10	39
3	9.0	16	13	44
4	27	44	36	59
5	47	51	45	37
6	9.0	10	8.6	11
	(8.7 ppm Mn in control soil)			

Extractable Zn, ppm

	Horizontal Position (Column #)			
Vertical Position (Row #)	1	2	3	4
1	5.6	4.6	4.6	9.7
2	4.7	4.5	5.5	16.
3	3.8	6.3	7.1	18.
4	8.6	14.	15.	29.
5	14.	10.	10.	13.
6	2.1	1.6	1.2	1.2
	(1.2 ppm Zn in control soil)			

Extractable Cu, ppm

	Horizontal Position (Column #)			
Vertical Position (Row #)	1	2	3	4
1	13	11	10	17
2	11	12	13	17
3	10	14	14	18
4	17	17	18	20
5	4.8	5.0	4.3	4.6
6	3.5	3.0	3.2	3.5
	(3.8 ppm Cu in control soil)			

Table 8. Extractable metals and pH in limestone-treated sediment spoil and underlying soil after 10 months exposure to weather. Sample positions correspond to Figure 2.

Sample pH

Vertical Position (Row #)	Horizontal Position (Column #)			
	1	2	3	4
1	7.06	6.93	6.73	3.98
2	4.52	3.91	4.23	3.96
3	4.30	4.22	4.12	3.89
4	3.94	3.62	3.48	3.78
5	4.74	5.09	5.23	5.72
6	5.17	5.29	5.33	5.23
	(pH 5.31 in control soil)			

Extractable Al, ppm

Vertical Position (Row #)	Horizontal Position (Column #)			
	1	2	3	4
1	4	5	6	54
2	43	41	45	51
3	51	44	50	62
4	59	59	84	62
5	39	30	25	17
6	25	25	25	27
	(26 ppm Al in control soil)			

Extractable Fe, ppm

Vertical Position (Row #)	Horizontal Position (Column #)			
	1	2	3	4
1	57	52	60	503
2	465	491	477	534
3	556	503	462	487
4	446	413	529	504
5	34	26	28	19
6	24	26	25	24
	(25 ppm Fe in control soil)			

Extractable Mn, ppm

Vertical Position (Row #)	Horizontal Position (Column #)			
	1	2	3	4
1	5.8	5.6	7.6	11
2	6.8	11	9.9	12
3	15	13	12	15
4	20	22	36	33
5	36	18	14	6.9
6	11	11	7.3	12
	(8.7 ppm Mn in control soil)			

Extractable Zn, ppm

Vertical Position (Row #)	Horizontal Position (Column #)			
	1	2	3	4
1	3.8	4.4	5.6	5.4
2	3.3	3.2	4.3	6.2
3	4.3	3.2	3.9	7.9
4	6.0	4.8	8.2	12.4
5	7.2	2.4	4.7	4.6
6	1.4	1.2	1.0	3.6
	(1.2 ppm Zn in control soil)			

Extractable Cu, ppm

Vertical Position (Row #)	Horizontal Position (Column #)			
	1	2	3	4
1	5.7	5.9	6.6	13
2	11	11	11	12
3	14	12	12	14
4	13	11	16	15
5	3.9	3.1	4.9	3.9
6	3.0	3.1	3.1	3.6
	(3.8 ppm Cu in control soil)			

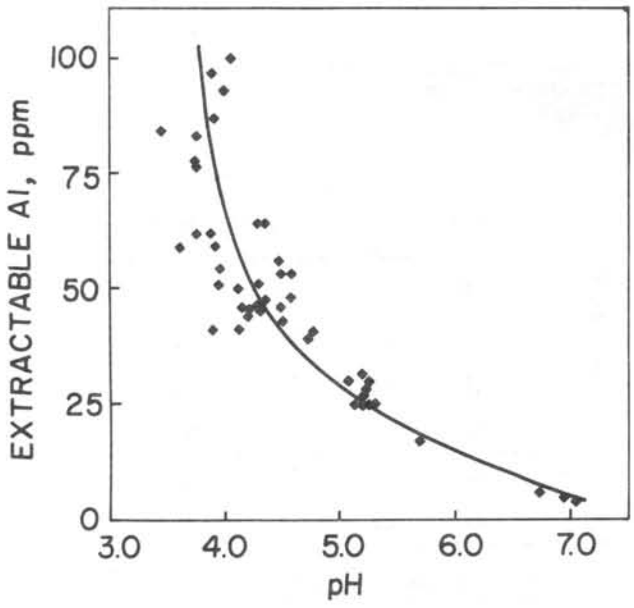

Figure 3. Extractable Al as a function of pH in untreated and limestone-treated sediment spoils and underlying soils.

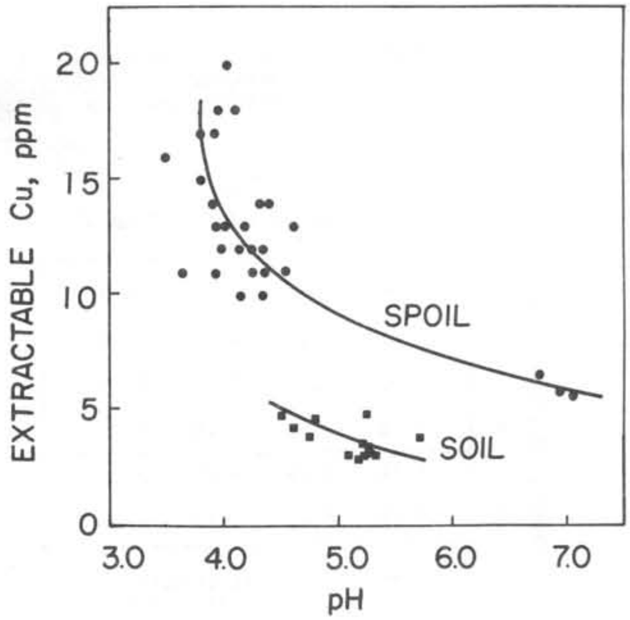

Figure 4. Extractable Cu as a function of pH in untreated and limestone-treated sediment spoils and underlying soils.

edge (pH(1,4) = 3.98) where the surface had not been cultivated and where rainfall tended to wash off the broadcast limestone.

Below the untreated block, the pH of the uppermost layer of field soil (row 5) was depressed by 0.5 to 0.8 pH units by acids or acid-forming metals leached from the spoils above. However, the pH depression was almost entirely restricted to this layer and was barely noticeable in the next layer (row 6). Beneath the other block, the limestone which had been broadcast prior to spreading the spoils, was reasonably successful in preventing the movement of acidity from the spoils into even the first layer of underlying soil.

Extractable metals varied within the blocks of spoil with location and especially with pH. Extraction of metals increased markedly with increasing acidity and was much reduced by the limestone treatment. The relation between extracted Al and pH appeared to be similar in both the spoils and the soils as shown in Fig. 3. This is not surprising because soluble and exchangable Al are closely related to pH as long as oxides of Al are present, which is almost always the case.

Unlike Al, extractable Cu in the spoils was considerably greater than in the soil, showing a strong influence of source as well as of pH (Fig. 4). The greater abundance of Cu results from many years of lake treatments with copper sulfate, which have raised the Cu content of sediments throughout the lake (Table 2). The spoils also contained much greater amounts of extractable Fe than did the field soil. In fact, Fe released by the spoils was an order of magnitude greater than that released by most acid soils of Connecticut. The source of this extractable Fe is the relatively large amount of ferrous Fe that accumulates under anoxic conditions in the fine particle size fraction of most lake sediments. As this sediment Fe is released during weathering under acid conditions, high levels of extractable Fe are maintained even under oxidizing conditions where ferrous Fe tends to be converted to the less soluble ferric form. The sensitivity of extractable Fe to pH was as great as for Al, note for example in Table 8 the drop from Fe(2, 1) = 465 ppm at pH(2, 1) = 4.52 to Fe(1, 1) = 57 ppm at pH(1, 1) = 7.06.

Manganese (Fig. 5) and, to a lesser extent, Zn differed from the other metals in that the soils underlying the spoils released more metal at a given pH than did the spoils above. Higher levels of extractable metal beneath the spoils resulted from the downward movement of Mn and Zn with draining water and their accumulation in the underlying soil. Movement of these metals is shown also by the reasonably steady increase in metal extracted with increasing depth, i.e., from row 1 to row 4, and by the elevated levels in row 5 compared to the control soil (Table 7). However, even with Mn and Zn, the increase was confined largely to the soil immediately underneath the spoils and little increase was noted in row 6, only a few cm below. Here too, liming was effective in reducing movement into even the first layer of soil.

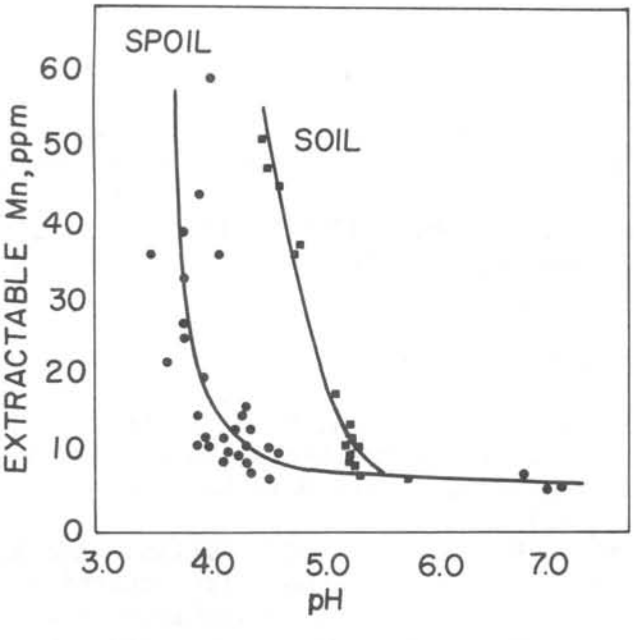

Figure 5. Extractable Mn as a function of pH in untreated and limestone-treated sediment spoils and underlying soils.

Growth Tests:

In the growth room, corn plants emerged in 7 days from the limed spoils, had good green color, and grew rapidly for 2 to 3 weeks. Thereafter growth slowed and these plants began to display symptoms of N and K deficiencies, ie., pale green color, withering of lower leaves, spindly growth, and necrosis of leaf margins near the tip. These symptoms appeared despite fertilization with calcium and potassium nitrate. Purple pigmentation of stems and leaves was observed, suggesting that the corn was also deficient in P. Analysis of harvested plants (Table 9) showed that Fe, Mn, Zn, and Cu were within normal ranges for these metals in corn tissues, although Mn and Zn were clearly at the high end of the normal range and Fe was near the low end.

Corn planted in pots of the unlimed acid spoils emerged 2 to 3 days later than did the corn in the limed spoil.

Table 9. Concentration of Fe, Mn, Zn, and Cu in Corn Grown in Weathered Dredge-Spoil from Bantam Lake.

Treatment	Fe	Mn	Zn	Cu
	---------------	ppm	---------------	
Acid spoils (pH 4.1)	67	500	190	15
Limed spoils (pH 6.0)	51	171	80	10
"Normal" range for young corn*	50-350	50-200	20-100	5-20

* Chapman (1966), Jones and Eck (1973)

Corn grew poorly in the acid spoil and displayed a complex combination of symptoms suggesting deficiencies of N and K as well as injuries from excess acidity and toxic levels of metals. Growth was slow, leaves were pale green, and even when very small, leaves began to die back from the tip. Older leaves were lost completely. Some plants were virtually dead after three weeks and were removed when plants were thinned. Roots also grew poorly and were stunted. Analysis of harvested plants showed that Mn and Zn were present at unusually high and probably injurious levels.

Deficiencies of N and K had been anticipated from earlier work with sediments from Bantam Lake (Part I), and these nutrients were added to pots in an attempt to correct these deficiencies. Despite this fertilization, N and K were not available in adequate amounts for corn in either the limed or acid spoils. Larger than usual application rates of N and K are apparently needed on these spoils. In addition, the limestone required to reduce the acidity and the toxicity of metals apparently creates a need for fertilization with P. This probably occurs because liming raises the pH and precipitates large amounts of Fe as hydrous oxides which fix P in unavailable forms.

CONCLUSIONS

The results from Part II confirm that dredged sediments from South Bay in Bantam Lake rapidly become acid after disposal. The acidic spoils released relatively large amounts of soluble metals, particularly Fe. Applications of limestone controlled the release of acidity, the release of soluble metals, and the transport of metals and acidity into underlying soil. Growth tests with corn suggested that at a minimum, large applications of limestone and large and probably repeated applications of N, P, and K fertilizer will be needed to establish good plant growth on sediment spoils from South Bay in Bantam Lake.

GENERAL SUMMARY AND CONCLUSIONS

The major problems with establishing vegetative cover on dredged spoils from Bantam Lake will be caused by poor physical characteristics, low pH and toxicity from excess soluble metals. The sands will be droughty and structureless while the fine-textured sediments will drain slowly, dry slowly, shrink and crack badly during drying, and when dry many will be extraordinarily hard. Dredged sediment will rapidly become acid after disposal and will release relatively large amounts of soluble metals, including Mn(II) and Fe(II). Toxicities from soluble heavy metals and excessive acidity will limit growth of plants. Applications of limestone and complete fertilizer (NPK) will probably be required but may not eliminate nutrient imbalances and acidity problems entirely. Alternately, covering the dried spoils with a surficial layer of soil might prove an easier method of establishing plant cover.

Some leaching of acids and soluble heavy metals from the dredged spoils into underlying soils will occur but only in relatively small amounts. Application of limestone beneath or within the spoils could reduce leaching of acids and metals but such treatment does not appear necessary.

Phosphorus and nitrogen in the backflow to the lake from spoils disposal areas may increase growth of algae and rooted weeds, but the effect should be small and of short duration. Small concentrations of Fe and Mn in the backflow are not of concern and may provide a benefit by precipitating some of the returning phosphorus.

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