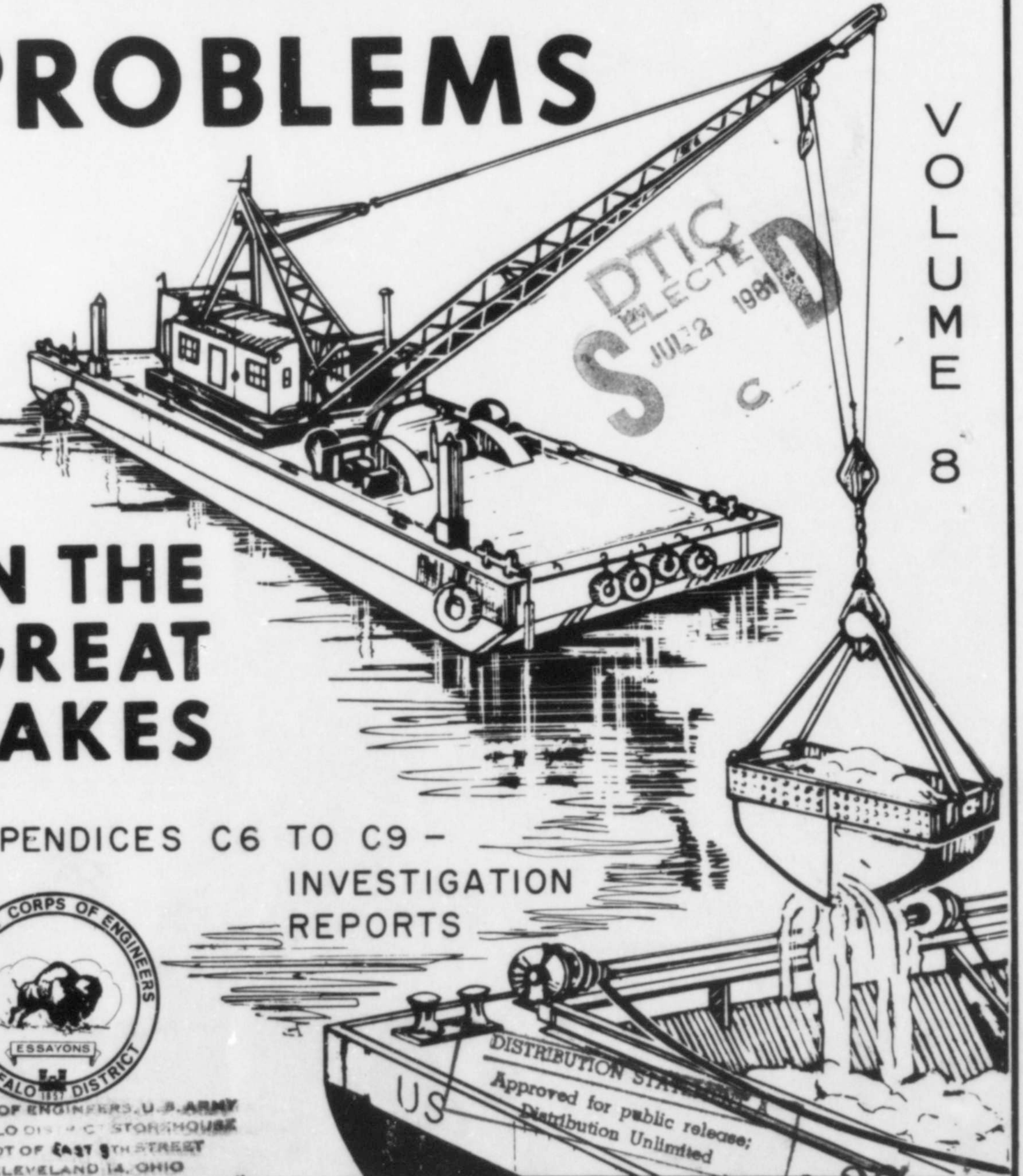
DREDGING *and* WATER QUALITY PROBLEMS

IN THE GREAT LAKES

VOLUME 8



APPENDICES C6 TO C9 - INVESTIGATION REPORTS

U. S. ARMY CORPS OF ENGINEERS
ESSAYONS
BUFFALO DISTRICT
1857

CORPS OF ENGINEERS, U.S. ARMY
BUFFALO DISTRICT STOREHOUSE
FOOT OF EAST 9TH STREET
CLEVELAND 14, OHIO

PLEASE RETURN TO

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (6)	2. GOVT ACCESSION NO. AD-A950	3. RECIPIENT'S CATALOG NUMBER 715
4. TITLE (and Subtitle) Dredging and Water Quality Problems In the Great Lakes. Volume 8. Appendices C6 to C9. Investigation Reports.		5. TYPE OF REPORT & PERIOD COVERED (9) Final rept.
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s)		8. CONTRACT OR GRANT NUMBER(s) (12) 388
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Engineer District, Buffalo 1776 Niagara Street Buffalo, New York 14207		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Engineer District, Buffalo 1776 Niagara Street Buffalo, New York 14207		12. REPORT DATE (11) 1969
		13. NUMBER OF PAGES 226
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report)
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Dredging
Water Quality
Water Pollution

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The present report presents the results of a study conducted by the Corps of Engineers with cooperation of the Federal Water Pollution Control Administration to evaluate the effects of water quality of current dredging practices including the disposal of dredged material in unconfined open water areas of the Great Lakes, as well as to develop the most practical methods for management of pollution problems that may be identified as resulting from dredging operations on the Lakes. The investigations conducted during the study included contruction and operation of diked areas, treatment

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

410090 LB

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) of the dredged material, modifications to dredge equipment and in dredging operations, functional studies of the effects on lake ecology of open-lake disposal, surveys of possible alterate disposal areas at 37 Great Lakes harbors and connecting channels, and an economic evaluation of benefits which might accrue from improved Great Lakes water quality.

Appendix C

INVESTIGATIONS

In addition to numerous sampling surveys, several investigations related to dredging and water quality problems were conducted for the present study. This appendix is an inventory of those investigations carried out during the course of the present study.

Investigations

Short Title	Investigating Agency	Appendix No.
Analysis of the Harbor Surveys	Board of Consultants	C1
Geochemical Summary of Polluted Sediments	FWPCA	C2
Flocculation Study (Saginaw, Michigan)	Dow Chemical Corp.	C3
Flocculation Study (Toledo, Ohio)	Dow Chemical Corp.	C4
Functional Tests	University of Wisconsin	C5
Treatment of Dredgings	Nebolsine, Toth, McPhee Associates	C6
Dredgings Disposal in Sewerage Systems	Chicago District, Corps of Engrs. and Chicago Metropolitan Sanitary District	C7
Benefits: (Feasibility Study)	University of Illinois	C8
Benefits: (Evaluation Study)	Greeley & Hansen	C9
Standard Laboratory Manual	FWPCA	C10
Bibliography Search	Wayne State University	C11

APPENDIX C6

ENGINEERING FEASIBILITY REPORT ON

SELECTED TREATMENT PROCESSES FOR GREAT LAKES DREDGINGS

FOR U.S. ARMY ENGINEER DISTRICT, BUFFALO

CORPS OF ENGINEERS

NEBOLSINE, TOTH, McPHEE ASSOCIATES
NEW YORK, N.Y.
SEPTEMBER, 1968

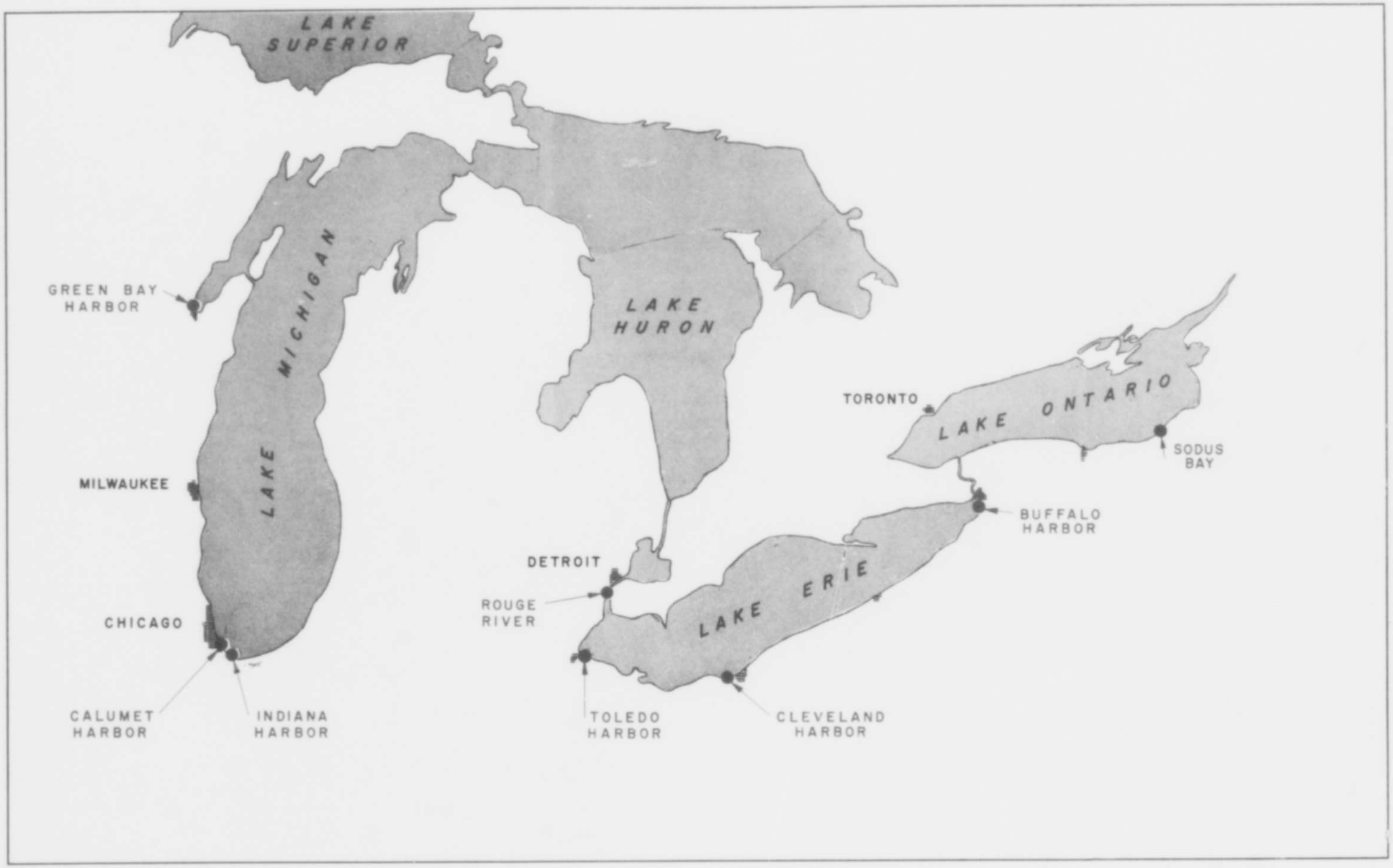
Engineering Feasibility Report On

SELECTED TREATMENT PROCESSES FOR GREAT LAKES DREDGINGS

For

U . S . Army - Engineer District, Buffalo
Corps of Engineers

Nebolsine, Toth, McPhee Associates
Consulting Engineers
New York, New York


LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
GREEN BAY HARBOR
MILWAUKEE
CHICAGO
CALUMET HARBOR
INDIANA HARBOR
DETROIT
ROUGE RIVER
TOLEDO HARBOR
CLEVELAND HARBOR
TORONTO
BUFFALO HARBOR
SODUS BAY

INDEX

PLATES

FIGURES

TABLES

APPENDICES

Page No.

Appendix E - Tests for Particle Separation from Dredgings

SUMMARY

To maintain water depths in Great Lakes' harbors, the Corps of Engineers dredges these harbors and associated waterways as a routine maintenance operation. The dredged materials, in the eight harbors studied in this report, range from about 100,000 to 1,000,000 cubic yards annually per harbor. At present, most are dumped in the deep waters of the Lakes.

The dredgings contain organic matter that contribute to pollution of the Lakes. This report was authorized to study methods of treating the dredgings so they would be non-polluting if returned to the Lakes.

About 15% of the dredgings consists of material that is sand size or larger. This fraction is fairly clean but does contain some polluting material, which would have to be removed. These large particles would be separated from the dredgings as they are being pumped from the dredges to a storage area on dry land. The remaining material would be allowed to settle for several days to compact. Excess water would be decanted and treated before discharge into the nearby harbors.

Various processes were investigated to treat the remaining solids which contain some 10% organic material. The processes included:

Anaerobic Stabilization	Wet Oxidation
Aerobic Stabilization	Fluid Bed Incineration
Chemical Oxidation	Multiple-Hearth Incineration

When the treatment process had a final liquid-solid product, the separation of the solids was studied.

The study of each process was divided into three sections: design considerations, capital costs and operating costs. Cost curves were developed for annual dredging rates of 100,000; 500,000; 1,500,000 and 3,000,000 cubic yards per year, and an expected treatment time, generally, of 270 days. With these cost curves it is possible to obtain costs for any combination of treatment processes. Variations in the concentration of solids and the quantity of volatile solids in the dredgings were also considered and cost curves were drawn for various reasonable combinations.

Each process studied has advantages and disadvantages, and each produces a final product that differs from the others. It was assumed that the stabilization of biodegradable volatile matter in the dredgings was the prime consideration for the purpose of comparing the end product of the treatment process.

For sludge thickened to 45% solids and with a volatile solids content of 10%, multiple-hearth incineration is the most economical treatment process, on an annual cost basis, followed very closely by aerobic stabilization. However, the capital costs of incinerators, to handle 1,000,000 cubic yards annually is some $12,000,000 while those for aerobic stabilization are $7,585,000. Thus the final decision on a treatment process may be based on factors other than lowest annual cost. Table 20 on Page 157 presents the costs of various treatment methods for a 1,000,000 cubic yard per year facility.

It is recommended that either the Buffalo or Cleveland harbor be used for pilot plant work to prove out the information contained in the report. Both harbors have dredgings with average characteristics and electric energy is readily available at existing dredging storage areas.

ENGINEERING FEASIBILITY REPORT ON SELECTED TREATMENT PROCESSES FOR GREAT LAKES DREDGINGS

A. BACKGROUND

1. Prior Practice of the Corps of Engineers

The United States Army Corps of Engineers is responsible for maintaining the navigable waters of the harbors on the Great Lakes. Maintenance consists principally of dredging material out of harbor areas and waterways to keep a minimum water depth. The Corps has been performing this work successfully for over one hundred years. In the past excavated materials have been hauled out to designated disposal areas in the Lakes and dumped.

Two types of maintenance dredging are utilized in cleaning the harbor channels. In the narrow confines of the harbors and rivers the dredging is done by clam shell dredges and attendant plant. The dredged material is loaded into bottom-dump scows and hauled for dumping in the designated dumping or spoil areas in the Lakes. In the other areas of the harbors and rivers the dredging is done by self-propelled hopper bottom hydraulic dredges. Material is sucked up by adjustable suction pipes and pumped into storage hoppers. After the hoppers are filled, the dredge makes a run to the spoil area in the Lake and empties its hoppers via bottom dump doors.

Some of the hopper type dredges are so equipped that they can pump out the material for on-land disposal if desired. In the past this operation has been performed at only two harbors - Toledo and River Rouge.

The dredgings contain considerable organic matter which becomes septic and could degrade the waters of the Lakes. If possible, it would be desirable to somehow treat this organic matter to make it innocuous or to dispose of the dredgings in some other manner.

2. <u>Present Plans of the Corps of Engineers</u>

Realizing that maintenance dredging of the Great Lakes harbors will have to continue , the Corps of Engineers has undertaken to study alternate methods for disposal of the dredgings without aggravating the pollution problem in the Lakes. One of the alternates to be studied is the treatment of the dredgings so they may be dumped, as at present, or used as stable fill without causing a nuisance.

Eight pilot harbors were designated to be studied. They are as follows:

1) Buffalo Harbor, Lake Erie
2) Cleveland Harbor, Lake Erie
3) Toledo Harbor, Lake Erie
4) Rouge River, Detroit River
5) Indiana Harbor, Lake Michigan
6) Calumet Harbor, Lake Michigan
7) Green Bay Harbor, Lake Michigan
8) Great Sodus Bay Harbor, Lake Ontario

Of the eight harbors, the first seven are generally heavily polluted, while the sediments from Great Sodus Bay Harbor are fairly low in pollutants.

3. Nebolsine, Toth, McPhee Associates' Participation in the Project

The Corps of Engineers retained Nebolsine, Toth, McPhee Associates under Contract DACW4969 C 0001 for Consultant Engineering Services for Feasibility Study of Methods of Treating Dredge Slurries to Eliminate Pollution.

The scope of the work to be performed under the contract was as follows:

a) Studies of the physical separation of inorganic solids from organic solids.

b) Studies of the dewatering, storing and conveying of inorganic solids for transport to a spoil area at a later time.

c) Studies of treatment of organic solids and its associated water.

d) Study of possibility of pumping the water portion of the dredgings to local sewage treatment plants for treatment.

e) Preparation of preliminary engineering designs and construction cost estimates.

f) Preparation of annual costs of treatment facilities.

g) Preparation of a report covering design parameters used and other considerations taken in designing the treatment facilities. Advantages and disadvantages of the alternates studied were to be reported and recommendations for further investigations were to be made.

The work to be performed by Nebolsine, Toth, McPhee Associates (NTMA) depended on information to be furnished by the Corps of Engineers and by other consultants to the Corps of Engineers. Laboratory investigation of the characteristics and treatability of bottom samples was to be performed by the Great Lakes Institute of the University of Wisconsin. NTMA was to perform no testing except to arrange for a collection of dredge samples for testing in the laboratories of equipment vendors. The report covering the work being done at the University of Wisconsin is due at approximately the same time as this report. To expedite the work to be done, NTMA made several visits to the University of Wisconsin and worked closely with the personnel assigned to the project. At the time this report was prepared some testing work was still unfinished. Where there was sufficient laboratory data to permit the selection of design parameters, NTMA has based its work on past experience with similar wastes and this report notes where such assumptions have been made.

TABLE NO. 1

SUMMARY OF DREDGING QUANTITIES AND CHARACTERISTICS FROM PILOT HARBORS [1]

	Buffalo Harbor	Cleveland Harbor	Toledo Harbor	Rouge River	Indiana Harbor	Calumet Harbor	Green Bay	Great Sodus Bay
Volume-cy/yr [2]	690,000	1,270,000	1,100,000	340,000	150,000	280,000	100,000	50,000
COD - mg/g	117.5	211	-	240	351	139.7	220	22.2
BOD - mg/g	-	13	0.8	3.1	-	-	-	-
Cl_2Demand-mg/g	-	28	-	-	-	-	-	-
Vol.Solids-mg/g	95.0	115	83	170	80	78	183.5	13.8
Oils & Grease, mg/g	7.8	28	1.5	16.9	39.5	14.8	31.9	-
Phosphorus, mg/g	0.9	4.0	-	0.4	1.0	1.2	3.5	1.4
Nitrogen, mg/g	2.3	4.0	-	0.1	2.3	1.0	6.9	1.0
Iron - mg/g	77.0	96	-	16.4	17.2	69.9	-	-
Million # of dry Solids/yr @ 1250 #/cy	862.5	1,587.5	1,375	425	187.5	350	125	62.5

(1) Data from F.W.P.C.A. and G.L.R.C. Reports

(2) Dredgings quantities at time samples were taken.

B. CHARACTERISTICS OF DREDGINGS

1. General

Maintenance dredging by the Corps of Engineers removes, from the river and harbor channels, sediments comprised of materials from agricultural and urban run-off, and domestic and industrial waste water discharges. The composition of the dredgings reflects the constituents in the contributing sources. For the most part they are composed of silts and clays from land run-off. However, they are often heavily polluted with objectionable contaminants. Prior to the pilot program the Federal Water Pollution Control Administration sampled sediments from some forty-four Great Lakes harbors and analyzed them as to degree of contamination. More extensive studies then were planned for eight pilot areas, seven of which are highly polluted and one relatively clean. The data on the characteristics of dredgings is limited. It is composed chiefly of samples collected within the last year. Two types of samples were collected; one was samples of in-place sediment, the other, samples of the contents of the hopper dredges. These samples and the analyses were discussed in reports on the pilot harbors by the FWPCA and the Corps of Engineers' Great Lakes Research Center. Table No. 1 summarizes the quantities and characteristics of dredgings from the pilot harbors based on the data in the reports.

As part of the pilot harbor program, a contract was let to the University of Wisconsin to analyze samples of sediment from the pilot harbors and to perform treatability tests on these samples. Five samples from each of seven harbors and three from one were taken at various points as representative of the materials to be dredged. The general location of these samples at each harbor is indicated on the maps of the harbors. (See Appendix A.) The analyses of these samples and laboratory treatability tests are being performed concurrently with the preparation of this report. However, data which was available is included to indicate the characteristics of the sediments.

2. Physical Characteristics

Table No. 2 presents the results of analyses of the sediment samples. The sample code letter is the first initial of the eight pilot areas previously discussed. The sediments, suspended in water, form a mass of sludge which varies in consistency depending upon the solids' characteristics. The in-place sediment samples usually contain about 40 to 50% solids by weight. However, the solids content can vary considerably outside this range as shown in Table No. 2. The solids are classified as follows:

Gravel - particles greater than 2 mm in size.

Sand - particles between 2 mm and 63 microns.

Silt - particles between 63 and 4 microns.

Clay - particles less than 4 microns.

These fractions occur in widely varying percentages from sample to sample. In addition, the dredgings will contain other debris such as broken glass, stones, bricks, pieces of metal, etc. In general, there is a greater percentage of coarse materials in the river sediments where currents are relatively

TABLE NO. 2
SUMMARY OF DATA ON BOTTOM SEDIMENT SAMPLES - UNIVERSITY OF WISCONSIN

Sample	Wet Density gm/ml	Solids %	Approx. Specific Gravity g/cc	Dry Solids g/l	COD mg/l	COD mg/gm Dry	g/g Solids Volatile %	Particle Size % Gravel	Particle Size % Sand	Particle Size % Silt	Particle Size % Clay
G 1	1.23	32.6	-	345	40,000	116	11.41	0	54.8	21.5	23.8
2	1.87	74.5	2.66	1219	17,600	13.7	1.91	7.2	9.9	30.9	52.0
3	1.13	26.0	1.77	288	38,300	133	13.38	0	0.8	44.5	54.7
4	1.13	27.4	1.70	315	48,400	153	15.00	0.3	43.7	24.9	31.2
5	1.49	56.4	2.45	789	42,300	53.6	5.75	45.6	36.2	9.2	8.9
I 6	1.33	43.7	2.32	598	70,100	117	8.11	0.2	47.7	11.0	41.0
7	1.19	30.3	2.12	348	60,300	173	15.02	2.6	27.7	62.6	7.0
8	1.22	27.8	2.96	355	77,300	218	10.23	1.1	20.2	71.0	8.7
9	1.21	28.2	2.55	386	141,500	368	17.20	0.0	17.9	70.2	11.9
10	1.21	35.0	2.83	472	217,500	460	16.13	5.8	33.5	50.2	10.5
R 1	1.38	49.5	2.27	655	142,000	217	9.81	2.1	42.4	20.2	35.4
2	1.26	39.7	2.11	485	83,900	173	13.42	2.4	15.0	56.8	25.8
3	1.30	49.0	1.91	677	46,900	69.2	8.52	1.0	50.0	33.3	15.6
4	1.15	36.2	1.58	416	142,600	342	16.22	2.6	43.0	36.3	15.3
5	1.41	44.5	2.84	705	106,000	151	8.57	1.3	54.4	33.2	11.2
B 1	1.08	28.2	1.37	217	23,250	107	9.68	0.0	.9	83.0	15.9
2	1.38	44.5	2.42	559	53,250	95.2	6.90	0.3	32.1	56.6	10.9
3	1.28	41.4	2.12	557	66,250	119	8.32	0	51.4	45.4	3.4
4	1.37	42.6	2.68	602	53,500	89.0	6.20	0.7	2.9	87.0	9.7
5	1.30	38.1	2.50	494	43,600	88.5	6.17	0.0	4.9	81.0	14.2
T 1	1.21	32.0	2.08	397	35,300	88.9	9.68	0	1.8	37.0	61.2
2	1.27	38.9	2.18	477	41,800	87.7	9.40	0	2.2	40.4	57.4
3	1.40	51.1	2.26	708	30,400	42.9	7.78	.6	21.4	39.9	38.0
4	1.22	36.2	2.01	465	47,100	101	10.10	0	10.2	71.6	18.2
5	1.36	49.1	2.41	695	31,100	44.8	6.15	3.3	18.7	47.2	30.8
Ca 1	1.07	15.0	1.77	207	21,700	105	6.95	0	52.2	40.0	11.2
2	1.46	45.0	3.32	748	64,600	86.5	5.61	0.7	12.8	69.8	16.7
3	1.34	43.8	2.42	555	69,200	124	8.75	0	13.0	58.8	28.2
4	1.39	51.0	2.28	706	63,700	90.1	7.00	0.5	25.4	34.5	39.6
5	1.35	40.7	2.74	618	41,600	67.3	6.80	0	0.8	39.5	59.7
Cl 1	1.32	41.5	-	542	141,500	261	11.40	0.2	8.9	83.5	7.4
2	1.43	41.6	-	692	91,200	132	7.53	6.3	9.9	75.0	8.5
3	1.28	40.4	-	522	101,500	194	10.60	0.3	10.3	83.4	3.1
4	1.35	45.5	-	615	52,650	85.5	6.89	0.0	6.1	64.5	29.4
5	1.43	55.2	-	830	44,900	54.0	5.54	2.6	10.4	55.3	31.5
S 1	1.29	39.0	2.42	511	44,000	86.0	6.56	0	10.6	23.0	16.6
2	1.62	62.0	2.68	1002	22,150	22.1	1.98	0	62.0	32.6	5.3
3	1.61	43.0	-	906	11,400	12.6	0.73	0	80.0	18.0	2.4
Average	1.32	41.5	2.27	560	64,080	131.7	9.08	2.3	24.9	49.8	23.0

* Sample from area not dredged by Corps of Engineers.

TABLE NO. 3

CYLINDER SETTLING AND FILTERABILITY TESTS - UNIVERSITY OF WISCONSIN

(Sediments diluted to ~200 g/l - Settled two hours)

Sample		Initial Tot. Solids g/l	Initial Tot. V.S. g/l	Supernatant (2) T.S. mg/l	Supernatant (2) V.S. mg/l	Supernatant (2) Turb. (1)	Supernatant (2) COD mg/l	Supernatant (2) P mg/l	Supernatant (2) N mg/l	Interfacial Settling Rate ft/day	Final Solids g/l	Supernatant Volume ml	Thickener (3) Unit Area Required	Sediment Filterability (4) Initial %Moisture	Sediment Filterability (4) Final % Moisture
G	1	238.0	25.8	-	-	5+	-	-	-	-	239	5	-	70.8	64.1
	2	190.8	11.1	-	-	1	-	-	-	-	197	30	-	-	-
	3	150.5	21.3	-	-	5+	-	-	-	-	-	-	-	74.5	70.1
	4	-	-	-	-	-	-	-	-	-	-	-	-	72.4	72.6
	5	79.9	10.5	1500	420	4	30	4.0	30.8	-	140	430	-	45.9	44.9
I	6	141.2	15.6	960	260	5+	40	1.0	30.8	22.71	321	560	5.59	46.6	34.8
	7	190.2	26.1	-	-	3	-	-	-	0.35	195	25	11.96	77.4	54.8
	8	178.6	16.9	-	-	1	172	1.2	35.2	1.09	194	80	13.02	71.0	50.0
	9	168.7	28.4	-	-	2	58	0.6	30.8	1.24	187	100	15.00	68.0	50.5
	10	-	-	-	-	-	-	-	-	-	-	-	-	62.7	38.5
R	1	138.2	19.8	1380	300	3	540	1.7	27.5	7.92	240	430	12.39	51.7	42.7
	2	168.3	20.6	700	140	2	72	0.7	27.5	8.14	234	280	6.56	61.7	49.2
	3	155.7	42.1	1460	460	4	810	1.05	40.7	21.13	339	540	5.26	49.9	40.0
	4	110.6	24.1	5360	1260	5	2740	11.4	27.5	8.24	184	400	14.03	62.9	62.2
	5	195.1	38.8	760	180	4	87	0.4	11.0	13.31	424	540	6.66	49.5	47.2
B	1	326.9	27.1	280	40	2½	570	0.4	48.4	1.35	376	130	9.45	80.2	42.3
	2	222.8	18.9	1700	380	5+	420	1.9	31.9	6.21	420	470	10.88	57.9	33.2
	3	167.6	13.3	1040	380	4½	556	-	30.8	7.99	424	605	14.46	58.7	33.5
	4	188.2	12.5	1100	240	2½	40	0.7	-	3.64	273	310	14.52	56.1	52.0
	5	182.0	12.6	-	-	2	214	0.6	15.4	0.53	192	50	17.22	62.1	47.0
T	1	181.9	15.6	-	-	1	-	-	17.6	0.79	198	80	18.08	67.4	63.3
	2	215.4	16.8	780	100	2½	6	1.20	11.0	4.75	342	370	11.57	72.9	59.3
	3	198.9	18.7	-	-	-	-	-	-	0	199	0	0	49.5	47.0
	4	206.1	19.8	-	-	3½	-	-	-	0.42	209	15	5.21	64.2	61.0
	5	-	-	-	-	-	-	-	-	-	-	-	-	51.1	33.5
Ca	1	-	-	-	-	-	-	-	-	7.60	-	-	-	81.6	33.3
	2	-	-	-	-	-	-	-	-	12.67	-	-	-	51.0	37.1
	3	174.2	19.9	620	200	2	10	0.35	15.4	2.69	306	430	29.42	58.0	48.7
	4	175.3	15.9	600	120	1½	-	0.15	11.0	2.06	313	440	39.06	50.0	45.7
	5	187.1	14.3	-	-	5+	-	-	15.4	0	187	0	0	55.1	53.2
Cl	1	198.5	28.0	1120	380	-	496	1.7	-	-	331	400	-	58.5	46.8
	2	176.7	35.8	980	200	-	320	-	-	-	305	420	-	58.4	37.6
	3	199.8	24.8	240	20	-	39	0.2	45.1	-	215	70	-	59.6	55.9
	4	205.6	14.4	1100	220	-	278	1.5	24.2	-	324	365	-	54.5	41.5
	5	189.6	11.3	960	180	-	166	1.6	41.8	-	372	490	-	-	-
S	1	206.6	15.1	620	20	3½	20	1.3	8.8	-	440	530	-	60.4	44.5
	2	180.1	5.0	740	120	4	40	-	13.2	-	667	730	-	38.3	31.1
	3	-	-	-	-	-	-	-	-	-	-	-	-	42.0	10.0

(1) Rated from 1-clear to 5-very turbid, as observed in photo.
(2) Liquid portion after 2 hours settling.
(3) Tons per square foot per day.
(4) Sediment filtered with vacuum for 30 minutes.

* Sample from area not dredged by Corps of Engineers

fast as compared to the sediments from the more open harbor areas. Harbor area sediments in some instances, however, can contain considerable sand deposited by littoral drift. The specific gravity of the solids is influenced predominantly by the siliceous nature of the silts and clays and thus is generally over 2.

The portion of the solids which are volatile and, presumably, organic for the most part, varies considerably. The average is about 10%. It is essentially this portion of the sludge, along with associated phosphorous, that makes it so objectionable.

The dredgings vary in color, the range from light grey to black indicates the occurrence of anaerobic decomposition in the muds. Some samples reflected the predominant color of industrial waste material, in particular, the reddish color of iron hydroxides.

The sludges from the river have been lying in place for a year or more and are at about maximum compaction. Re-suspending the solids by dilution and then resettling resulted in a more dilute sludge. This is indicated by short term settling curves run on samples diluted to 10% and 20% solids at the University of Wisconsin. The results of these tests are summarized in Table No. 3.

In the plain settling tests, raw mud samples were diluted to approximately 20% solids, mixed, and allowed to settle in a one-liter cylinder for two hours. Analyses of the supernatant and calculations of the settling rate and unit area requirements were made. As can be seen from the initial and final solids, there is a large variation from sample to sample in compaction. Comparing the final solids with the solids concentration of the raw muds shown in Table No. 2, it can be observed that the sludges have not compacted back to the original values. The interfacial settling rate is for the period in which the sludge compacts at a constant rate, after which the rate decreases considerably. Although variations from sample to sample are great, most samples would require long detention periods to attain the solids content in the original samples (weeks to months). The unit thickener area calculated is only for the final solids concentration attained in the test and would have to be greatly increased for compaction to the original solids content.

Phosphorus content in the supernatant varied; it was generally less than 1 mg/l. The higher values occurred usually when the turbidity of the supernatant was high due to poor settleability of fines in the sample. Suspended solids were not run on the samples but an estimate of clarity was made by observing photos of the supernatants.

Filterability tests were run on the raw mud samples using a Buchner funnel under vacuum. The final columns show the change in moisture content of the samples after filtering for thirty minutes. There is considerable variation in the filterability of the samples. In general, the increase in solids content was relatively slight.

Mud washing studies were run in which sediment samples were diluted to about 10% solids, aerated and settled. Table No. 4 shows the results. The initial supernatant is the layer of solids-water above material which

TABLE NO. 4

MUD WASHING TESTS-UNIVERSITY OF WISCONSIN

(Sediments diluted to 100 g/1 - Settled two hours.)

Sample		Initial Solids g/1	Init. Supernatant (1) Tot. Sol. g/1	Init. Supernatant (1) Volatile Sol. g/1	Grit % Dry Wt.	Final Supernatant (2) Tot. Sol. mg/1	Final Supernatant (2) Volatile Sol. mg/1	Final Supernatant (2) COD mg/1	Final Supernatant (2) P mg/1	Final Supernatant (2) N mg/1	Observed Turbidity	Settling Rate Ft./day	Final (3) Solids g/1
G	1	74.8	57.8	10.7	22.7	2,100	400	553			4	28.51	149.6
	2	88.7	83.3	7.5	6.1	900	200	63			1	4.07	128.2
	3	68.2	65.8	10.6	3.5	680	260	319			3	11.97	120.7
	4	-	-	-	-	-	-	-			-	10.03	-
	5	-	-	-	-	-	-	-			-	-	-
I	6	-	-	-	-	-	-	-			-	-	-
	7	115.4	103.8	16.0	10.1	5,020	2,700	40	0.55	22.0	2½	21.65	245.5
	8	94.2	77.4	9.7	17.8	640	380	167	0.50	20.9	2	31.68	265.4
	9	84.3	77.6	15.3	8.0	240	80	198			3½	24.82	255.5
	10	-	-	-	-	-	-	-			-	-	-
R	1	48.6	41.3	7.8	15.0	1,000	300	71			3	36.96	211.3
	2	99.7	95.1	13.5	4.6	-	-	99			1¼	28.51	243.2
	3	95.2	38.0	9.2	60.0	950	300	246			-	70.75	544.0
	4	54.4	40.0	10.0	26.5	2,600	450	754			-	62.30	259.0
	5	106.3	44.8	5.6	57.8	750	150	132			-	36.70	545.1
B	1	131.6	118.2	11.9	10.2	850	250	541			-	22.70	376.0
	2	58.9	66.6	5.4	-	700	150	287			-	14.78	392.7
	3	60.1	45.6	5.2	24.1	800	250	562			-	15.49	522.6
	4	61.5	56.2	4.4	8.6	650	200	139			-	16.05	286.0
	5	86.3	76.0	5.3	11.9	1,000	300	359			-	14.15	292.5
T	1	-	-	-	-	-	-	-			-	-	-
	2	-	-	-	-	-	-	-			-	-	-
	3	94.3	93.4	8.5	1.0	710	220	142			3	6.44	161.2
	4	98.0	93.3	9.0	4.8	1,540	284	24	1.85	48.4	4½	39.07	237.9
	5	-	-	-	-	-	-	-			-	-	-
Ca	1	-	-	-	-	-	-	-			-	-	-
	2	102.6	86.4	6.3	15.8	1,250	200	285			-	72.86	570.0
	3	109.3	92.3	9.4	15.5	600	200	113			-	46.99	321.5
	4	136.7	112.4	4.1	17.8	450	100	70			-	12.85	297.2
	5	92.3	91.2	8.8	1.2	560	180	67			1¼	4.22	148.9
Cl	1	70.2	68.7	9.7	2.1	700	200	296			-	32.21	275.3
	2	53.3	68.6	5.7	-	400	-	4			-	44.35	209.0
	3	112.4	113.1	11.7	-	960	100	218			-	23.50	258.4
	4	73.0	62.4	4.9	14.5	800	200	111			-	-	-
	5	62.0	50.4	13.0	18.7	850	200	127			-	-	-
S	1	83.1	48.5	4.9	41.6	8,500	200	253			-	13.02	197.9
	2	47.3	2.1	0.4	95.5	1,800	350	294			-	34.85	175.2
	3	58.2	2.2	0.3	96.1	1,800	300	260			-	-	-
Average		84.0	69.1	3.1	22.6	1,372	325	226			1=clear 5-opaque	27.91	295.9

(1) Mud-liquid mix after 2 minutes settling.
(2) Clear liquid after 2 hours settling.
(3) Solids in <u>sludge layer</u> after 2 hours settling.

* Sample from Area not dredged by Corps of Engineers

settled in two minutes; this material is presumably grit. Grit quantities varied considerably in the various samples from a low of 1.0% to a high of 96% in the relatively clean Sodus Bay Samples.

The final supernatant is the liquor above the sludge after two hours' settling. Final supernatants contained some turbidity, phosphates, nitrogen and COD. Approximate settling rates for the solids and the final solids concentration after two hours' settling are also shown in Table No. 4. The average solids concentration in the sludge layer after two hours was 295.9 g/l as compared to the average of 560 g/l solids concentrations of the original undisturbed samples.

Separation of the heavier sand-gravel portions of the solids would seem quite possible by hydraulic methods. Some fines and organics, however, would need be washed from the grit obtained in the initial separation in order to obtain a clean material.

3. Chemical Characteristics

As previously mentioned, by far the greater portion of the dredgings is soil; silica is the main constituent. Samples of the sediments were analyzed for other chemical constituents, as shown in Table No. 2. The volatile solids in the sediments are mostly composed of organic materials both from the natural environment and from human activities. Some inorganic materials such as those with water of hydration could also, however, contribute to the volatile solids content. The range of volatile solids content is considerable with the average being about 10%.

Chemical oxygen demand tests were performed on samples of dredgings and the results are shown in Table No. 2. This value, which to a great extent measures organics in terms of oxygen required to convert them to CO_2 and water, is quite significant. Presumably by either chemical or bacteriological action over a period of time, much of the COD would have to be satisfied to stabilize this material.

Phosphorus, one of the most significant compounds involved in the high eutrophication rates in the Lakes is found in significant quantities in the sediments. This phosphorus, for the most part, appears to be insoluble or at least adsorbed on soil particles. The objection to this chemical, particularly in the organic form, is that through biological action and slight chemical solubility, it becomes available as a nutrient to bacteria and algae which hasten the aging of the Lakes.

Nitrogen has also been measured in significant quantities in the muds. This material is also a nutrient to the plankton in the lake. Nitrogen enrichment of the lake, however, is not as controllable as phosphorus and since other natural sources are heavy contributors the nitrogen contributed by the mud is somewhat less significant than the phosphorus contribution.

Iron and oils or greases have been found in high quantities from some of the harbors and are indicative of industrial pollution. The oils or greases contribute to the volatile solids and chemical oxygen demands of the sediment, and can be a source of organic matter for undesirable biological growths in the lake bottoms.

4. Biological Characteristics

The biological characteristics and the effect of the sludges on various forms of biological life are being studied at the University of Wisconsin, concurrently with the preparation of this report. The available findings on the effects on biological life at the time of the writing of this report were very incomplete. However, indications were generally that the sediments mixed with pure cultures of various plankton would initially depress plankton growth followed by a subsequent increase in growth. In a reported test, sediment from one harbor showed high toxicity to a plankton species after several days' exposure.

Only a few harbor sediments were analyzed for biological oxygen demand as shown in Table No. 1. These results indicated a fairly low BOD as compared to the measured COD. Considering the tremendous quantities of dredgings, the value, in terms of total pounds, could be quite significant. If acclimatized seed were used for the BOD tests, the BOD values may change considerably so that this parameter would assume greater importance.

The University of Wisconsin performed tests on the aerobic and anaerobic treatability of the various harbor sediment samples collected. Aerobic studies were made on sediments diluted to about 4000 mg/l total solids. With such dilutions, however, the COD values were quite low. The data was incomplete at the time of preparation of this report and no conclusions as to the extent of reduction of biological demand, volatile solids or COD could be made. Aerobic tests on sludges at 10% solids were also performed.

The results are shown in Table No. 5. Significant COD reductions on some samples were obtained after five days of aeration. Table No. 6 shows the reduction in COD obtained by aerating supernatant obtained by settling 10% sludges for 6 1/2 hours. Unfortunately, BOD tests were not performed on these sludge samples. However, it might be presumed that if the sludges had a BOD demand it would indicate that they were not toxic and that this demand could be satisfied by aeration. Correlation of the destruction of volatile solids and BOD reduction with time of aeration would require testing.

The anaerobic studies were performed by seeding samples of sediments with a locally obtained digester sludge in closed digesters at room temperature and observing the gas production. These tests gave an initial indication of the response of the sediments to anaerobic decomposition. Because of difficulties in sampling accurately and the necessarily small size sample tested, the most significant data obtained from these studies was gas production. Even the most prolific gas producing sludges, however, yielded only about one cubic foot of gas per pound of volatile solids after twenty-five days of digestion. Table No. 7 summarizes some of the data available on anaerobic decomposition. While these tests are by no means conclusive, since such parameters as temperature, mixing, continuous feed, adaptation of micro-organisms, etc. were not all controlled or determined, they do give some indication of the activity of these sludges. It can be observed that for some sludges essentially no anaerobic biological action occurred, while for a few, considerable gas production was observed. In general, under test conditions, anaerobic activity appeared to be quite low.

TABLE NO. 5

AEROBIC TREATMENT OF SLUDGES

10% SOLIDS CONCENTRATION
AERATION PERIOD 4 DAYS
UNIVERSITY OF WISCONSIN TESTS

Sample	COD mg/l			% Overall COD
	Initial	Sludge	Supernatent*	Reduction **
R-1	16,000	32,800	664	45.0
R-6	35,000	58,300	430	0
G-3	18,650	17,850	1000	Slight-No Significant Settling
Ca-4	15,800	33,800	82	11.4
T-3	12,800	19,850	78	19.3
I-9	38,500	87,300	258	14.9
Cl-1	34,000	59,600	398	17.3
Cl-3	16,320	13,900	291	65.0
B-2	18,800	47,600	410	10.6
B-4	10,800	20,800	623	15.7
S-1	11,320	45,800	488	0
S-2	6,400	33,300	618	36.0

* Liquid above solids after settling for 2 hours.

** Calculated based on sludge and supernatent COD

TABLE NO. 6

AEROBIC TREATMENT OF SUPERNATANT FROM MUD SETTLING

AERATION PERIOD 6-1/2 HOURS

Sample	COD mg/l Initial	COD mg/l Final	% COD Reduction
* R-1	458	247	55
G-1	357	274	23
G-3	128	158	0
Ca-5	13	21	0
T-3	75	79	0
T-4	220	203	7.5
B-1	208	75	64
B-4	23	35	0
I-6	178	75	58
I-9	395	96	75.6
Cl-3	145	147	0
* S-1	65	40	38.5

* These samples were settled to 20% total solids instead of 10%

TABLE NO. 7

SUMMARY OF ANAEROBIC TREATMENT DATA FROM UNIVERSITY OF WISCONSIN

Sample		Total Solids[1] g/l	Volatile Solids[2] g/l	COD Initial g/l	COD Final g/l	25-Day Gas Production CF/#VS (3)
G	1	177.0	19.7	23.1	25.0	0.350
	2	188.0	9.6	3.6	3.3	0.133
	3	143.8	19.2	25.4	24.5	0.393
	4	157.5	23.7	29.8	26.1	0.666
	5	394.3	22.6	25.8	21.9	0.223
I	6	598.2	48.6	38.4	47.6	0.103
	7	226.1	31.6	29.8		Poor
	8	182.0	19.1	29.8		Poor
	9	219.6	36.6	45.6		Fair
	10	175.2	37.3	70.6		Fair
R	1	654.9	64.3	94.6	86.5	0.370
	2	485.1	65.1	101.5	89.3	0.168
	3	676.6	57.7	62.4	78.5	0.777
	4	416.2	79.2	72.5	70.5	0.975
	5	704.6	60.4	78.5	93.2	0.173
B	1	328.8	24.1	31.2		Good
	2	192.2	19.2	30.2		Good
	3	193.9	17.8	40.3		Poor
	4	231.0	11.2	17.1		Poor
	5	214.2	10.9	19.8		None
T	1	198.7	19.3	12.9	14.7	0.356
	2	238.3	22.4	16.2	19.2	0.199
	3	354.2	27.5	20.5	20.9	0.149
	4	232.5	23.5	22.2	22.0	0.366
	5	173.5	10.5	7.8	8.4	0.187
Ca	1	103.5	7.2	9.5	11.8	0.368
	2					
	3	555.5	48.7	97.3	87.8	0.020
	4	530.0	36.7	67.0	69.6	0.112
	5	540.0	43.4	36.1	33.8	0.053
Cl	1	225.0	23.1	49.2		Poor
	2	264.7	20.6	24.6		Poor
	3	227.6	24.0	36.4		Good
	4	219.7	16.6	7.9		Fair
	5	229.7	13.6	5.9		Fair
S	1*	200.3	14.5	18.5		Poor
	2	111.0	6.4	5.5		None
	3	54.7	2.3	0.6		Poor

(1) In sample under anaerobic test. (2) Volatile portion of total solids.
(3) I, B, Cl, S started 7/25/68, data not received as of 9/6/68. Comment based on observed raw data. (Cubic feet per pound of volatile solids.)
*Sample from area not dredged by Corps of Engineers.

C. TREATMENT CONSIDERATIONS

1. General

During the study of treatment processes for the dredgings, it became evident that the material would have to be stored on dry land for some time prior to treatment. The storage areas would serve as surge basins as the treatment rate would be constant, while the feed from the dredges would be intermittant and at varying rates.

The storage areas and treatment processes raise three problems:

a) To handle the bottom deposits, the dredging operations ultimately have to dilute the solids to a 10 to 20% concentration (dry solids by weight). The hopper bottom dredges are required to do this in order to pump the dredgings from their hoppers to to the storage areas. The clam shell type dredges would not normally require the dilution of the excavated material, but in order to unload the scows, to the storage areas, the only feasible way that will minimize pollution of the adjacent harbor waters is to use a hydraulic dredge taking suction inside the scow.

To dilute the harbor bottoms requires a large volume of water. When the diluted sludge is allowed to stand for a period of days, the heavier solids settle and compact. The water remaining contains light suspended particles. To keep the storage areas to a minimum size, the water that separates from the solids should be discharged back to the adjacent harbor waters. Before this can be done, the suspended solids in the water will have to be reduced to a minimum. This is the first problem.

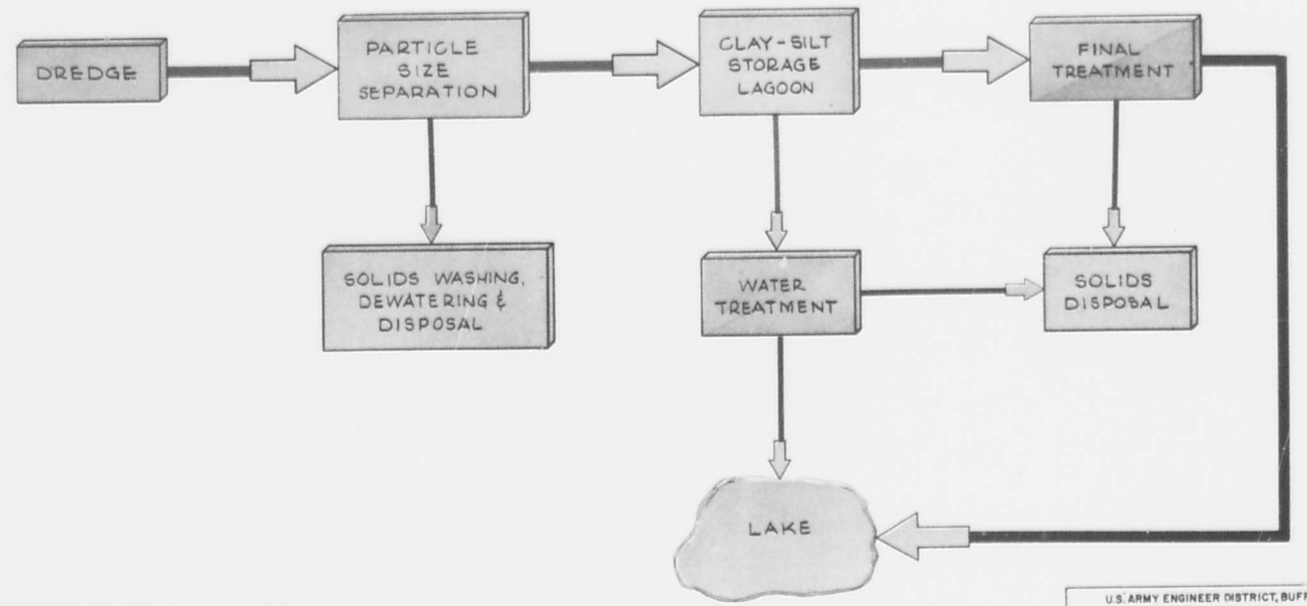
b) The solids removed from the harbor bottoms are made up of particles ranging in sizes from 4 to 5 inch pieces of broken concrete to fine clay and silt particles. The larger particles down to fine sand (100 microns) are generally inert and could be used as a clean stable fill or deposited on the lake bottom without causing pollution. The separation of these larger inert particles from the finer particles is the second problem.

c) After the larger inert particles are removed from the dredgings, the remaining smaller particles will have to be treated before they can be considered acceptable for stable fill or for deposit on the bottom of the lakes. These smaller particles contain volatile solids, oxygen demanding solids, bio-degradable solids, oils and greases and phosphorus compounds. The treating of these solids to a form that will make them acceptable for use as stable fill or for depositing on the bottom of the lakes is the third problem.

In all of the three basic problems there are many other associated factors such as storing of dredged materials, rehandling of the dredged materials, pumping of sludges and handling of the treated water and solids.

2. Basic Operation Assumed

In preparing treatment processes a basic flow-materials pattern had



U.S. ARMY ENGINEER DISTRICT, BUFFALO
CORPS OF ENGINEERS

BASIC FLOW DIAGRAM

NEBOLSINE, TOTH, McPHEE ASSOCIATES
CONSULTING ENGINEERS
NEW YORK, N.Y.

DATE SEPT-6-68
SCALE NONE

PLATE 1

to be assumed. The treatment rate would depend on the relative economics of all of the variables that have to be considered. The basic flow pattern is shown on Plate No. 1.

Wherever economically feasible, the larger particles will be separated and washed as the dredgings are pumped from the dredges and scows. The larger clean particles will be discharged to scows for hauling to designated disposal areas. The sludge containing the smaller particles will be discharged to a diked-off storage area. The water separated from this sludge will be treated to remove sufficient suspended solids so that the water can be discharged to the adjacent harbor waters. The thickened solids will be extracted from the storage area and treated for reduction of contaminants. The treated solids will be handled and transported to scows for hauling to designated disposal areas. The water separated from the treated solids will be treated to remove excess suspended solids and bio-chemical oxygen demand (BOD).

The same storage area will be utilized for each year's dredging until such time as the maintenance dredgings no longer require treatment before being dumped into the lake.

3. Utilization of Adjacent Sewage Treatment Facilities

On possible method of treating the organic fractions of the dredgings is to convey them to nearby sewage treatment plants for processing. The quantity of dredgings was the major consideration in investigating this alternate. Before being dumped into any portion of a municipal sewerage system, the dredgings would have to be diluted to very thin consistency to prevent depostion in the sewers. This diluted sludge would have to contain less than 1% solids by weight and in all probability less than 1/2 of 1%.

Using a 1/2 of 1% sludge, the daily volume to be handled for various yearly dredgings, equalized over one year would be as follows:

Volume of Dredgings/yr.	Pounds of (a) (b) Dredgings/yr.	Pounds of (c) Sludge/day	Gallons (d) Per Day
100,000 c.y.	107×10^6	59×10^6	6,950,000
500,000 c.y.	535×10^6	293×10^6	34,750,000
1,000,000 c.y.	1070×10^6	506×10^6	69,500,000

(a) Corps of Engineers estimate 1 c.y. of average dredging contains 1250 lbs. of dry solids.

(b) Assume 15% of solids removed as sand and gravel.

(c) Assume 365 days per year and 0.5 percent sludge by weight.

(d) Based on 8.4 pounds per gallon.

It is evident that if a 0.5 percent sludge was to be accepted, the addition of dredgings from a 100,000 cubic yard per year operation would be equal to accepting a sewage flow from an increase in population of 69,500 people and for a 1,000,000 cubic yard per year operation, a sewage flow from an increase of 695,000 people. Nowhere in the pilot areas being studied does this appear to be feasible.

The other alternative was the pumping of a heavier sludge to the adjacent treatment works for treatment and disposal with the sewage sludges. Once again the quantities to be handled are the determining factor. Assuming 10% sludge by weight, the daily volumes to be handled for various yearly dredgings, equalized over one year, would be as follows:

Volume of Dredgings/yr.	Pounds of (a) (b) Dredgings/yr.	Pounds of (c) Sludge/Day	Cubic Feet (d) Per Day
100,000 c.y.	107×10^6	2.9×10^6	44,500
500,000 c.y.	535×10^6	14.7×10^6	222,000
1,000,000 c.y.	1070×10^6	29.3×10^6	444,000

(a) Corps of Engineers estimate 1 c.y. of average dredging contains 1250# of dry solids.

(b) Assume 15% of solids removed as sand and gravel.

(c) Based on 10% sludge by weight and 365 days per year.

(d) Based on 66 pounds per cubic foot.

In a domestic sewage treatment plant 1000 people contribute approximately 150 pounds per day of dry sludge solids. This is equivalent to 40 cubic feet assuming 6% solids in the sludge. Based on this comparison, then a 100,000 cubic yard per year dredging operation would be equivalent to an additional population of 1,110,000 and for a 1,000,000 cubic yards per year dredging operation, the equivalent would be 11,100,000 people. Once again it is evident that no treatment plant in the pilot areas could accept these additional loads. Not only would the volume be excessive, but because of low volatile solids concentrations in the dredgings, the operation of any anaerobic digestion, wet oxidation or incineration facilities may prove to be troublesome.

Because of the volumes to be handled, treating the dredgings in adjacent sewage treatment plants was not investigated further.

4. Subdivision of Operations

To develop a series of cost curves so the total costs for handling, treating and disposing of the maintenance dredgings by various methods can be evaluated, the operations have been broken down as follows:

a) The separation of sand and gravel and larger size particles from the dredgings as the dredgings are discharged from the dredges or scows, and the handling of the larger particles.

b) The storing of the smaller particles.

c) The rehandling of the smaller particles up to the treatment process.

d) The treating of the smaller particles. This operation is further broken down into unit processes:

I. Aerobically stabilizing solids.

II. Anaerobically stabilizing solids.

III. Chemically stabilizing solids.

IV. Wet oxidizing solids.

V. Incineration of solids.

e) The treatment of contaminated water fraction of the dredgings. This is required both in the water separated from the dredged solids in parts (a) and (b) above and the water separated from the anaerobically stabilized, chemically stabilized and wet oxidized solids.

f) The dewatering of treated solids and handling of solids up to the point of transporting them to the disposal areas.

By combining (b), (c), (e) and (f) with one of the treatment operation under (d), a complete treatment process can be established. The following sections of this report will analyze in detail the design, construction costs and operating costs of each of the operations listed above. The cost of removing sand and gravel from the dredgings cannot be easily associated with the treatment costs, therefore the cost figures that have been developed are to be used with the dredging costs.

D) UNIT OPERATION STUDIES

In studying the various unit operations, as described in the following sections, a series of design conditions were picked so that cost curves covering a broad range of annual dredging quantities could be established. The basic design conditions selected were as follows:

Annual Dredgings	Treatment Time	Pounds of Dry Solids per Day
3,000,000 cu. yds.	270 days	13,750,000
1,500,000 cu. yds.	270 days	6,875,000
500,000 cu. yds.	270 days	2,290,000
100,000 cu. yds.	270 days	458,000

The 3,000,000 cubic yards annual quantity has been selected to establish a point on the cost curves for analysis of certain unit operations that might be considered at higher rates and portable from harbor to harbor.

The 270 days used above was selected instead of 365 days because of the anticipated problem associated with dredging and operating equipment during the extreme winter months. There are two exceptions to the 270 day period used, in the case of the aerobic treatment unit operation, 240 days has been used and in the case of the anaerobic treatment unit operation, 365 days has been used.

Corresponding to the above treatment rates of dry solids per day, annual operating and maintenance costs are also developed. Total annual costs of amortization, interest, operating and maintenance costs have been completed and converted to costs per cubic yard and presented both in tabular form and a graphic plot of annual cobuc yards versus cost per cubic yard.

In establishing the capital or first costs of the Unit Operations studies, the following subdivisions of costs were obtained and totalled:

1) Cost of installed equipment.

2) Cost of structures and buildings.

3) Cost of foundations.

4) Cost of electric power supply.

5) Cost of site work.

The cost of installed equipment was obtained from the vendors since the nature of this study was a feasibility study and the cost was all-inclusive. All vessels, pumps, compressors, piping, etc. were included in the vendor's prices. All costs throughout the report are 1968 prices and no escalation has been included.

The cost of buildings has been estimated on a unit of $20.00 per square foot for industrial type buildings including an allowance for office and laboratory space.

The cost of foundation work is based on the weight of the equipment plus an allowance for buildings and auxiliary structures multiplied by a unit cost of $30.00 per ton for piling and concrete work. Pilings were assumed to be "H" sections, 50 feet long.

The cost of electric supply is based on generating power by diesel generators at the treatment sites. This solution was used due to the fact that in several of the locations selected for the treatment, the availability of electric service was very questionable. If, after the individual projects have been investigated in more depth, the local electric utilities are competitive with on-the-site generation, then the choice can be made. In either case, the overall cost of providing the electric energy required should not be materially different. Appendix No. B contains a set of curves used to develop electrical installations and operating costs.

A factor of 5% of the overall construction cost has been used to cover the cost of site development, assuming the filling-in of sites is done by the spoiling of dredgings. The 5% should be sufficient to cover roadways, drainage, etc.

For annual maintenance a percentage of the installed equipment and structure costs has been used. Depending on the type of operation, the percentage varies from 1% for facilities with minimum mechanical operation to 15 % for high speed mechanical equipment such as centrifuges.

E. SEPARATION OF PARTICLE SIZES

1) General

Sieve analysis of dredging samples from all of the pilot areas studied indicated that all samples had some particles larger than 63 microns (see Table No. 2). The use of 63 microns as the dividing line is based on the standard of the soils engineers that classify particles above 63 microns as sand and everything below as silt or clay.

A tabulation of the averages of the sieve analyses for the eight (8) pilot areas is as follows:

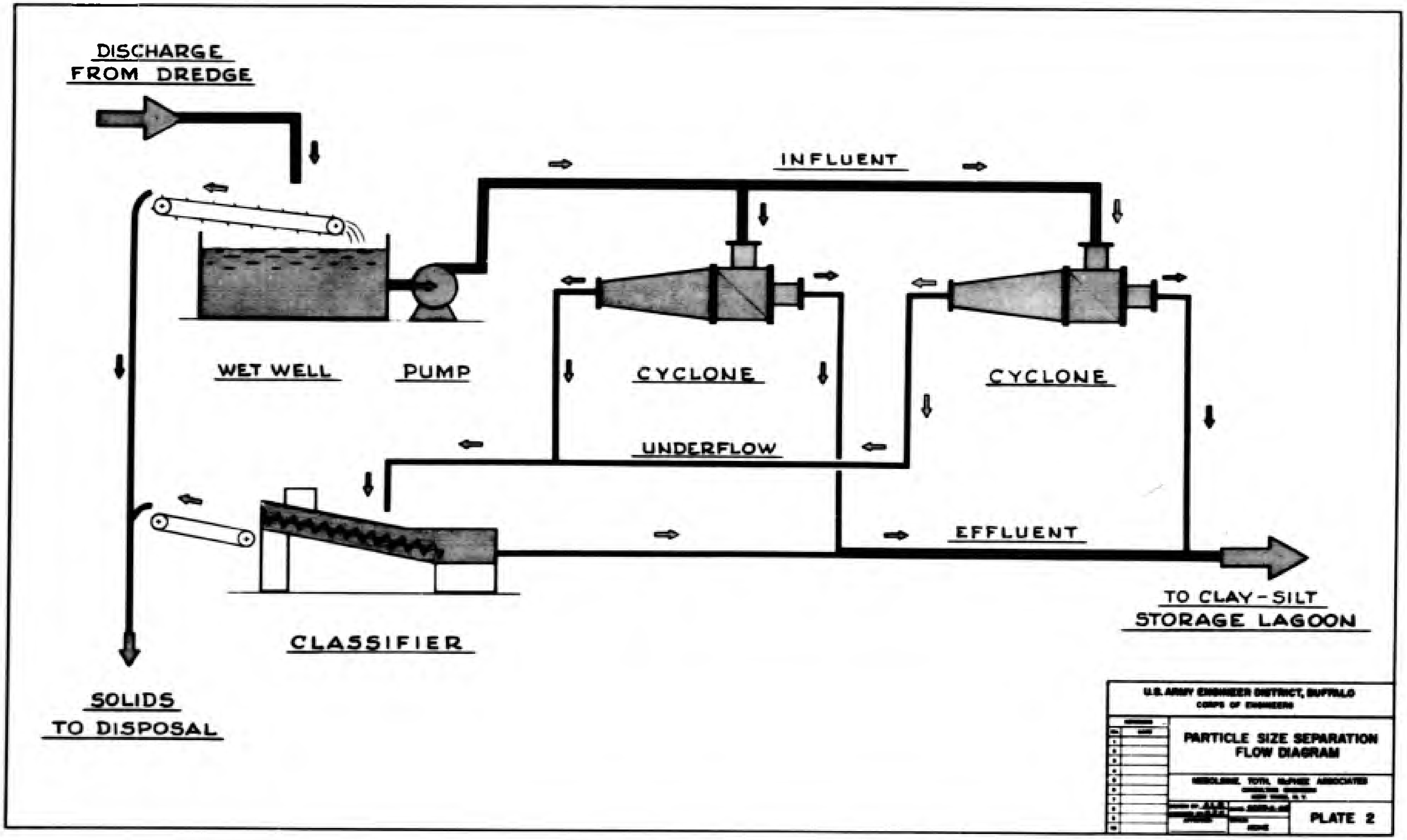
	Larger than 63 Microns	Less than 63 Microns
Sodus Bay	50.9%	49.1%
(Average Lake Ontario)	50.9%	49.1%
Buffalo Harbor	22.9%	77.1%
Cleveland Harbor	11.0%	89.0%
Toledo Harbor	11.7%	88.3%
(Average Lake Erie)	15.2%	84.8%
Rouge River	42.8%	57.2%
(Average Rouge River)	42.8%	57.2%
Indiana Harbor	31.7%	68.3%
Calumet Harbor	21.1%	78.9%
Green Bay Harbor	39.7%	60.3%
(Average Lake Michigan)	30.8%	69.2%

The average of all the harbors exclusive of Sodus Bay is 25.2% with the range of the individual samples from 0.8% to 81.8%. The 81.8% is probably not correct since the analysis of the sample showed 45.6% larger than 2 mm. Considering the size of the sample used, a pebble of this size or larger could upset the analysis completely. For the purpose of generalizing conditions in this report, a percentage of 15% for all dredgings has been assumed to represent all particles larger than 70 microns.

The mud washing test results reported in Table 4 of Section B show that there is a higher concentration of volatile solids in the grit fraction than in the silt-clay fraction. For the average condition of all samples, the original dredgings contained 9.1 percent volatile solids. After particle separation the silt-clay fraction contained 8.1 percent volatile solids and the grit fraction 12.4 percent. The grit fraction represented 22.6 percent of all of the solids present in the dredgings.

For Rouge River the average conditions of all samples, the original dredgings contained 11.3 percent volatile solids, the silt-clay fraction 9.0 percent and the grit fraction 15.9 percent. The grit fraction represented 35 percent of all of the solids. This individual harbor indicated the same basic characteristics as the average conditions for all of the harbors treated.

The separation of the larger particles (70 microns plus) may be advantageous in the treatment of the Great Lakes' dredgings. The larger particles are more easily drained of their water fraction and will therefore consolidate to more stable fill even without treatment. If the higher percentage of volatile solids present a problem then these particles can be more economically treated than the smaller particles. The economics are primarily due to the higher concentration of solids possible plus the higher volatile solids and subsequent higher heat content.


DISCHARGE FROM DREDGE
INFLUENT
WET WELL
PUMP
CYCLONE
CYCLONE
UNDERFLOW
EFFLUENT
CLASSIFIER
TO CLAY-SILT STORAGE LAGOON
SOLIDS TO DISPOSAL
U.S. ARMY ENGINEER DISTRICT, BUFFALO
CORPS OF ENGINEERS
PARTICLE SIZE SEPARATION FLOW DIAGRAM
PLATE 2

In all of the above the unknown is the nature of the volatile solids. If the volatile solids are principally organic then the grit fraction may easily putrify and become obnoxious, on the other hand, if principally the volatile solids are inorganic or not easily bio-degradable, the grit may be very stable. Another unknown is whether or not the volatile solids are agglomerated into larger particles or adhered to the surface of the inert sands and gravel. If this was the case then a violent washing of the grit, either before or after separation, would result in a very stable fraction.

To further investigate this matter a large sample of dredgings from the Rouge River (220 gallons) was obtained and shipped to a manufacturer of particle separation and other treatment equipment for test on the separation of 70 micron and 10 micron particles plus settling, centrifuging and incineration of the different fractions of the dredgings. Rouge River was selected for the work since it had high volatile solids and a high percentage of particles larger than 63 microns. (See Appendix "E" for complete test report).

Liquid-cyclone-classifier combinations have been used successfully for liquids-solids separation in sewage and industrial applications for several years. Plate No. 2 is an outline of the cyclone-classifier process which consists of rough screening of the material as discharged by the dredge, pumping the screened dredgings through cyclones, discharging the cyclone overflow to an equalization lagoon and classifying the cyclone underflow.

The liquid cyclone is a device which converts pressure into velocity thereby increasing the gravity settling forces on the liquid to be treated. The solids in the liquid accumulate along the walls of the cyclone and are drawn off the bottom through an apex valve. The liquids portion is overflowed through a vortex pipe. The underflow is directed to a classifier where the concentrated particles settle and are dewatered up an incline by a ladder type scraper.

The average results of the manufacturer's tests concerning the sand and gravel particle size separation are as follows:

	Sample as Received	Cyclone Overflow	Cyclone Underflow
% Dry Solids	23.2	22.5	58.3
% Volatile Solids	14.05	17.3	9.62
BOD (mg/l)	20,000	-	-
COD (mg/l)	81,000	-	-
Total Phosphorus (ppm)	629	-	778
Soluble Phosphorus (ppm)	4	-	3
Bomb Calorimeter (BTU/lb.)	1450	-	-
% of Solids in Feed	100%	89.8%	10.2%

Particle size determinations are as follows:

	% CUMULATIVE PLUS		
Tyler Mesh	Sample as Received	Cyclone Overflow	Cyclone Underflow
6	.158	.23	.91
8	.42	.33	1.36
10	.63	.90	1.99
14	1.05	1.21	2.66
20	1.58	1.53	3.84
28	2.64	2.12	5.73
35	3.70	2.90	8.74
48	5.17	3.60	15.28
65	7.3	4.44	28.23
100	10.2	5.94	45.43
150	13.6	8.01	58.73
200	17.1	11.33	67.40
325	25.6	19.1	75.07

From the test results the use of liquid cyclones would reduce the amount of solids to be treated and also produce a dewatered sludge, which could be used either as landfill or returned to the lakes if the volatile solids loading could be reduced. Further test work should be performed on samples from all harbors under consideration since the amount of sample used in the above tests was relatively small and definite conclusions cannot be made at this time.

Based on the above test data the costs of constructing and operating particle separation facilities have been investigated.

2. Design Considerations

Instead of using the four design loadings listed in the prior section of this report a different set of conditions was considered. Since the sand and gravel size fractions of the dredging solids may not require any additional treatment, it was decided that the best point in the treatment process to accomplish this would be as the dredgings were discharged into the storage area. By doing it at this point the rehandling of the larger size particles would be eliminated.

The design loadings used to size the sand and gravel separation units was based not on annual dredgings but on actual dredge discharge rates. These dredge discharge rates for Cleveland and Buffalo Harbors are as follows:

DREDGES

	Markham	Lyman, Hoffman & Haines	Scows Unloading	Average
Cleveland Harbor				
Loads per day	19.7	17.1	-	-
Vol. discharged per load (cubic yards)	3910	1665	-	-
Flow rate during discharge (gpm)	23,400	8000	10,000	-
Discharge % Solids	27.2	19.85	15.0	22.3%

Buffalo Harbor				
Loads per day	-	14.6	-	-
Vol. discharged per load (cubic yards)	-	1395	-	-
Flow rate during discharge (gpm)	-	8000	10,000	-
Discharge % solids	-	22.9	15.0	22.9%

From the above available data three flow rates were chosen for study in selecting particle size separation units. The flows are 23,400 gpm, 10,000 gpm and 8,000 gpm, which represent the expected flows from the various dredges and scows now in service in the Great Lakes harbors under study in this report.

The amount of cubic yards dredged and subsequently to be treated by the particle size separation units was also considered in preparing costs. The amount of dredgings to be treated was assumed to be 50% of the total amount of cubic yards dredged by each type of dredging operation under consideration. The dredges will have to be scheduled so that the particle size separation unit will be available in the harbors needed when a dredging operation is to start. This could be accomplished by staggering the harbors to be treated so that the particle size separation units would be moved from one harbor to another while the dredge was operating in a harbor that did not require treatment.

The following is the approximate total annual dredging for each type of dredge operation:

	Approximate Total Annual Dredgings Million Cu. Yds.	50% of Annual Dredgings Million Cu.Yds.
Markham	6	3
Hoffman, Lyman & Haines	6 Total 2 Each	 1
Scows	1	.5

The following is a list of the harbors under study and the principal type of dredging used in each harbor:

HARBOR	DREDGE TYPE
Sodus Bay	Hoffman
Buffalo	Hoffman and Scow
Cleveland	Markham, Hoffman and Scows
Toledo	Markham
Rouge River	Hoffman
Indiana	Scows
Calumet	Scows and Hoffman
Green Bay	Markham and Scows

As stated above, it was assumed that 15% of the dredgings are greater than 70 microns in size and would be removed by these units.

3. <u>Capital Cost Estimates</u>

In addition to the equipment costs received from the various manufacturers, estimates were made of the approximate barge prices to carry the nec-

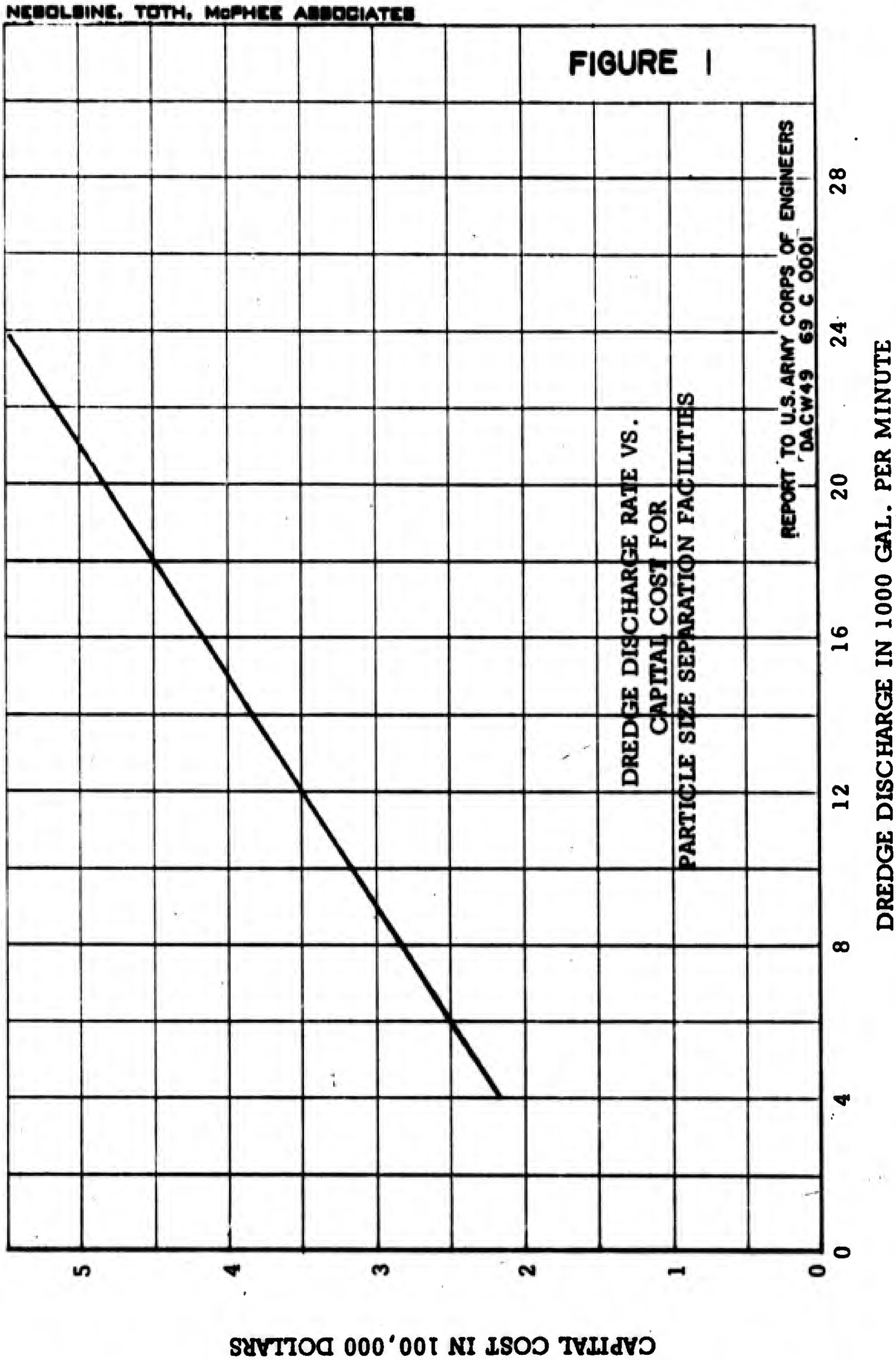


FIGURE 1
DREDGE DISCHARGE RATE VS.
CAPITAL COST FOR
PARTICLE SIZE SEPARATION FACILITIES
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001
DREDGE DISCHARGE IN 1000 GAL. PER MINUTE
0
4
8
12
16
20
24
28
CAPITAL COST IN 100,000 DOLLARS
0
1
2
3
4
5

essary equipment. For the three design conditions the following summary was developed:

	Markham	Scows	Hoffman, Lyman & Haines
Dredge Discharge	23,400	10,000	8,000
Lbs/min.dry solids	49,500	-	16,900
15% of dredgings (#/min)	7,430	-	2,540
Installed Equipment	$200,000	$110,000	$ 90,000
Barge	100,000	70,000	70,000
Electric Service	131,000	68,000	68,000
Sub-Total	$431,000	$248,000	$228,000
Engineering & Contin.	108,000	62,000	57,000
TOTAL	$539,000	$310,000	$285,000

Based on these three design points Fig. No. 1 was developed. This curve provides the means of estimating the capital cost of particle size separation facilities for any dredge discharge in gallons per minute. The capital costs from this curve are also used in developing the costs for financing the construction of the project. A term of ten years and 4-5/8% annual interest is used for this purpose, or a factor of 12.72% per year of the capital costs.

4. Operating Costs

Daily operating costs for particle size separation units are made up of the following:

I. Operating Labor and Supervision.

II. Utility Costs (fuel, electricity, water.)

III. Maintenance (labor and materials).

For the item of Operating Labor and Supervision, the following table of the 24-hour manpower requirements was estimated:

Dredge Discharge Rate (gpm)	23,400	10,000	8,000
Superintendent	0	0	0
Foreman	1	1	1
Operators	3	3	3
Asst. Operators	3	0	0
Chemists	0	0	0
Asst. Chemists	0	0	0
Laborers	3	3	3
TOTALS	10	7	7

Appendix C lists the daily labor costs used. The services of a Superintendent and a chemist have not been included due to the fact that the particle size separation units will be used in conjunction with some other subsequent treatment facility where these services will be readily available:

Electricity requirements are as follows:

Dredge Discharge (gpm)	23,400	10,000	8,000
Electricity KWH/year	160,000	28,500	64,000*

* The greater KWH usage for a smaller facility is due to the greater operating time per year.

Appendix B lists the utility costs used.

TABLE NO. 8

SUMMARY OF COST FOR SEPARATION OF PARTICLE SIZES

DREDGE	C.Y. Per Year Dredged (Millions)	Capital Cost	Annual Finan-ing Cost	Annual Labor Cost	Annual Utilities Cost	Annual Maint. Cost	Total Annual Operat. & Maint. Cost	Total Annual Cost	Cost Per C.Y.
Markham 23,400 gpm	3	539,000	69,000	153,000	2,500	54,000	209,500	278,500	.09
Scows 10,000 gpm	.5	310,000	39,000	109,000	300	31,000	136,700	175,700	.35
Hoffman, Lyman and Haines 8,000 gpm	1	285,000	36,000	109,000	1,000	29,000	139,000	175,000	.18

Maintenance, labor and material costs were estimated to be 10% of the installed cost of equipment. They are as follows:

Dredge Discharge (gpm)	Annual Maintenance Cost
23,400	$59,000
10,000	31,000
8,000	29,000

The summary of the Operating, Utility and Maintenance Costs for the three (3) dredge discharge rates is shown on Table No. 8 for each type of dredge investigated.

The costs per cubic yard presented on Table No. 8 cover only the cost of particle size separation from the dredgings. The costs in this table should be added to costs of each harbor and is not to be included in the treatment costs.

F. STORING AND HANDLING DREDGINGS

1. General

The operation of the Corps of Engineers dredges plus contract dredges in the Great Lakes is a vast undertaking. In Lake Erie alone it is estimated that future annual maintenance dredgings will approach 6,500,000 cubic yards. All of the maintenance dredging is done in approximately a nine-month period or an average of approximately 700,000 cubic yards per month. To attempt to treat this quantity of dredgings in an in-stream or continuous process does not appear to be the most economical approach. Some equalization, by storing, will be necessary to permit a reasonable design of treatment facilities.

The dredgings, as noted before, are of two types, the diluted type dredging from the hopper type hydraulic dredge and the excavated, firmer type dredging from a clam shell type dredge. The river and harbor bottoms in their undisturbed form contain approximately 40% solids. The hopper type dredge dilutes the bottom material to about 20% solids by weight, while the clam shell type dredge removes the bottom material substantially in its undisturbed form. In either case, when the dredged material is discharged to a storage area it will contain approximately 20% solids.

2. Design Considerations

Two costs are to be developed under this section of the report and they are as follows:

a) Cost of providing storage facilities.

b) Cost of rehandling stored dredgings.

a) In the first case, that of developing cost of providing storage facilities, a series of work curves have been developed for use in arriving at the annual cost per cubic yard for the storage facilities. These work curves are contained in the Appendix D of this report and are as follows:

I. Series of curves for estimating the cost of a three-sided, 20-foot deep storage area with various dike sections.

II. Same as I except for four-side storage area.

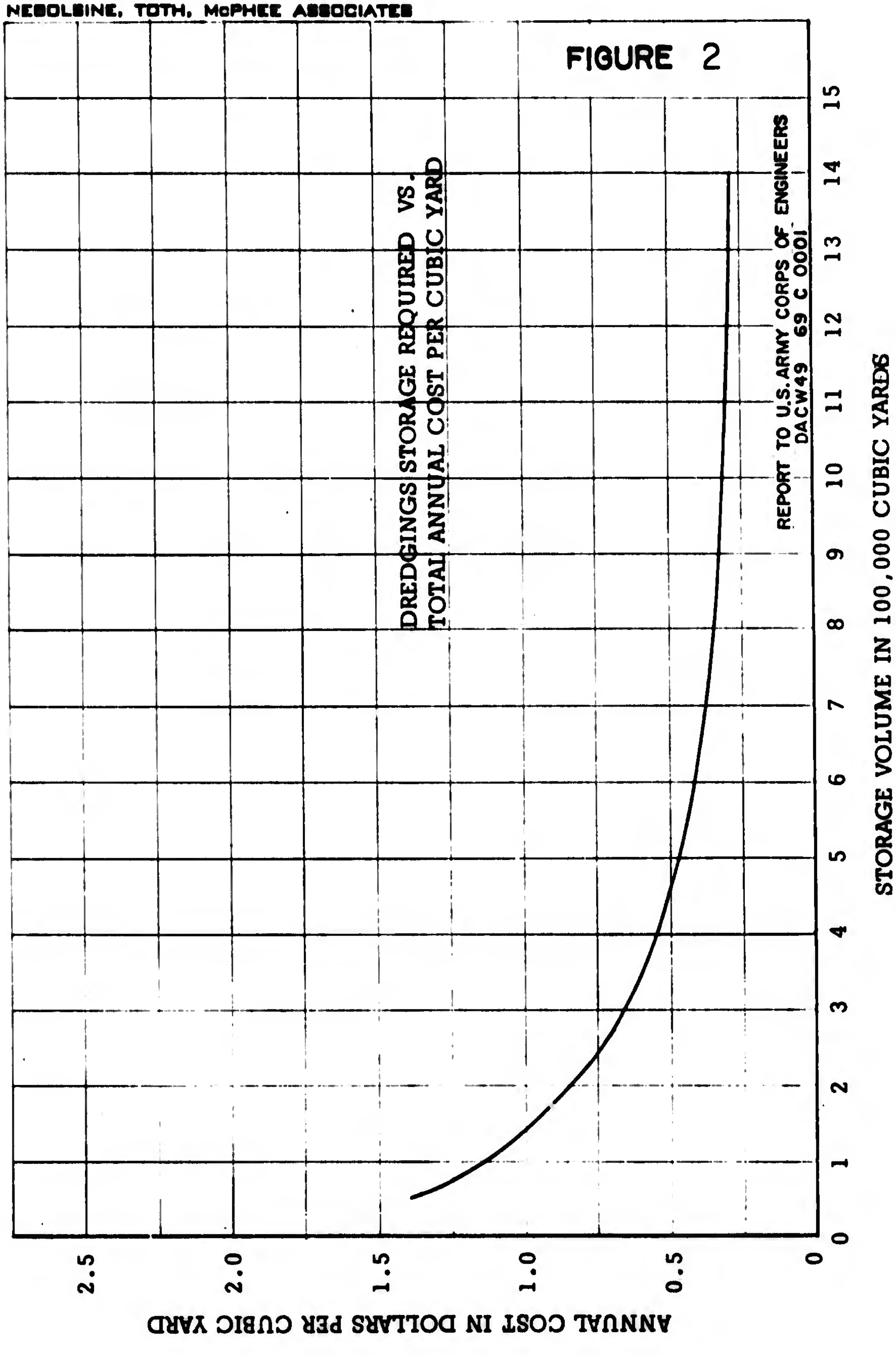
III. A plot of the anticipated dredging rates for the pilot harbors versus days.

IV. A plot of the construction cost of a three-sided storage area with 3 to 1 sloped dike, versus total storage volume.

The above curves cover the range of storage volume from 0 up to 1,200,000 cubic yards. Based on the data from the above curves a composite curve showing the annual cost per cubic yard versus either annual dredging volume or storage volume has been prepared. This new curve is shown on Fig. 2. The annual costs are based on the construction plus 25% for engineering and contingencies and a repayment term of ten years at 4-5/8% annual interest. (Equal annual repayment factor of 12.72%).

This curve can be used two ways. It can be used directly by assuming the storage required for any particular harbor is equal to the annual dredging volume for that harbor or the dredging rates versus time curve contained

FIGURE 2


DREDGINGS STORAGE REQUIRED VS.
TOTAL ANNUAL COST PER CUBIC YARD
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001
STORAGE VOLUME IN 100,000 CUBIC YARDS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
ANNUAL COST IN DOLLARS PER CUBIC YARD
0
0.5
1.0
1.5
2.0
2.5

in Appendix D can be used to estimate the reduced storage area required due to the treatment rate during the time the dredging is going on.

b) In the second case, that of developing cost of rehandling stored dredgings, a series of design considerations has to be made as follows:

I. In the case of aerobic and anaerobic stabilization of the dredgings, the maximum concentration of solids fed to these units should not exceed 10%. The anaerobic stabilization process will also require a greater discharge pressure than the aerobic stabilization.

II. In the case of wet-oxidation and chemical stabilization of the dredgings the maximum concentration of solids should not exceed 20%.

III. In the case of multi-hearth and fluid bed incineration of the dredgings, the maximum concentration of solids obtainable should be used.

IV. In addition to the above three considerations, the following variables for daily dredging were assumed as design points:

Annual Dredgings	Volume (1)	Dry Solids (1)(2)
3,000,000 c.y.	9,500 c.y./day	11.85×10^6 lbs./day
1,500,000 c.y.	4,750 c.y./day	5.93×10^6 lbs./day
500,000 c.y.	1,583 c.y./day	1.98×10^6 lbs./day
100,000 c.y.	317 c.y./day	0.40×10^6 lbs./day

(1) Based on 270 days per year and 15% of dredgings removed as sand and gravel.
(2) Based on 1250 #/cy dry solids

3. Capital Cost Estimates

The cost of furnishing dredges plus the cost of discharge piping and booster pumping for the daily cubic yardage rates and the percent solids in their discharges were obtained from the dredge manufacturers. For the four design points and the design considerations as required by the various processes, the following summary was developed:

CASE I - 10% SLURRY - NO BOOSTER (Aerobic Stabilization)

Annual Dredging (c.y.)	3,000,000	1,500,000	500,000	100,000
85% of Dredgings #/day	11.85×10^6	5.93×10^6	1.98×10^6	0.40×10^6
Cost of Dredge	$300,000	$180,000	$114,000	$ 95,000
Cost of Piping	51,650	47,000	37,750	34,280
Work Boat	21,000	21,000	21,000	21,000
Site Work	18,650	12,400	8,650	7,500
Sub-Total	$391,300	$260,400	$181,400	$157,780
Engineering & Conting.	97,800	65,100	45,350	39,450
TOTAL	$489,100	$325,500	$226,750	$197,230

CASE II - 10% SLURRY - WITH BOOSTER (Anaerobic Stabilization)

Annual Dredging (c.y.)	3,000,000	1,500,000	500,000	100,000
85% of Dredgings(#/day)	11.85×10^6	5.93×10^6	1.98×10^6	0.40×10^6
Cost of Dredge	$300,000	$180,000	$114,000	$ 95,000
Cost of Piping	51,650	47,000	37,750	34,280
Work Boat	21,000	21,000	21,000	21,000
Booster Pump	72,000	30,000	20,000	10,000
Site Work	22,230	13,900	9,640	8,000
Sub-Total	$466,880	$291,900	$202,390	$168,280
Engineering & Conting.	117,500	72,700	50,600	42,070
TOTAL	$584,380	$364,600	$252,990	$210,350

CASE III - 20% SLURRY - NO BOOSTER (Wet Oxidation and Chemical Stabilization)

Annual Dredgings (c.y.)	3,000,000	1,500,000	500,000	100,000
85% of Dredgings (#/day)	11.85×10^6	5.93×10^6	1.98×10^6	0.40×10^6
Cost of Dredge	$180,000	$144,000	$ 95,000	$ 85,500
Cost of Piping	47,000	37,750	34,280	33,000
Work Boat	21,000	21,000	21,000	21,000
Site Work	12,400	10,100	7,500	6,950
Sub-Total	$260,400	$212,850	$157,780	$146,450
Engineering & Conting.	65,100	53,200	39,450	36,600
TOTAL	$325,500	$266,050	$197,230	$183,050

CASE IV-45% SLURRY - WITH BOOSTER & WHEEL EXCAVATOR (Incineration)

Annual Dredgings (c.y.)	3,000,000	1,500,000	500,000	100,000
85% of Dredgings (#/day)	11.85×10^6	5.93×10^6	1.98×10^6	0.40×10^6
Cost of Dredge	$300,000	$240,000	$200,000	$170,000
Cost of Piping	37,750	34,280	33,000	32,000
Work Boat	21,000	21,000	21,000	21,000
Booster Pump	20,000	14,000	10,000	9,000
Site Work	18,900	15,450	13,200	11,600
Sub-Total	$397,650	$324,730	$277,200	$243,600
Engineering & Conting.	99,400	81,200	69,300	60,900
TOTAL	$497,050	$405,930	$346,500	$303,500

Based on these four design points Fig. No. 3 was developed. This series of curves provides the means of estimating the capital costs of handling stored dredgings for any daily handling rates.

4. Operating Costs

a) For the storage areas for the dredged materials there is no fixed schedule of manpower and utilities for operating and maintenance. A percentage of 1% of the capital costs has been assumed for annual maintenance and repairs of the dikes. This cost is included in the annual costs as shown on Fig. No. 4.

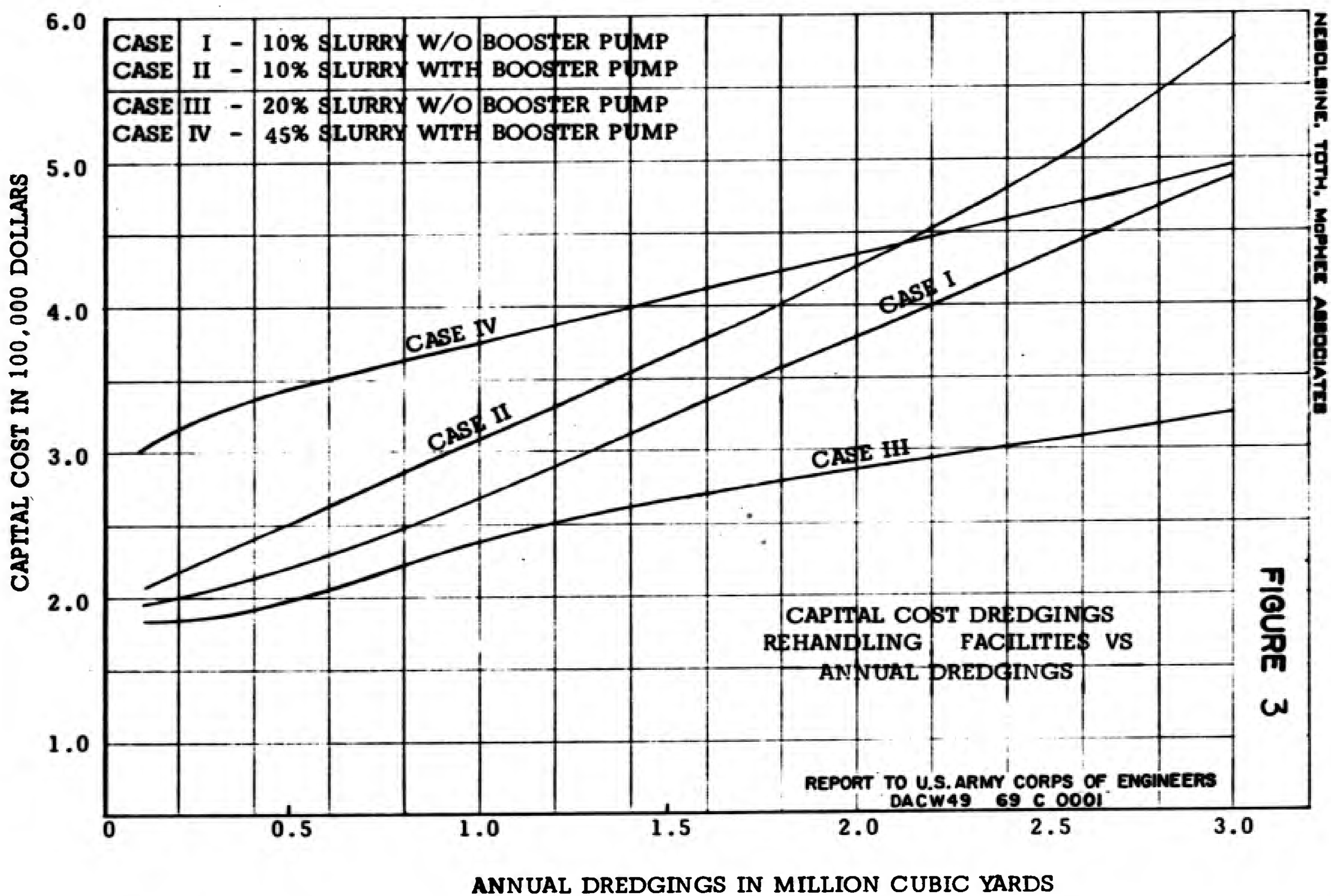
b) Annual operating costs for handling the stored dredgings are made up of the following:

I. Operating labor and supervision.

II. Utility costs (fuel, electricity, etc.).

III. Maintenance (labor and materials).

The item of Operating Labor and Supervision for the rehandling of dredgings is different from that which exists for the present harbor dredging operation. The type of dredging required will be of a permanent nature and since the type of dredge is small the number of operating personnel selected was based on conditions that exist within the Corps for small dredges. Based on this assumption the following is an estimate of the manpower per twenty-four hours:


NESOLSINE, TOTH, McPHEE ASSOCIATES
FIGURE 3
CASE I - 10% SLURRY W/O BOOSTER PUMP
CASE II - 10% SLURRY WITH BOOSTER PUMP
CASE III - 20% SLURRY W/O BOOSTER PUMP
CASE IV - 45% SLURRY WITH BOOSTER PUMP
CASE I
CASE II
CASE III
CASE IV
CAPITAL COST DREDGINGS
REHANDLING FACILITIES VS
ANNUAL DREDGINGS
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001
CAPITAL COST IN 100,000 DOLLARS
ANNUAL DREDGINGS IN MILLION CUBIC YARDS
6.0
5.0
4.0
3.0
2.0
1.0
0
0.5
1.0
1.5
2.0
2.5
3.0

Captain	1
Operators	3
Asst.Engineer	3
Pipeline Labor	6
Launch Opr.	3
Deckhand	3
TOTAL	19

Appendix C lists the hourly wages, including all payroll burdens used. To calculate annual costs the daily cost has been multiplied by 365 days although the operating period is only 270 days per year.

Fuel and lubrication requirements for the dredges and pumps are as follows:

Annual Dredgings - c.y.	3,000,000	500,000	100,000
85% of Dredgings - #/day	11.85×10^6	1.98×10^6	0.40×10^6
CASE I - 10% Sludge (No Booster)			
Fuel - gals/year	339,015	104,166	56,818
Lubrication, etc		(75% of fuel costs)	
CASE II- 10% Sludge (With Booster)			
Fuel - gals/year	594,696	208,333	113,636
Lubrication, etc.		(75% of fuel costs)	
CASE III - 20% Sludge (No Booster)			
Fuel - gals/year	261,363	73,863	51,136
Lubrication, etc.		(75% of fuel costs)	

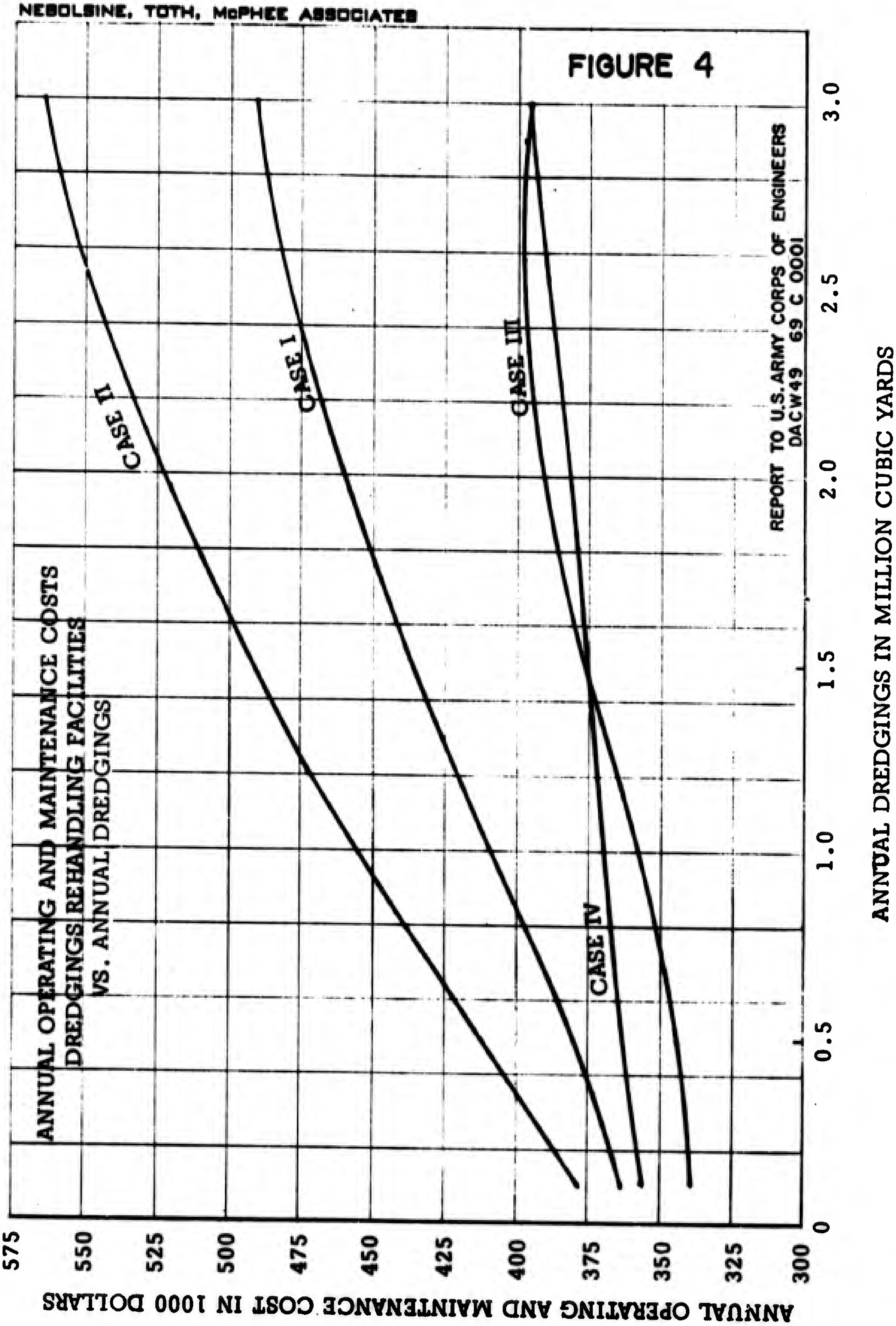
CASE IV - 45% Sludge
(With Booster)

Fuel - gals/year	208,333	111,742	92,803
Lubrication, etc.		(75% of fuel costs)	

Appendix B lists the costs for the fuel, electricity and water requirements that were used. For major maintenance, labor and material costs a factor of 9% of the cost of the equipment was used for annual costs.

The summary of the operating and maintenance costs for the four cases has been plotted and is shown on Fig. No. 4.

Using Fig. No. 3 and Fig. No. 4 Table No. 9 has been prepared which summarizes all of the various costs for handling the stored dredgings and converts the total annual cost to costs per cubic yard. Fig. No. 5 shows a curve for the average costs per cubic yard versus annual dredged quantities for all conditions.



NEBOLSINE, TOTH, McPHEE ASSOCIATES
FIGURE 4
ANNUAL OPERATING AND MAINTENANCE COSTS
DREDGINGS REHANDLING FACILITIES
VS. ANNUAL DREDGINGS
CASE I
CASE II
CASE III
CASE IV
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001
ANNUAL DREDGINGS IN MILLION CUBIC YARDS
0
0.5
1.0
1.5
2.0
2.5
3.0
ANNUAL OPERATING AND MAINTENANCE COST IN 1000 DOLLARS
300
325
350
375
400
425
450
475
500
525
550
575

TABLE NO. 9

SUMMARY ANNUAL COSTS OF REHANDLING DREDGINGS

Annual Dredgings in Cu.Yds.	Capital Costs	Annual Financing Costs	Labor Costs	Fuel Costs	Lubrication & Minor Maintenance	Major Maintenance	Total Annual Operating & Mainten.Cost	Total Annual Costs	Cost Per Cu.Yard
CASE I - 10% SLUDGE, NO BOOSTER PUMP									
3,000,000	$490,000	$62,300	$314,000	$44,750	$34,600	$33,500	$426,850	$489,150	0.163
1,500,000	325,000	41,300	314,000	34,500	25,800	22,300	396,600	437,900	0.291
500,000	227,000	28,700	314,000	13,750	10,300	15,600	353,650	380,250	0.760
100,000	197,000	25,000	314,000	7,500	5,600	13,500	340,600	365,600	3.656
CASE II-10% SLUDGE, WITH BOOSTER PUMP									
3,000,000	584,000	74,300	314,000	78,500	59,000	39,800	491,300	565,600	0.188
1,500,000	365,000	46,300	314,000	61,500	46,200	25,000	446,700	493,000	0.328
500,000	253,000	32,200	314,000	27,500	20,600	17,300	379,400	411,600	0.823
100,000	210,000	26,700	314,000	15,000	11,250	14,400	354,650	381,350	3.813
CASE III-20% SLUDGE, NO BOOSTER PUMP									
3,000,000	326,000	41,500	314,000	34,500	25,900	22,300	396,700	438,200	0.146
1,500,000	266,000	33,900	314,000	25,750	19,300	18,200	377,250	415,250	0.276
500,000	197,000	25,000	314,000	9,750	7,300	13,500	344,550	369,550	0.739
100,000	183,000	23,300	314,000	6,750	5,050	12,600	338,400	361,700	3.617
CASE IV-45% SLUDGE, NO BOOSTER PUMP									
3,000,000	497,000	63,200	314,000	27,500	20,600	34,000	396,100	459,300	0.153
1,500,000	406,000	51,600	314,000	19,500	14,600	27,800	375,900	427,500	0.285
500,000	347,000	44,000	314,000	14,750	11,000	23,800	363,550	407,550	0.815
100,000	304,000	38,600	314,000	12,250	9,200	20,900	356,350	394,950	3.949

(a) Based on 10 year period at 4-5/8% annual interest.

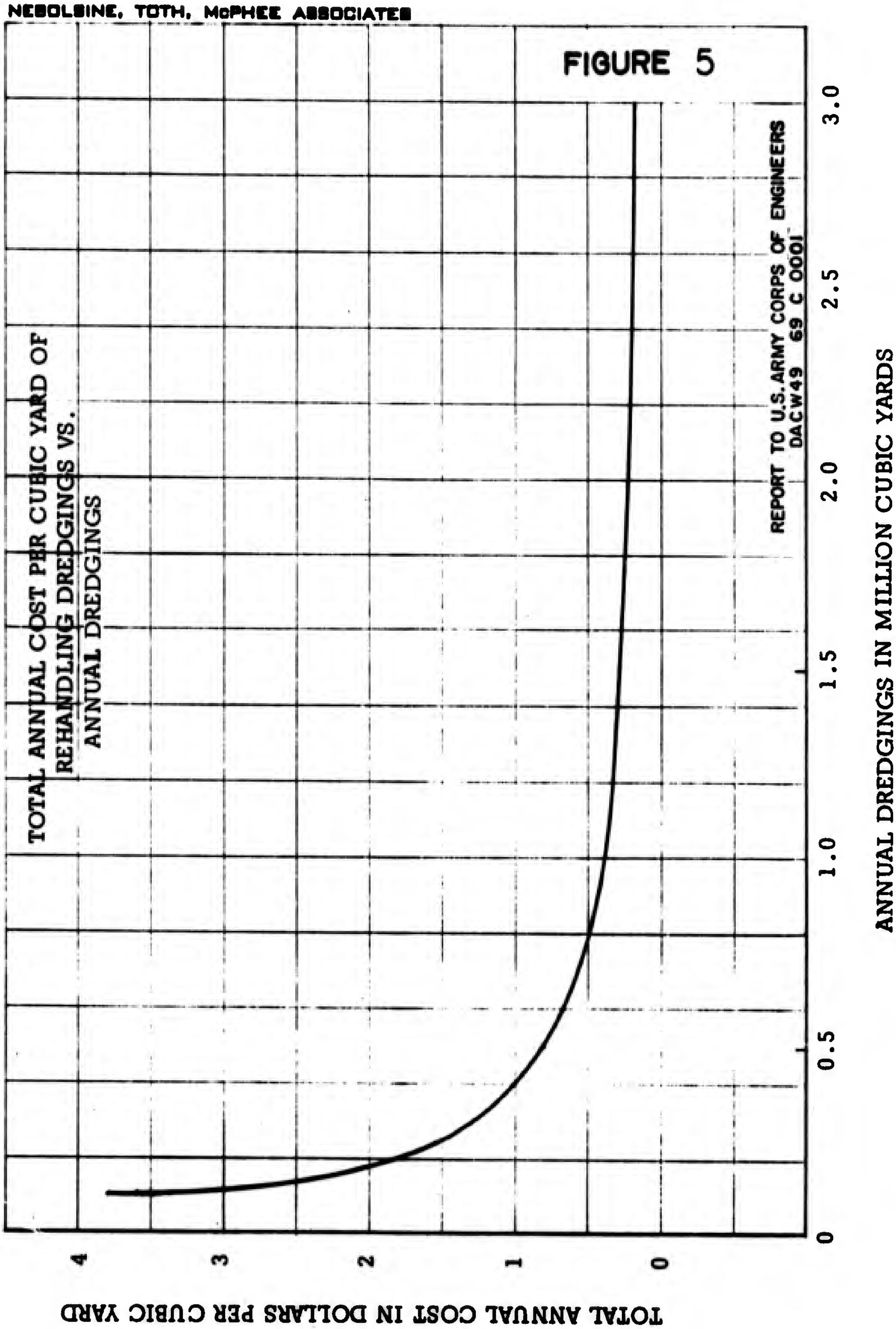

TOTAL ANNUAL COST PER CUBIC YARD OF REHANDLING DREDGINGS VS. ANNUAL DREDGINGS
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001
0
0.5
1.0
1.5
2.0
2.5
3.0
ANNUAL DREDGINGS IN MILLION CUBIC YARDS
4
3
2
1
0
TOTAL ANNUAL COST IN DOLLARS PER CUBIC YARD

FIGURE 5

G. TREATMENT OF SEPARATED WATERS

1. General

The transporting of the dredged solids from the dredges to the storage areas requires that the solids have to be diluted. In diluting the solids the fine material present is re-suspended in the water fraction and does not readily resettle. The material will settle however if given sufficient time, say several days or more. (See Section A.)

In handling the dredged solids the basic operation will provide several days storage for a period during the start-up when the storage area is initially empty up to the time when it approaches being full. The 20% sludge being pumped into the storage area will take time to reconsolidate to approximately the solids consistency that the dredgings were in when they rested on the bottom of the harbors.

To minimize the contamination of the waters in the harbor, adjacent to the storage areas, some means will have to be provided to intercept the overflow from the storage area and treat it for removal of suspended solids. The suspended solids removed will be discharged back into the storage area and the treated water discharged to the harbor.

In addition to the water separated from the dredgings solids during their initial handling, there are other water streams that will have to be handled and treated before they will be acceptable for discharge to the adjacent harbor waters. These streams are as follows:

I. The water separated from the substantially anaerobically stabilized dredgings. This water will contain fine suspended material carrying some BOD. The separation of the suspended solids should remove sufficient BOD to permit the discharge of the water directly to the adjacent harbor waters. The flow pattern of the anaerobic treatment operation is such that as the solids are withdrawn from the storage area in a 10% concentration, the water separated from these sludges will be returned to the storage area. Since in some cases the dredging operations will be going on simultaneously with the treatment operation, the water separated from the treated dredgings will mix with the water separated from the new dredgings and will overflow to the harbor.

II. The same situation will exist for the water separated from the dredgings treated by the aerobic process, except in this case the water should not contain excessive BOD's.

III. The same situation will exist for the water separated from the chemical stabilization process as for the anaerobic process unless chemicals inhibit BOD.

IV. The same situation will exist for the waters separated from the wet-oxidation process. In this case, however, the BOD in the water will be soluble and will have to be removed by a bio-oxidation process before discharge into the Lakes.

V. The waters separated from the solids in multi-hearth and fluid bed incineration operation will contain fine suspended material that will require some treatment prior to being discharged to the waters of the harbor or lake.

2. Design Considerations

The rate of overflow or outflow from the storage areas will be equal to rate of inflow from the dredges. An analysis of all the harbor dredgings operations indicate that the equalized overflow rate will range from 1300 to 16,000 gpm. These rates will not be uniform over the dredging operation period but will vary greatly. The discharge rates for the hopper type dredges are known, along with the time required to unload a scow, but the turn-around time for each harbor and different sections of the harbors will vary tremendously. The establishment of a curve of the varying costs per cubic yard versus varying annual dredged quantities cannot be prepared accurately.

Instead a curve has been established and applied to the varying volumes of the annual dredgings:

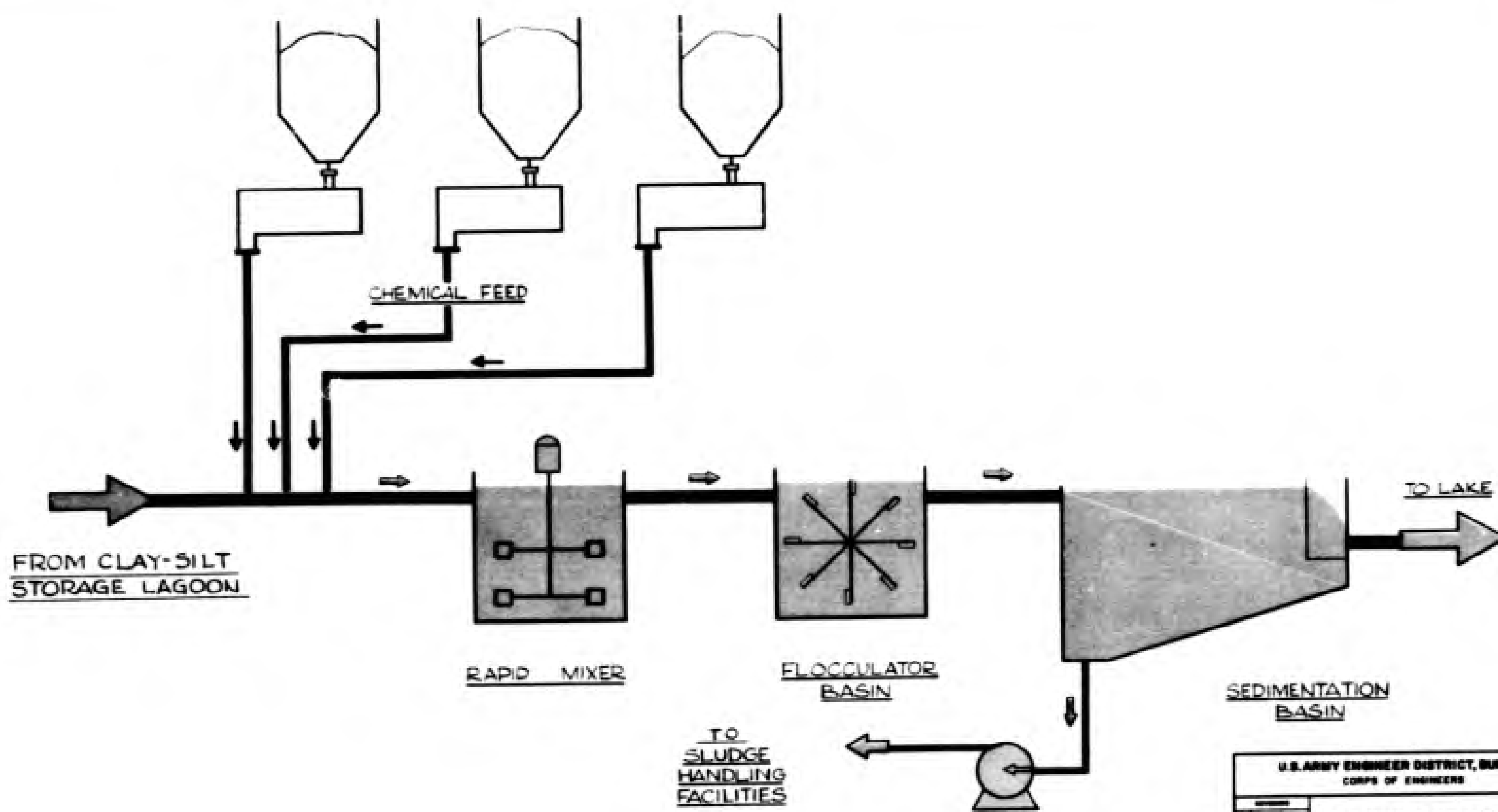
Volume of Dredgings (Cu.yds./year)	Volume of Water (1000 gals.)
3,000,000	700,000
1,500,000	350,000
500,000	117,000
100,000	23,400

The above tabulation is based on treating only 50% of the water displaced since until the storage area is half full of solids, it is felt the treatment of this overflow water will not be required. The total volume has been calculated on the difference between the volume of the original dredgings and their volume when slurried to 20%. Although water is removed from the storage areas during the treatment operations the separated water will be returned after treatment thereby keeping the discharge of contaminated water to a minimum. Plate 3 shows a flow diagram for the treatment process used in establishing the unit treatment costs. The unit treatment costs are based on the capital cost of the facilities amortized over a ten-year period at 4-5/8% interest plus operating and maintenance costs. A unit cost of $0.08 per 1000 gallons was calculated using this approach. Based on this cost the annual costs for treating the overflow from the varying annual dredged quantities is as follows:

Volume of Dredgings (Cu. Yd./Year)	Volume of Water (1000 gals.)	Treatment Cost	Cost Per Cu. Yd.
3,000,000	700,000	$56,000	$0.019
1,500,000	350,000	28,000	0.019
500,000	117,000	9,350	0.019
100,000	23,400	1,870	0.019

Since a fixed cost per 1000 gallons of water was used, the cost per cubic yard is also constant for the various annual volumes of dredgings. This is not exactly true, but because of the small difference that may be present, any error will in turn be small.

Fig. No. 6 is a plot of the cost per cubic yard versus the annual volume of dredgings.

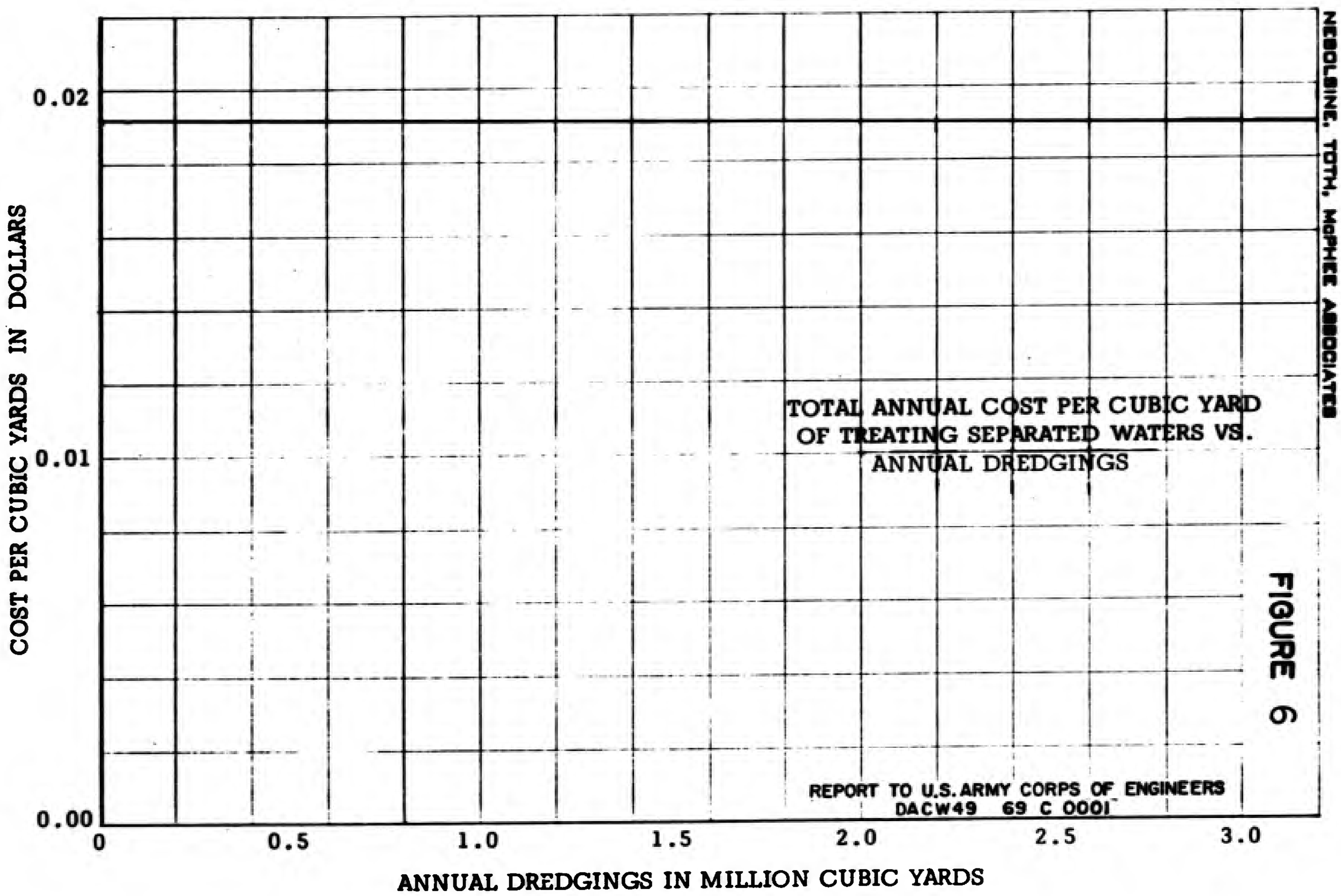


U.S. ARMY ENGINEER DISTRICT, BUFFALO
CORPS OF ENGINEERS

TREATMENT OF SEPARATED WATERS — FLOW DIAGRAM

NEBOLSINE, TOTH, McPHEE ASSOCIATES

PLATE 3


NEBOLSINE, TOTH, McPHEE ASSOCIATES
FIGURE 6
TOTAL ANNUAL COST PER CUBIC YARD
OF TREATING SEPARATED WATERS VS.
ANNUAL DREDGINGS
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001
COST PER CUBIC YARDS IN DOLLARS
0.02
0.01
0.00
0
0.5
1.0
1.5
2.0
2.5
3.0
ANNUAL DREDGINGS IN MILLION CUBIC YARDS

H. Anaerobic Stabilization

1. General

A method of treating sludges removed in the treatment of sewage is to anaerobically digest the solids. Anaerobically means basically biological action without the presence of dissolved oxygen. In the digestion operation the organic volatile solids present are converted by anaerobic micro-organisms to humus-like solid matter, sludge liquor and sludge gasses. The sludge or solids remaining are stable and difficult to break down by any further biological action. The water fraction of the digested sludge contains fine suspended solids, some immediate oxygen demand and some bio-chemical oxygen deamnd. The majority of the bio-chemical oxygen demand (carbonaceous) is normally associated with the suspended solids. If the supernatant from an aerobic digester is clarified its carbonaceous BOD is negligible.

Since the volatile solids in the maintenance dredgings from the harbors of the Great Lakes is of major concern, the reduction of these solids by anaerobic digestion was considered.

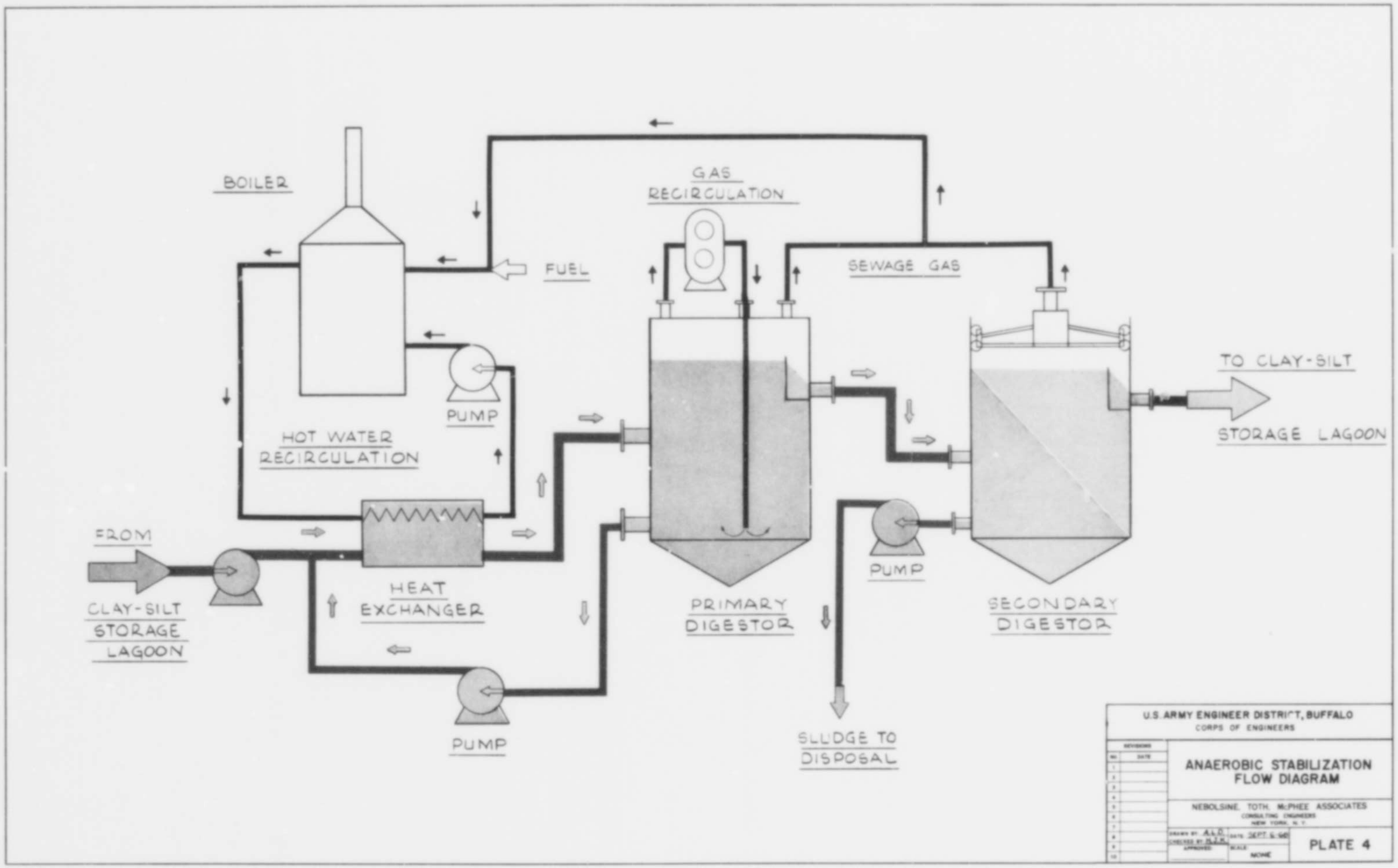
As shown on Table 1 and 2 in Section B the maintenance dredgings contain varying amounts of volatile solids. Table 1 which lists the sampling of the eight pilot harbors by the FWPCA and Great Lakes Research group shows a variation from 1.38 percent for Great Sodus Bay to 18.4 percent for Green Bay. Table No. 2 that lists the work done at the University of Wisconsin shows a variation from 3.1 percent for Great Sodus Bay to 13.3 percent for Indiana Harbor. The average of the 38 samples tested by the University of Wisconsin shows the volatile solids concentration to be approximately

9.1 percent. The University tested the 38 samples of bottom sediments from the eight pilot harbors and reported, as shown on Table No. 6 of Section B, that all but two samples produced gas thereby indicating that anaerobic activity was taking place. The tests did not measure the reduction in volatile solids but the gas prodution rates of less than 1 cubic foot per pound of volatile solids did indicate that the volatile solids present were not the same as those normally encountered in sewage sludge. The production of 10 cubic feet of gas per pound of volatile solids is not uncommon in the anaerobic digestion of sewage solids. If gas production rates are used as a parameter to measure the bio-degradable volatile solids in the dredgings, then it would appear that only 10 percent of the volatile solids present are similar to sewage solids. This would indicate that only one percent of the average total solids present in the maintenance dredgings are similar to sewage solids or one half of a percent are bio-degradable.

2. Design Considerations

In designing anaerobic digestion systems there are three basic considerations to be made as follows:

a) The detention time in the system or the loading rate. In this case we have assumed twenty days' detention with a 10% sludge of the silt and clay sized particles being fed to the digesters.


BOILER
GAS RECIRCULATION
FUEL
SEWAGE GAS
PUMP
HOT WATER RECIRCULATION
FROM
CLAY-SILT STORAGE LAGOON
HEAT EXCHANGER
PRIMARY DIGESTOR
SECONDARY DIGESTOR
TO CLAY-SILT
STORAGE LAGOON
PUMP
PUMP
SLUDGE TO DISPOSAL
U.S. ARMY ENGINEER DISTRICT, BUFFALO
CORPS OF ENGINEERS
ANAEROBIC STABILIZATION FLOW DIAGRAM
NEBOLSINE, TOTH, McPHEE ASSOCIATES
PLATE 4

b) The detention time is related to the temperature at which the system is maintained. The optimum mesophilic temperature is 35°C and in this case we are assuming that this temperature can be maintained.

c) The production and characteristics of the gas are important. The laboratory investigations indicate gas production rates of less than 1 cubic foot per pound of volatile solids in the feed to the digester. As stated before, normally in sewage sludges production rates of 10 cubic feet per pound of volatile solids is not uncommon. Without more exact laboratory work the rate of one cubic foot per pound of volatile solids is used in the analysis presented in this section. The gas production affects the operating cost and if additional laboratory work indicates higher gas rates the annual costs can be easily adjusted.

Based on these considerations an anaerobic digestion system as shown on Plate 4 was designed. These conditions are as follows:

Annual Dredging Quantities (c.y.)	Total Dry Solids/Day(1) to Digesters	Volatile Dry Solids(2) to Digesters/Day
1,500,000	4,370,000 pounds	515,000 pounds
1,000,000	2,910,000 pounds	343,000 pounds
500,000	1,450,000 pounds	171,000 pounds
100,000	291,000 pounds	34,300 pounds

(1) Based on 15% of dredgings removed as sand and gravel and 365 days/yr.
(2) Based on 10% volatile solids in initial dredgings.

A basic tank size of 150 feet in interior diameter with forty feet of side wall depth and a 25 foot deep conical bottom was used. For the three design points the following number of digesters would be required:

Annual Dredgings Quantities (c.y.)	Primary Digesters	Secondary Digesters
1,500,000	7	9
1,000,000	5	6
500,000	3	5
100,000	- - - - 1 - - - -	

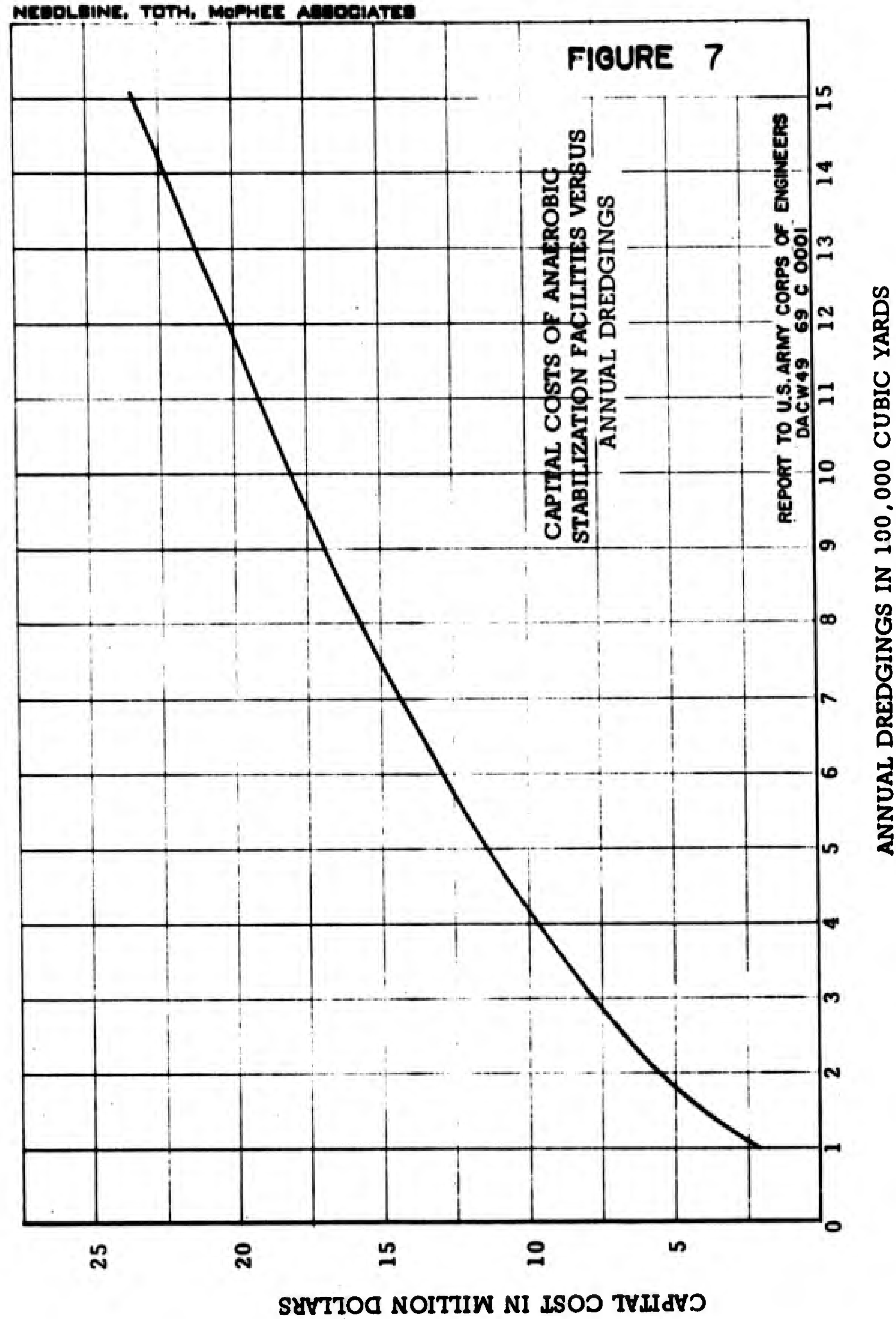
The tanks would be constructed from reinforced concrete, with the primary tanks having fixed roofs and the secondary tanks equipped with floating cover gas holders. Mixing equipment would be provided to accelerate the operation. Earth would be bermed up around the tank walls for insulation and fresh solids would be heated to 35°C or higher.

Using the 1 cubic foot of gas production per pound of volatile solids and 720 BTU/c.f. of gas, the system will not be in balance when the heat differential between the sludge and digester is 20° F or more. Additional fuel will be required to operate the digesters during part of the year.

3. Capital Costs

The capital costs for the four design conditions are summarized as follows:

NESOLSINE, TOTH, McPHEE ASSOCIATES



Dredgings - C.Y./Year	1,500,000	1,000,000	500,000	100,000
Cost of Structures	4,710,000	3,210,000	2,430,000	360,000
Mechanical Equipment	6,866,000	4,720,000	3,274,000	690,000
Building	660,000	520,000	230,000	80,000
Foundation	5,200,000	3,600,000	2,600,000	325,000
Electric Service	1,064,000	729,000	410,000	126,000
Site Work	925,000	639,000	447,000	79,000
Sub-Total	19,425,000	13,418,000	9,391,000	1,660,000
Engineering & Contingencies	4,856,000	3,354,000	2,348,000	415,000
TOTAL	24,281,000	16,772,000	11,739,000	2,075,000

Based on these four design points, Fig. 7 was developed. This curve provides the means of estimating the capital cost of anaerobic facilities for any annual dredging quantities. The capital costs from the curve can be used to develop the annual costs for financing the construction of any sized project. A term of ten years and 4-5/8 percent annual interest is used for this purpose or a factor of 12.72 per cent per year of the total capital costs.

4. Operating Costs

Annual operating costs for the anaerobic digestion facilities are made up of the following:

a. Operating Labor and Supervision.

b. Utility Cost (Fuel, electricity, water).

c. Maintenance (Labor and materials).

For the items of Operating Labor and Supervision the following table of the 24 hour manpower requirements was estimated:

Dredgings - C.Y./Year	1,500,000	1,000,000	500,000	100,000
Superintendent	1	1	0	0
Foreman	3	3	1	1
Operators	9	6	4	3
Ass't. Operators	9	6	3	2
Chemists	2	1	1	1
Ass't. Chemists	3	3	2	0
Laborers	8	6	4	2
TOTALS	35	26	15	9

Appendix C lists the hourly wages, including all pay burdens used. To calculate annual costs the daily cost has been multiplied by 365 days of operation per year.

The utility requirements for the operation of the anaerobic digestors are as follows:

Dredgings - Cu.yds/year	1.5×10^6	1.0×10^6	0.5×10^6	0.1×10^6
Fuel (BTU x 10^6)/yr.	423,000	282,000	141,000	28,000
Electricity KWH x 10^6/yr.	25	18.4	11.1	3.3

Appendix B lists the costs for electricity. For annual maintenance a factor of 1 per cent of the equipment costs was used. A summary of the

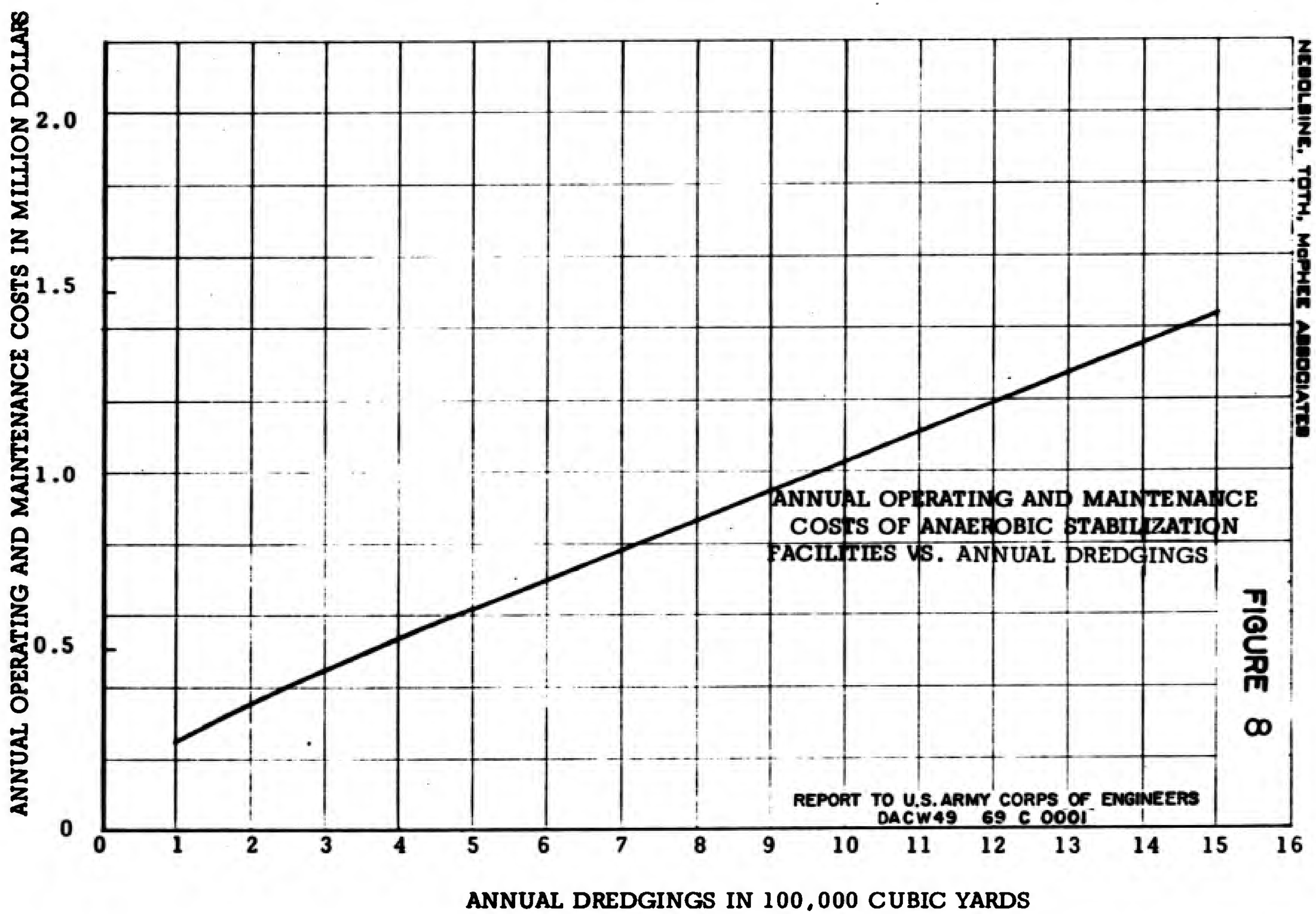

NEBOLSINE, TOTH, McPHEE ASSOCIATES
ANNUAL OPERATING AND MAINTENANCE COSTS OF ANAEROBIC STABILIZATION FACILITIES VS. ANNUAL DREDGINGS
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001
ANNUAL OPERATING AND MAINTENANCE COSTS IN MILLION DOLLARS
0
0.5
1.0
1.5
2.0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
ANNUAL DREDGINGS IN 100,000 CUBIC YARDS

FIGURE 8

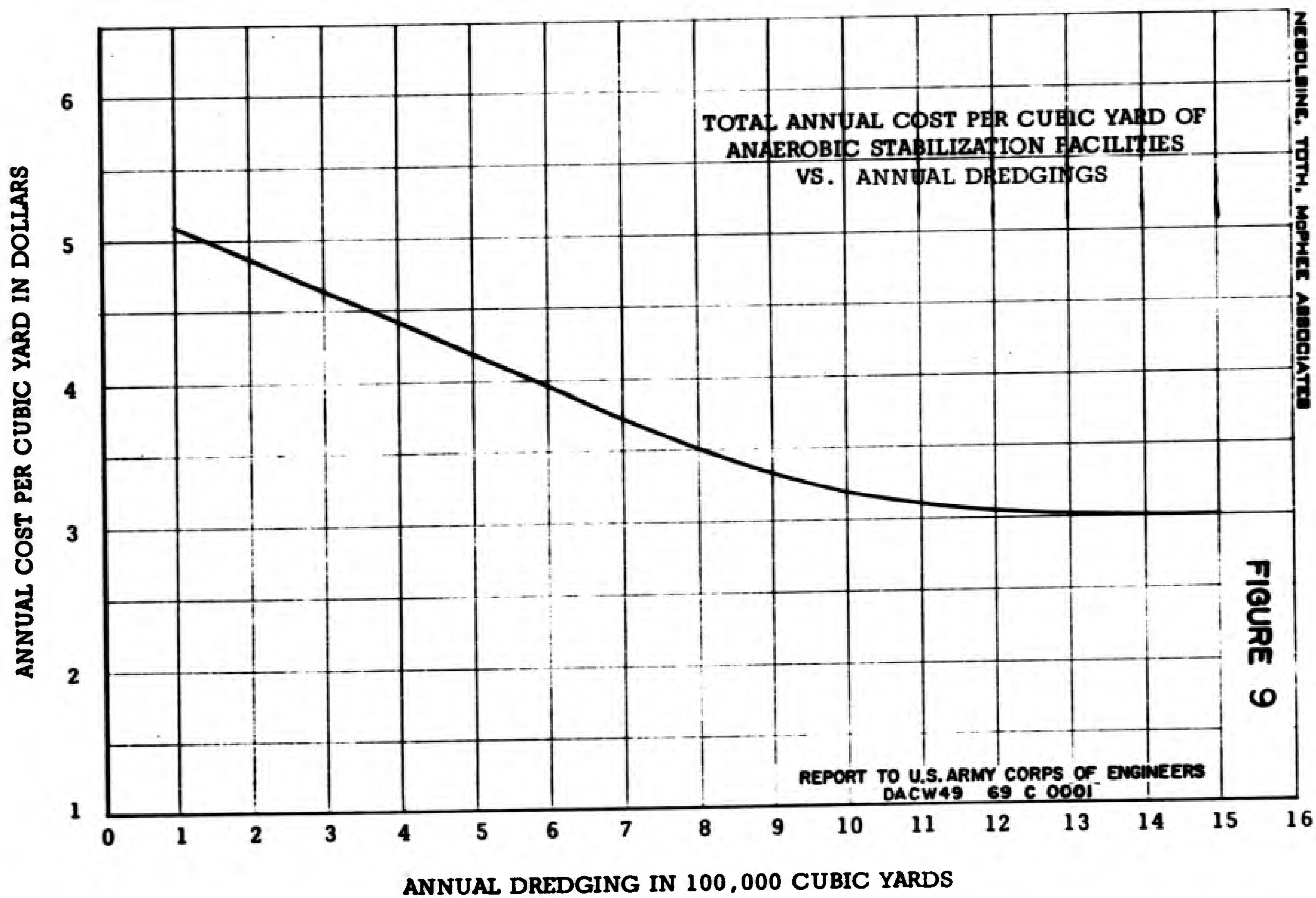
TABLE NO.10

SUMMARY ANNUAL COSTS

OF ANAEROBICALLY STABILIZING DREDGINGS

Dredgings C.Y./Year	Capital Cost	Annual Financing Cost	Annual Labor Costs	Annual Utility Costs	Annual Maintenance Costs	Annual Operating & Maint. Cost	Total Annual Cost	Total Annual Operating Cost $/cu.yd.
1,500,000	24,281,000	3,089,000	563,400	625,000	243,000	1,431,000	4,520,000	3.01
1,000,000	16,772,000	2,133,000	420,900	444,000	168,000	1,033,000	3,166,000	3.17
500,000	11,739,000	1,493,000	241,800	249,000	117,000	608,000	2,101,000	4.20
100,000	2,075,000	264,000	155,200	70,000	21,000	246,000	510,000	5.10

(a) Based on 10 years at 4-5/8% annual interest.


NESBOLSINE, TOTH, McPHEE ASSOCIATES
FIGURE 9
TOTAL ANNUAL COST PER CUBIC YARD OF
ANAEROBIC STABILIZATION FACILITIES
VS. ANNUAL DREDGINGS
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001
ANNUAL COST PER CUBIC YARD IN DOLLARS
1
2
3
4
5
6
ANNUAL DREDGING IN 100,000 CUBIC YARDS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

operating and maintenance costs for the four design points has been calculated and has been plotted on Fig. 8.

Using Fig. 7 and Fig. 8, Table 10 has been prepared and summarizes all of the various costs and converts the annual costs to costs per cubic yard. Fig. 9 shows a plot of cost per cubic yard versus annual dredged quantities.

The cost of handling the digested solids is covered in Section N and the water fraction is covered in Section G.

I. AEROBIC TREATMENT

1. General

One of the most objectionable aspects of the dredgings dumped into the lake is that the organic material entrapped in the sediment undergoes biological degradation, thus depleting available dissolved oxygen resources to undesirable levels, which is deleterious to the life of the aquatic environment. Based on the information available, as previously described in Section H, Anaerobic Treatment, the bio-degradable volatile solids appear to be between 0.5 to 1.0 percent of the total solids. In the case of aerobically stabilizing the maintenance dredgings the measure of stability is the remaining BOD of the solids. Very little test work has been done on the BOD of the maintenance dredgings. Table No. 1 shows BOD's from 800 ppm for Toledo Harbor to 13,000 ppm for Cleveland Harbor. Although all samples have been tested for COD there is insufficient data on the corresponding BOD to draw a correlation. The University of Wisconsin in their work on the 38 samples from the eight pilot harbors did measure COD reductions on tests for 11 out of 14 samples. Different samples for each harbor showed different results to the extent that one sample was aerobically oxidized and another was not. Table No. 5 in Section B shows these results. The Wisconsin tests were run for only four days and showed COD reductions, except for those that showed no activity, from 10.6 to 45 percent reduction of COD. Again with no correlation between COD and BOD it is not possible to tell what a 45 percent COD reduction means as far as BOD goes.

As a deterrent it is proposed to treat the dredgings biologically, at accelerated rates, under controlled aerobic conditions before returning them to the lake. In order to accomplish this, the stored degritted organic silt-clay fraction will be diluted to about 10% solids and pumped into a lagoon. Oxygen will be supplied and the material maintained in suspension by surface aeration devices. Following the lagoon the solids will be concentrated and hauled to the lake for disposal. (See Section N.)

2. Design Considerations

Unfortunately, there is a dearth of information on many of these parameters that are involved in selecting the process variables for designing aerobic treatment units. The most important parameter, the required quality of the solids to be ultimately produced by treatment, is not know. If this data were known, it would probably become obvious whether or not biological treatment could produce an acceptable material. Hence, without this needed data it is assumed for purposes of this, as well as the other alternates being studied, that the selected treatment will satisfactorily produce materials for disposal, presumably to a deep section of the lake.

There is essentially no available data on the effect of aerobic digestion on the various sediments, such as reductions in volatile solids, or BOD. All the data gathered to date shows a wide variation in characteristics of samples, even from the same harbor. In order to simplify the feasibility study, average compositions were assumed. When detailed design becomes imminent, large scale pilot studies for each harbor would presumably be performed to accurately characterize the sediments and to obtain more precise design criteria.

The basic considerations for designing aerobic treatment systems are as follows:

a) The sludge to be treated has 15% by weight grit removed prior to storage, and contains 10% volatile solids of which a fraction is biologically degradable.

b) It was assumed that the biological oxygen demand of the sludge would be satisfied and that the residual organic volatile solids would be relatively stable.

c) A detention time of fifteen (15) days under aerobic conditions was selected for design. This figure was essentially based upon reported data in the literature on the aerobic digestion of sewage sludges, undoubtedly a major constituent in many of the harbor sediments.

d) Since the lagoon is to be in the open and probably will freeze in winter, a treatment period of eight (8) months (240 days) was used for design.

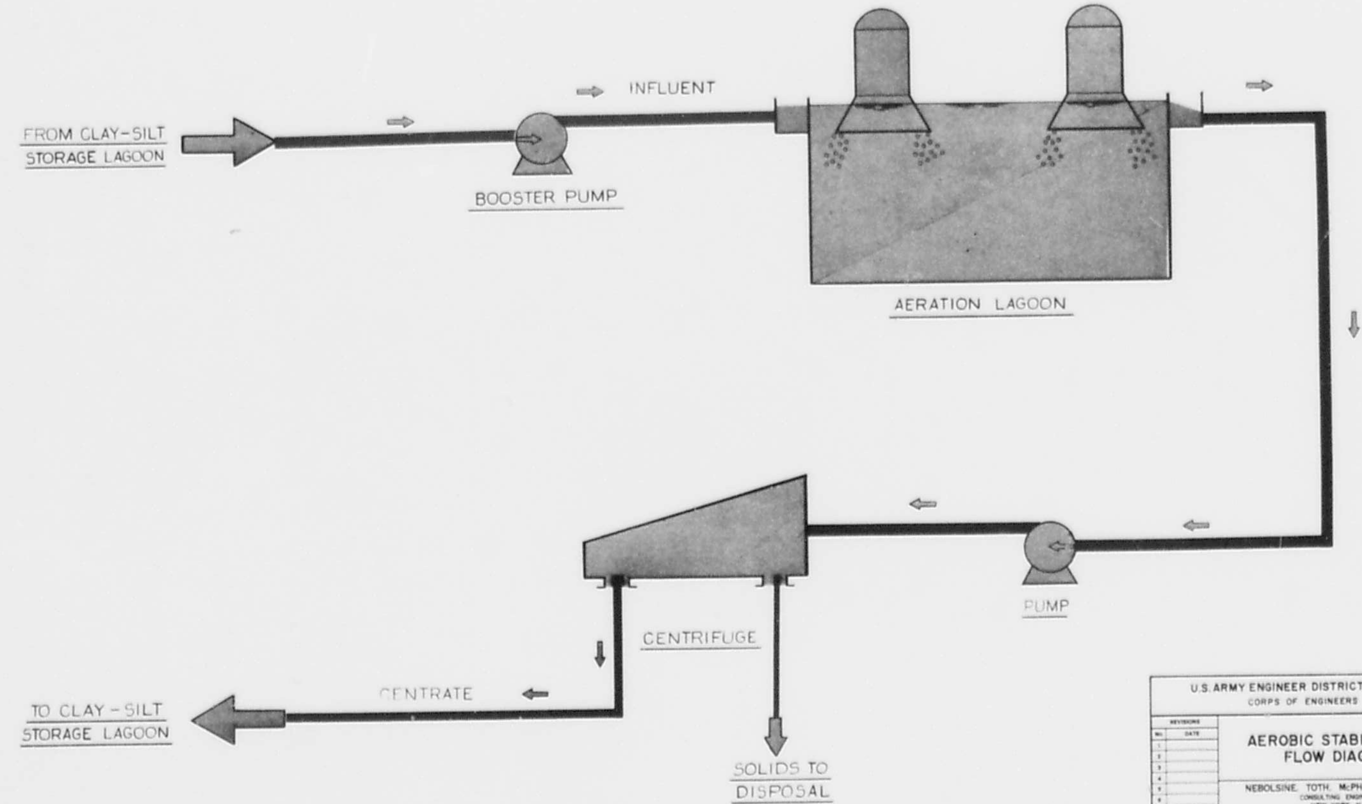
e) The solids content in the aeration lagoon was set at 10%.

f) In order to maintain the bacteria, oxygen and organic solids in close contact, a mixer horsepower requirement of 0.1 HP per 1000 gallons was used. Assuming that 40% (a conservatively high figure) of the volatile solids would be oxidized, it was determined that the horsepower required for mixing would be more than adequate to supply sufficient oxygen for biological degradation.

Based on these considerations, aerobic digestion systems as shown on the schematic flow diagram, Plate No. 5, were designed. These conditions and significant design sizes are shown on the following table:

Yearly Dredgings Cu.yards	Treatment Rate-MGD 10% Solids 8 mos./yr	Volume Aerobic Lagoon Cu.ft.	Mechanical Aerators (Number)	Horsepower Required
1,500,000	7.50	15,000,000	72	11,200
1,000,000	5.00	10,000,000	48	7,200
500,000	2.50	5,000,000	24	3,600
100,000	0.50	1,000,000	4	700

The stored organic silt-clay fraction of the dredgings are diluted with centrifuge overflow (centrate) from the continuously treated solids to 10% solids and pumped into the first of a four-compartment aeration lagoon. The sludge mixture is oxygenated by the mechanical surface aerators as it flows through the aeration basins. The effluent is pumped to a bank of solid bowl centrifuges where solids are concentrated to approximately 50% (varies according to material). The cake is conveyed from the centrifuges to a barge for subsequent hauling and disposal in the lake or to the trucks for haulage to land



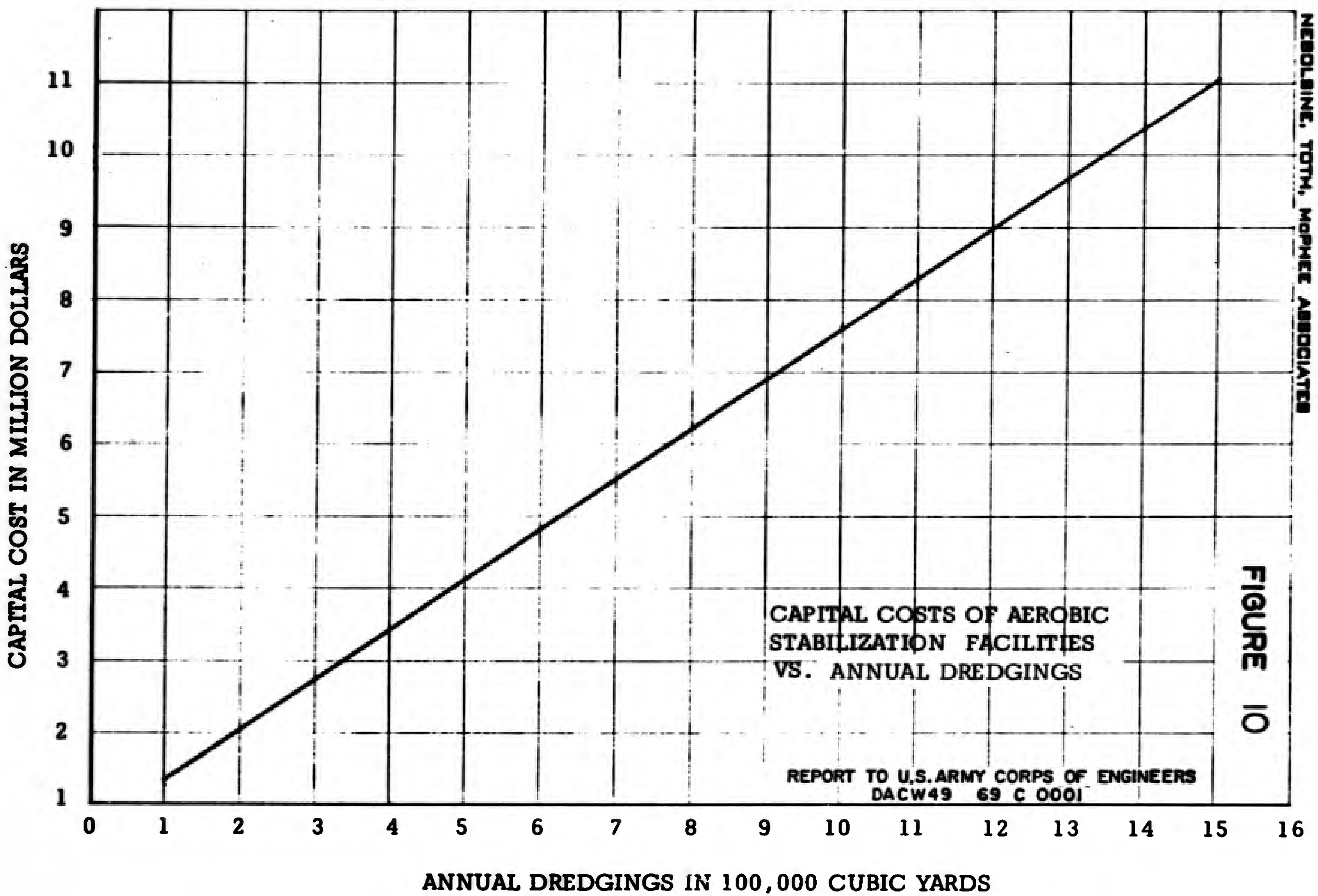
U.S. ARMY ENGINEER DISTRICT, BUFFALO
CORPS OF ENGINEERS

AEROBIC STABILIZATION
FLOW DIAGRAM

NEBOLSINE, TOTH, McPHEE ASSOCIATES
CONSULTING ENGINEERS
NEW YORK, N.Y.

DATE SEPT. 6 '66 SCALE NONE

PLATE 5


NEBOLSINE, TOTH, McPHEE ASSOCIATES
FIGURE 10
CAPITAL COSTS OF AEROBIC
STABILIZATION FACILITIES
VS. ANNUAL DREDGINGS
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001
CAPITAL COST IN MILLION DOLLARS
1
2
3
4
5
6
7
8
9
10
11
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
ANNUAL DREDGINGS IN 100,000 CUBIC YARDS

fill areas. The cost of dewatering the treated slurry is not included in the costs presented in this section but is covered in Section N. The centrate as previously described is returned to the storage lagoon to dilute the sediment.

3. Capital Costs

The capital costs for the four design conditions are summarized as follows:

Dredgings (C.Y./year)	1,500,000	1,000,000	500,000	100,000
Cost of Structures	$2,302,000	1,833,000	1,320,000	561,000
Mechanical Equipment	3,040,000	1,905,000	957,000	211,000
Buildings	612,000	432,000	252,000	32,000
Electric Service	2,470,000	1,609,000	829,000	176,000
Site Work	421,000	289,000	168,000	49,000
Sub-Total	8,845,000	6,068,000	3,526,000	1,029,000
Engineering & Conting.	2,211,000	1,517,000	881,000	257,000
TOTAL	$11,056,000	7,585,000	4,407,000	1,286,000

Based on these four design points, Fig. No. 10 was developed. This curve provides the means of estimating the capital cost of the aerobic facilities for any annual dredging quantities. The capital costs from the curve can be used to develop the annual cost for financing the construction of any sized project. A term of ten years and 4-5/8% annual interest is used for this purpose or a factor of 12.72% per year of the total capital costs.

4. Operating Costs

Annual operating and maintenance costs for the aerobic treatment facilities are made up of the following:

I. Operating Labor and Supervision.

II. Utility costs (fuel, electricity, water).

III. Maintenance, (labor and materials).

For the items of Operating Labor and Supervision the following table for the 24-hour manpower requirements was estimated:

Dredgings (cu. yds/year)	1,500,000	1,000,000	500,000	100,000
Superintendent	1	0	0	0
Foreman	1	1	1	1
Operators	6	4	4	3
Chemists	1	1	1	1
Asst. Chemists	1	1	1	1
Laborers	2	2	2	2
TOTALS	12	12	9	8

Appendix C lists the hourly wages, including all payroll burdens used. To calculate annual costs the daily cost has been multiplied by 365 days although the operating period is only 240 days per year.

The utility requirements for the operation of the aerobic lagoons are as follows:

Dredgings - (cu.yds/year)	1,500,000	1,000,000	500,000	100,000
Electricity $\frac{KWH \times 10^6}{Year}$	49	31	16	3

Appendix "B" lists the costs of electricity. For annual maintenance a factor of 1% of the equipment costs was used. A summary of the operating and maintenance costs for the four design points has been calculated and has been plotted on Fig. No. 11.

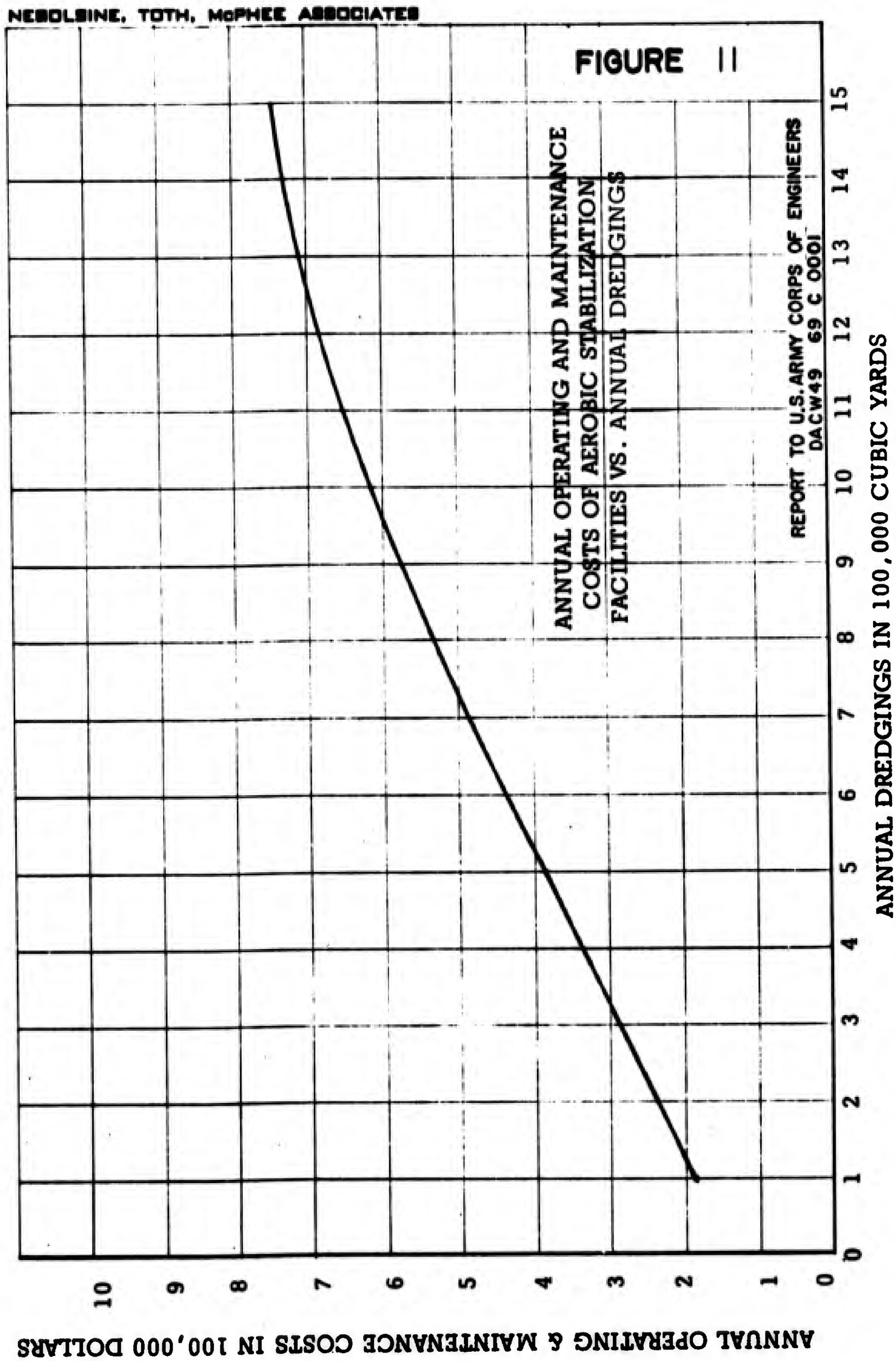

NEBOLSINE, TOTH, McPHEE ASSOCIATES
FIGURE 11
ANNUAL OPERATING AND MAINTENANCE COSTS OF AEROBIC STABILIZATION FACILITIES VS. ANNUAL DREDGINGS
REPORT TO U.S. ARMY CORPS OF ENGINEERS DACW49 69 C 0001
ANNUAL DREDGINGS IN 100,000 CUBIC YARDS
ANNUAL OPERATING & MAINTENANCE COSTS IN 100,000 DOLLARS
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
0 1 2 3 4 5 6 7 8 9 10

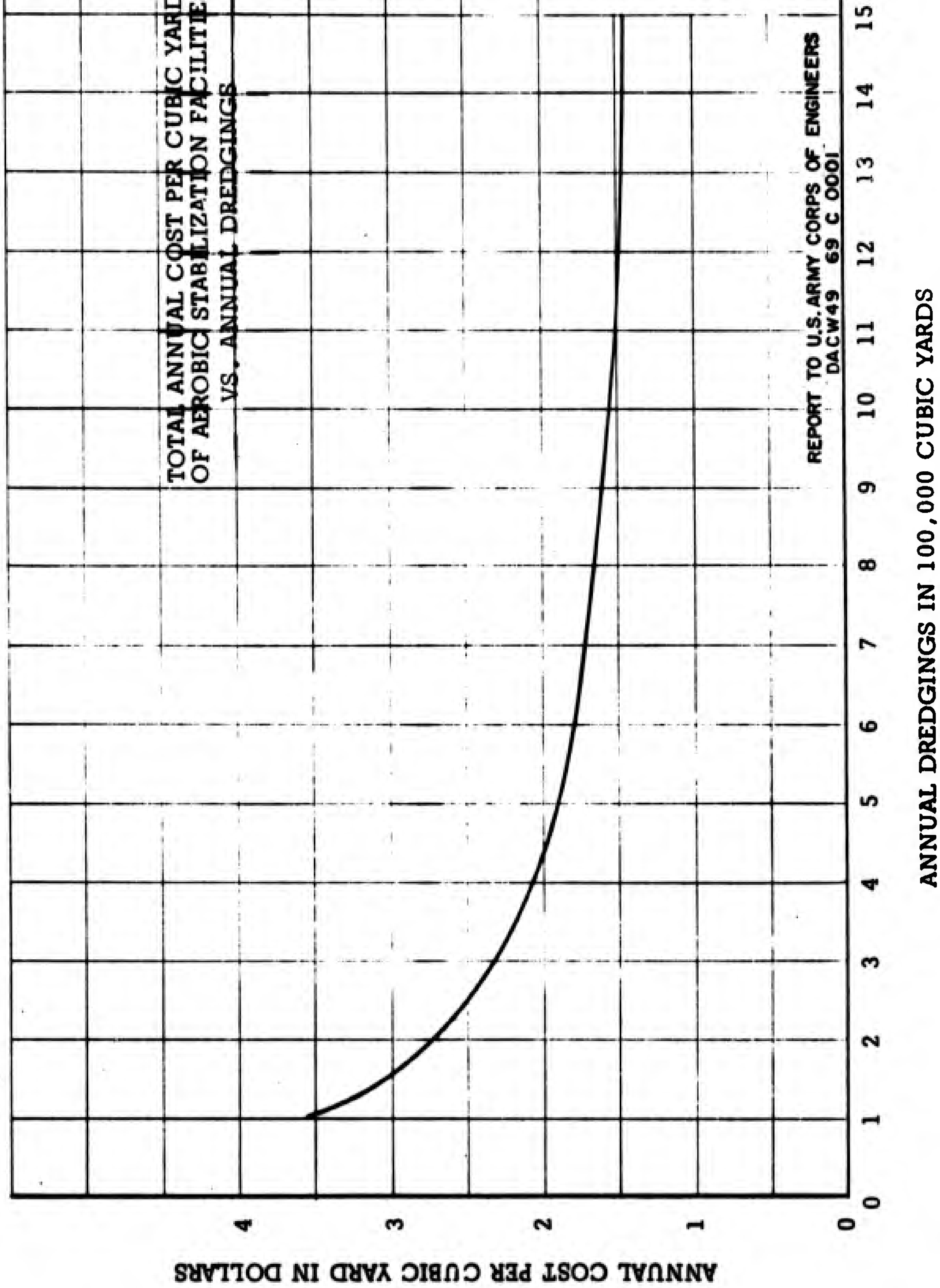
TABLE NO. 11

SUMMARY ANNUAL COSTS FOR AEROBICALLY STABILIZING DREDGINGS

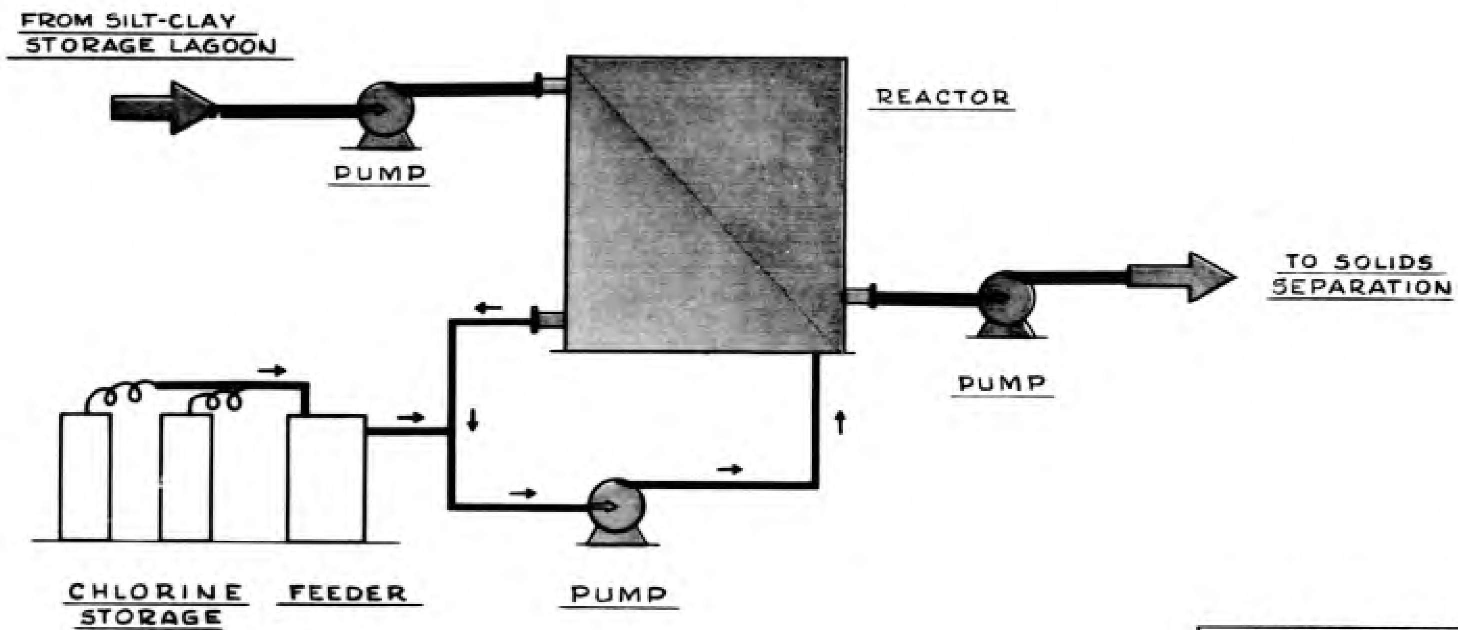
Annual Dredgings cu.yds.	Capital Cost	Annual Financing Costs (a)	Annual Labor Costs	Annual Utilities Costs	Annual Maintenance Costs	Annual Oper. and Mainten. Costs	Total Annual Costs	Annual Cost Per cu.yd.
1,500,000	$11,056,000	$1,406,000	$215,000	$417,000	$111,000	$743,000	$2,149,000	$1.43
1,000,000	7,585,000	965,000	215,000	324,000	76,000	615,000	1,580,000	1.58
500,000	4,407,000	561,000	149,000	200,000	44,000	393,000	954,000	1.90
100,000	1,286,000	164,000	131,000	47,000	13,000	191,000	164,000	3.55

(a) Based on 10 years at 4-5/8% annual interest.

FIGURE 12


TOTAL ANNUAL COST PER CUBIC YARD
OF AEROBIC STABILIZATION FACILITIES
VS. ANNUAL DREDGINGS
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001
ANNUAL DREDGINGS IN 100,000 CUBIC YARDS
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
ANNUAL COST PER CUBIC YARD IN DOLLARS
0 1 2 3 4

Using Figure No. 10 and Figure No. 11, Table No. 11 has been prepared and summarizes the costs and converts the annual costs to costs per cubic yard. Figure No. 12 shows a plot of cost per cubic yard versus annual dredged quantities. The cost of handling the digested solids is covered in Section N.



U.S. ARMY ENGINEER DISTRICT, BUFFALO
CORPS OF ENGINEERS

CHEMICAL OXIDATION FLOW DIAGRAM

NEBOLSINE, TOTH, McPHEE ASSOCIATES

PLATE 6

J. CHEMICAL OXIDATION

1. General

The volatile matter contained in the dredgings can be reduced through the use of the "Purifax" process, which employs the principle of chemical oxidation. Purifax, Incorporated has installed and successfully operated their process over the past several years to oxidize sewage sludges and septic tank pumpings.

The process is outlined on Plate No. 6 and consists basically of a reactor to which the main process flow, mixed with chlorine, is pumped through and a pump which recycles an amount through the reactor equal to approximately ten times the main throughput. The recycle flow is the medium through which chlorine is introduced to the main process flow.

Demonstration tests were run on samples from three points in the Buffalo Harbor region (see Drawing in Appendix A.) The following table of results was obtained from Purifax, Inc.:

BUFFALO HARBOR MUD SAMPLE NO. 1

CHARACTERISTIC	RAW	PURIFAX EFFLUENT	PURIFAX SUPERNATANT
pH (electrometric)	5.70	2.90	3.00
Turbidity, units	-	-	25
Chlorides, ppm as Cl	425	2730	2730
Ether Solubles, ppm	1035	407	54
% Reduction	-	60.7	94.8

Chemical Oxygen Demand, ppm	7567	6772	482
% Reduction	-	11.8	92.5
B.O.D., 5-day, 20° C, ppm	1200	1015	180*
% Reduction	-	15.4	85.1
Odor	Strong Petroleum	Lt. Cl_2; Fresh	Lt. Cl_2; fresh
Physical Appearance	Black; oily liquid	Brown; non-oily liquid	Clear; lt. yel.

*Interference

BUFFALO HARBOR MUD SAMPLE NO. 2

CHARACTERISTIC	RAW	PURIFAX EFFLUENT	PURIFAX SUPERNATANT
pH (Electrometric)	6.10	4.30	4.45
Turbidity, units	-	-	45
Chlorides, ppm as Cl	305	3580	3455
Ether solubles, ppm	551	482	140
% Reduction	-	12.5	74.8
Chemical Oxygen Demand, ppm	15,265	6185	469
% Reduction	-	59.6	97.0
B.O.D., 5-day, 20° C, ppm	1000	763	120*
% Reduction	-	23.7	88.0
Odor	Strong Petroleum	Lt. Cl_2; fresh	Lt. Cl_2; fresh
Physical Appearance	Black; oily liquid	Brown; non-oily liquid	Clear; lt. yel.

*Interference

BLACK ROCK CHANNEL MUD

CHARACTERISTIC	RAW	PURIFAX EFFLUENT	PURIFAX SUPERNATANT
pH (electrometric)	6.00	5.30	5.25
Turbidity, units	-	-	25
Chlorides, ppm as Cl	668	3520	3400
Ether Solubles, ppm	687	340	82
% Reduction	-	50.5	88.1
C.O.D., ppm	48,711	7390	427
% Reduction	-	84.8	99.1
B.O.D., 5-day, 20°C, ppm	4498	600	120*
% Reduction	-	86.8	97.5
Odor	Strong Petroleum	Lt. Cl_2; fresh	Lt. Cl_2; fresh
Physical Appearance	Black; oily liquid	Brown; non-oily liquid	Clear Lt. yel.

*Interference

It was unfortunate that data on phosphorus was not taken but for this report the phosphorus content will be assumed to be similar to other samples taken in the same area. The COD reduction with this process is as good as or better than that obtained in the Aerobic process covered in Section I and, therefore, the dry solids treated may be acceptable for depositing on the bottom of the lakes without too much concern as far as exerting bio-chemical demand or contributing any soluble phosphorus if most of the water fraction can be separated. Based on this conclusion, the costs of constructing and operating chemical oxidation facilities have been investigated. The cost of separating water fractions, treating these fractions and handling of the solids are covered in another section of this report.

2. Design Considerations

The design loadings listed in the previous sections of this report were used to size four plants. Purifax furnished delivered costs for units to be used plus their chlorine and electric energy requirements. Based on these costs an installed cost curve was developed covering the ranges required. In sizing the equipment for this process it was assumed that 15% of the dredgings were eliminated as inert sand and gravel particles.

3. Capital Cost Estimates

In addition to the costs received from Purifax, estimates were made of the floor area of building required to house the equipment, control center, offices and laboratory. A unit price of $20 per square foot was applied to the area required to develop building requirements. A similar procedure was used to determine the capital costs for foundations, electric service and site work. For the four design conditions the following summary was developed:

Annual Dredgings (c.y.)	3.0×10^6	1.5×10^6	0.5×10^6	0.1×10^6
85% of Dredgings #/Day	11.85×10^6	5.93×10^6	1.98×10^6	0.40×10^6
Installed Equipment	$910,000	$488,000	$329,000	$165,000
Buildings	53,000	34,000	23,000	12,000

NEBOLSINE, TOTH, McPHEE ASSOCIATES

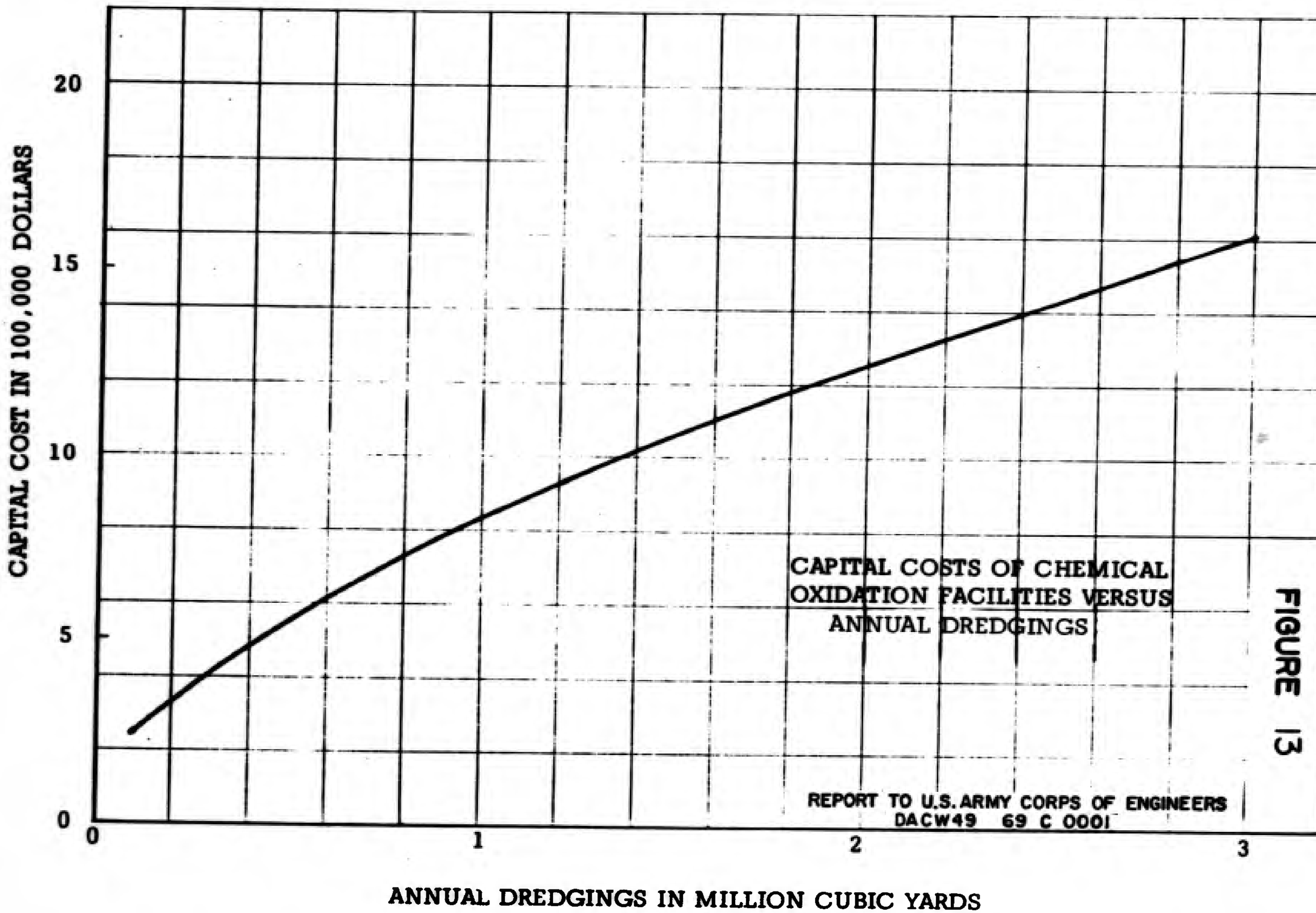


FIGURE 13

Foundations	$ 7,000	$ 4,000	$ 3,000	$ 2,000
Electric Service	251,000	126,000	63,000	13,000
Site Work	61,000	33,000	21,000	10,000
Sub-Total	$1,282,000	$685,000	$439,000	$201,000
Engineering & Contingencies	321,000	171,000	110,000	50,000
TOTAL	$1,603,000	$856,000	$549,000	$252,000

Based on these four design points Fig. 13 was developed. This curve provides the means of estimating the capital cost of chemical oxidation facilities for any daily loading of pounds of dry solids in the dredgings. The capital costs from this curve also are used in developing the annual costs for financing the construction of the project. A term of ten years and 4-5/8% interest is used for this purpose or a factor of 12.72% per year of the total capital costs.

4. Operating Costs

Annual Operating Costs for wet oxidation units are made up of the following:

I. Operating Labor and Supervision.

II. Utility Costs (fuel, electricity, water).

III. Maintenance (labor and materials).

For the item of Operating Labor and Supervision the following table of the 24-hour manpower requirements was estimated:

Annual Dredgings (c.y.)	3.0×10^6	0.5×10^6	0.1×10^6
85% of Dredgings #/Day	11.85×10^6	1.98×10^6	0.40×10^6
Superintendent	0	0	0
Foreman	1	1	1
Operators	3	3	3
Asst. Operators	3	0	0
Chemists	1	1	1
Asst. Chemists	0	0	0
Laborers	3	3	3
TOTAL	11	8	8

The requirements for the fourth design point were not estimated since three points appeared to be sufficient.

Appendix B lists the daily labor costs including all payroll burdens that have been used. To calculate the annual cost the daily cost has been multiplied by 365 days although the operating period is only 270 days per year.

Fuel oil, electricity and water requirements were obtained from Purifax and are as follows:

Annual Dredgings (c.y.)	3.0×10^6	0.5×10^6	0.1×10^6
85% of Dredgings #/Day	11.85×10^6	1.98×10^6	0.40×10^6
Electricity KWH $\times 10^6$/year	4.80	1.20	0.24
Chlorine # $\times 10^6$/year	41.5	7.40	1.57

NEBOLSINE, TOTH, McPHEE ASSOCIATES

FIGURE 14

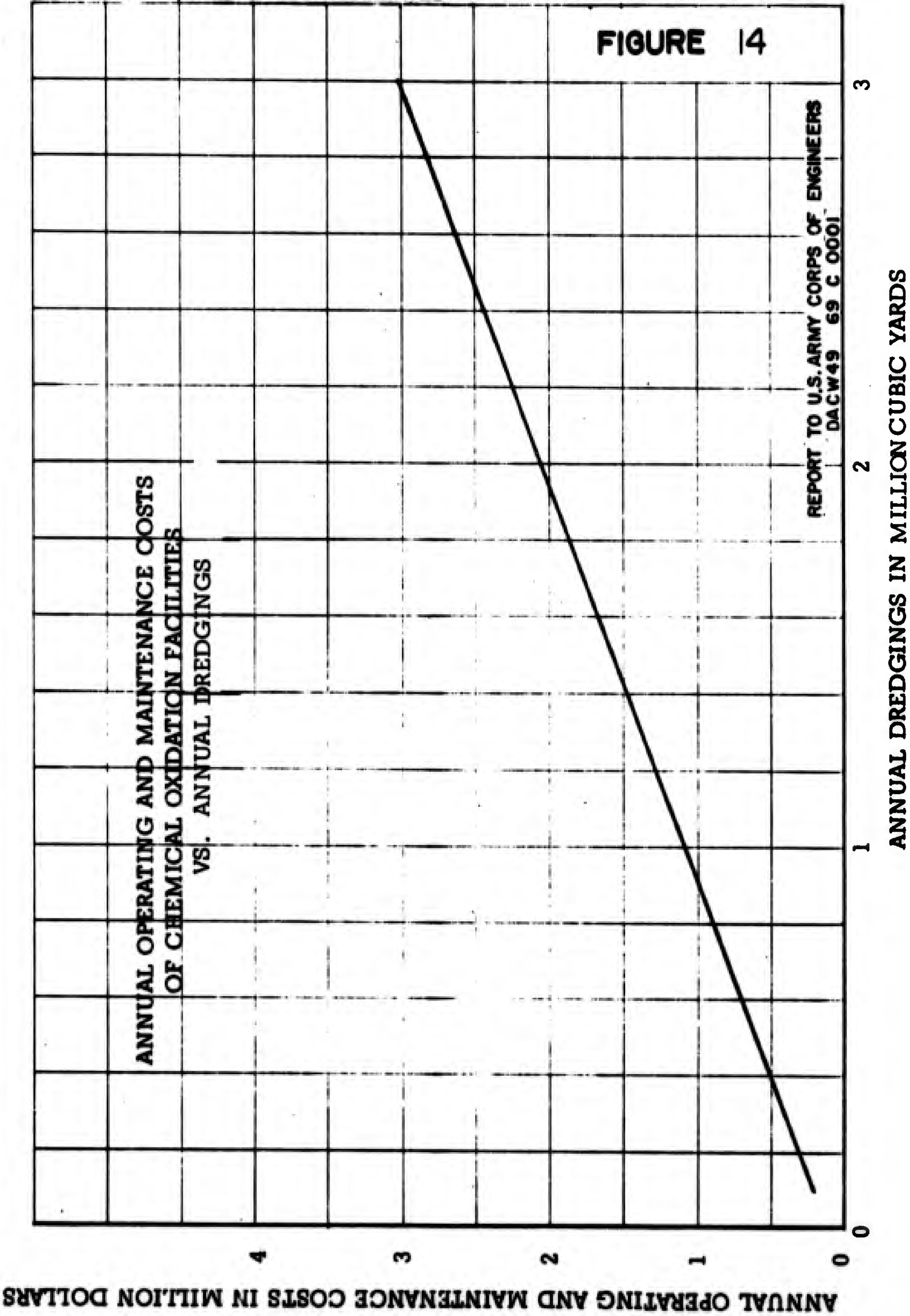
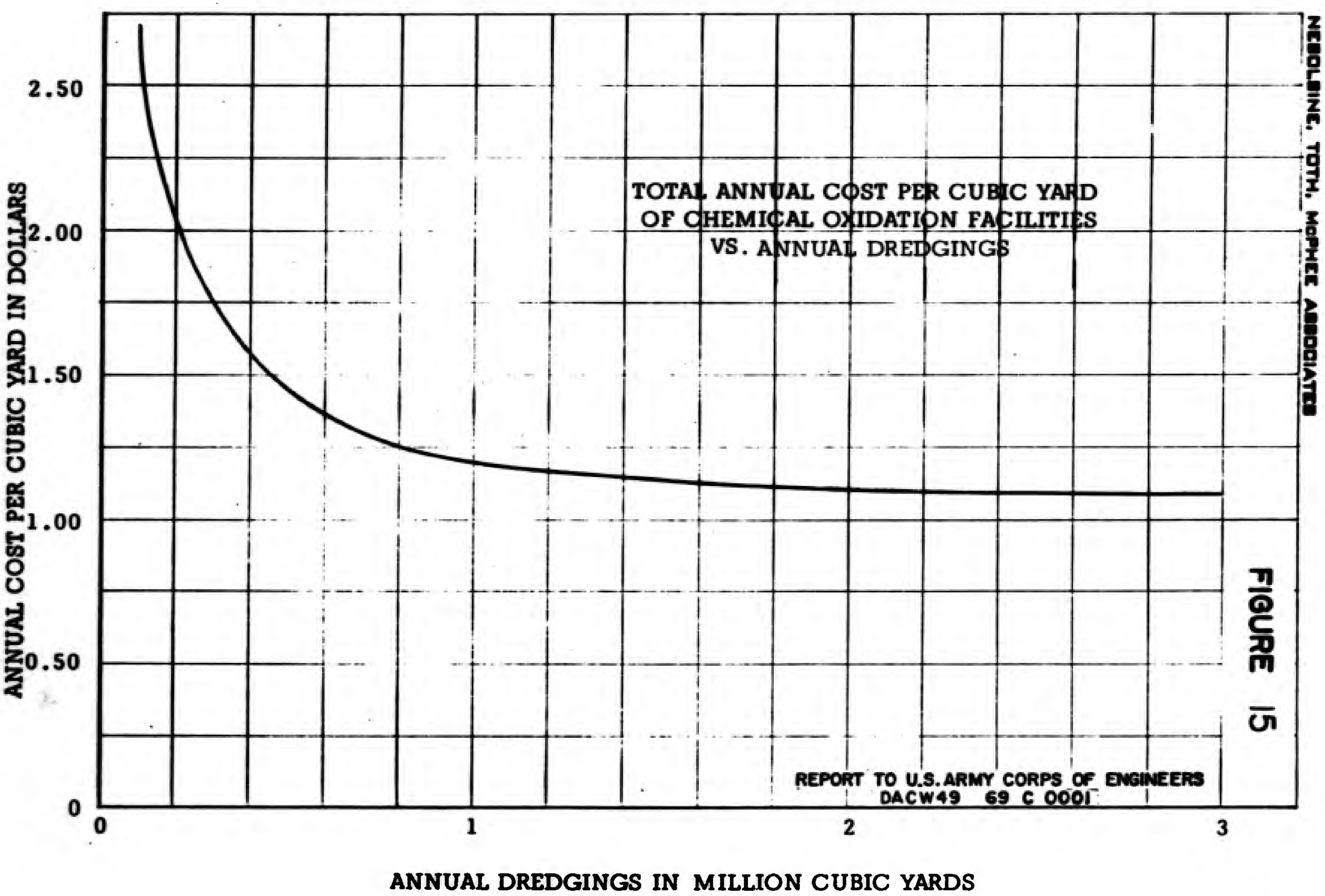


TABLE NO. 12

SUMMARY ANNUAL COST FOR CHEMICAL OXIDATION

Annual Dredging Cu. Yds.	Capital Cost	Annual Financing Cost (a)	Annual Utility Cost	Annual Labor Cost	Annual Mainten-ance Cost	Total Annual Oper. & Maint. Cost	Total Annual Cost	Cost Per Cu. Yd.
3.0×10^6	$1,603,000	$204,000	$2,910,000	$171,000	$16,000	$3,097,000	$3,301,000	$ 1.10
1.5×10^6	856,000	109,000	1,455,000	127,000	9,000	1,591,000	1,700,000	1.13
0.5×10^6	549,000	70,000	520,000	127,000	5,000	652,000	722,000	1.44
0.1×10^6	252,000	32,000	110,000	127,000	3,000	240,000	272,000	2.72

(a) Based on 10 years at 4-5/8% annual interest.



NESOLSINE, TOTH, McPHEE ASSOCIATES
FIGURE 15
TOTAL ANNUAL COST PER CUBIC YARD
OF CHEMICAL OXIDATION FACILITIES
VS. ANNUAL DREDGINGS
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001
ANNUAL COST PER CUBIC YARD IN DOLLARS
2.50
2.00
1.50
1.00
0.50
0
1
2
3
ANNUAL DREDGINGS IN MILLION CUBIC YARDS

Appendix B lists the unit prices for utilities that have been used.

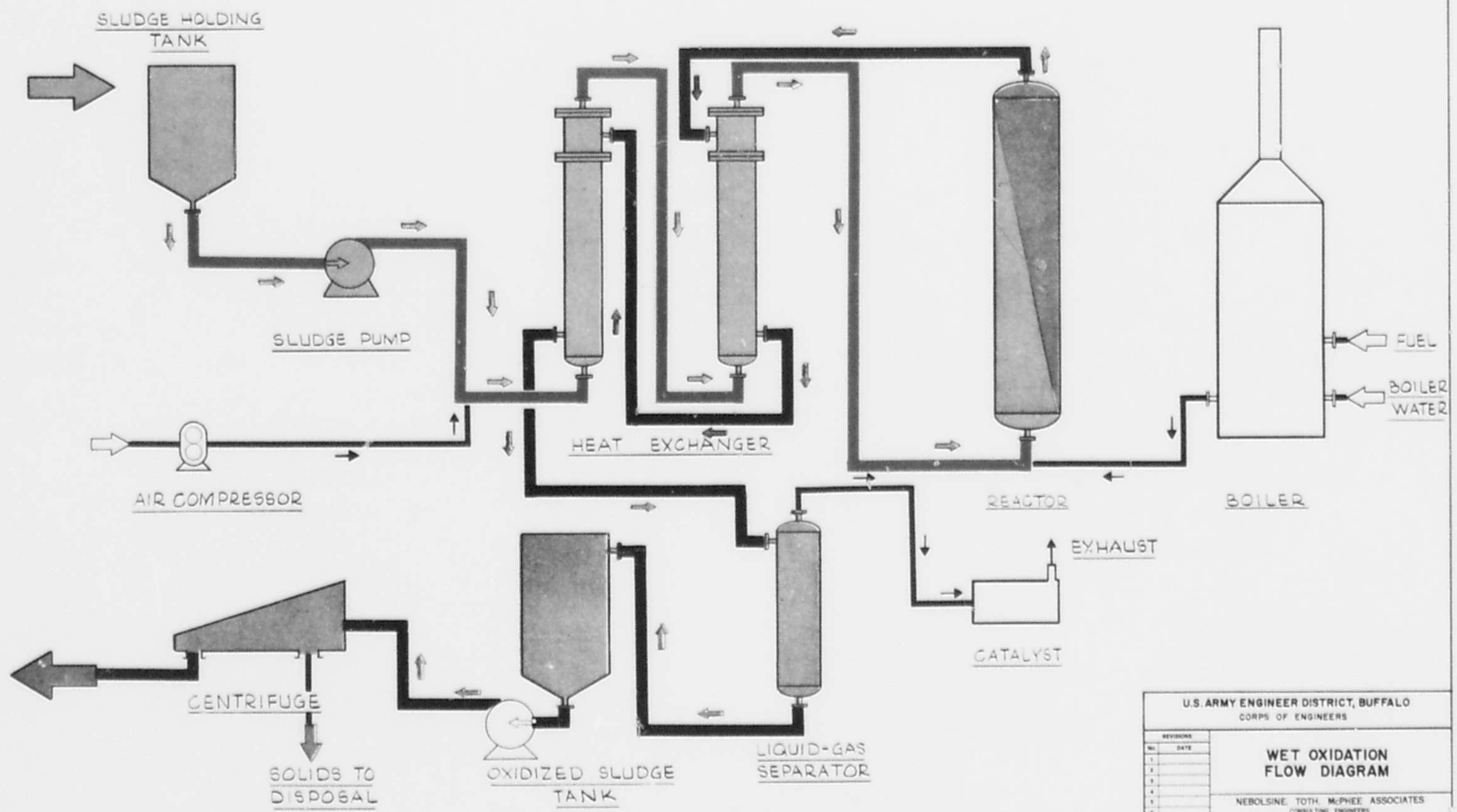
On maintenance, labor and material, costs are approximately equal to 1% of the installed costs of the equipment. They are as follows:

Annual Dredgings (c.y.)	Dredgings (#/day)	Daily Maintenance Costs
3.0×10^6	13.75×10^6	\$59
0.5×10^6	2.29×10^6	19
0.1×10^6	0.458×10^6	11

The summary of the Operating, Utility and Maintenance Costs for the three (3) dredging rates (85%) have been plotted and are shown on Fig. 14.

Using Fig. 13 and Fig. 14, Table No. 12 has been prepared which summarizes all of the various costs and converts the total annual costs to costs per cubic yard of dredgings. A plot of costs per cubic yard versus annual quantity of dredgings is shown on Fig. 15.

The costs per cubic yard presented on Fig. 15 covers only the cost of chemically oxidizing the silt-clay fractions of the dredgings. The costs on this curve should be added to costs for handling, storing and treating the dredgings prior to and following chemical oxidation operation.



U.S. ARMY ENGINEER DISTRICT, BUFFALO
CORPS OF ENGINEERS

WET OXIDATION
FLOW DIAGRAM

NEBOLSINE, TOTH, McPHEE ASSOCIATES
CONSULTING ENGINEERS
NEW YORK, N.Y.

DRAWN BY TMcN DATE SEPT 6 68 SCALE NONE

PLATE 7

K. WET OXIDATION

1. General

As noted in the previous sections on "Characteristics of the Dredgings" all of the dredgings contained some volatile matter either as oils and greases or other organic materials. One method of reducing volatile matter is to wet oxidize it. Depending on the pressure used in the wet oxidation unit, the degree of volatile matter reduced can be varied. At low pressure (300 psi) 10 to 20 percent may be reduced and at high pressure (1200 psi) 70 percent or more may be reduced.

The Zimpro Division of the Sterling Drug Company has installed and successfully operated wet oxidation units on sewage sludges over the past several years. The process is outlined on Plate No. 7. Basically the process consists of pumping heated sludges, mixed with sufficient air, under pressure, into a reactor where some of the volatile solids are reduced. At the same time as the volatile matter is being reduced, the chemical oxygen and bio-chemical oxygen demand of the solids is also reduced.

One bench scale test run was made on a sample taken from the bottom of Lake Michigan at the entrance of Indiana Harbor (see Drawing in Appendix A). The sample is from the same location as Sample CE-12-0 taken on 12/12/67 by the Federal Water Pollution Control Administration. The characteristics of the bottom samples as reported by the FWPCA and as found by Zimpro are as follows:

	ZIMPRO	FWPCA
Percent Total Solids	---	37.9%
Percent Volatile Solids	6.9%	6.6%
	(In mg/kg)	
Chemical Oxygen Demand	124,000	261,500
NH_3 as N	320	264
NO_3 as N	--	22
Org. Nitrogen	--	757
Total Phosphorus	2,310	786
Total Soluble Phosphorus	--	1.32
Phenol	--	0.97
Oil and Grease	--	27,900
Total Iron	--	57,000
Cyanide	--	5.7
Sulphide	--	351
Copper	--	95.5
Zinc	--	1,480
Lead	--	396
Chromium	--	79.2

Zimpro tested the dredging at three different wet oxidation pressures, 300 psi, 800 psi and 1200 psi. The results of these three tests are as follows:

	300 psi	800 psi	1200 psi
COD Reduction	7.7%	18.7%	37.0%
Volatile Solid Reduction	15.6%	47.2%	70.6%
COD of Oxidized Slurry (c)	116.3 g/l	100.7 g/l	57.7 g/l
COD of Filtrate (c)	6.7 g/l	18.7 g/l	19.3 g/l
COD of Filter Cake (c)	106.4 g/l	68.9 g/l	27.8 g/l
BOD of Filtrate (a)	3.4 g/l	9.3 g/l	9.7 g/l
Specific Filtration Resistance (b)	6.5	3.5	3.1

(a) Estimate of 50% of COD

(b) Original Sample 150

(c) Size of Samples and lab technique results in ability to balance total COD.

One important factor brought out in the Zimpro work is that in the water separated from the solids there were no measurable phosphorus and that even after reqashing the filter cake there still wasn't any measurable phosphorus in the wash water.

The difference between high and low pressure wet oxidation, in addition to those noted before, is that at the low pressure, less of the volatile products are solubilized in the water fraction.

Bio-degradability tests have been run on the dried solids from both high and low pressure tests and in both cases oxygen uptake rates are negligible. It appears that dredging solids treated in a low pressure (300 psi) wet oxidation unit may be acceptable for depositing on the bottom of the lakes without too much concern, as far as exerting bio-chemical oxygen demand or contributing any soluble phosphorus, if most of their water fraction can be separated. The treated solids also are more drainable than the untreated dredgings, therefore, may be more suitable for use as stable fill. Based on these conclusions, the costs of constructing and operating wet oxidation treatment facilities have been investigated.

2. Design Considerations

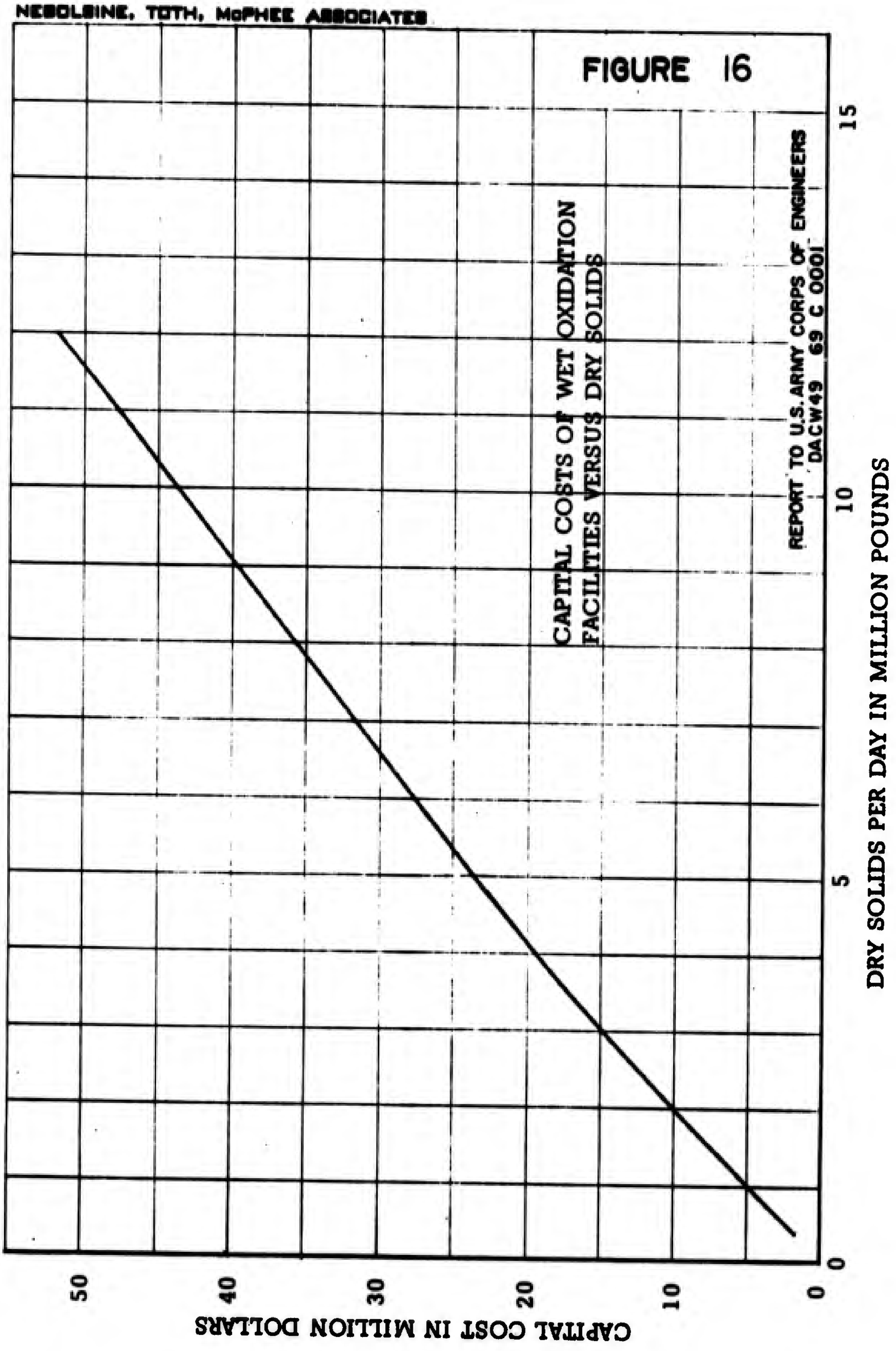
The design loadings listed in the prior section of this report were used to size four plants. Zimpro furnished installed costs for 100 ton per day (dry solids) plants plus their fuel and electric energy requirements. Based on Zimpro costs an installed cost curve was developed covering the ranges required. The cost for the largest plant was estimated to be 10% less per reactor than for the smallest plant. This percentage was discussed with Zimpro and they accepted it as reasonable. In sizing the wet oxidation equipment, it was assumed that 15% of the dredgings were eliminated as inert sand and gravel sized particles.

3. Capital Costs Estimates

In addition to the installed cost received from Zimpro, estimates also were made of the floor area of building required to house the auxiliary equipment, control center, offices and laboratory. A unit price of $20.00 per square foot was applied to the area developed to meet the building requirements. A similar procedure was used to determine the capital costs for foundations, electric service and site work. For the four design conditions the following summary was developed.

NEBOLSINE, TOTH, McPHEE ASSOCIATES

FIGURE 16



Dredgings (c.y./yr)	3,000,000	1,500,000	500,000	100,000
85% of Dredgings (#/day)	11.85×10^6	5.93×10^6	1.98×10^6	0.40×10^6
Installed Equipment	$34,500,000	$18,000,000	$6,500,000	$1,200,000
Buildings	2,230,000	1,360,000	530,000	188,000
Foundations	200,000	100,000	35,000	7,000
Electric Service	2,505,000	1,294,000	475,000	99,000
Site Work	1,972,000	1,038,000	377,000	75,000
Sub-Total	$41,407,000	$21,792,000	$7,917,000	$1,569,000
Engineering & Contingencies	10,352,000	5,448,000	1,979,000	392,000
TOTALS	$51,759,000	$27,240,000	$9,896,000	$1,961,000

Based on these four design points Fig. No. 16 was developed. This curve provides the means of estimating the capital cost of wet oxidation facilities for any daily loading of pounds of dry solids in the dredgings. The capital costs from this curve also are used in developing the annual costs for financing the construction of the project. A term of ten years and 4-5/8% annual interest is used for this purpose or a factor of 12.72% per year of the total capital costs.

4. Operating Costs

Annual operating costs for wet oxidation unit are made up of the following:

I. Operating Labor and Supervision.

II. Utility Costs (Fuel, electricity, water).

III. Maintenance (Labor and material).

For the item of Operating Labor and Supervision the following table of the 24-hour manpower requirements was estimated:

Annual Dredgings (cubic yards)	3.0×10^6	0.5×10^6	0.1×10^6
85% of Dredgings (#/day)	11.85×10^6	1.9×10^6	0.40×10^6
Superintendent	1	0	0
Foreman	3	1	1
Operators	9	4	3
Asst. Operators	9	3	2
Chemists	2	1	1
Asst. Chemists	8	3	0
Laborers	18	7	1
TOTALS	50	19	8

The requirements for the fourth design point were not estimated since three points appeared to be sufficient.

Appendix C lists the labor costs including all payroll burdens, that have been used. To calculate the annual costs the daily cost has been multiplied by 365 days although the operating period is only 270 days per year.

Fuel oil, electricity and water requirements were obtained from Zimpro and are as follows for the:

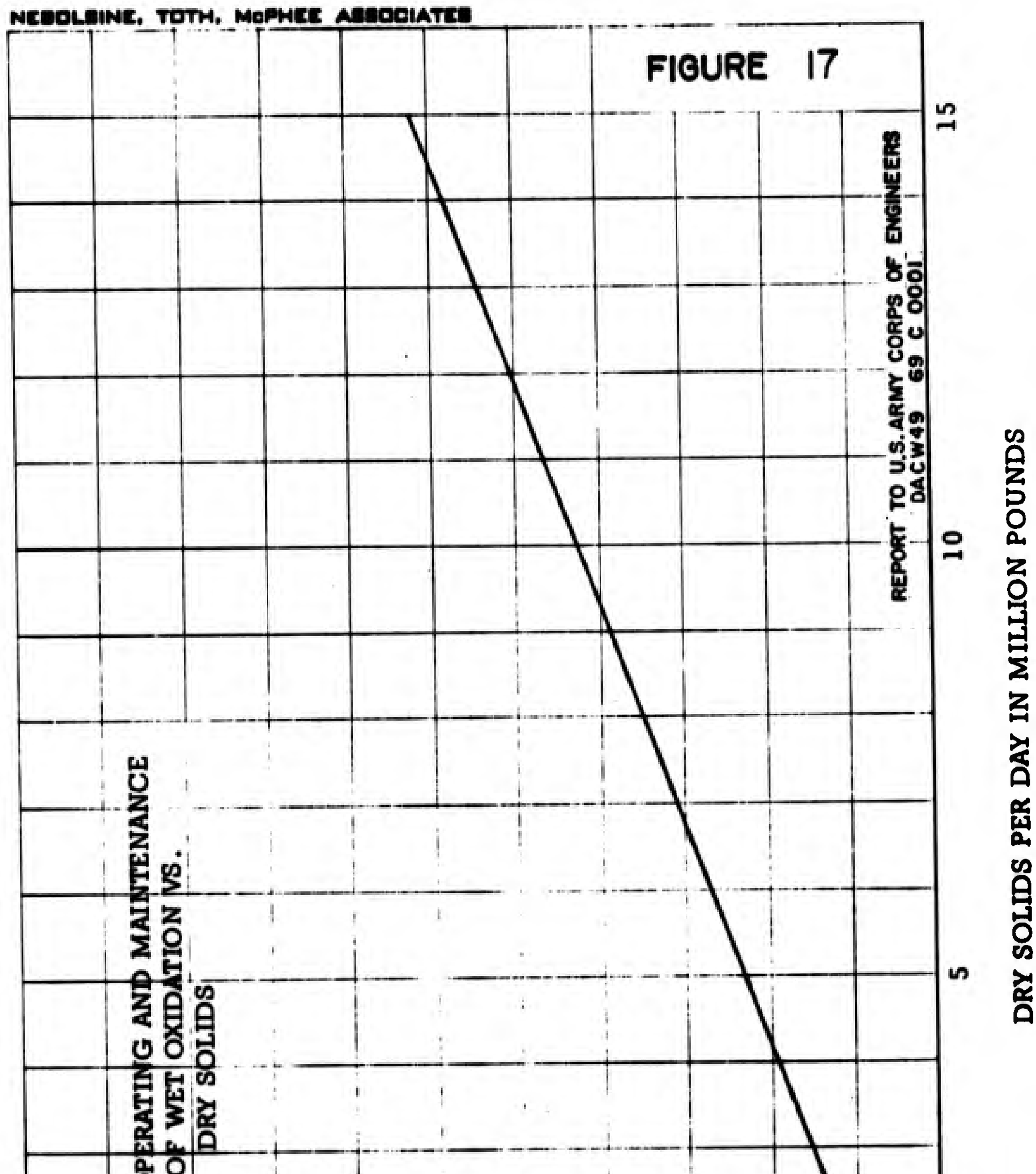

NEBOLSINE, TOTH, McPHEE ASSOCIATES
FIGURE 17
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001
ANNUAL OPERATING AND MAINTENANCE COSTS OF WET OXIDATION VS. DRY SOLIDS
0
5
10
15
DRY SOLIDS PER DAY IN MILLION POUNDS
0
1
2
3
4
ANNUAL OPERATING AND MAINTENANCE COSTS IN MILLION DOLLARS

TABLE NO. 13

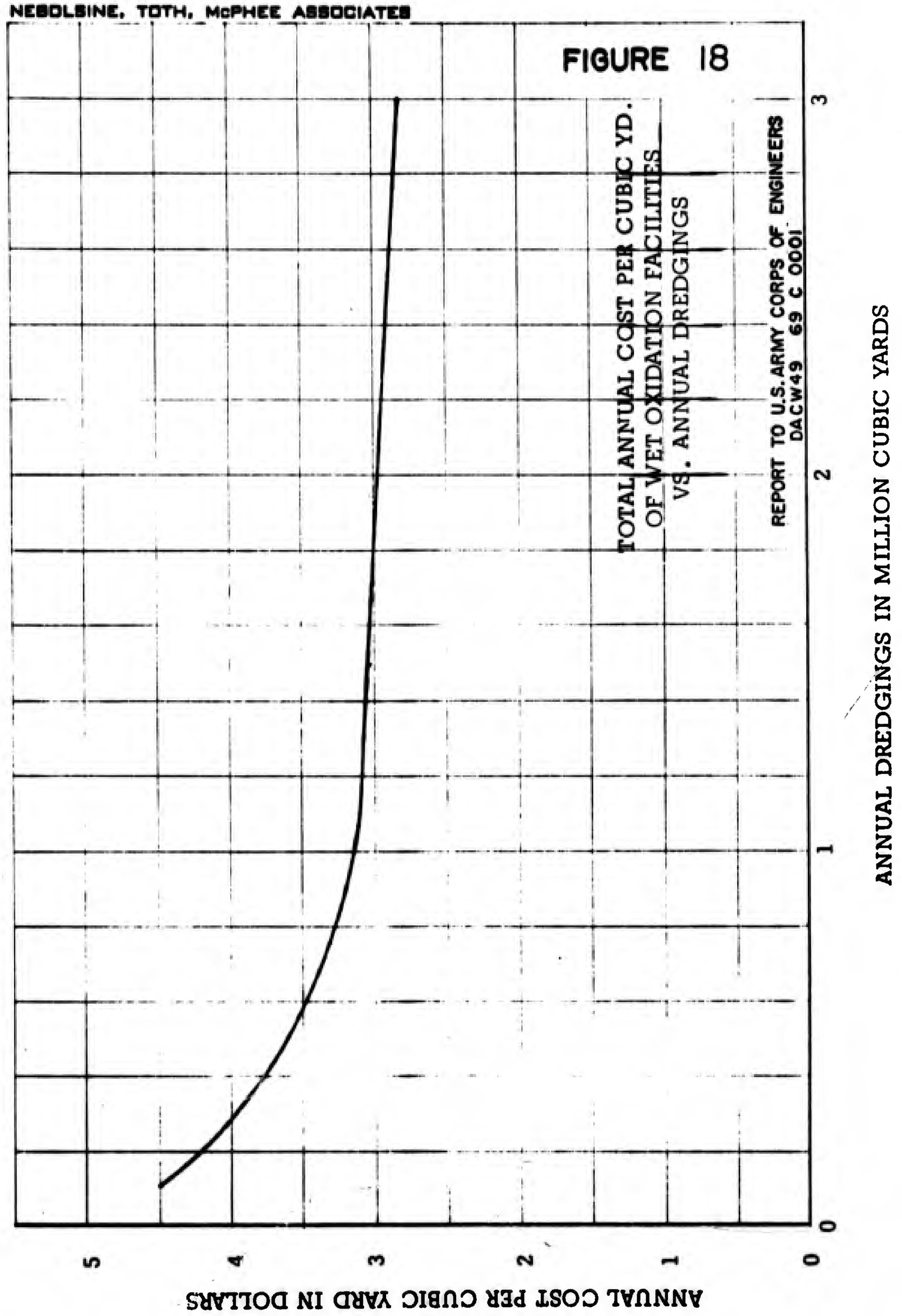
SUMMARY OF WET OXIDATION

ANNUAL COSTS

Annual Dredged Quantities Cu.Yds.	Capital Costs	Annual (a) Financing Costs	Operating Labor Costs	Utility Costs	Maintenance Cost	Total Annual Operating & Maintenance Costs	Total Annual Costs	Cost Per Cu.Yd.
3,000,000	$51,759,000	$6,584,000	$742,000	$681,000	$518,000	$1,941,000	$8,525,000	$2.84
1,500,000	27,240,000	3,465,000	400,000	426,000	272,000	1,098,000	4,563,000	3.04
500,000	9,896,000	1,259,000	277,000	175,000	99,000	551,000	1,810,000	3.62
100,000	1.961,000	249,000	134,000	43,000	20,000	197,000	446,000	4.46

(a) Based on 10 years at 4-5/8% annual interest.

NEBOLSINE, TOTH, McPHEE ASSOCIATES



Annual Dredgings (c.y.)	3.0×10^6	0.5×10^6	0.1×10^6
Dredging #/Day	13.75×10^6	2.29×10^6	0.458×10^6
85% of Dredgings (#/day)	11.85×10^6	1.98×10^6	0.40×10^6
Cooling Water, gpd	2,890,000	500,000	100,000
Boiler Feedwater, gpd	191,000	33,000	7,000
Electricity, KWH/D	205,000	35,600	7,100
Fuel, BTU x 10^6 /D	1,160	200	40

Appendix B lists the unit prices used in caluclating the utility costs. For maintenance, labor and material costs, costs made available by Zimpro were used. These costs are approximately equal to 1% of the installed costs of the equipment. They are as follows:

Annual Dredgings (c.y.)	Dredgings #/Day (85%)	Daily Maintenance Costs
3.0×10^6	11.85×10^6	1900/day
0.5×10^6	1.98×10^6	370/day
0.1×10^6	0.40×10^6	74/day

The summary of the Operating and Maintenance Costs for the three (3) dredging rates (85%) have been plotted and are shown on Fig. No. 17.

Using Fig. No. 16 and Fig. No. 17, Table No. 13 has been prepared which summarizes all of the various costs and converts the total annual costs to costs per cubic yard of dredgings. A plot of costs per cubic yard versus annual quantity of dredgings is shown on Fig. No. 18.

The costs per cubic yard presented on Fig. No. 18 cover only the cost of wet-oxidizing the silt-clay fractions of the dredgings. The costs on this curve should be added to costs for handling, storing and treating the dredgings prior to and following the wet oxidation operation.

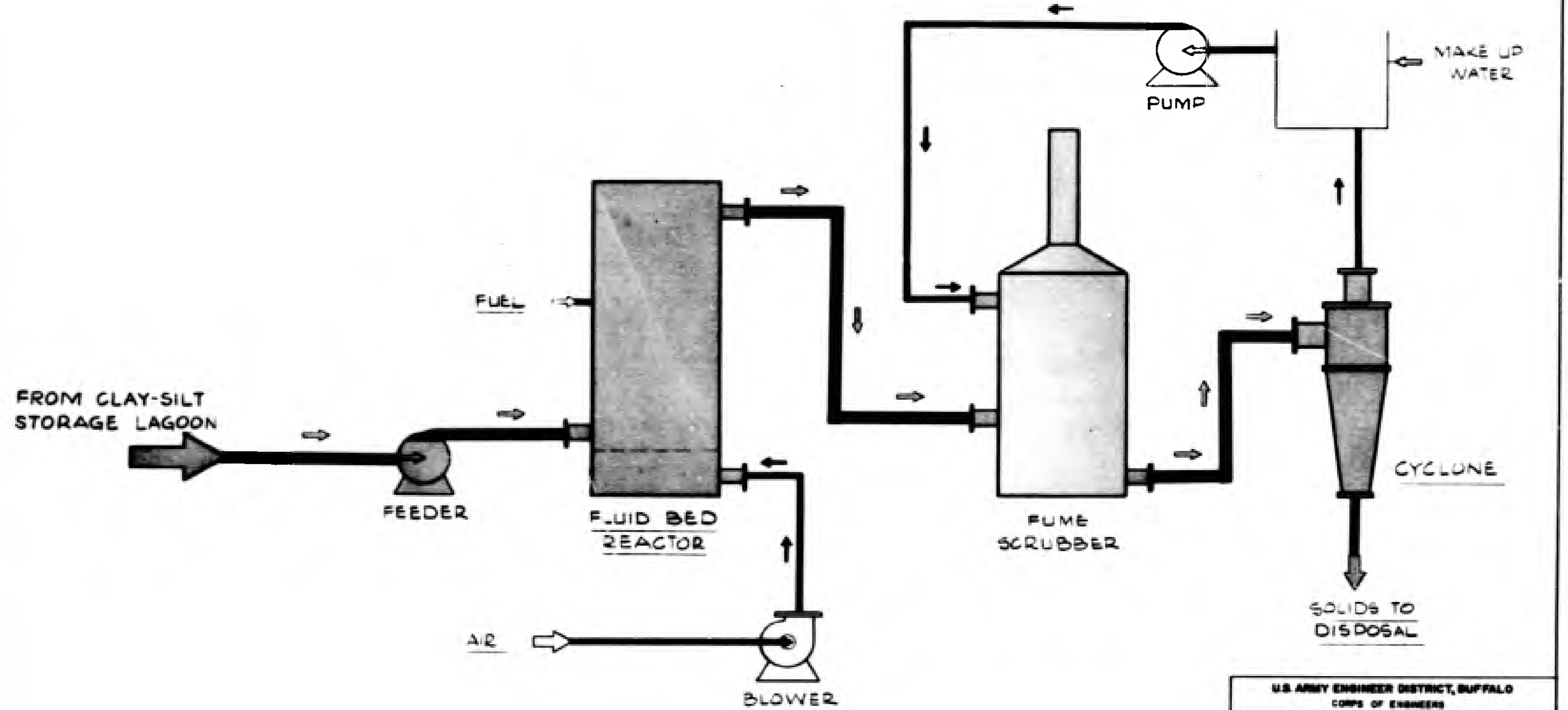
5. Additional Costs to be Considered

In the wet oxidation plant some of the volatile solids that have been removed end up as chemical (COD) and bio-chemical (BOD) oxygen demand in the water fraction. It is estimated that 50% of the COD in the water fraction is bio-chemical oxygen demand (BOD). This water cannot be discharged to the lake or adjacent harbor without the removal of a sufficient amount of the BOD. The treated solids are fairly stable, however, and can be separated from their water fraction and disposed of without any additional treatment being required.

Vacuum filtrating or centrifuging would concentrate the solids but in both cases the concentrated material will always contain some water containing high BOD's. Referring back to the results of the test runs made by Zimpro, it will be noted that the filtrate contained 3.4 g/l of BOD. Unless the solids from the Zimpro reactor are washed sufficiently it will be impossible to remove sufficient soluble BOD to permit the discharge of the treated solids to the lake as bottom deposits. If washing was to be resorted to the biological oxidation of the waste waters would present a problem approaching that of direct aerobic treatment of the dredgings, as described in Section I.

Based on these facts, it appears that the only possible use for the Zimpro process is in conditioning the solids for use as land fill. Even in this case the water draining from the solids will either have to be contained and if it cannot be contained, then treated for the removal of a reasonable amount of BOD and fine suspended solids.

The costs of dewatering the sludge from the reactor and treating the separated water is covered in Section N and are to be added to the costs developed under this section.



U.S. ARMY ENGINEER DISTRICT, BUFFALO
CORPS OF ENGINEERS

FLUID BED INCINERATION FLOW DIAGRAM

NEBOLSINE, TOTH, McPHEE ASSOCIATES

PLATE 8

L. FLUID BED INCINERATION

1. General

The previous sections on "Characteristics of Dredgings" note that all of the dredgings contain some volatile matter either as oils and grease or other organic materials. A positive method of reducing this volatile matter is by incineration. In incineration the operating costs are influenced by the amount of moisture and the BTU content of the sludge charged to the furnace. Fluid bed type of incineration has, for several years, been used to convert sewage and industrial waste sludges into an easily disposable stable ash. Fume scrubbing equipment, auxiliary to the incinerator, eliminates air pollution problems.

This process is outlined on Plate No. 8 and basically consists of a system to distribute the sludge to the incinerator, the incinerator and fume scrubbing and ash handling systems.

A sludge with 45% solids, by weight, will be fed to the incinerators based on the assumption that the solids will compact in the storage area to approximately the same degree as it packs in the harbors, where values in excess of 50% solids have been consistently observed.

A value of 1850 BTU/# of dry solids in the dredgings has been used to determine the supplementary fuel requirements.

2. Design Considerations

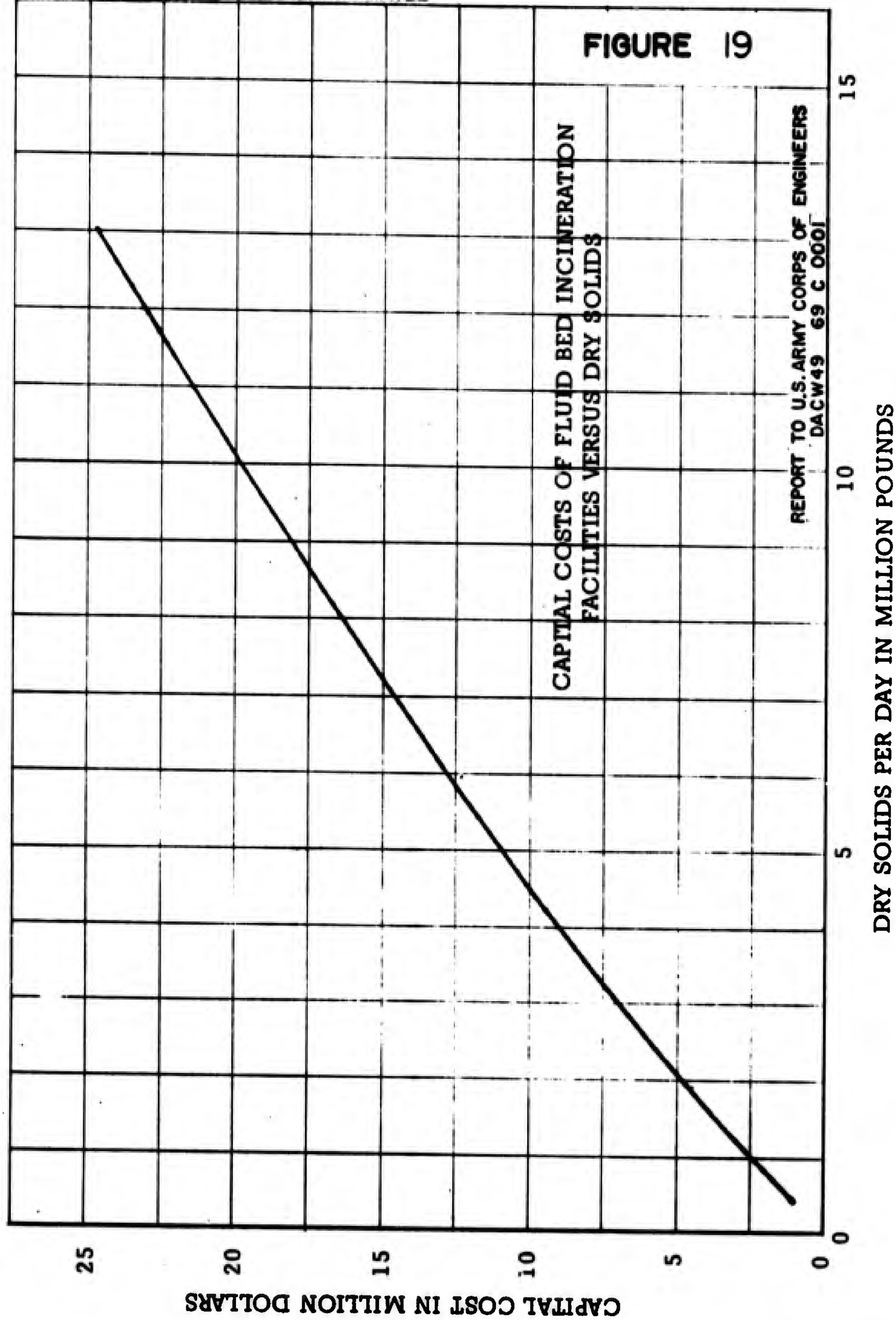
The design loadings listed in a prior section of this report were used to size four incinerator plants. Various manufacturers furnished installed costs of units with varying capacities as well as fuel and electric energy requirements. Based on the installed costs obtained, a curve was developed covering the ranges in plant size required. In sizing the incineration plants, it was assumed that 15% of the dredgings were eliminated as stable sand and gravel particles.

3. Capital Cost Estimates

In addition to the installed equipment costs received from the manufacturers, estimates were made of the floor area of buildings required to house the auxiliary equipment, electric control center, office and laboratory. A unit price of $20.00 per square foot was applied to the area required to develop the building requirements. A similar procedure was used to determine the capital costs for foundations, electric service and site work. For the four design conditions, the following summary was developed:

Annual Dredgings (c.y./yr.)	3.0×10^6	1.5×10^6	0.5×10^6	0.1×10^6
Dredgings (85%) #/Day	11.85×10^6	5.93×10^6	1.98×10^6	0.40×10^6
Installed Equipment	$12,250,000	$6,800,000	$2,460,000	$ 615,000
Building	1,120,000	650,000	248,000	38,000
Foundations	180,000	120,000	36,000	9,000
Electric Service	3,633,000	1,841,000	760,000	208,000
Site Work	859,000	471,000	175,000	44,000
Sub-Total	$18,042,000	$9,882,000	$3,679,000	$ 914,000
Engineering & Contingencies	4,511,000	2,470,000	920,000	228,000
TOTALS	$22,553,000	$12,352,000	$4,599,000	$1,142,000

FIGURE 19


CAPITAL COSTS OF FLUID BED INCINERATION
FACILITIES VERSUS DRY SOLIDS
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001
DRY SOLIDS PER DAY IN MILLION POUNDS
0
5
10
15
CAPITAL COST IN MILLION DOLLARS
0
5
10
15
20
25

Based on these four design points Fig No. 19 was developed which provides the means of estimating capital cost of fluid bed incineration facilities for any daily loading of pounds of dry solids in the dredgings. The capital costs from this curve are also used in developing the annual costs for financing the construction of the project. A term of ten years and 4-5/8% annual interest is used for this purpose or a factor of 12.72% per year of the total capital costs.

4. Operating Costs

Annual operating costs for fluid bed incineration units are made up of the following:

a. Operating Labor and Supervision

b. Utility costs (fuel, electricity, water)

c. Maintenance (labor and materials)

For the item of Operating Labor and Supervision the following table of the 24-hour manpower requirements was estimated:

Annual Dredgings (c.y/yr)	3.0×10^6	0.5×10^6	0.1×10^6
85% of Dredgings (#/day)	11.5×10^6	1.98×10^6	0.40×10^6
Superintendent	1	0	0
Foreman	1	1	1
Operators	6	3	3
Asst. Operators	6	0	0
Chemists	1	1	1
Asst. Chemists	1	0	0
Laborers	6	6	3
TOTALS	22	11	8

The requirements of the fourth design point were not estimated since three points appeared to be sufficient.

Appendix C contains the daily labor costs, including all payroll burdens that are used. To calculate annual costs the daily cost has been multiplied by 365 days although the operating period is only 270 days per year.

Fuel oil, electricity and water requirements were obtained from the incinerator manufacturer and are as follows:

Annual Dredgings (#/Day)	3.0×10^6	0.5×10^6	0.1×10^6
85% of Dredgings (#/Day)	11.85×10^6	1.98×10^6	0.40×10^6
Electricity, KWH/Y	1,200,000	240,000	60,000
Fuel, BTU x 10^6/Y	12.56	3.2	.435

Appendix B contains the unit prices used for utility costs.

On maintenance: labor and material costs were estimated to be approximately equal to 1% of the installed costs of the equipment, based on a 12-month period. They are as follows:

Annual Dredgings (cy)	85% of Dredgings (#/Day)	Daily Maintenance Costs (270 days)
3.0×10^6	11.85×10^6	$840/day
0.5×10^6	1.98×10^6	170/day
0.1×10^6	0.40×10^6	41/day

The summary of the Operating and Maintenance Costs for the three (3) dredging rates (85%) have been plotted and are shown on Fig. No. 20.

Using Fig. No. 19 and Fig. No. 20, Table No.14 has been prepared and summarizes all of the various costs and converts the total annual costs

NEBOLSINE, TOTH, McPHEE ASSOCIATES

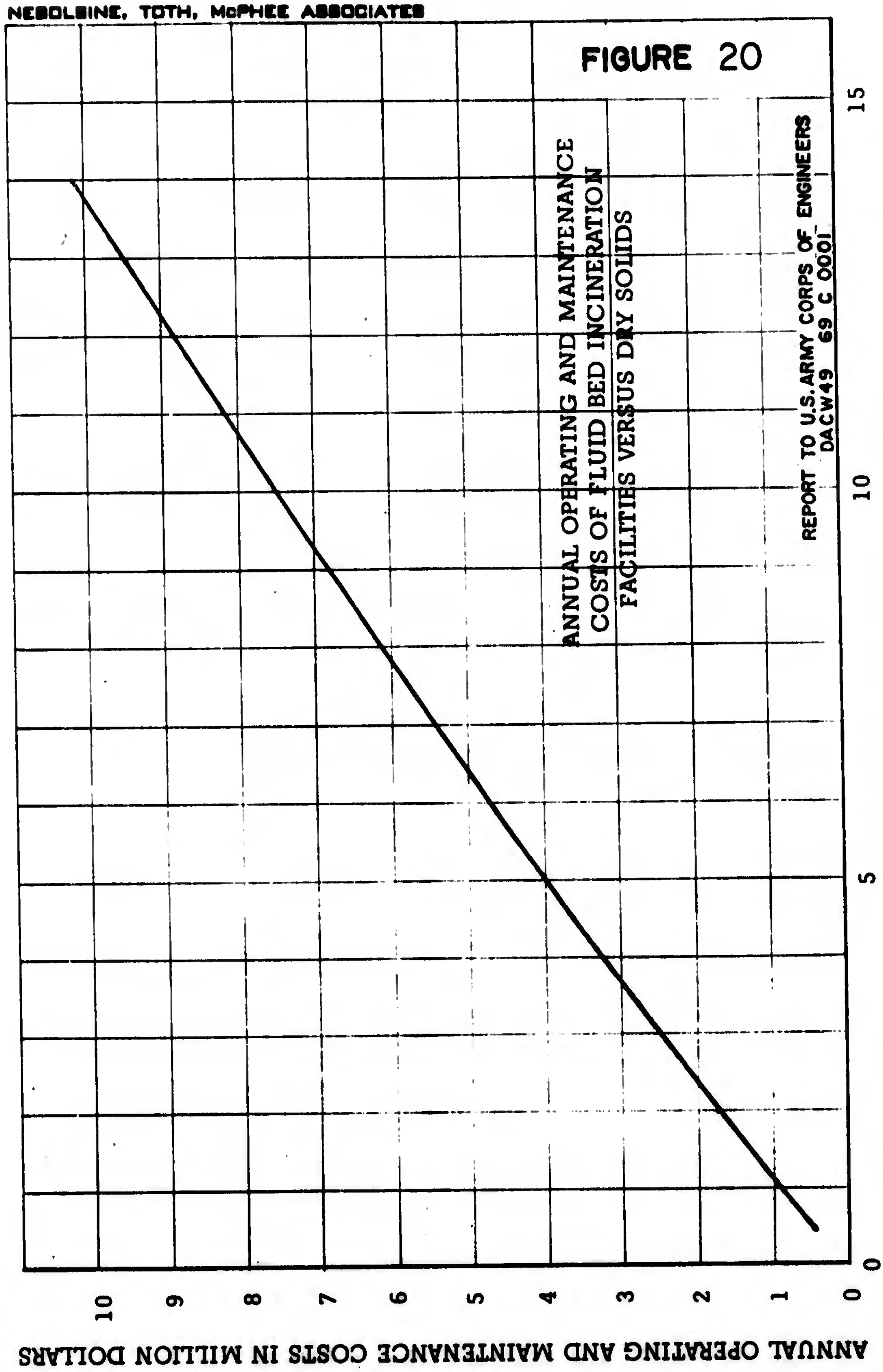


TABLE NO. 14

SUMMARY OF ANNUAL COSTS FOR

FLUID BED INCINERATION

Annual Dredgings Cu.Yds.	Capital Cost	Annual Financial Cost	Annual Utility Cost	Annual Labor Costs	Annual Mainten- ance Costs	Total Annual Oper. & Mainten. Costs	Total Annual Cost	Cost Per Cu.Yd.
3.0 x 10	$22,553,000	$2,869,000	$8,071,000	$349,000	$226,000	$8,646,000	$11,515,000	$3.84
1.5 x 10	12,353,000	1,571,000	4,169,000	196,000	124,000	4,589,000	6,160,000	4.11
0.5 x 10	4,599,000	585,000	1,518,000	245,000	46,000	1,809,000	2,394,000	4.79
0.1 x 10	1,142,000	145,000	323,000	127,000	11,000	461,000	606,000	6.06

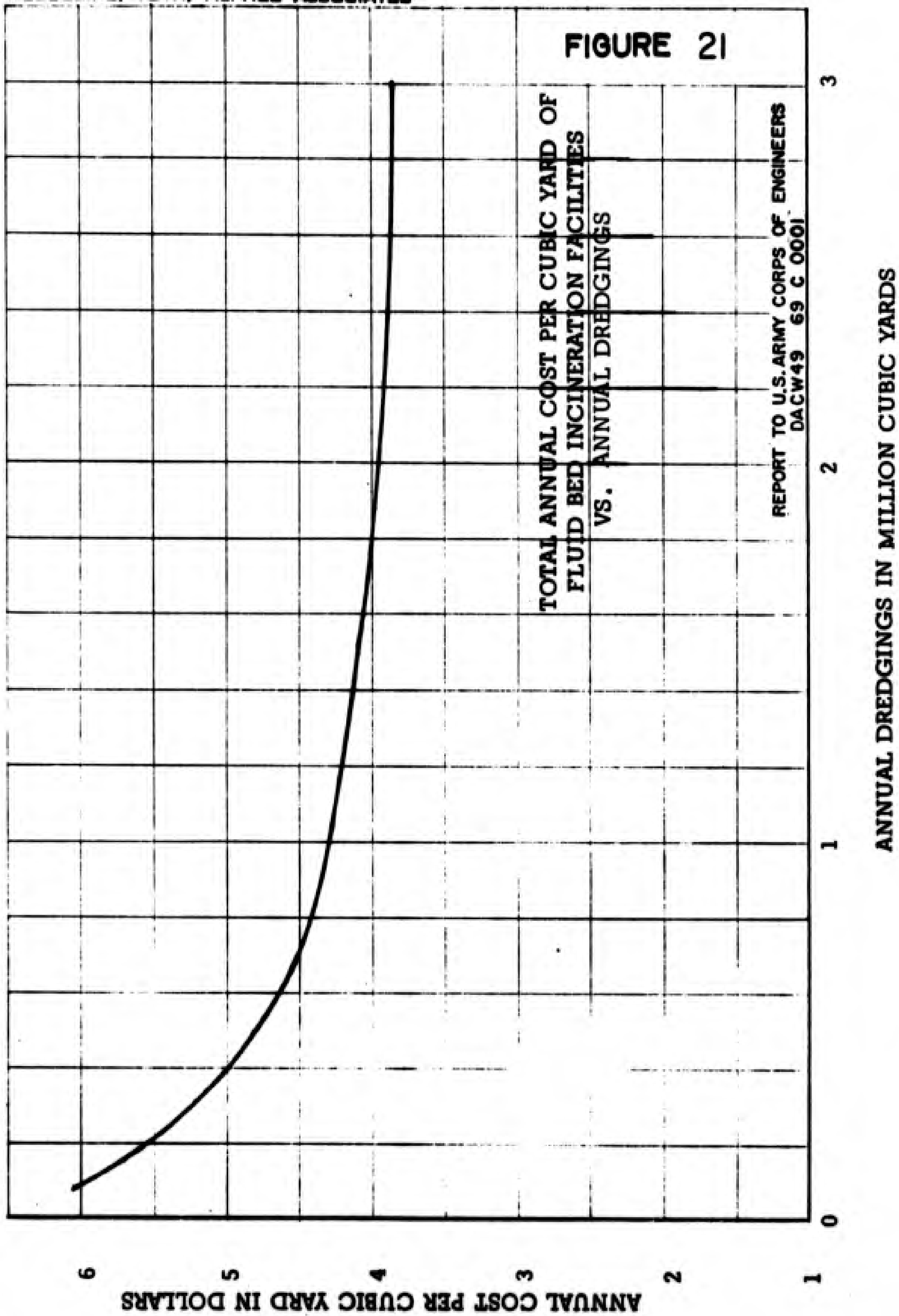


FIGURE 21
TOTAL ANNUAL COST PER CUBIC YARD OF
FLUID BED INCINERATION FACILITIES
VS. ANNUAL DREDGINGS
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001
0
1
2
3
ANNUAL DREDGINGS IN MILLION CUBIC YARDS
6
5
4
3
2
1
ANNUAL COST PER CUBIC YARD IN DOLLARS

to costs per cubic yard of dredgings. A plot of costs per cubic yard versus annual dredging quantities is shown on Fig. No. 21.

The costs per cubic yard presented on Fig. No. 21 cover only the cost of incineration of the silt-clay fractions of the dredgings. The costs on this curve should be added to costs for handling, storing and treating the dredgings prior to and following the fluid bed incineration operation.

5. Possible Variation

A possible variation that should be considered in the treatment of the dredgings by incineration is the construction of a floating treatment plant of sufficient size so that one or two such plants would be capable of treating the dredgings of a lake, or section of a lake, in the nine or ten month available working period.

A preliminary investigation of this possible variation based on treating the estimated total annual maintenance dredgings from the four (4) pilot operations in Lake Erie has been made. The estimated maintenance dredging quantities for the Lake Erie pilot operations are:

Buffalo Harbor	575,000 cubic yards
Cleveland Harbor	1,270,000 cubic yards
Toledo Harbor	1,140,000 cubic yards
Rouge River	300,000 cubic yards
TOTAL	3,285,000 cubic yards

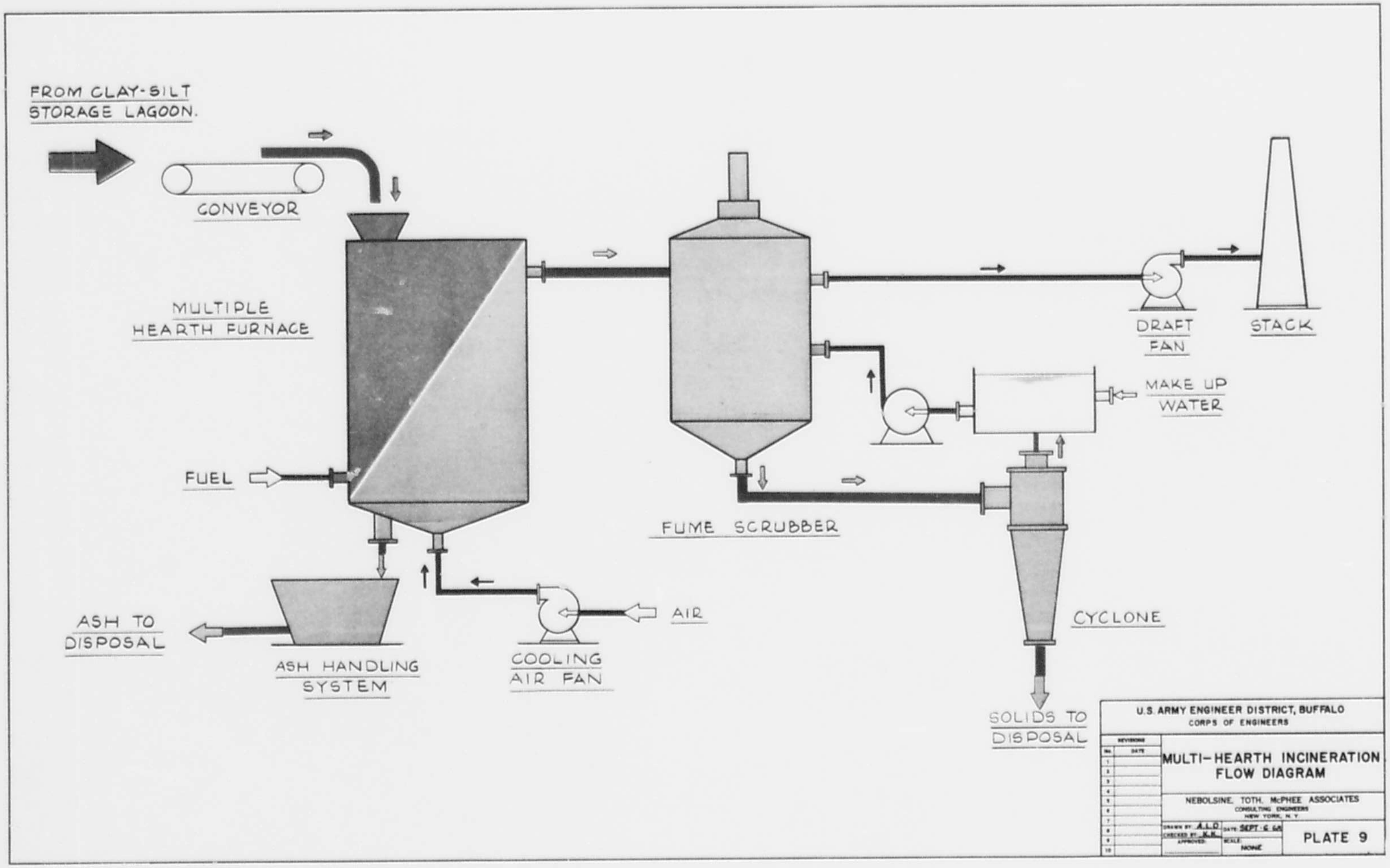
To treat 3,285,000 cubic yards in a nine month's period (270 days) would require a daily treatment rate of 11,400 cubic yards per day or 13,000,000 pounds per day (1250 #/cu.yd. dry solids and 85% of dredgings). The cost of a single plant to handle 85% (clay and silt fractions) of this quantity is estimated to cost $24,600,000 (Fig. No. 19). The annual cost of financing, operating and maintaining such a plant is estimated to cost $12,630,000 (Fig. No. 20 plus 12.72% of capital cost).

The cost per cubic yard for the 3,285,000 cubic yards per year of dredgings is estimated to cost $3.84.

The above cost estimates assume that the cost of providing the marine equipment and moving it from harbor to harbor is approximately equivalent to the cost of providing foundations for the same equipment on shore. A comparison of the unit cost developed above with the individual unit costs for each harbor is as follows:

Buffalo Harbor	575,000 cu. yds. @ $4.65/cu.yd.	= 2,673,750
Cleveland Harbor	1,270,000 cu. yds. @ 4.10/cu. yd.	= 5,207,000
Toledo Harbor	1,140,000 cu. yds. @ $4.15/cu.yd.	= 4,731,000
Rouge River	300,000 cu. yds. @ $5.20/cu.yd.	= 1,560,000
	TOTAL	$14,171,750
All Harbors	3,285,000 cu. yds. @ $3.84/cu.yd.	= $12,630,000

With this annual savings possible, it appears that an investigation in greater depth would be justified.


FROM CLAY-SILT STORAGE LAGOON.
CONVEYOR
MULTIPLE HEARTH FURNACE
FUEL
ASH TO DISPOSAL
ASH HANDLING SYSTEM
COOLING AIR FAN
AIR
FUME SCRUBBER
DRAFT FAN
STACK
MAKE UP WATER
CYCLONE
SOLIDS TO DISPOSAL
U.S. ARMY ENGINEER DISTRICT, BUFFALO
CORPS OF ENGINEERS
MULTI-HEARTH INCINERATION FLOW DIAGRAM
NEBOLSINE, TOTH, McPHEE ASSOCIATES
CONSULTING ENGINEERS
NEW YORK, N.Y.
PLATE 9

M. MULTIPLE HEARTH INCINERATION

1. General

As previously stated in many of the preceding sections of this report all of the dredgings contained some volatile solids either as grease and oils or other organic materials. Another positive method of reducing volatile matter is by multiple hearth incineration, where again the operation costs are principally influenced by the amount of moisture and BTU content of the sludge charge to the furnace. This type of incinerator has been used for many years to convert sewage and industrial waste sludges into an easily disposable stable ash. Fume scrubbing equipment auxiliary to the incinerator eliminates air pollution problems.

The process is outlined on Plate No. 9 and basically consists of a system to distribute the sludge to the incinerator, the incinerator and fume scrubbing and ash handling systems.

A sludge with 45% solids, by weight, will be fed to the incinerators based on theassumption that the solids will compact in the storage area to the same degree as it packs in the harbors, where values in excess of 50% solids have been consistently observed.

For the initial investigation a value of 1850 BTU/# of dry solids based on 10% volatile solids, has been used to determine the supplementary fuel requirements.

2. Design Considerations

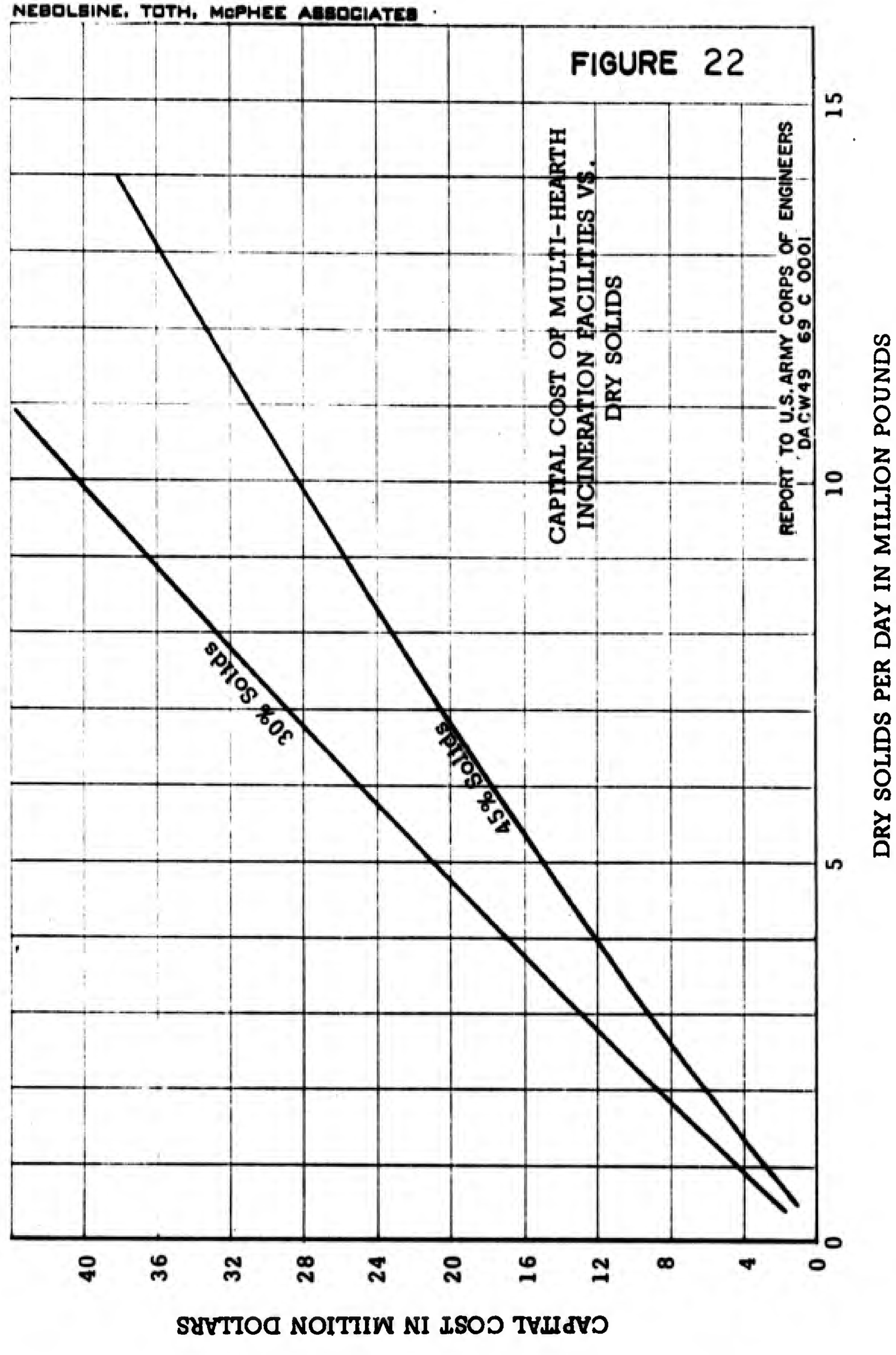
The design loadings listed in a prior section of this report were used to size four incineration plants. Various manufacturers furnished installed costs of units with varying capacities as well as fuel and electric energy requirements. Based on the installed costs obtained, a curve was developed covering the ranges in plant size required. In sizing the incineration plants, it was assumed that 15% of the dredgings were eliminated as sand and gravel sized particles.

3. Capital Cost Estimates

In addition to the installed equipment costs received from the manufacturers, estimates were made of the floor area of buildings required to house the auxiliary equipment, electric control center, office and laboratory. A unit price of $20.00 per square foot was applied to the area required to develop the building requirements. A similar procedure was used to determine the capital costs for foundations, electric service and site work. For the four design conditions, the following summary was developed:

Annual Dredgings (c.y/yr)	3,000,000	1,500,000	500,000	100,000
85% of Dredgings (#/day)	11.85×10^6	5.93×10^6	1.98×10^6	0.40×10^6
Installed Equipment	$21,500,000	$11,150,000	$3,850,000	$675,000
Building	900,000	450,000	90,000	30,000
Foundations	735,000	336,000	126,000	21,000
Electric Service	1,570,000	834,000	218,000	101,000
Site Work	1,235,000	639,000	214,000	41,000
Sub-Total	$25,940,000	$13,409,000	$4,498,000	$868,000
Engineering & Contingencies	6,485,000	3,352,000	1,125,000	217,000
TOTAL	$32,425,000	$16,761,000	$5,623,000	$1,085,000

NEBOLSINE, TOTH, McPHEE ASSOCIATES



Based on these four design points, Fig. No. 22 was developed which provides the means of estimating capital cost of multiple hearth facilities for any daily loading of pounds of dry solids in the dredgings. The capital cost from this curve is also used in developing the annual costs for financing the construction of the project. A term of ten years and 4-5/8% annual interest is used for this purpose or a factor of 12.72% per year of the total capital costs.

4. Operating Costs

Annual operating costs for multiple hearth incineration units are made up of the following:

I. Operating labor and supervision

II. Utility costs (electricity, fuel, water)

III. Maintenance, (labor and materials)

For the item of operating labor and supervision the following table of the 24-hour manpower requirements was estimated:

Annual Dredgings (c.y/yr)	3.0×10^6	0.5×10^6	0.1×10^6
85% of Dredgings (#/day)	11.5×10^6	1.98×10^6	0.40×10^6
Superintendent	1	0	0
Foreman	1	1	1
Operators	6	3	3
Asst. Operators	6	0	0
Chemists	1	1	1
Asst. Chemists	1	0	0
Laborers	6	6	3
TOTALS	22	11	8

The requirements of the fourth design point was not estimated since three points appeared to be sufficient.

Appendix C contains the daily labor costs, including all payroll burdens that were used. To calculate annual costs the daily cost has been multiplied by 365 days although the operating period is only 270 days per year.

Fuel oil, electricity and water requirements were obtained from the incinerator manufacturer and are as follows:

Dredgings - #/Day	13.75×10^6	2.29×10^6	0.458×10^6
85% of Dredgings	11.7×10^6	1.95×10^6	0.389×10^6
Electricity, KWH/D	126,000	21,600	7,200
Fuel BTU x 10^6/D	11,700	1,950	390

Appendix "B" contains the unit prices used for utility costs.

On maintenance: labor and material costs were estimated to be approximately equal to 1% of the installed cost of the equipment, based on a 12-month period. They are as follows:

Total Dredgings #/Day	85% of Dredgings (#/day)	Daily Maintenance Costs
13.75×10^6	11.85×10^6	$800 / Day
2.29×10^6	1.98×10^6	145 / Day
0.458×10^6	0.40×10^6	30 / Day

The summary of the Operating and Maintenance Costs for the three dredging rates (85%) have been plotted and are shown on Fig. No. 23.

Using Fig. No. 22 and Fig. No. 23, Table No. 15 has been prepared and summarizes all of the various costs and converts the total annual costs

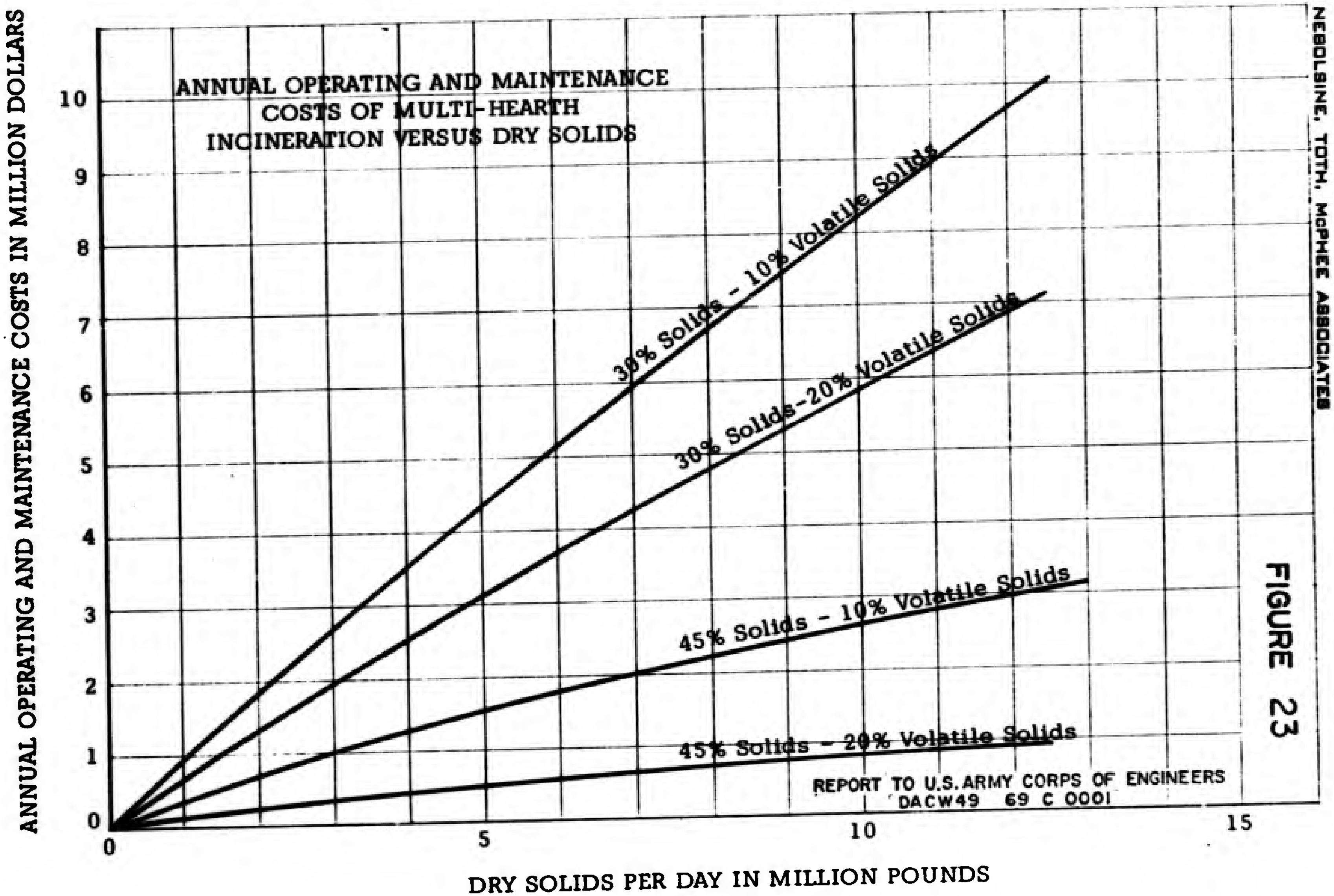

NEBOLSINE, TOTH, McPHEE ASSOCIATES
ANNUAL OPERATING AND MAINTENANCE
COSTS OF MULTI-HEARTH
INCINERATION VERSUS DRY SOLIDS
30% Solids - 10% Volatile Solids
30% Solids-20% Volatile Solids
45% Solids - 10% Volatile Solids
45% Solids - 20% Volatile Solids
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001
ANNUAL OPERATING AND MAINTENANCE COSTS IN MILLION DOLLARS
0
1
2
3
4
5
6
7
8
9
10
DRY SOLIDS PER DAY IN MILLION POUNDS
0
5
10
15

FIGURE 23

TABLE NO. 15

SUMMARY OF ANNUAL COSTS

FOR MULTI-HEARTH INCINERATION

Annual Dredgings Cu.Yds.	Capital Cost	Annual Financial Cost	Annual Utility Cost	Annual Labor Cost	Annual Mainten. Cost	Total Annual Oper.&Main. Cost.	Total Annual Cost	Cost Per Cu.Yd.
3.0×10^6	$32,425,000	$4,124,000	$2,259,000	$349,000	$324,000	$2,932,000	$7,056,000	$2.35
1.5×10^6	16,761,000	2,132,000	1,200,000	296,000	168,000	1,664,000	3,796,000	2.53
0.5×10^6	5,623,000	715,000	404,000	245,000	56,000	705,000	1,420,000	2.84
0.1×10^6	1,085,000	138,000	95,000	127,000	11,000	233,000	371,000	3.71

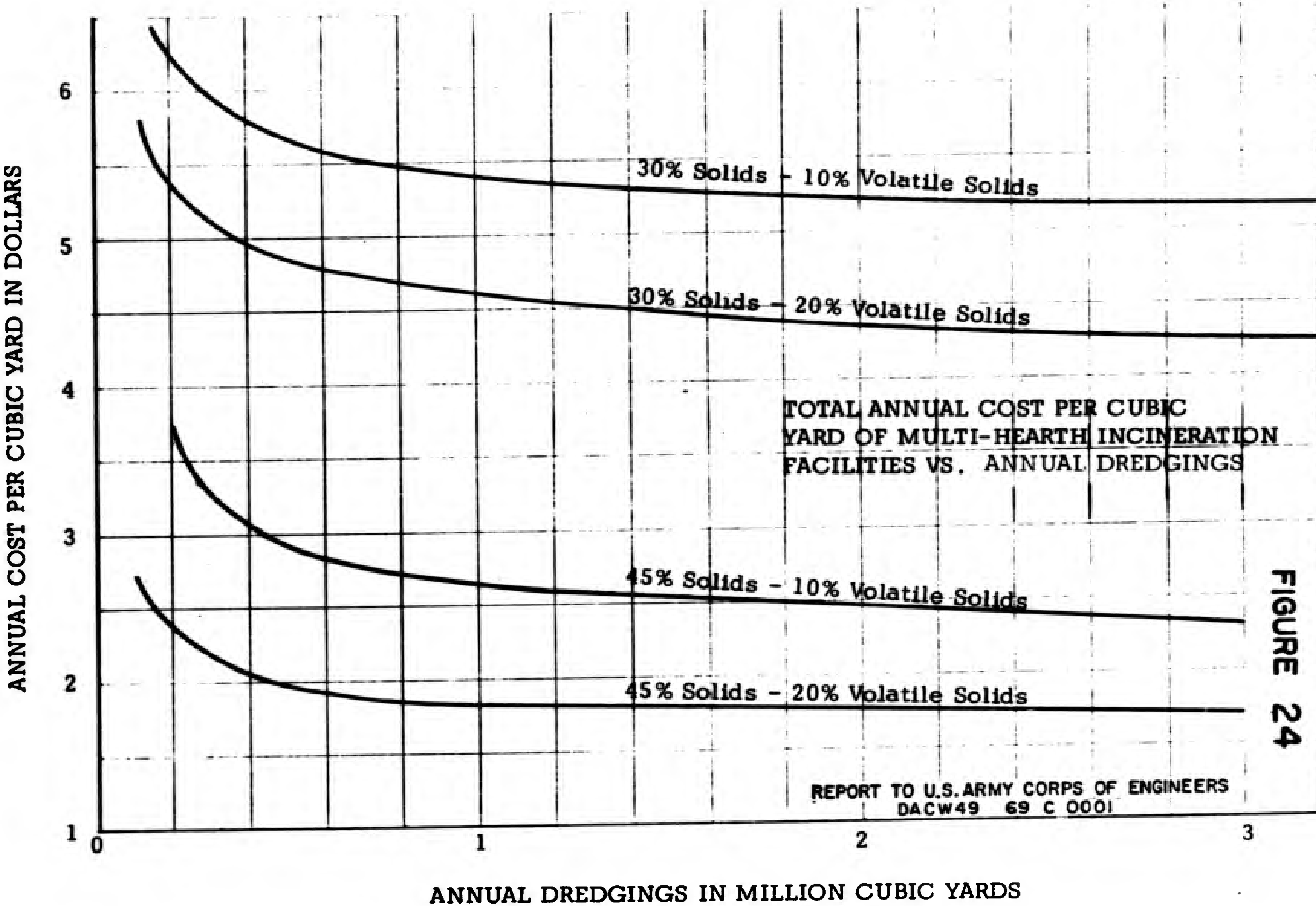

TOTAL ANNUAL COST PER CUBIC YARD OF MULTI-HEARTH INCINERATION FACILITIES VS. ANNUAL DREDGINGS
30% Solids - 10% Volatile Solids
30% Solids - 20% Volatile Solids
45% Solids - 10% Volatile Solids
45% Solids - 20% Volatile Solids
ANNUAL COST PER CUBIC YARD IN DOLLARS
1
2
3
4
5
6
ANNUAL DREDGINGS IN MILLION CUBIC YARDS
0
1
2
3
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001

FIGURE 24

to costs per cubic yard of dredgings. A plot of costs per cubic yard versus annual quantity of dredgings is shown on Figure No. 24.

The costs per cubic yard presented on Figure No. 24 covers only the cost of incineration of the silt-clay fractions of the dredgings. The costs of this curve should be added to costs for handling, storing and treating the dredgings prior to and following the multiple hearth incineration operation.

Since multiple hearth incineration seems to be the most economical method of treating the dredgings, it was decided to further investigate other combinations of percent solids and percent volatile solids in the dredgings. These combinations are as follows:

% Solids	% Volatile Solids
45*	10*
45	20
30	10
30	20

*Initial Assumptions

The 45% solids versus 10% volatile solids combination has been analyzed and the cost summaries are presented in Table No. 15. The cost summaries for the other combinations are as follows:

45% Solids and 20% Volatile Solids

Annual Dredgings (Cu.Yds.)	Capital Cost	Total Annual Oper. & Main. Cost	Total Annual Cost	Cost Per Cu.Yd.
3.0×10^6	$32,425,000	$943,000	$4,124,000	$1.69
1.5×10^6	16,761,000	570,000	2,702,000	1.80
0.5×10^6	5,623,000	256,000	971,000	1.94
0.1×10^6	1,085,000	136,000	274,000	2.74

30% Solids and 10% Volatile Solids

3.0×10^6	$46,922,000	$9,437,000	$15,405,000	5.14
1.5×10^6	24,683,000	4,858,000	7,998,000	5.33
0.5×10^6	8,451,000	1,730,000	2,805,000	5.61
0.1×10^6	1,951,000	406,000	659,000	6.59

30% Solids and 20% Volatile Solids

3.0×10^6	$46,927,000	$6,728,000	$12,696,000	4.23
1.5×10^6	24,683,000	3,560,000	6,700,000	4.47
0.5×10^6	8,451,000	1,319,000	2,394,000	4.79
0.1×10^6	1,991,000	326,000	579,000	5.79

The combination of 45% solids and 20% volatile solids appears to be an extremely efficient condition for treating maintenance dredging. The principal reason for the extremely low cost is that the operation is positively thermally self sufficient. Until such time as extensive calorific testing is done on dredging samples the exact magnitude of the economics cannot be computed.

The other two combinations result in considerably higher costs and if such conditions were to be encountered then the multi-hearth process would not be economically suited for treating the dredgings.

The costs per cubic yard for all four conditions are shown graphically on Figure 24.

N. SEPARATION OF TREATED SOLIDS

1. General

As noted in Section G of this report, several of the unit operations being studied require the separation of the dredging solids from their water fraction. The treated sludges will range in solids from 10 to 20% by weight. In some cases the sludges could be disposed of as is but due to the large water volume associated with the solids, the cost of transporting these sludges any distance would not be economical. In the case where the treated solids are to be hauled out into the lakes for depositing on the bottom, the estimated cost of hauling is $0.50 per cu. yd. One cubic yard of dredgings at 20% solids by weight contains approximately 600 pounds of dredgings while a cubic yard of 50% solids contains 1100 pounds or more of dredgings. If the cost of concentrating 20% solids to 50% or more is less than $0.50 per cubic yard then the concentrating is justified. The concentration will be required in those cases where the water fraction has to be separated for treatment. If the concentration is from 10 to 50% then even a cost of $1.50 per cubic yard is justified.

Two methods of concentrating the solids in the treated sludges were considered. The simplest is to discharge the sludge to a lagoon and let the forces of gravity do the work. The variables governing the degree of concentration are as follows:

a) The depth of the lagoon
b) The detention time in the lagoon
c) The method of removing the solids from the bottom of the lagoon.

Based on a preliminary estimate of a reasonably sized lagoon, (several weeks' detention and 20 foot depth) a concentration of 30% solids might be possible.

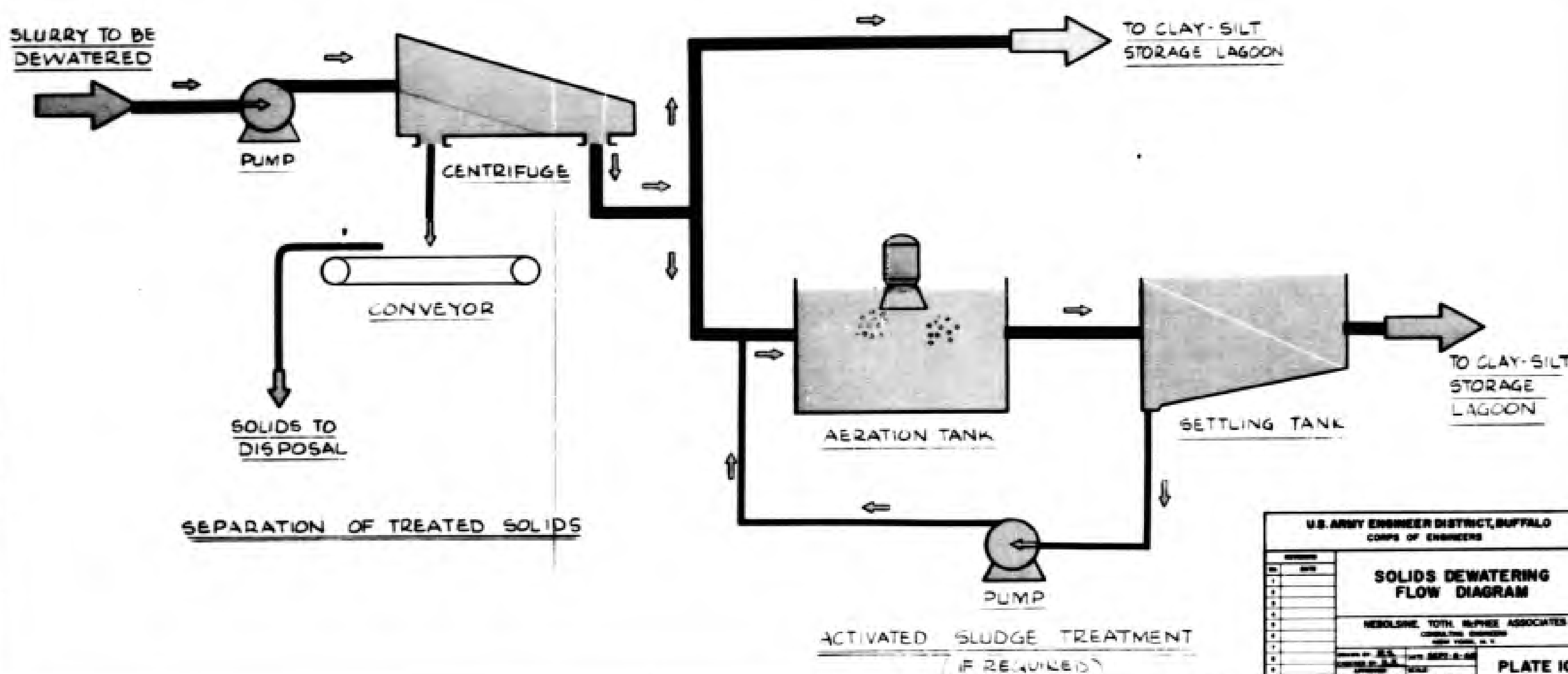
The second method considered is the centrifuging of the sludge. Based on past experience, a 50% solids cake was estimated. Rather than make two independent cost analyses, the cost of centrifuging was fully investigated. It was found to be cheaper based solely on the cost of hauling the dewatered solids at a unit price of $0.50 per cubic yard for concentrating from 10% or less to 50%, except when the annual yardage was less than 500,000 per year.

2. Design Considerations

For the separation of the treated dredging solids, solid bowl centrifuges were selected. The effluent from the treatment units will be pumped to a bank of solid bowl centrifuges where the solids will be concentrated to approximately 50%. The centrifuges have been sized at 12,500 pounds per unit per hour.

The centrate, where no additional treatment is required, will be discharged back to the dredgings storage area for additional clarification. In the case where bio-oxidation of the centrate is required, such as in the case of wet-oxidation and chemical oxidation processes, the centrate will go through an additional treatment process. The cake from the centrifuge will be conveyed to barges or other conveyances for hauling to the selected disposal areas.

Based on these considerations a solids dewatering system as shown in Plate No. 10 was designed for the following conditions:



U.S. ARMY ENGINEER DISTRICT, BUFFALO
CORPS OF ENGINEERS

SOLIDS DEWATERING
FLOW DIAGRAM

NEBOLSINE, TOTH, McPHEE ASSOCIATES

PLATE 10

Annual Dredging Quantities (cu.yds.)	Total Dry Solids Per Day	Cake to Disposal 50% Solids (cu.yd./day)
1,500,000	6,875,000 lbs.	3800
1,000,000	4,780,000 lbs.	2530
500,000	2,390,000 lbs.	1270
100,000	475,000 lbs.	253

For the bio-oxidation of BOD, in the centrate from solids separation of the slurry, an activated sludge treatment will consist of aerating a mixture of 50% return sludge and the centrate for five days. After aeration the mixed liquor will be settled and the sludge returned to the aeration tanks and the clarified water discharged to the storage area.

3. Capital Cost Estimates

a) Capital costs for solids separation facilities are summarized as follows:

Dredgings (CY/yr)	1,500,000	1,000,000	500,000	100,000
85% Dredgings (#/D) (a)	5.93×10^6	3.96×10^6	1.98×10^6	0.40×10^6
Centrifuges	$ 770,000	$ 540,000	$ 304,000	$ 80,000
Conveyors	48,000	37,500	27,000	19,500
Buildings	1,023,000	760,000	375,000	92,000
Foundations	6,600	4,500	2,400	600
Electric Service	1,570,000	1,097,000	603,000	162,000
Site Work	171,000	122,000	66,000	18,000
Sub-Total	$3,588,000	$2,561,000	$1,377,000	$372,100
Eng. & Conting.	897,000	640,000	344,000	93,000
TOTAL	$4,485,000	$3,201,000	$1,721,000	$465,000

(a) Dry solids based on 240 days/year.

Based on the above Fig. No. 25 was developed. This curve provides the means of estimating the capital cost of solids separation facilities for any annual dredging quantities. The capital costs from this curve can be used to develop the annual cost for financing the construction of any size project. A term of ten years and 4-5/8% annual interest is used for this purpose or a factor of 12.72% per year of the total capital costs.

b) The capital costs for the bio-oxidation facilities for the centrate from the solids separation from the treated sludge have been developed from cost curves used for treating domestic sewage. Fig. No. 26 shows the capital costs of facilities versus daily rate of pounds of dry solids processed per day.

4. Operating Costs

a) Operating costs for solids separation facilities are made up of the following:

I. Operating labor and supervision

II. Utility costs (fuel, electricity, water)

III. Maintenance (labor and materials)

For the items of operating labor and supervision, the following tables of the 24-hour manpower requirements was estimated:

Dredgings (Cu.yd./yr)	1,500,000	1,000,000	500,000	100,000
Operators	6	6	3	3
Laborers	3	3	0	0

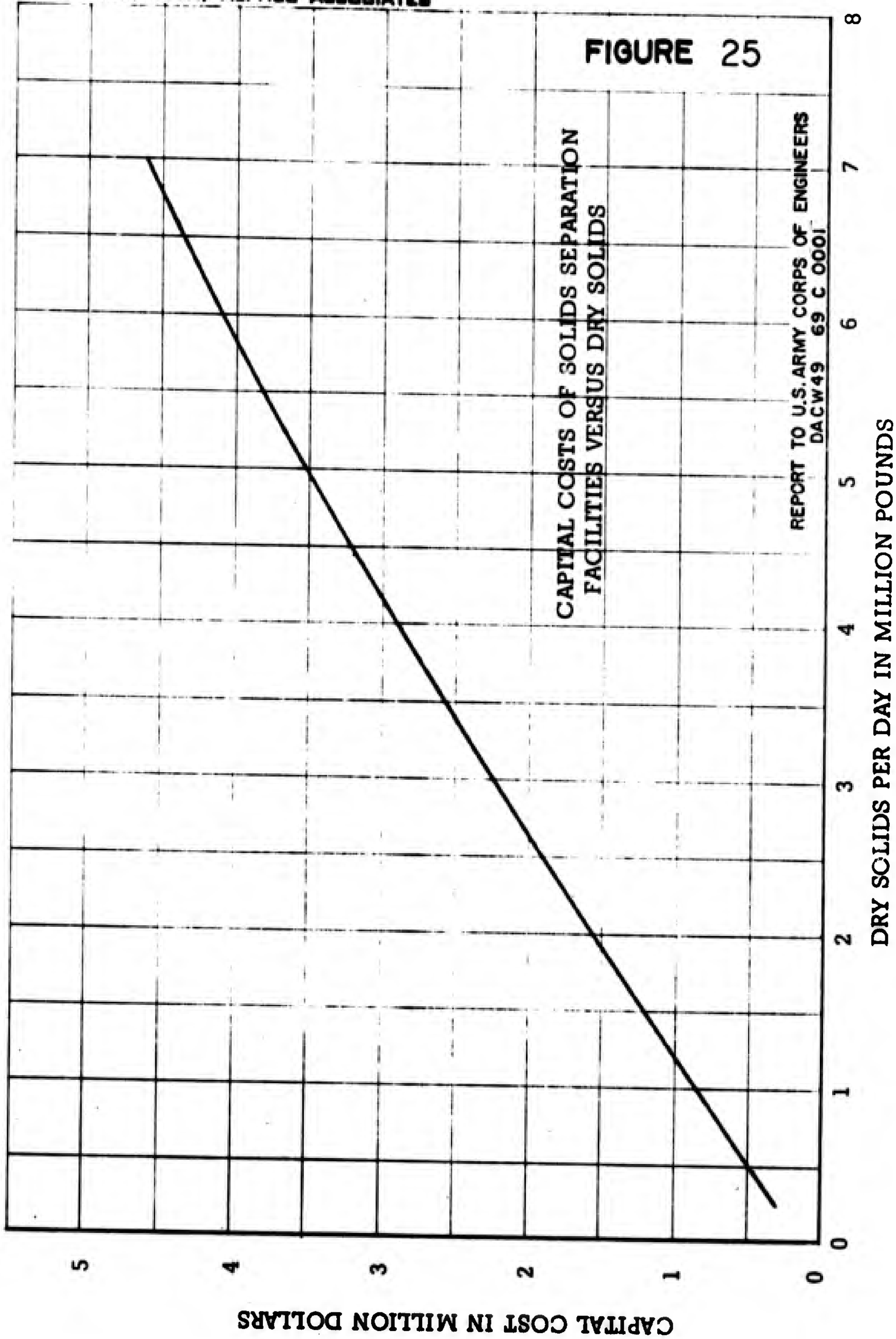


FIGURE 25
CAPITAL COSTS OF SOLIDS SEPARATION
FACILITIES VERSUS DRY SOLIDS
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001
DRY SOLIDS PER DAY IN MILLION POUNDS
0
1
2
3
4
5
6
7
8
CAPITAL COST IN MILLION DOLLARS
0
1
2
3
4
5

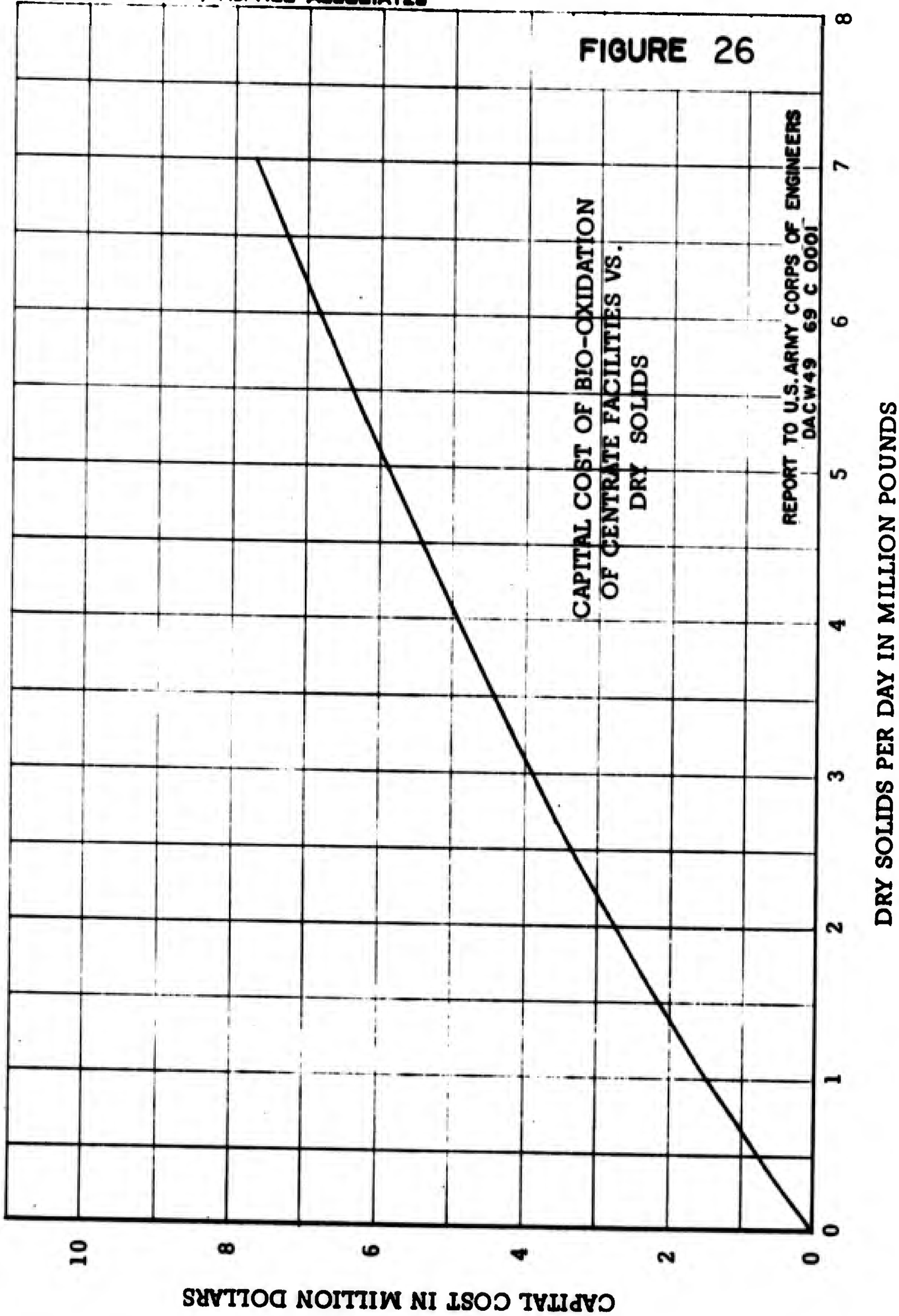


FIGURE 26
CAPITAL COST OF BIO-OXIDATION
OF CENTRATE FACILITIES VS.
DRY SOLIDS
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001
0
1
2
3
4
5
6
7
8
DRY SOLIDS PER DAY IN MILLION POUNDS
0
2
4
6
8
10
CAPITAL COST IN MILLION DOLLARS

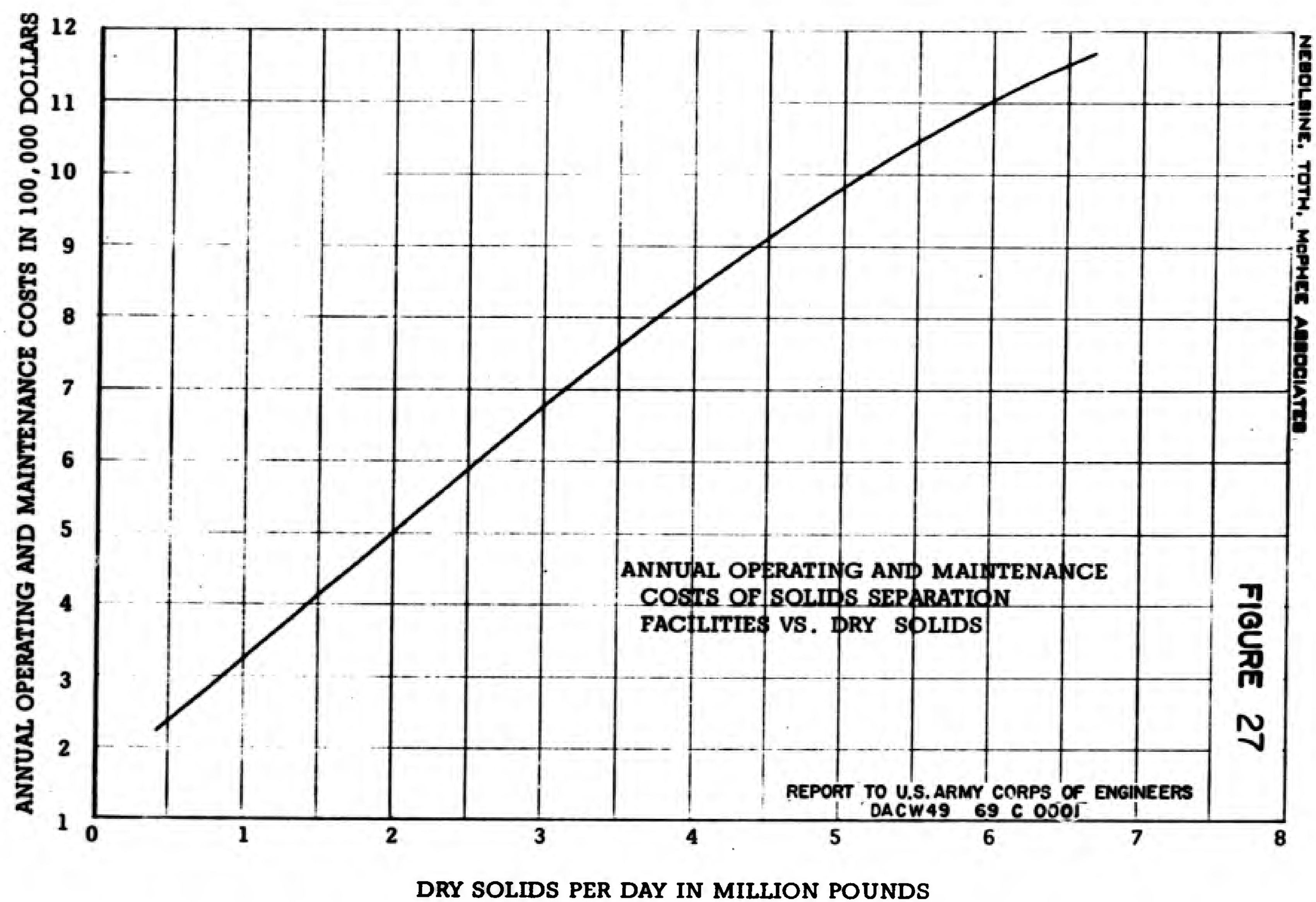
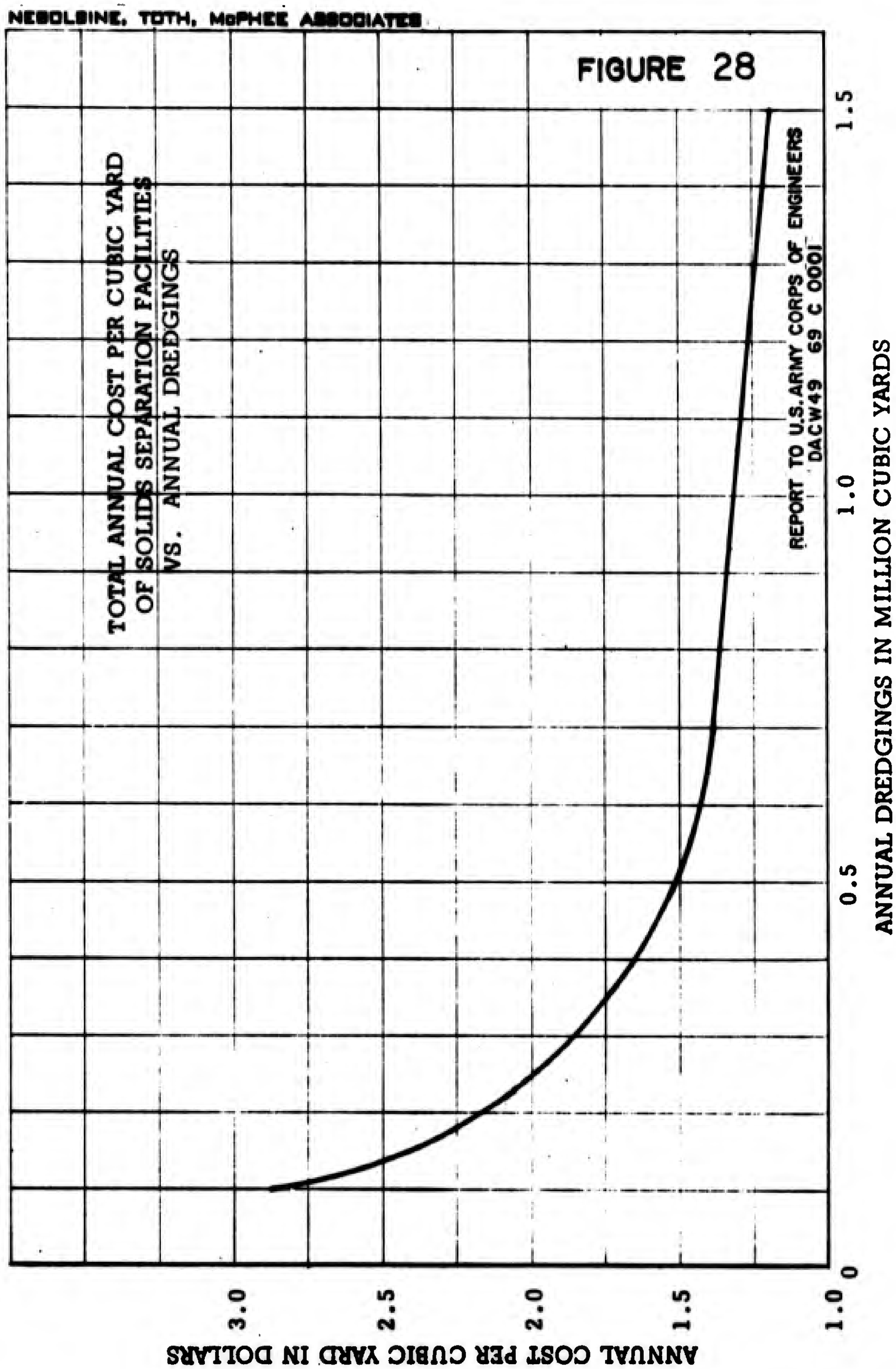

NEBOLSINE, TOTH, McPHEE ASSOCIATES
FIGURE 27
ANNUAL OPERATING AND MAINTENANCE COSTS OF SOLIDS SEPARATION FACILITIES VS. DRY SOLIDS
REPORT TO U.S. ARMY CORPS OF ENGINEERS DACW49 69 C 0001
ANNUAL OPERATING AND MAINTENANCE COSTS IN 100,000 DOLLARS
1
2
3
4
5
6
7
8
9
10
11
12
0
1
2
3
4
5
6
7
8
DRY SOLIDS PER DAY IN MILLION POUNDS

TABLE NO. 16

SUMMARY OF ANNUAL COSTS

DEWATERING SOLIDS

Annual Dredgings Cu. Yd.	Capital Cost	Annual Financing Costs	Annual Labor Costs	Annual Utility Costs	Annual Maintenance Costs	Total Annual Operat. & Mainten. Costs	Total Annual Cost	Cost Per Cu. Yd.
1,500,000	$4,485,000	$570,000	$142,000	$364,000	$673,000	$1,179,000	$1,749,000	$1.17
1,000,000	3,201,000	407,000	142,000	282,000	480,000	904,000	1,311,000	1.31
500,000	1,721,000	219,000	109,000	172,000	258,000	539,000	758,000	1.52
100,000	465,000	59,000	109,000	48,000	70,000	228,000	286,000	2.86


NEBOLSINE, TOTH, McPHEE ASSOCIATES
FIGURE 28
TOTAL ANNUAL COST PER CUBIC YARD
OF SOLIDS SEPARATION FACILITIES
VS. ANNUAL DREDGINGS
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001
ANNUAL DREDGINGS IN MILLION CUBIC YARDS
0
0.5
1.0
1.5
ANNUAL COST PER CUBIC YARD IN DOLLARS
1.0
1.5
2.0
2.5
3.0

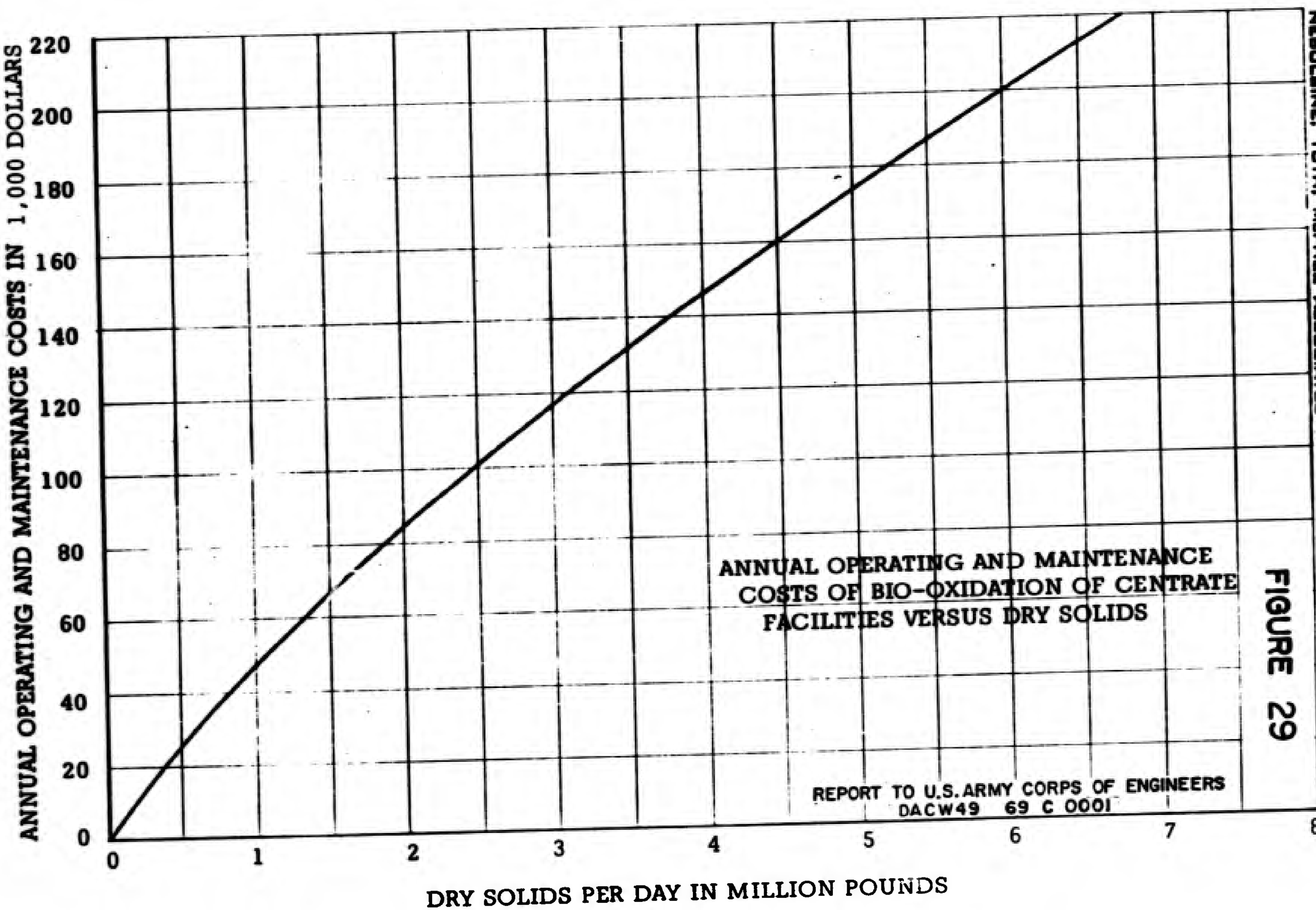

NEBOLSINE, TOTH, McPHEE ASSOCIATES
ANNUAL OPERATING AND MAINTENANCE COSTS IN 1,000 DOLLARS
220
200
180
160
140
120
100
80
60
40
20
0
0
1
2
3
4
5
6
7
8
DRY SOLIDS PER DAY IN MILLION POUNDS
ANNUAL OPERATING AND MAINTENANCE COSTS OF BIO-OXIDATION OF CENTRATE FACILITIES VERSUS DRY SOLIDS
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001

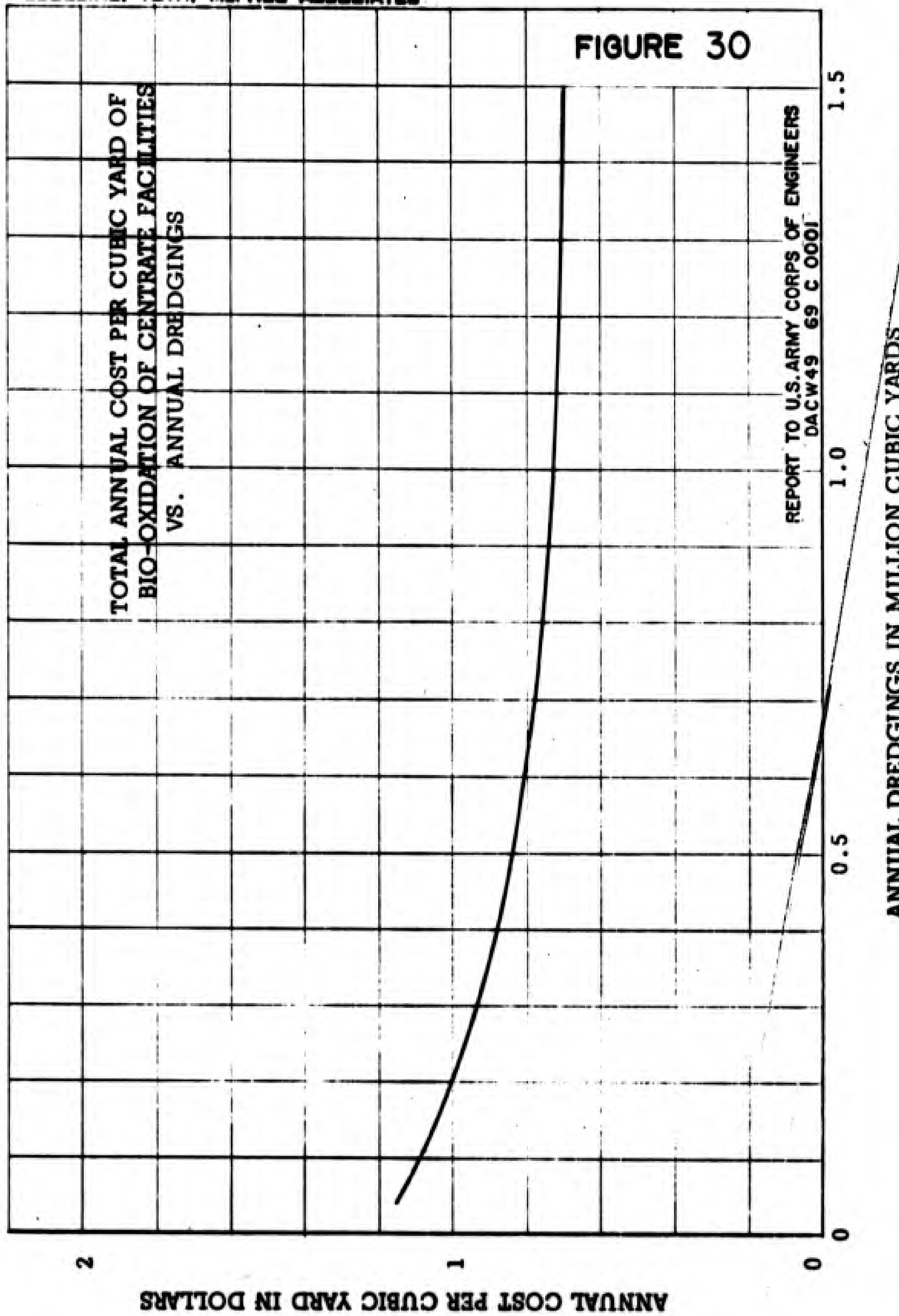
FIGURE 29

TABLE NO. 17

SUMMARY COSTS OF BIO-OXIDATION OF CENTRATE

ANNUAL DREDGINGS C.Y.	CAPITAL COSTS	ANNUAL FINANCING COSTS	ANNUAL OPERATING & MAINTENANCE COSTS	TOTAL ANNUAL COSTS	COST PER C.Y.
1,500,000	$6,700,000	$853,000	$196,000	$1,048,000	$0.70
1,000,000	4,800,000	611,000	143,000	754,000	0.75
500,000	2,700,000	344,000	82,000	426,000	0.85
100,000	700,000	89,000	20,000	109,000	1.09

NESOLSINE, TOTH, McPHEE ASSOCIATES



The above labor is minimal since supervisory personnel for the entire operation has been included under the major unit operation. Appendix "C" lists the hourly wages, including all payroll burdens, used. To calculate annual costs, the daily cost has been multiplied by 365 days although the operating period is only 270 days per year.

The utility requirements for the operation of the solids separation facilities are shown as follows:

Dredgings (Cu.yd./yr)	1,500,000	1,000,000	500,000	100,000
#/Day dry solids	6.65×10^6	4.43×10^6	2.22×10^6	0.44x106
Electricity (KWH/day)	127,000	87,000	46,000	11,500

Appendix "B" lists the costs of electricity. For annual maintenance a factor of 15% of the equipment costs has been used. A summary of the operating and maintenance costs for the four design points has been calculated and is plotted on Fig. No. 27.

Table No. 16 and Fig. No. 28 show the cost per cubic yard versus annual dredged quantities.

b) Operating costs for bio-oxidation of the centrate again are based on curves developed in the past for operation of sewage treatment bio-oxidation facilities and are shown on Fig. No. 29.

Table No. 17 and Fig. No. 30 show the cost per cubic yard versus annual dredged quantities.

O. CONCLUSIONS

1. General

The reader should bear in mind that the information given in this report is based on very limited data.

Characteristics of the harbor bottoms are based on sampling done by the Federal Water Pollution Control Administration and the Corps of Engineers. About 100 samples were taken to represent the several million cubic yards of maintenance dredgings. Based on this limited sampling all of the characteristics of the bottom deposits had to be generalized.

In all of the unit operations studied average conditions were assumed to develop design conditions. What may be fully applicable for one area may not be so for another. Since the purpose of this report is to establish possible treatment processes and their capital and operating costs, the data presented, while limited, is sufficient for these purposes. The costs shown are valid estimates for the assumptions made.

As previously mentioned in this report one essential piece of information required for the selection of design processes is the quality standards which the effluents and sludges must meet before being dumped either on land or to the deeper portions of the lake. In all instances, it has been assumed that the stabilization of the biological activity of the sludges is the prime criteria, and once stabilized, these sludges would be acceptable for disposal. However, it is recognized that the various treatments will produce different quality effluents. Biological treatments will satisfy oxygen demands and will destroy some percentage of bio-degradable volatile solids, leaving as a residual volatile solids that are relatively biologically inert. Chemical treatment will destroy those solids, mostly organic, reacting with the chemical used. Wet oxidation will destroy most of the volatile solids, but will put some bio-degradable materials into solution. Incineration will effectively destroy all volatile solids and produce an inert dry solids residue. None of the treatment processes, however, would remove organic chemicals. Thus, in considering cost factors, it is also necessary to consider the effectiveness of the treatment process in relation to the ultimate disposal of the materials and the standards of requirements governing such disposal.

In the previous sections of this report, costs have been presented for ten unit operations. The individual sections do not list any advantages or disadvantages aside from costs of the unit operations being developed. These advantages and disadvantages follow:

2. <u>Advantages and Disadvantages of Unit Operations Presented</u>

a) <u>Separation of Particle Sizes</u>

This unit operation offers the benefit of reducing the volume and weight of the dredgings to be stored and treated. This benefit will vary from harbor to harbor depending on the quantity of removable particles, larger than 70 microns. Therefore in the analysis of each harbor, the cost of separation against the cost of treating all of the dredgings has to be weighed. The curves presented are flexible enough to permit this evaluation.

The disadvantages of separation of particle sizes may be that some volatiles are also included in the larger fraction. Quite possibly the larger particle size fraction may require treatment before discharge. This must be ascertained by additional investigation of the nature of the volatiles in this fraction.

b) Storing and Handling Dredings

This operation is essential. It acts as a buffer between the erratic time cycle of the dredgings and a reasonable treatment time cycle. It is therefore not weighed on its advantages and disadvantages.

c) Treatment of Separated Waters

This is similar to the Storing and Handling of Dredgings - it is an essential step to treat contaminated water, separated from the dredgings before being discharged.

d) Anaerobic Stabilization

This unit operation has the advantages of an easily operated treatment that could run 365 days a year. The process, however, requires a large land area. Another disadvantage is that it is a biological process and therefore subject to upset by toxic materials that could be in the dredgings. A third disadvantage is the necessity of treating the liquid that separates from the solids during treatment before it would be acceptable for discharge.

e) Aerobic Stabilization

This biological process has advantages and disadvantages similar to the anaerobic process. However, the area requirements could be satisfied by a diked lake area rather than using existing land, and the control would be simpler. The time period for treatment would have to be shortened to about eight (8) months per year due to freezing winter conditions.

f) Chemical Stabilization

Control of the process would be simpler and land requirements for chemical treatment are less than for the biological treatment processes. Treatment by this process, however, results in a sludge whose water fraction requires additional treatment. This increases the number of treatment steps.

g) Wet Oxidation

This is similar to the Chemical Oxidation Process, resulting in a separated liquor requiring biological treatment.

h) Fluid Bed Incineration

This process has the advantages of producing a completely inert residue. It requires, for maximum efficiency, a minimum amount of moisture in the solids. In some cases a mechanical solids concentration step prior to the introduction to the furnaces may be required.

i) Multi-Hearth Incineration

This process is similar to the Fluid Bed Incineration

j) Separation of Treated Solids

This process is essential to all of the operations that produce sludges with 10% or less solids by weight or where the water fraction requires additional treatment.

TABLE NO. 18

SUMMARY OF COSTS FOR TREATING 100,000 CUBIC YDS BY VARIOUS TREATMENT PROCESSES

	Anaerobic Stabiliz. Fig.9	Aerobic Stabiliz. Fig.12	Chemical Stabiliz. Fig.15	Wet Oxidat. Fig.18	Fluid Bed Inciner. Fig.21	Multi-Hearth Inciner. 45%TS-10%VS Fig.24	Multi-Hearth Inciner. 45%TS-20%VS Fig.24	Multi-Hearth Inciner. 30%TS-10%VS Fig.24	Multi-Hearth Inciner. 30%TS-20%VS Fig.24
Storing Dredgings Fig.2	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30
Rehandling Dredgings Fig.5	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50
Treat Separated Waters Fig.6	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Treat Dredgings	5.10	3.55	2.70	4.55	5.90	3.71	2.74	6.59	5.79
Solids Separation Fig.28	2.86	2.86	2.86	2.86	-	-	-	-	-
Bio-Oxidize Centrate Fig.30	1.09	-	1.09	1.09	-	-	-	-	-
TOTALS	$13.869	$11.229	$11.469	$13.319	$10.719	$ 8.529	$ 7.559	$11.409	$10.609

TABLE NO. 19

SUMMARY OF COSTS FOR TREATING
500,000 CUBIC YDS BY VARIOUS TREATMENT PROCESSES

	Anaerobic Stabiliz. Fig. 9	Aerobic Stabiliz. Fig. 12	Chemical Stabiliz. Fig. 15	Wet Oxidat. Fig.18	Fluid Bed Inciner. Fig.21	Multi-Hearth Inciner. 45%TS-10%VS Fig.24	Multi-Hearth Inciner. 45% TS-20% VS Fig.24	Multi-Hearth Inciner. 30% TS-10% VS Fig.24	Multi-Hearth Inciner. 30% TS-20% VS Fig.24
Storing Dredgings Fig.2	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
Rehandling Dredgings Fig.5	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80
Treat Separated Waters Fig.6	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Treat Dredgings	4.22	1.90	1.43	3.60	4.80	2.84	1.94	5.61	4.79
Solids Separation Fig.28	1.52	1.52	1.52	1.52	-	-	-	-	-
Bio-Oxidize Centrate Fig	0.83	-	0.83	0.83	-	-	-	-	-
TOTALS	$9.319	$6.169	$6.529	$8.699	$7.549	$5.589	$4.689	$8.359	$7.539

TABLE NO. 20

SUMMARY OF COSTS FOR TREATING
1,000,000 CUBIC YARDS BY VARIOUS TREATMENT PROCESSES

	Anaerobic Stabiliz. Fig. 9	Aerobic Stabiliz. Fig. 12	Chemical Stabiliz. Fig. 15	Wet Oxidation Fig. 18	Fluid Bed Inciner. Fig.21	Multi-Hearth Inciner. 45%TS-10%VS Fig.24	Multi-Hearth Inciner. 45%TS-20%VS Fig.24	Multi-Hearth Inciner. 30% TS-10% VS Fig.24	Multi-Hearth Inciner. 30% TS-20%VS Fig.24
Storing Dredgings Fig.2	0.630	0.630	0.630	0.630	0.630	0.630	0.630	0.630	0.630
Rehandling Dredgings Fig.5	0.400	0.400	0.400	0.400	0.400	0.400	0.400	0.400	0.400
Treat Separated Waters Fig.6	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Treat Dredgings	3.200	1.550	1.200	3.160	4.300	2.620	1.740	5.40	4.62
Solids Separation Fig.28	1.290	1.290	1.290	1.290	-	-	-	-	-
Bio-Oxidize Centrate Fig.30	0.740	-	0.740	0.740	-	-	-	-	-
TOTAL	$6.279	$3.889	$4.279	$6.239	$5.349	$3.669	$2.789	$6.499	$5.669

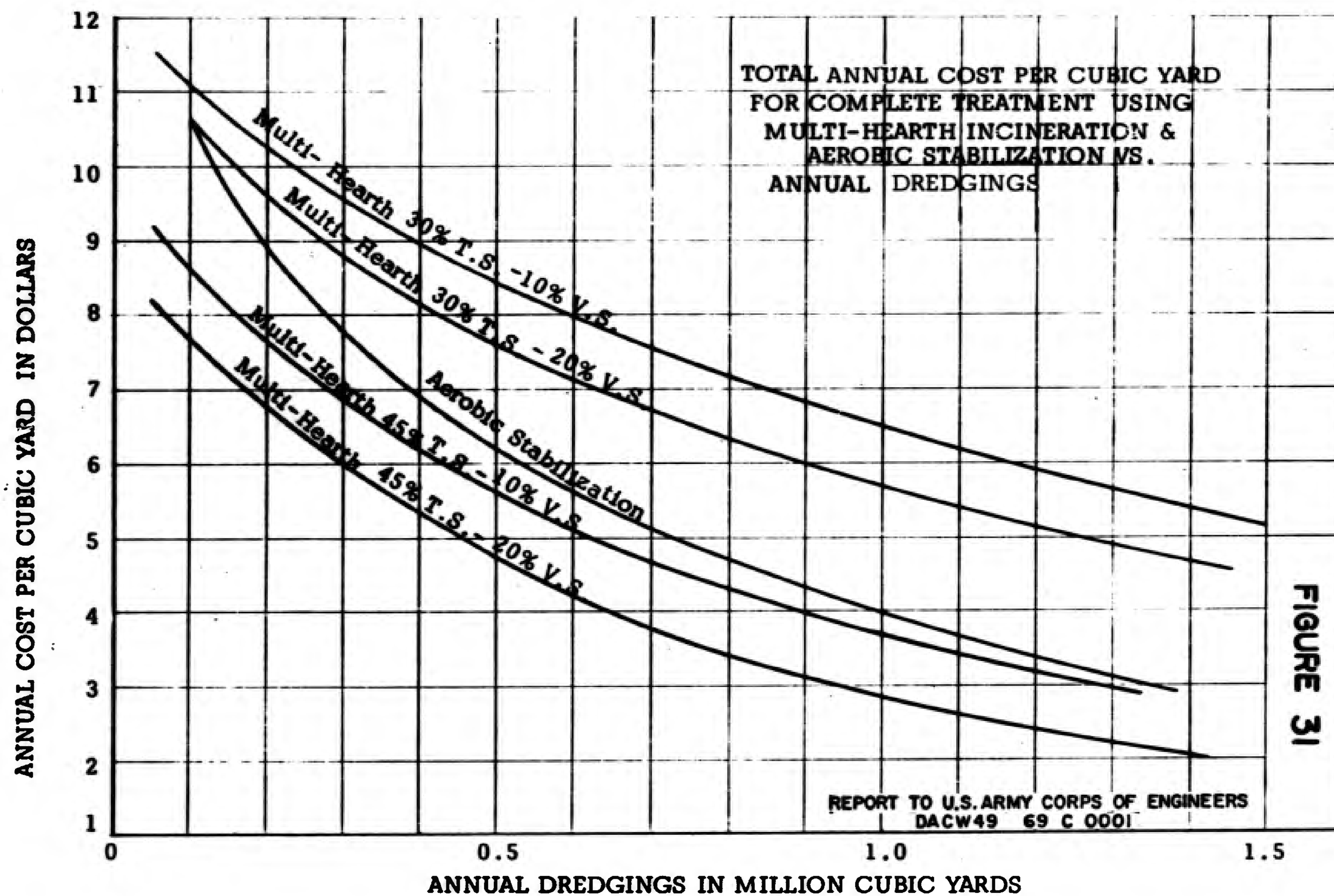

TOTAL ANNUAL COST PER CUBIC YARD
FOR COMPLETE TREATMENT USING
MULTI-HEARTH INCINERATION &
AEROBIC STABILIZATION VS.
ANNUAL DREDGINGS
Multi- Hearth 30% T.S. -10% V.S.
Multi-Hearth 30% T.S. - 20% V.S.
Aerobic Stabilization
Multi-Hearth 45% T.S. -10% V.S.
Multi-Hearth 45% T.S. - 20% V.S.
ANNUAL COST PER CUBIC YARD IN DOLLARS
ANNUAL DREDGINGS IN MILLION CUBIC YARDS
12
11
10
9
8
7
6
5
4
3
2
1
0
0.5
1.0
1.5
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001

FIGURE 31

3. Using Data Presented

For the unit operations studied a final cost curve of cost per cubic yard of dredgings versus total annual quantity of dredgings has been presented. By using these curves in various combinations, complete treatment processes and associated costs can be obtained.

To assist in analyzing the data presented, a theoretical harbor has been assumed having the following characteristics:

a) Annual maintenance dredgings of 100,000, 500,000 and 1,000,000 cubic yards.

b) Dredged material contains 10% volatile solids.

c) Dredged materials, after separation of 15% of the solids as sand and gravel sized particles, can be thickened by storage to 45% solids.

d) Silt and clay sized particles have a heat value of 1850 BTU/lb.

Based on these assumptions Tables 18, 19 and 20 have been prepared covering the six (6) basic treatment processes and the three plant capacities.

tables indicate that the least expensive treatment is by incineration using multi-hearth furnaces. Using the same assumptions except for changing the annual yardage to cover 500,000 to 1,500,000 yards per year, also show that multi-hearth incineration is the most economical.

The difference in cost between multi-hearth incineration and aerobic stabilization for the assumptions made before is only 6% at 500,000 cubic yards per year or more. Below this quantity multi-hearth incineration is much less expensive (see Figure No. 31). The accuracy of the cost estimates made is not sufficient to allow an exact statement to be made that the multi-hearth treatment is unquestionably the least expensive for this set of assumptions. When the volatile solids are assumed at 20% then the difference is approximately 40% and it can safely be concluded that multi-hearth incineration is the most economical process.

If the assumptions were changed as follows then the multi-hearth would not be the least expensive.

Dredged materials after separation of 15% of its solids, as sand and gravel sized particles, can be thickened to only 30% solids and contain 10% volatile solids.

In this case the least expensive treatment process would be aerobic stabilization. This is also the case where the solids are 30% and the volatile solids are 20% or more.

In weighing the various pro's and con's to determine which solution is preferable, consideration of the first costs or capital costs of the facilities required should also be made. The capital costs of multi-hearth incineration and aerobic stabilization for a 1,000,000 c.y./yr. facility and solids concentrations up to 45% are as follows:

Aerobic Stabilization	$ 7,585,000
Multi-Hearth Incineration	12,000,000

Considering the unknown time for which the treatment facilities would be needed, the large difference in capital cost would possibly swing the preference to the aerobic treatment.

4. Application of Data to Pilot Harbors

a) General

The characteristics of the dredgings that is probably most important in determining the need for treatment is BOD and/or COD. Following is a tabulation of the available data on average BOD's and COD's for each of the 8 pilot harbors:

	FWPCA		Univ. of Wisconsin
	BOD*	COD*	COD* (1)
Great Sodus Bay	-	22,200	17,350
Buffalo Harbor	-	117,500	99,700
Cleveland Harbor	13,000	211,000	165,300
Toledo Harbor	800	-	73,100
Rouge River	3,100	240,000	190,500
Indiana Harbor	-	351,000	267,000
Calumet Harbor	-	139,700	95,600
Green Bay	-	220,000	94,000

* Expressed as ppm.

(1) Averages from Table 2, Sodus Bay Sample S-1 not included.

Table No. 5, in Section B, shows that some samples from all harbors could be treated aerobically. One sample from both Great Sodus Bay and Rouge River dredgings did not respond to aerobic treatment. Whether this was due to toxic substances in the sludge or to the lack of biodegradable material is unknown.

The only pilot harbor where it is questionable if treatment of the dredgings is required is Great Sodus Bay. The quantity of annual dredgings is small and the average COD of the dredgings is also small in comparison to the other harbors.

Assuming that aerobic stabilization treatment is the preferred method its application to each harbor and the annual cost per cubic yard per harbor can be calculated.

Assuming that all pilot harbors would require this treatment of their dredgings, Table 21 has been prepared. This table shows the annual cost per cubic yard and the total annual costs.

5. Continuing Work Required

The treating of dredgings by aerobic stabilization appears to be a feasible and economic method of stabilizing the dredgings to a reasonable degree. The work presented in this report is based on very limited data and before any design of aerobic treatment of the dredgings is undertaken, additional test work should be done, as follows:

a) A representative harbor should be selected for a pilot plant investigation. Buffalo or Cleveland would lend themselves to such an undertaking since storage facilities are presently available and electric energy is convenient to either site. The volatile solids content and COD of the dredgings from these harbors are average and representative.

TABLE NO. 21

SUMMARY OF COSTS FOR AEROBICALLY TREATING DREDGINGS FROM EIGHT PILOT HARBORS

		Great Sodus Bay	Buffalo Harbor	Cleveland Harbor	Toledo Harbor	Rouge River	Calumet and Indiana Harbors	Green Bay
Annual Dredgings C.Y.		50,000	575,000	1,270,000	1,140,000	300,000	240,000	121,000
Storage Required C.Y.		50,000	500,000	800,000	1,110,000	300,000	240,000	121,000
Storing Dredgings	Fig. 2	$1.40/cy	$0.47/cy	$0.35/cy	$0.30/cy	$0.66/cy	$0.75/cy	$1.05/cy
Rehandling Dredgings	Fig.5	$3.80/cy	0.70/cy	0.30/cy	0.35/cy	1.30/cy	1.50/cy	2.80/cy
Treat Separated Waters	Fig. 6	$0.02/cy	0.02/cy	0.02/cy	0.02/cy	0.02/cy	0.02/cy	0.02/cy
Aerobic Treatment	Fig.12	$4.50/cy	1.84/cy	1.47/cy	1.50/cy	2.35/cy	2.50/cy	3.30/cy
Solids Separation	Fig.28	$3.50/cy	1.45/cy	1.25/cy	1.28/cy	1.86/cy	2.00/cy	2.60/cy
Cost per Cu.Yard		$13.22/cy	4.48/cy	3.39/cy	3.45/cy	6.19/cy	6.77/cy	9.77/cy
Total Annual Cost		$661,000	$2,576,000	$4,305,000	$3,933,000	$1.857,000	$1,624,800	$1,183,170

b) The following should be studied in the pilot plant:

I. Separation of sand and gravel sized particles.

II. Characteristics of the separated solids, emphasis on volatile and bio-degradable matter.

III. Thickening of the silt-clay particles to the maximum concentration.

IV. Calorific content of the sand-gravel and of the silt-clay sized particles.

V. Aerobic stabilization of the silt-clay sized particles.

VI. Thickening or centrifuging of the treated silt-clay particles.

VII. Bio-assay work on the effects of the treated dredgings on growth of algae.

c) On completion of the pilot plant work, preferably for a nine to ten months' period during a dredging season, a restudy of the costs of treating the dredgings should be made.

APPENDIX A

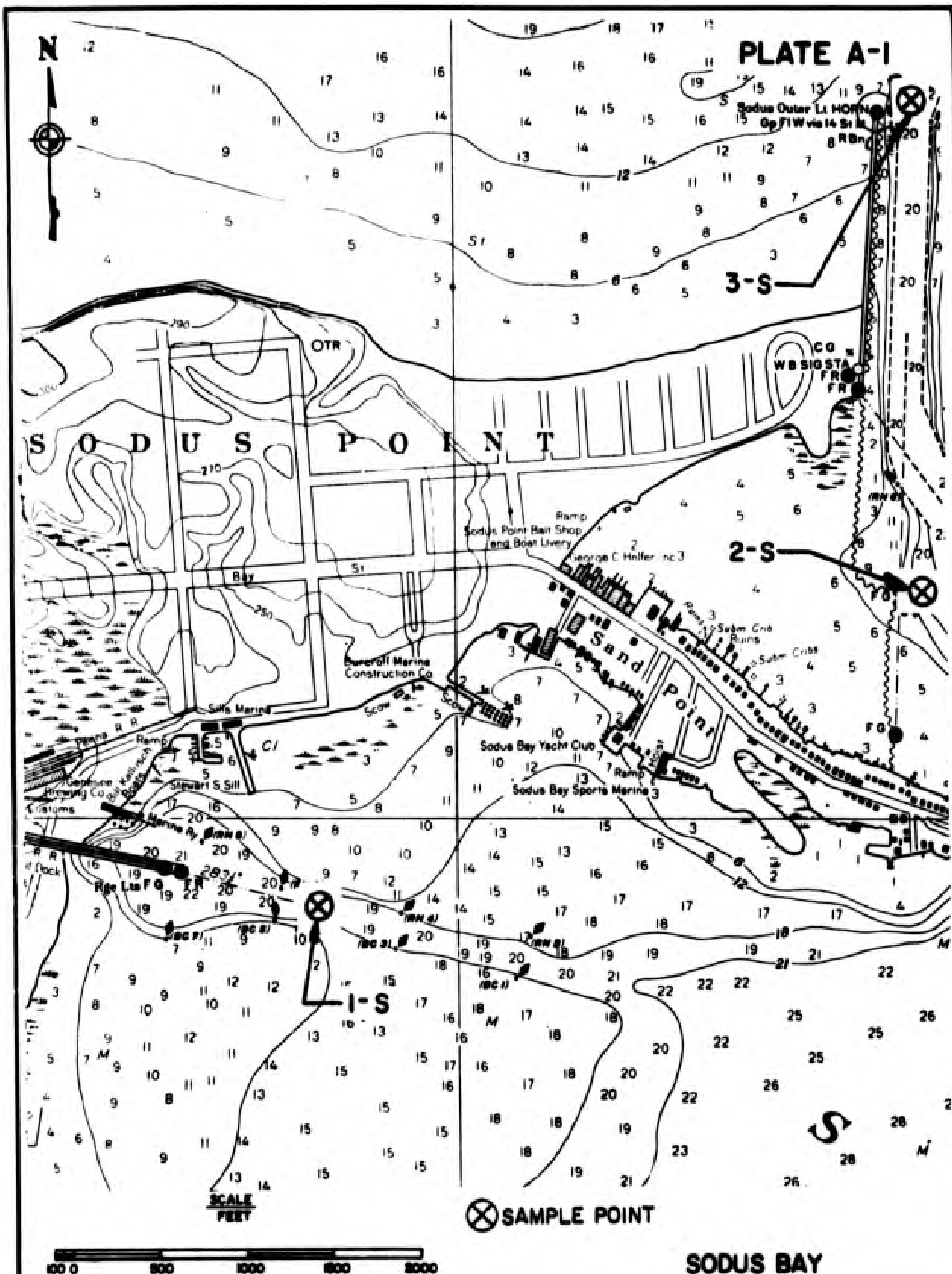
APPENDIX A

DRAWINGS

PLATE NUMBER	TITLE
A-1	Great Sodus Bay
A-2	Buffalo Harbor
A-3	Cleveland Harbor
A-4	Toledo Harbor
A-5	Rouge River
A-6 *	Calumet River
A-7	Green Bay

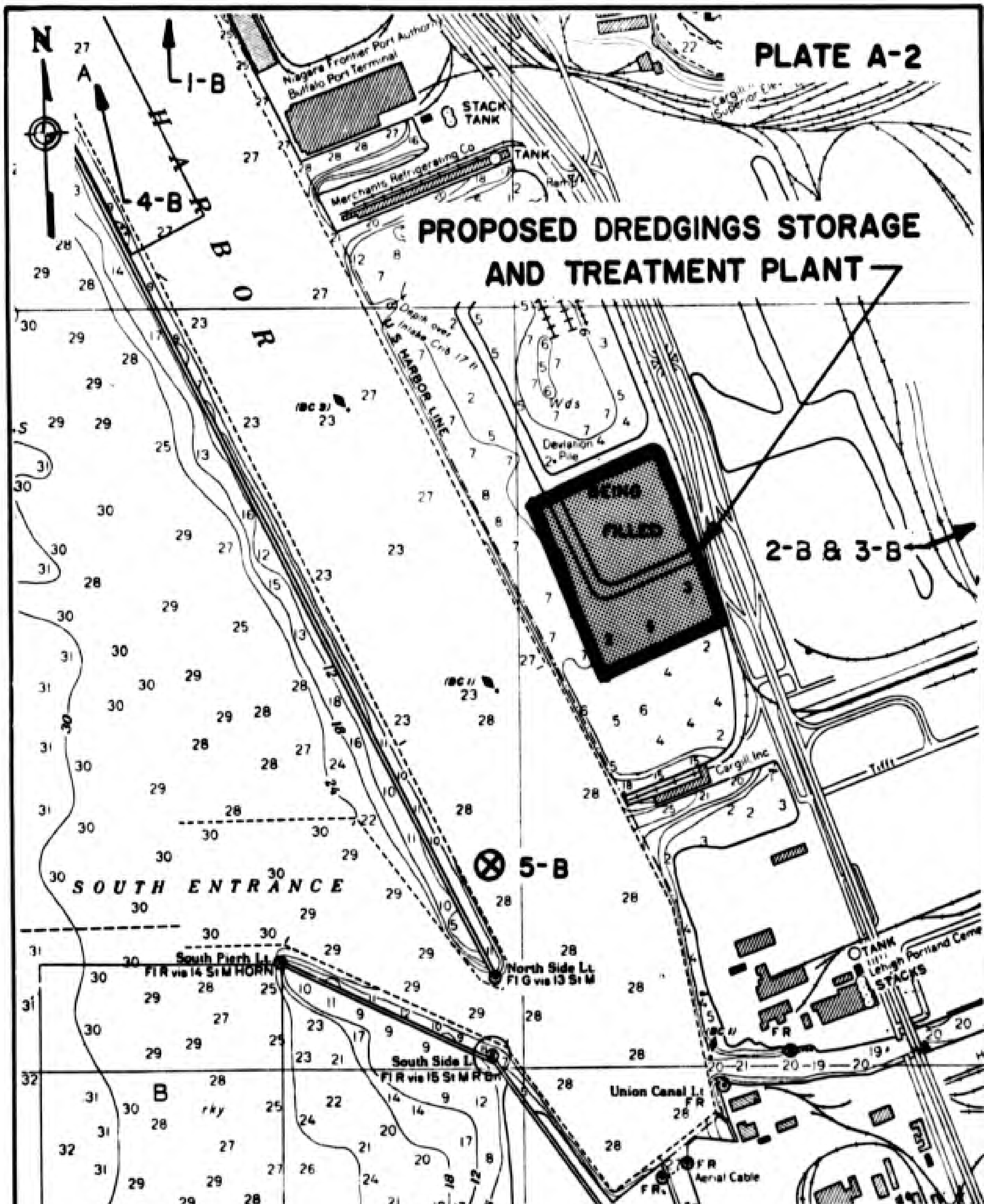
* Includes facilities for Indiana Harbor.

The following drawings show the areas tentatively selected for storage and treatment of dredgings for each pilot harbor. In the case of the Great Sodus Bay no treatment is anticipated, therefore no storage or treatment area is shown. The area shown on Plate No. A-6 is for both the Calumet River and Indiana Harbor. Dredgings from Indiana Harbor would be hauled to the site indicated.



NEBOLSINE, TOTH, McPHEE ASSOCIATES
SEPTEMBER, 1968

REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001



⊗ SAMPLE POINT

SCALE
FEET

1000 0 1000 2000

BUFFALO HARBOR

NEBOLSINE, TOTH, McPHEE ASSOCIATES
SEPTEMBER, 1968

REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001

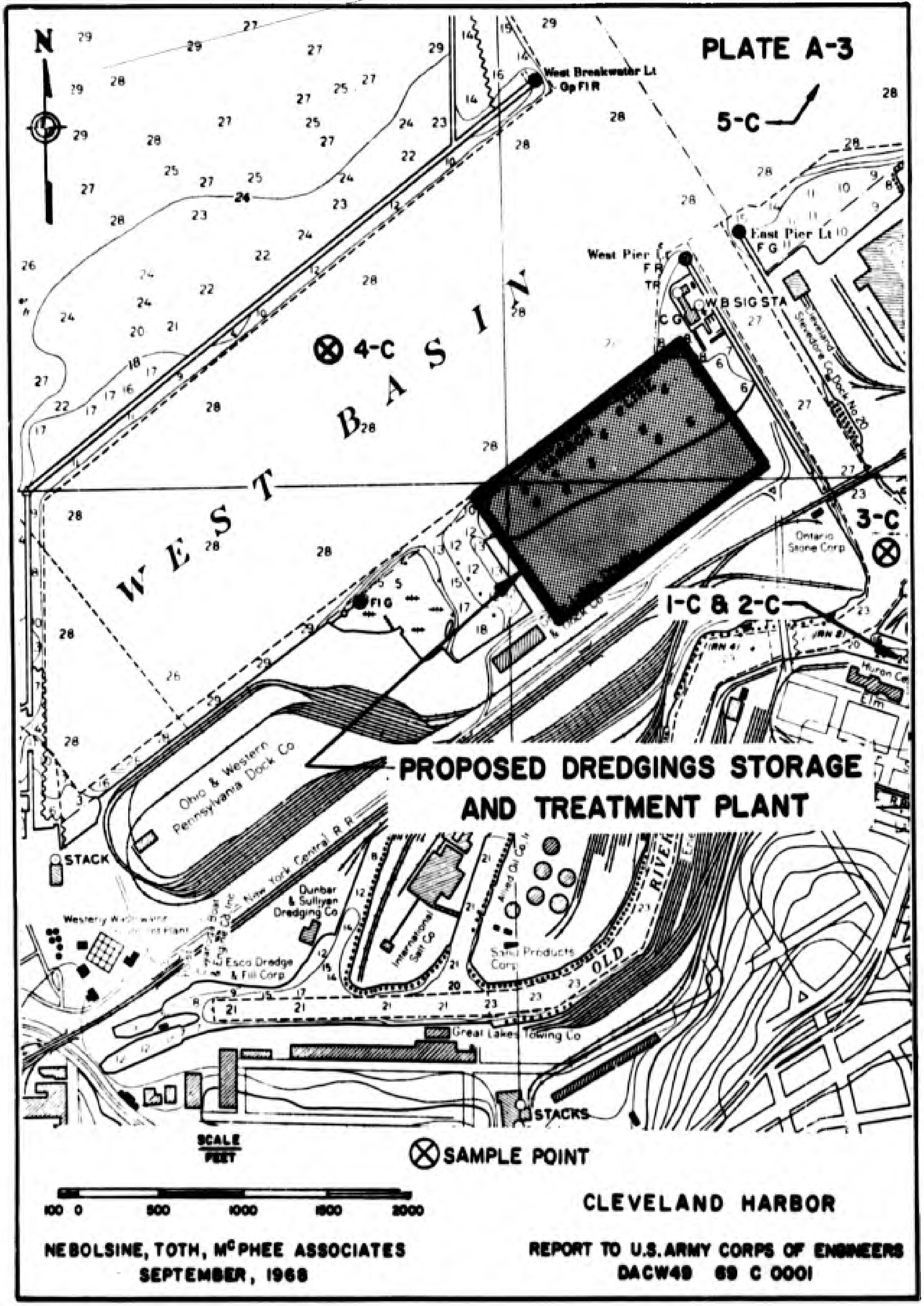


PLATE A-3
N
WEST BASIN
4-C
5-C
3-C
1-C & 2-C
West Breakwater Lt
East Pier Lt
West Pier
W.B SIG STA
Ontario Stone Corp
Ohio & Western Pennsylvania Dock Co
New York Central R.R.
Dunbar & Sullivan Dredging Co
Esco Dredge & Fill Corp
International Salt Co
Allied Oil Co.
Sand Products Corp
Great Lakes Towing Co
OLD RIVER
STACK
STACKS
PROPOSED DREDGINGS STORAGE AND TREATMENT PLANT
SAMPLE POINT
SCALE FEET
100 0 500 1000 1500 2000
CLEVELAND HARBOR
NEBOLSINE, TOTH, McPHEE ASSOCIATES
SEPTEMBER, 1968
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001

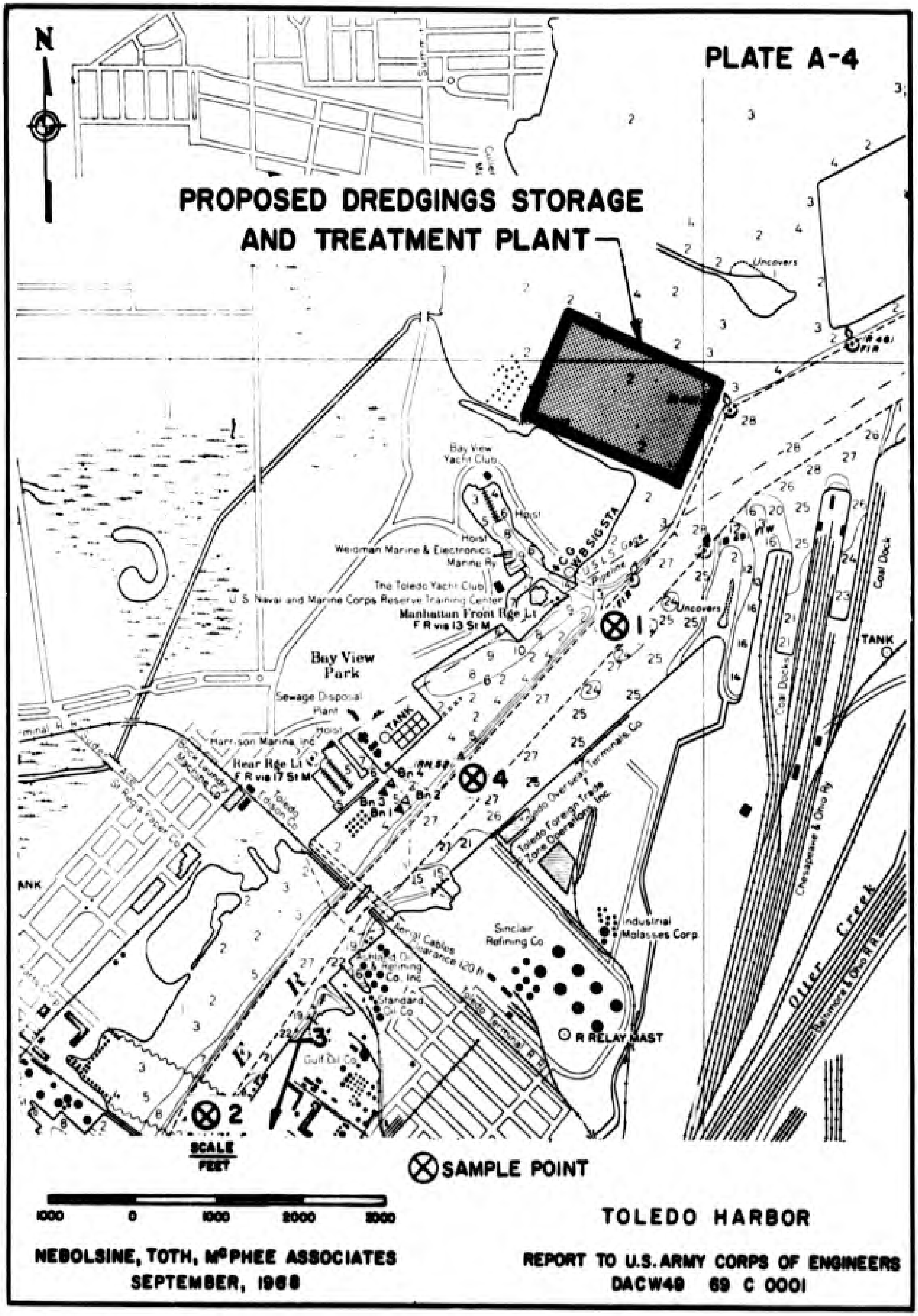
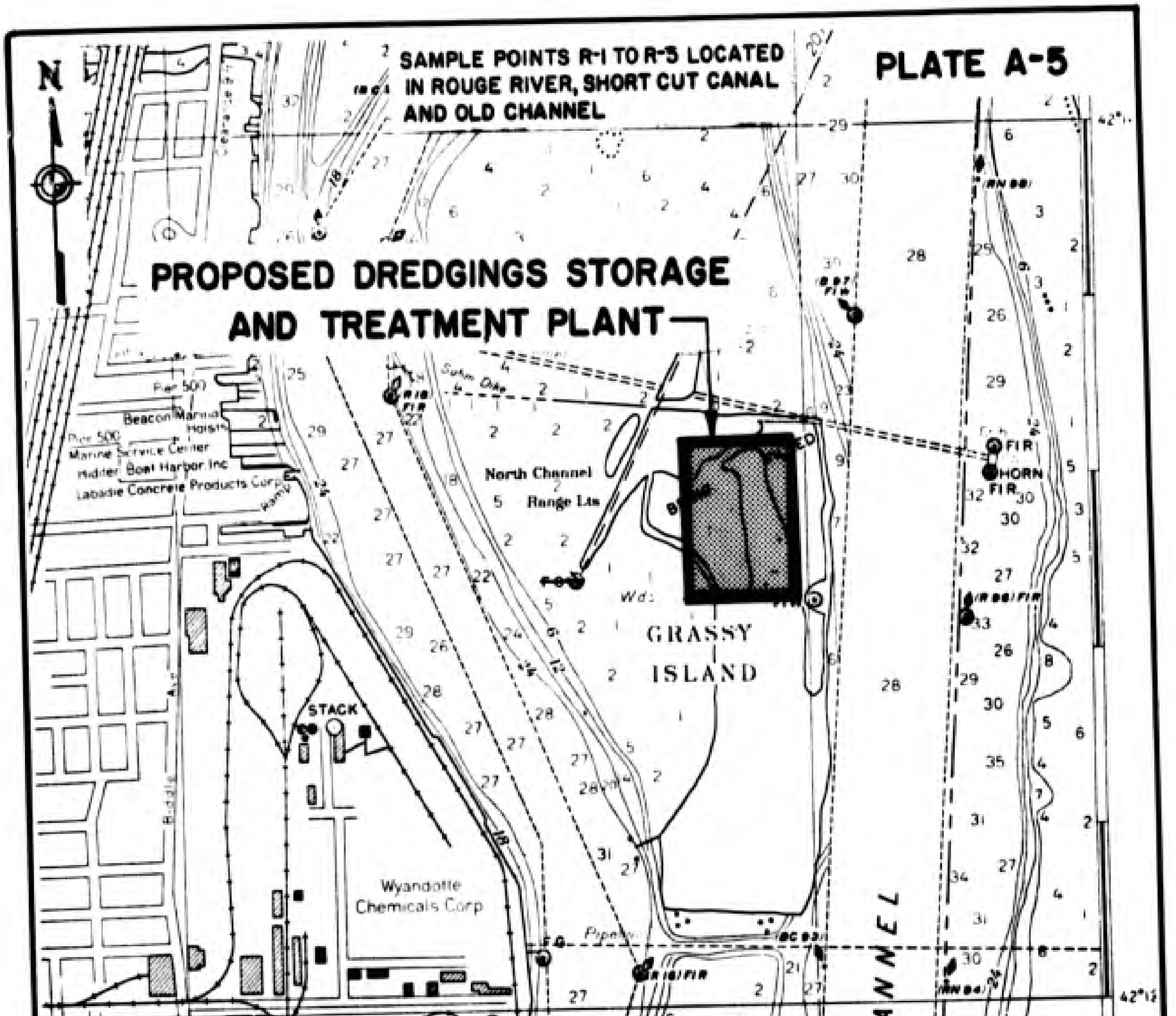
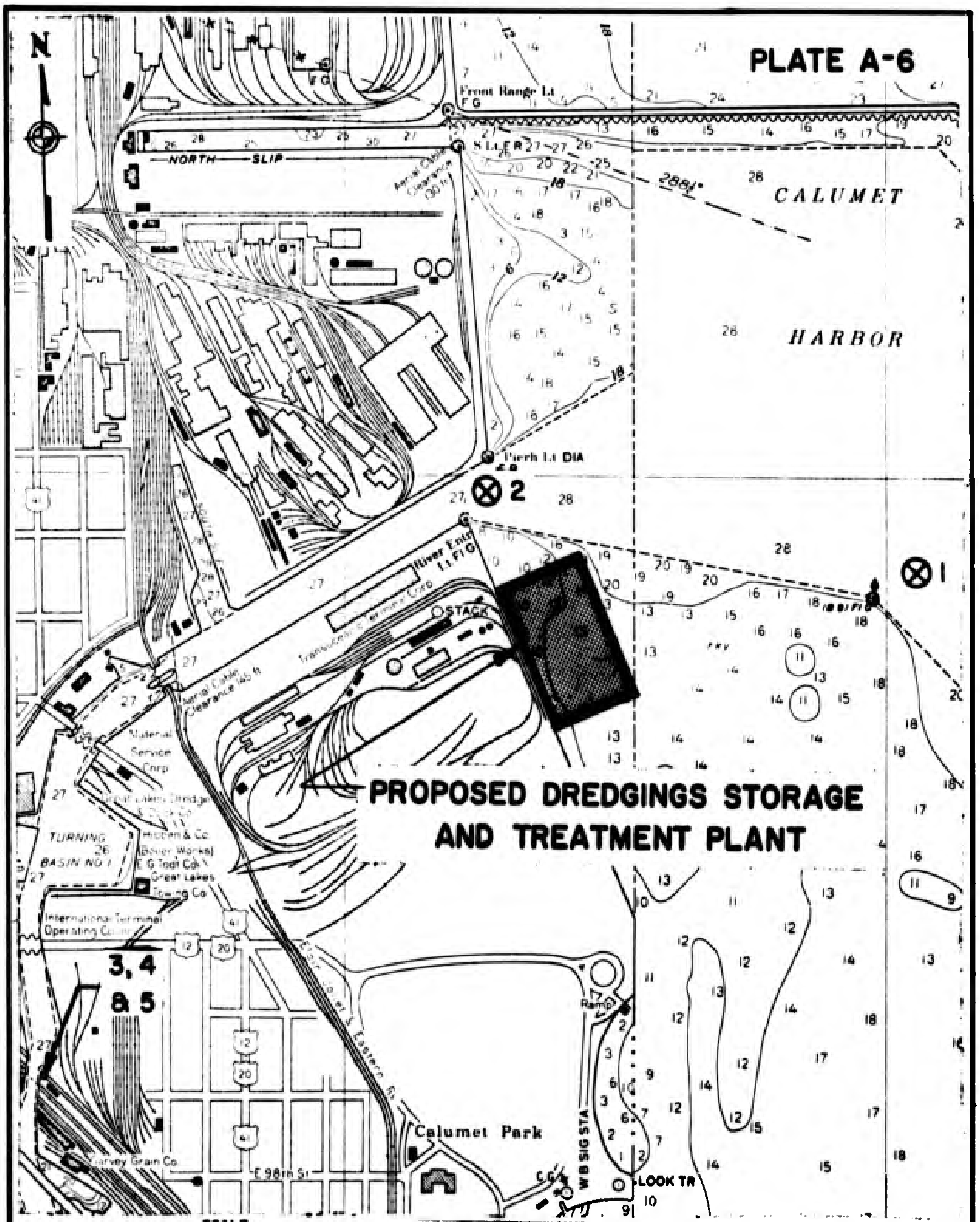


PLATE A-4
PROPOSED DREDGINGS STORAGE AND TREATMENT PLANT
N
Bay View Park
Bay View Yacht Club
The Toledo Yacht Club
U.S. Naval and Marine Corps Reserve Training Center
Manhattan Front Rge Lt
Sewage Disposal Plant
Harrison Marina Inc
Rear Rge Lt
Toledo Edison Co
Toledo Overseas Terminals Co
Toledo Foreign Trade Zone Operations Inc.
Sinclair Refining Co
Industrial Molasses Corp
Standard Oil Co
Gulf Oil Co
R RELAY MAST
Coal Docks
Coal Dock
Chesapeake & Ohio Ry
Otter Creek
TANK
SAMPLE POINT
SCALE
FEET
1000 0 1000 2000 3000
TOLEDO HARBOR
NEBOLSINE, TOTH, McPHEE ASSOCIATES
SEPTEMBER, 1968
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001


SAMPLE POINTS R-1 TO R-5 LOCATED IN ROUGE RIVER, SHORT CUT CANAL AND OLD CHANNEL
PLATE A-5
N
PROPOSED DREDGINGS STORAGE AND TREATMENT PLANT
Pier 500
Beacon Marina Hoists
Pier 500
Marine Service Center
Ridder Boat Harbor Inc
Labadie Concrete Products Corp
North Channel Range Lts
GRASSY ISLAND
STACK
Wyandotte Chemicals Corp
STACKS
CHANNEL
CHANNEL
Wyandotte Boat Club
Wyandotte Yacht Club
Wyandotte General Hospital
Eberts Bros Co
Depth over Crib 25 feet
HORN
SCALE FEET
1000 0 1000 2000
SAMPLE POINT
ROUGE RIVER
NEBOLSINE, TOTH, McPHEE ASSOCIATES
SEPTEMBER, 1968
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001



SCALE
FEET

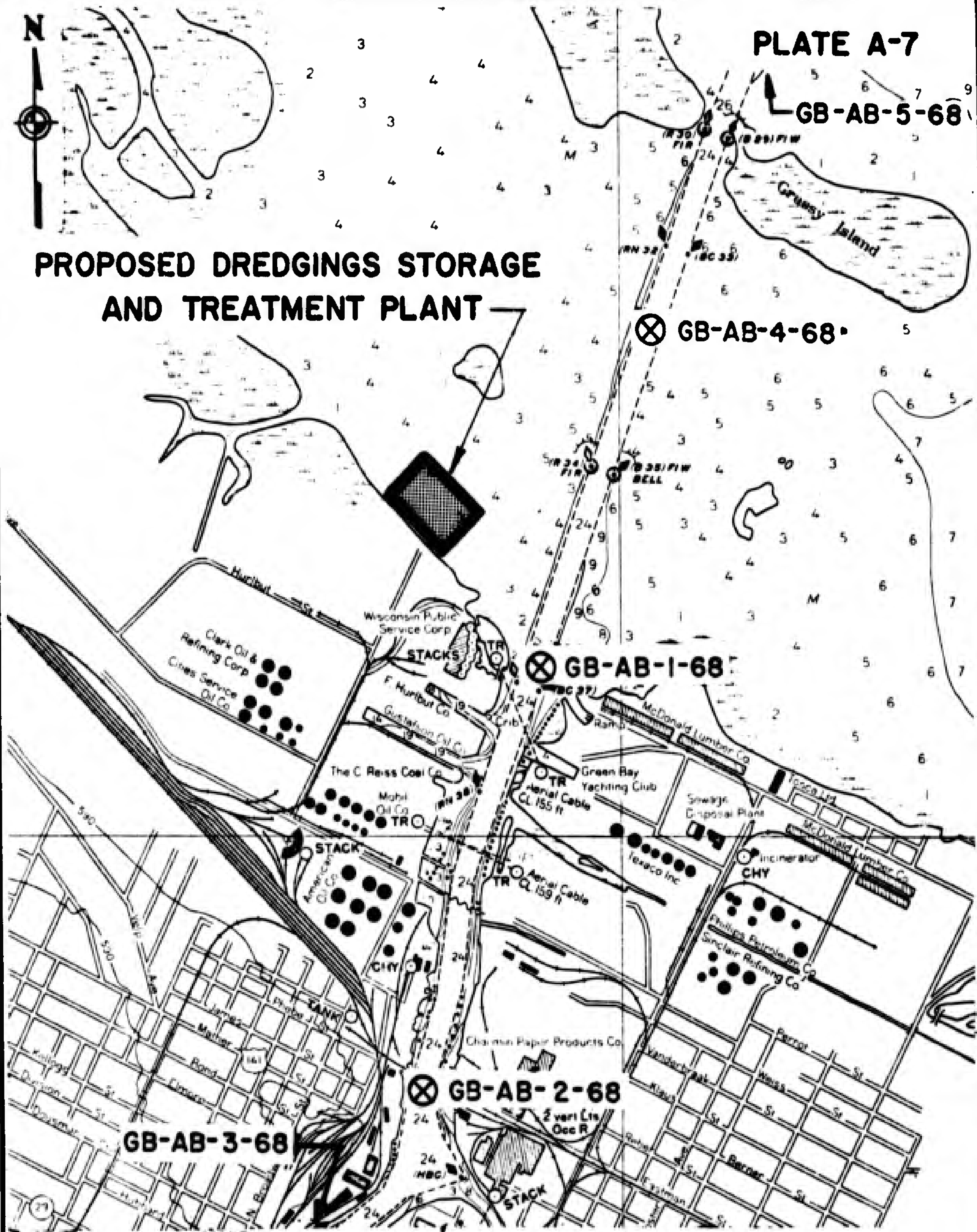
1000 0 1000 2000

⊗ SAMPLE POINT

CALUMET HARBOR

NEBOLSINE, TOTH, McPHEE ASSOCIATES
SEPTEMBER, 1968

REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001



SCALE
FEET

1000 500 0 1000 2000 3000 4000

⊗ SAMPLE POINT

GREEN BAY

NEBOLSINE, TOTH, McPHEE ASSOCIATES
SEPTEMBER, 1968

REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001

APPENDIX B

APPENDIX B

UTILITY COSTS

1) Utility costs for operating the facilities described in this report were assumed to be as follows:

a) Machinery fuel and lubrication costs:

I. Fuel consumption 0.36# per brake horsepower per hour. (#2 Diesel Oil)

II. No. 2 Diesel oil, $0.1314 per gallon or $0.0175 per pound.

III. Lubrication costs assumed as equal to 75 percent of fuel costs. This figure includes minor maintenance.

b) Cooling water - assumed to be harbor water pumped at the treatment site. Cost - $0.015/1000 gallons.

c) Boiler feed water - assumed to be harbor water treated at the site. Cost - $0.20/1000 gallons.

d) Heating fuel - $0.60/million BTU.

e) Electric energy - as described in Section 'D', "Unit Operations Studies", the cost of electric energy is based on generating power by diesel generators at the site. This approach was used because of the inaccessability of many of the pilot harbor treatment sites to local power lines.

The cost of furnishing electric energy is divided into three major sub-divisions as follows:

I. The cost of the engine-generators and their auxiliary equipment plus the cost of distributing the power to the treatment facilities.

II. The cost of providing a building for generators, auxiliaries and switch gear.

III. The cost of operating and maintaining the equipment.

Since the cost studies prepared for the treatment facilities are subdivided into capital costs and operating and maintenance costs, the capital costs of providing electric power has been computed for 2 subdivisions following I and II above. These costs versus total KW installed capacity are plotted in Figures B-1 and B-2 which are included in this appendix. The costs from Figure B-1 is carried as a separate cost in the capital cost tabulations but the cost of buildings from Figure B-2 has been included with the cost of the other required buildings. The cost of operating and maintaining the electric generating equipment from Figure B-3 is added to the other operating and maintenance costs.

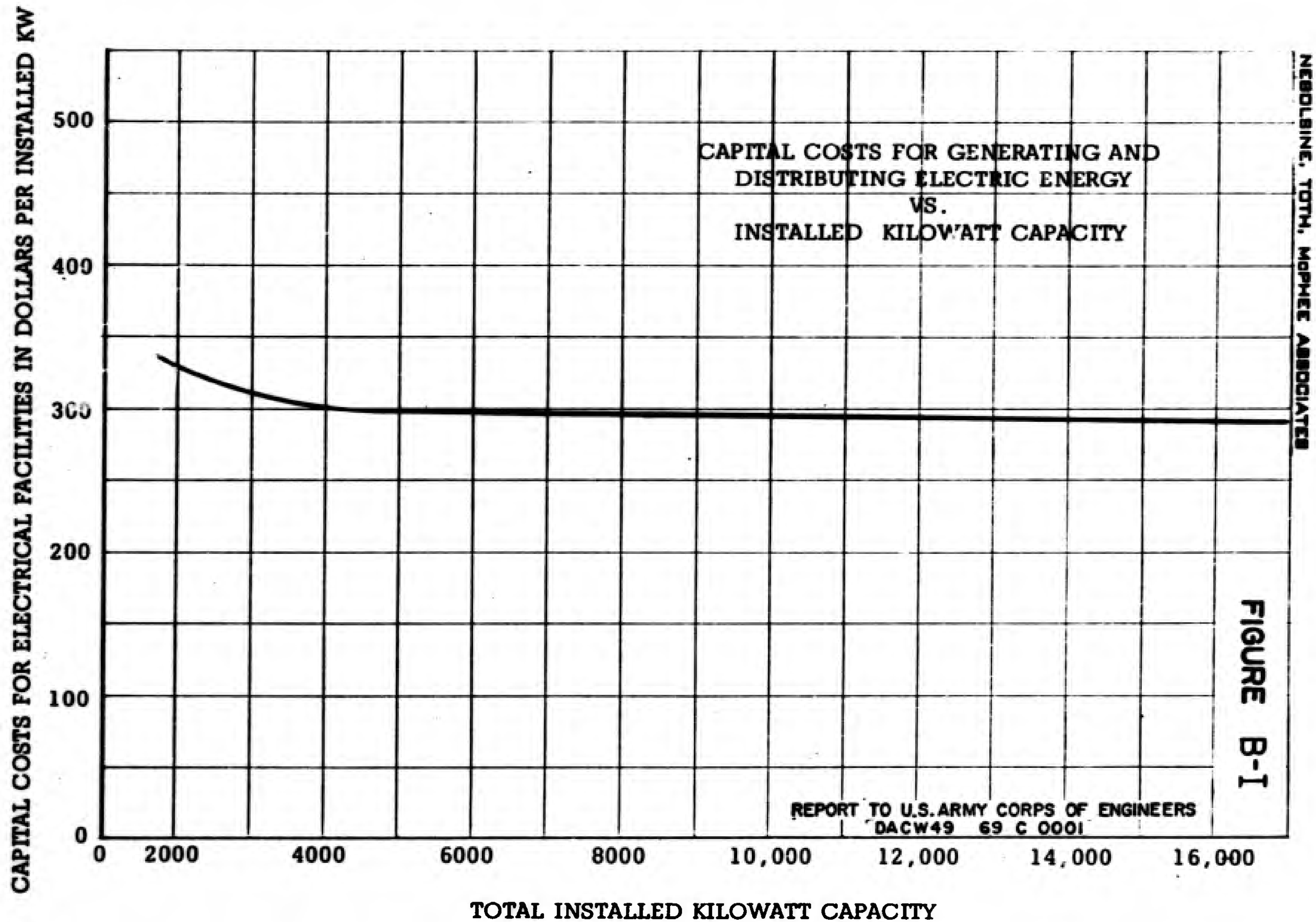
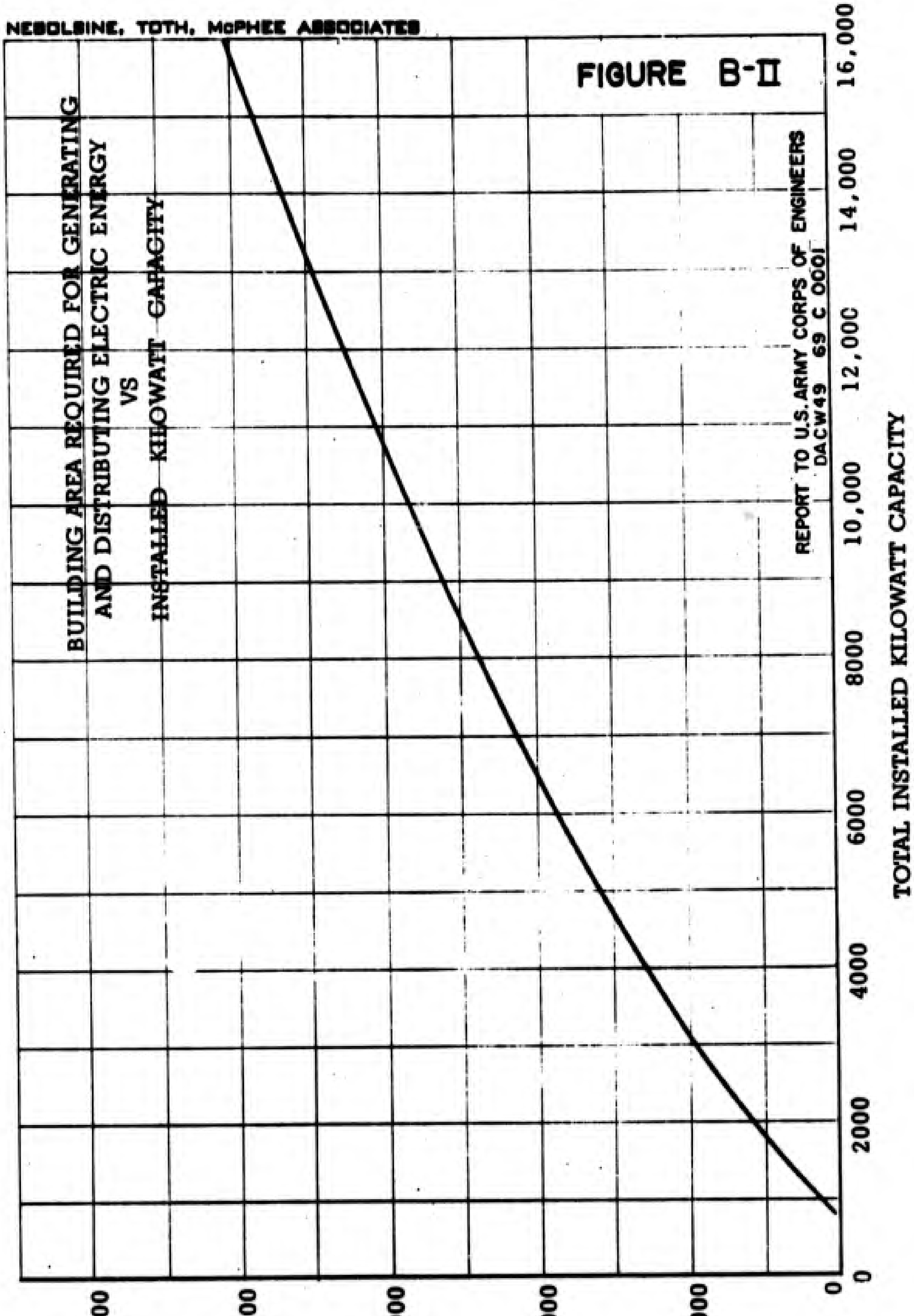
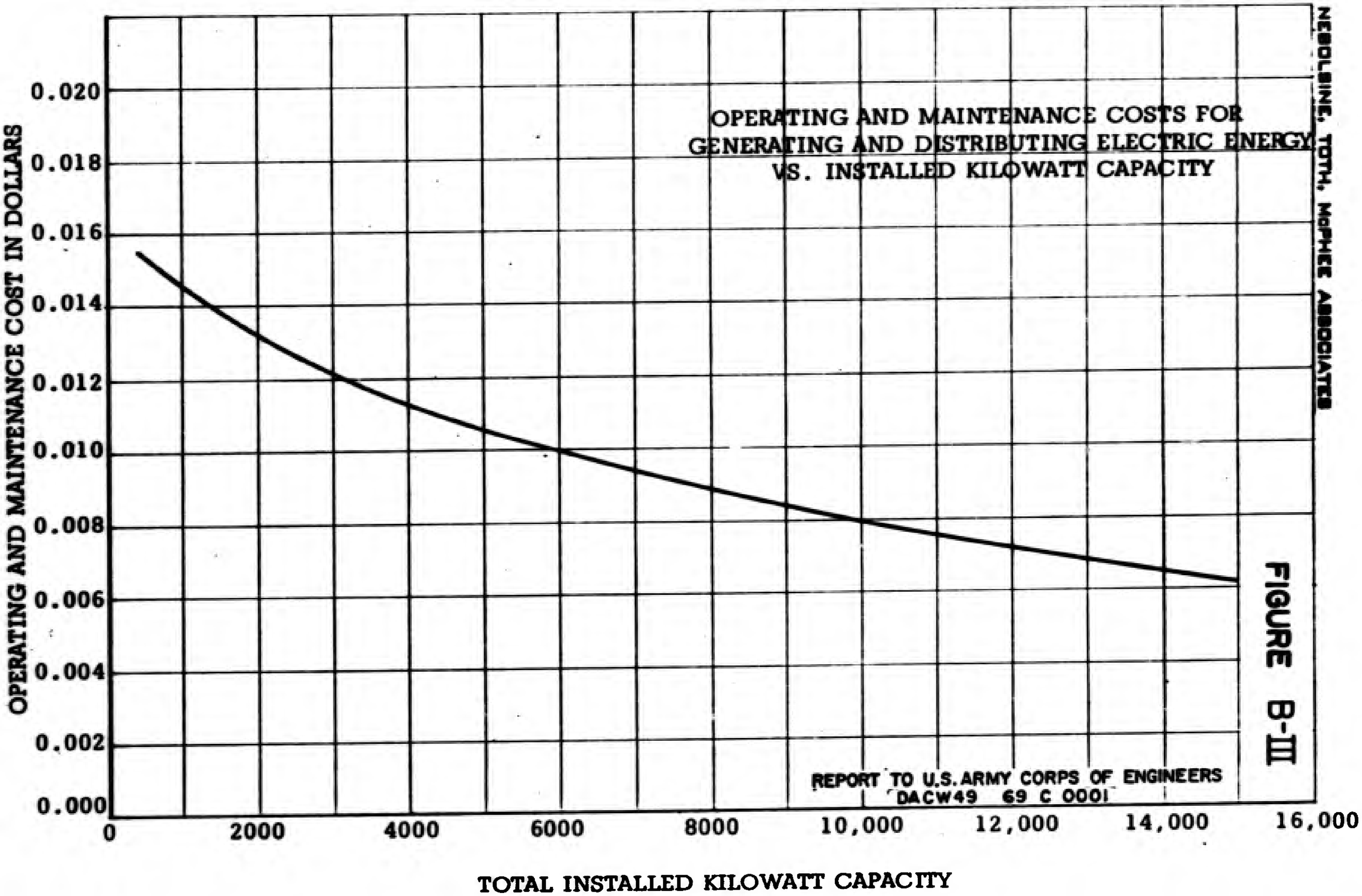

CAPITAL COSTS FOR GENERATING AND DISTRIBUTING ELECTRIC ENERGY VS. INSTALLED KILOWATT CAPACITY
REPORT TO U.S. ARMY CORPS OF ENGINEERS DACW49 69 C 0001
NEBOLSINE, TOTH, McPHEE ASSOCIATES
CAPITAL COSTS FOR ELECTRICAL FACILITIES IN DOLLARS PER INSTALLED KW
500
400
300
200
100
0
2000
4000
6000
8000
10,000
12,000
14,000
16,000
TOTAL INSTALLED KILOWATT CAPACITY

FIGURE B-I


NESBLSINE, TOTH, McPHEE ASSOCIATES
FIGURE B-II
BUILDING AREA REQUIRED FOR GENERATING AND DISTRIBUTING ELECTRIC ENERGY
VS
INSTALLED KILOWATT CAPACITY
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001
TOTAL INSTALLED KILOWATT CAPACITY
0
2000
4000
6000
8000
10,000
12,000
14,000
16,000
FLOOR AREA BUILDING REQUIRED IN SQUARE FEET
0
10,000
20,000
30,000
40,000
50,000



OPERATING AND MAINTENANCE COSTS FOR
GENERATING AND DISTRIBUTING ELECTRIC ENERGY
VS. INSTALLED KILOWATT CAPACITY
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001
OPERATING AND MAINTENANCE COST IN DOLLARS
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
0
2000
4000
6000
8000
10,000
12,000
14,000
16,000
TOTAL INSTALLED KILOWATT CAPACITY
NEBOLSINE, TOTH, McPHEE ASSOCIATES

FIGURE B-III

APPENDIX C

APPENDIX C

LABOR COSTS

1) ON-SHORE TREATMENT FACILITIES

To establish salaries for on-shore installations, salary scales for similar workers in industry were selected. The rates include normal payroll burdens such as social security, hospitalization, pensions, etc., but do not include vacation or sick leave. In applying these rates where treatment operations are only 270 days a year, it has been assumed that 45 additional days will be needed for normal maintenance and that the remaining 45 days will be consumed by sick leave and vacation. The hourly rates used are as follows:

a) Superintendent	$10.00/hr
b) Foreman	7.50/hr
c) Operators	6.25/hr
d) Asst. Operators	5.00/hr
e) Chemist	6.25/hr
f) Asst. Chemist	5.00/hr
g) Laborer	3.75/hr

Yearly salaries are based on 2080 hours per year.

2) FLOATING EQUIPMENT

Due to the fact that there are existing contracts with labor on dredges in the Great Lakes, it was assumed that marine personnel for dredging operations associated with the treatment operations would have to be paid on a similar basis. The Table on the following page shows how the daily salary of a dredge crew is computed.

The work schedule of the crew, except for Captain and Chief Engineer, is 7 days on, 2 days off; 7 days on, 2 days off, 7 days on and three days off; then repeat. The Captain and Chief Engineer were assumed to work 58 hours per week, 48 hours straight time and 10 hours overtime. Crews work 40 hour weeks before overtime. The annual total manpower costs for 270 days per year were computed to be as follows:

a)	Captain	$15,526
b)	Operators	11,549
c)	Chief Engineer	15,526
d)	Asst. Engineer	11,234
e)	Oilers	10,157
f)	Deck and Pontoon Foreman	11,073
g)	Pipeline Foreman	11,073
h)	Pipeline Men	10,092
i)	Tug Operator	10,842
j)	Deck Hands	10,537

TABLE C-1

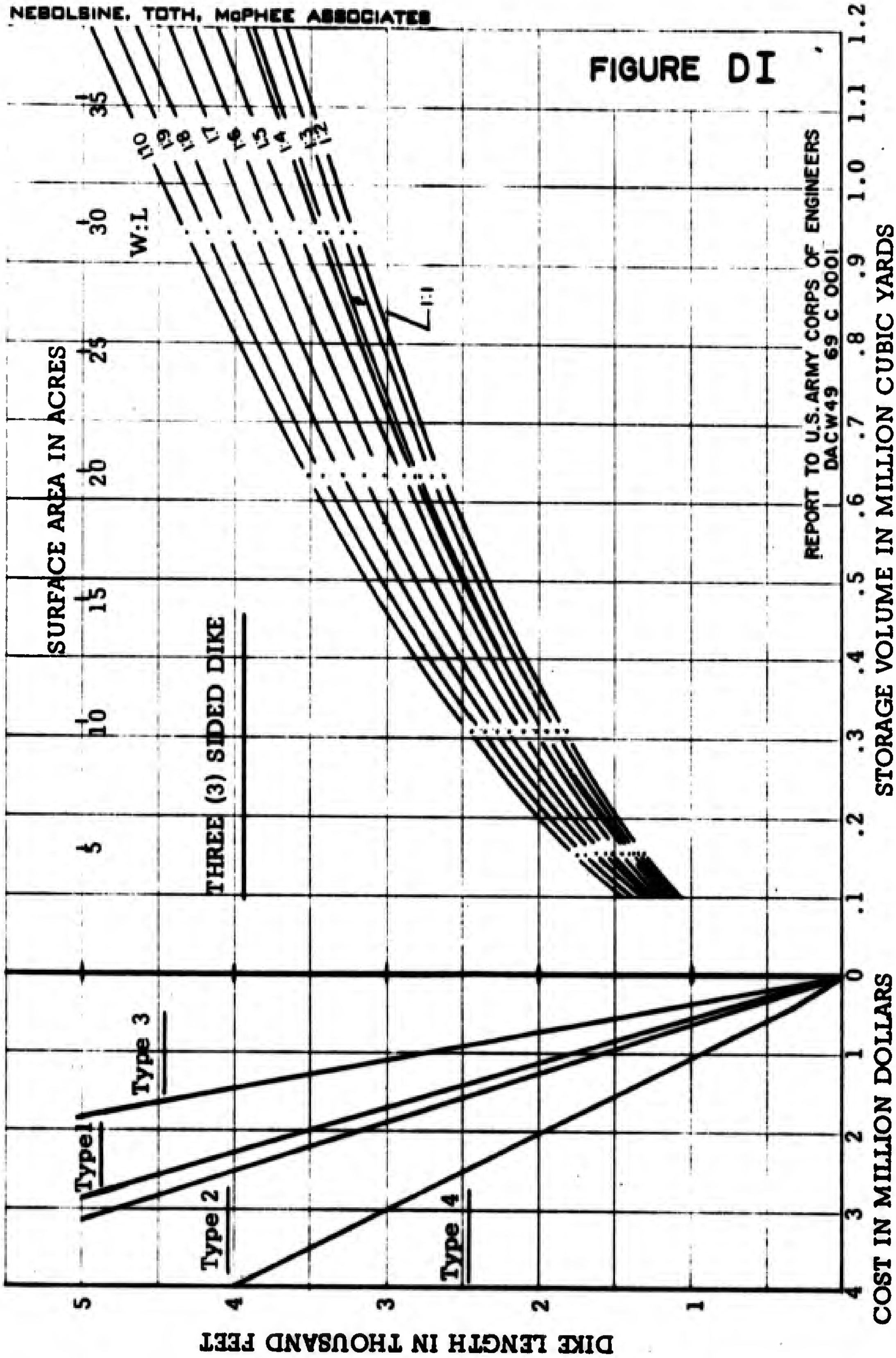
DREDGE CREW - SALARY COMPUTATIONS

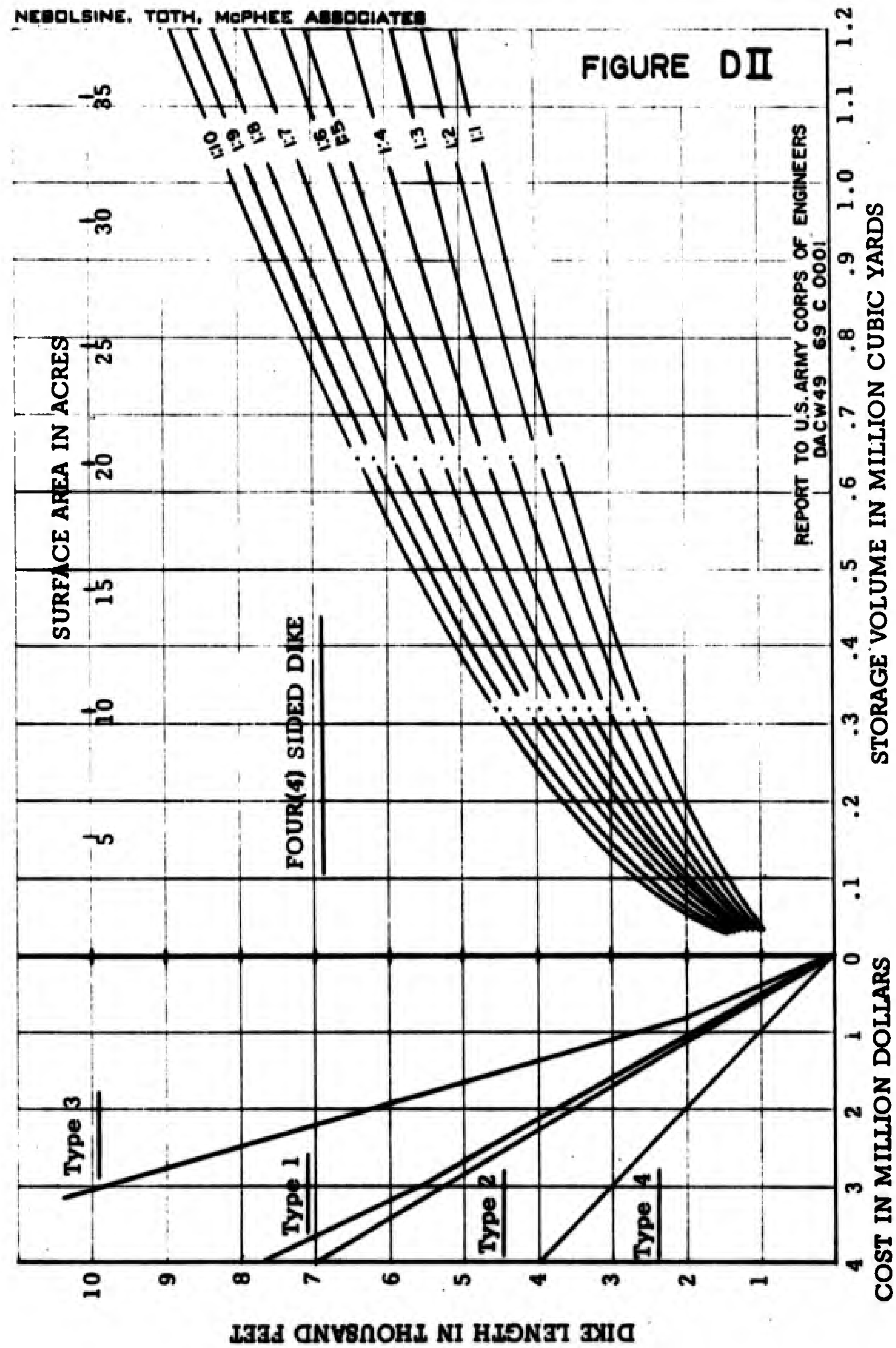
Job Classification	Daily Rate	Welfare	Pension	Portal Time	Travel Expense	Mileage Expense	Vacation Pay*	Holiday Pay *	Total Cost Per Day
Captain	39.28	1.69	1.20	1.75	0.50	2.40	2.21	1.53	50.56
Operator	38.96	1.69	1.20	1.75	0.50	2.40	2.19	1.52	50.21
Chief Engineer	39.28	1.69	1.20	1.75	0.50	2.40	2.21	1.53	50.56
Asst. Engineer	37.75	1.69	1.20	1.75	0.50	2.40	2.13	1.47	48.89
Oiler	33.54	1.69	1.20	1.75	0.50	2.40	1.89	1.39	44.28
Deck & Pontoon Foreman	37.13	1.69	1.20	1.75	0.50	2.40	2.09	1.44	48.20
Pipeline Foreman	37.13	1.69	1.20	1.75	0.50	2.40	2.09	1.45	48.21
Pipeline Men	33.28	1.69	1.20	1.75	0.50	2.40	1.87	1.32	44.01
Tug Captain	35.34	1.69	1.20	1.75	0.50	2.40	1.99	1.38	47.45
Deckhands	33.01	1.69	1.20	1.75	0.50	2.40	1.86	1.29	44.90

* Based on 270-Day year.

Overtime is paid at 50% of daily rate plus total cost per day.

APPENDIX D

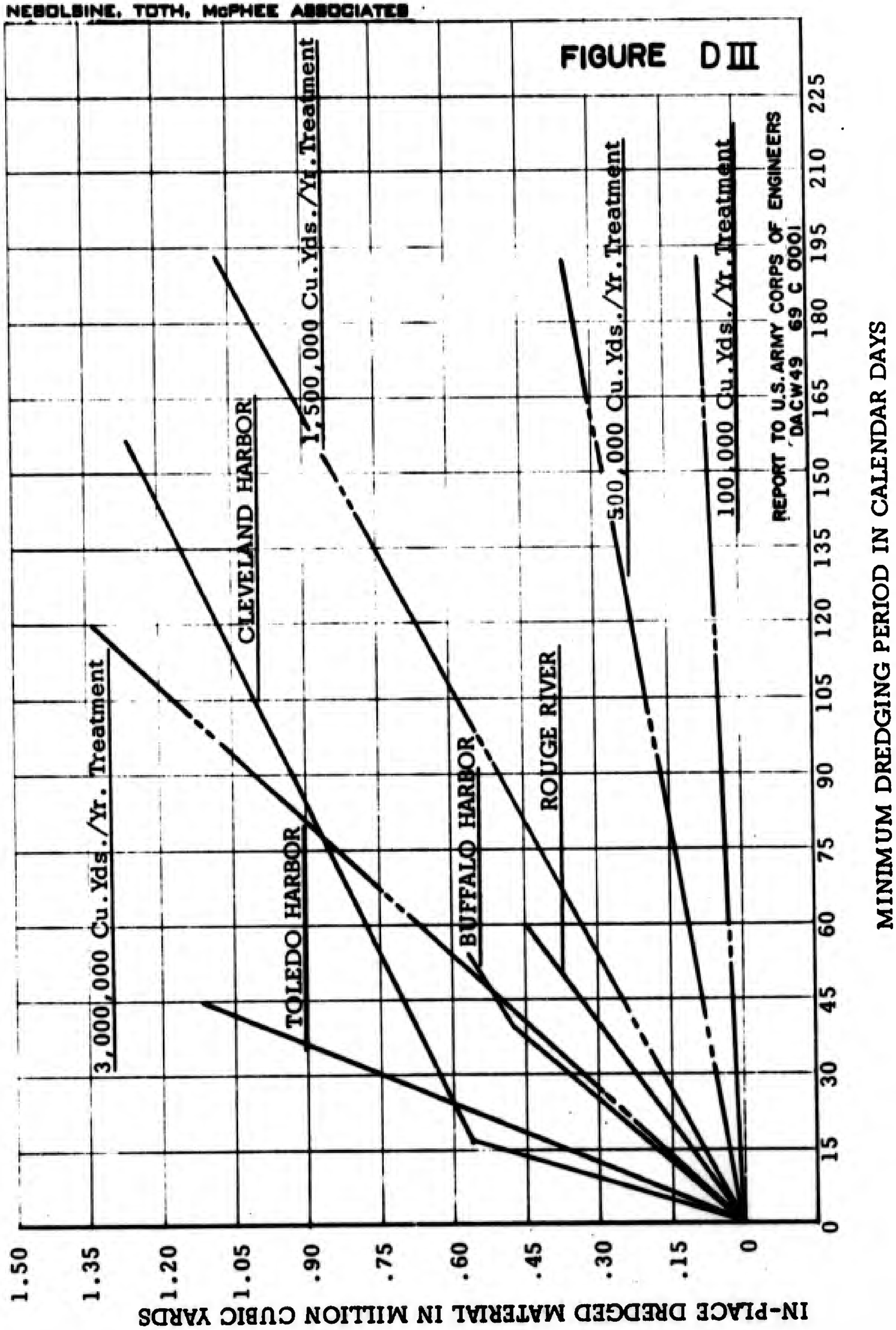

NEBOLSINE, TOTH, McPHEE ASSOCIATES
FIGURE DI
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001
SURFACE AREA IN ACRES
5
10
15
20
25
30
35
W:L
1:10
1:9
1:8
1:7
1:6
1:5
1:4
1:3
1:2
1:1
THREE (3) SIDED DIKE
Type 1
Type 2
Type 3
Type 4
STORAGE VOLUME IN MILLION CUBIC YARDS
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
COST IN MILLION DOLLARS
0
1
2
3
4
DIKE LENGTH IN THOUSAND FEET
1
2
3
4
5

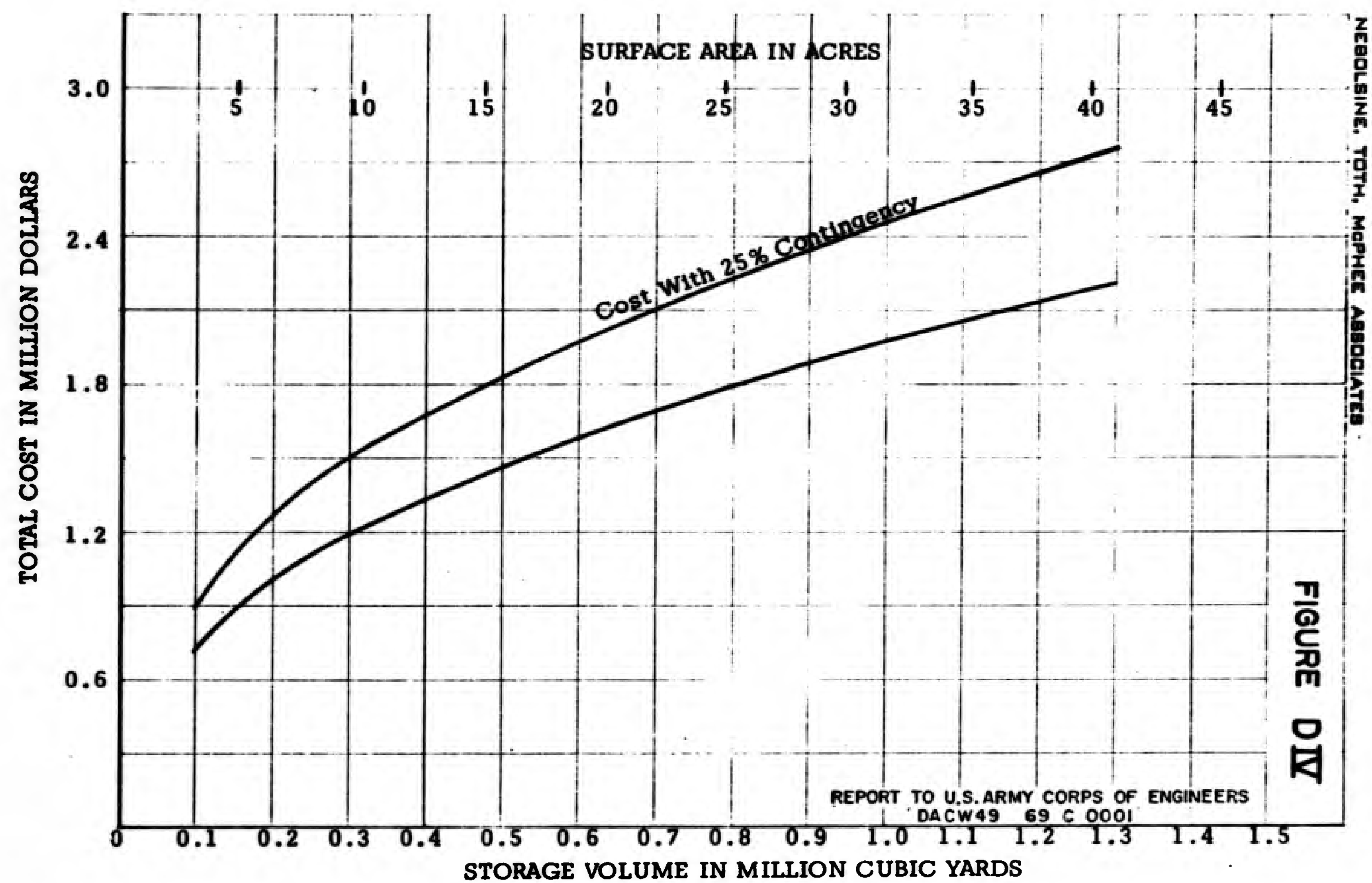


NEBOLSINE, TOTH, McPHEE ASSOCIATES
FIGURE DII
SURFACE AREA IN ACRES
FOUR(4) SIDED DIKE
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001
STORAGE VOLUME IN MILLION CUBIC YARDS
COST IN MILLION DOLLARS
DIKE LENGTH IN THOUSAND FEET
Type 1
Type 2
Type 3
Type 4
1:1
1:2
1:3
1:4
1:5
1:6
1:7
1:8
1:9
1:10

NEBOLSINE, TOTH, McPHEE ASSOCIATES

FIGURE D III




NEBOLSINE, TOTH, McPHEE ASSOCIATES
FIGURE D IV
SURFACE AREA IN ACRES
5
10
15
20
25
30
35
40
45
TOTAL COST IN MILLION DOLLARS
3.0
2.4
1.8
1.2
0.6
Cost With 25% Contingency
REPORT TO U.S. ARMY CORPS OF ENGINEERS
DACW49 69 C 0001
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
STORAGE VOLUME IN MILLION CUBIC YARDS

APPENDIX "E"

TESTS FOR PARTICLE

SEPARATION FROM DREDGINGS

I. GENERAL

A test program was conducted to investigate the use of a 12" cyclone for primary separation of the volatile matter in channel dredgings, a 50 mm cyclone for secondary separation of the 12" cyclone overflow, a thickening test on the 12" cyclone overflow, a classification test of the 12" cyclone underflow, and spin tests on the underflow from the thickening test.

Primary separation in the 12" cyclone effected about a 200 mesh separation with about a 10% volatile concentration in the underflow. The volatile solids concentration in the 50 mm cyclone ranged between 4.5% and 8.7%. Thickening tests show a unit area requirement of 186 sq.ft./ton solids/ 24 hours producing an underflow concentration of 30% solids. Classification tests did not show satisfactory reduction of the volatile content of the sands. Centrifuge spin tests indicated that excessive amounts of flocculant aids would be required for effective dewatering.

II. SAMPLE

Four (4) 55 gallon drums of channel dredgings were used for tests performed on 20 August, 1968. The sample was marked D108-1 through 4 for identification. The entire sample was consumed in the test work.

Chemical and size analyses are presented in Tables E1 and E2.

III. OBJECT OF TESTS

To separate the organic and phosphate bearing fractions from stable channel dredging solids.

The purpose of this program was to investigate the use of a 12" cyclone for primary separation, the use of a 50 mm cyclone for separation of the primary overflow, the adaptability of thickening to 12" cyclone overflow, the use of a classification technique to produce a less than 1% volatile solids sand fraction, and the possibility of dewatering the sludge from the thickening and settling tests by either filtering or centrifuging.

IV. SUMMARY

The sample as received contained coarse wood and refuse and was screened on a 1-inch mesh prior to testing in the 12" cyclone. Three tests were then run at varying conditions. Size analyses presented in Table E-2 show that about a 200 mesh separation was effected. However, a considerable amount of cattail stalks, wood and other light debris reported to the overflow.

Solids recovery to the 12" cyclone underflow ranged between 6.7% and 16.1% at solids concentrations from 56.1% to 61.1%. Underflow volatile solids and total phosphorus concentrations were about 10% and 800 ppm (total phosphorus), respectively. The phosphorus concentration of the feed was 629 ppm (total phosphorus), showing a small net concentration in the underflow. The volatile solids concentration dropped from 14% in the feed to the 10% concentration in the underflow. Subsequent classification test work on the 12" cyclone underflow showed that three decants on a 325 mesh separation basis only reduced the volatile solids concentration of the sands to 6.8%.

The sands contain coarse volatile matter which classifies approximately comparable to the non-volatile sands. It is possible that the volatile matter and sands are agglomerated, indicating that a mechanical scrubbing prior to secondary separation is required. The sands dewatered well showing horizontal filtration rates of 1250 lbs./ft.^{2}/hr. and a residual cake moisture of 8.5%.

Subsequent test work on the 12" cyclone overflow also showed little separation of volatile matter. The 50 mm cyclone results showed a lower volatile concentration than the 12" cyclone tests, but still amounted to between 4.5% and 8.7% for weight recoveries of between 7.8% and 17.1%. A thickening test on the 12" cyclone overflow showed a unit area requirement of 186 sq. ft./ton solids/24 hours, producing an underflow concentration of 30% solids for a 24 hour detention time.

Centrifugal spin tests on thickener underflow indicated excessive flocculant aid dosages would be required to obtain improved dewatering. Tests without flocculant aid showed poor solids recoveries with attendant dirty concentrates.

V. CONCLUSIONS AND RECOMMENDATIONS

Classification techniques on the samples tested did not prove satisfactory for volatiles reduction in the sands fraction. As indicated, tests including a light attrition scrub prior to classification may free volatile matter and produce an acceptable product. It is recommended more work be done in the primary separation area. Other samples should be investigated to insure that the test work as performed is representative of how most dredging sludges will act.

Dewatering of the dredged sludge can be accomplished through either filtration or centrifugation. However, additional work is required to estimate the cost of dewatering versus the combustion of the thickener underflow directly in an incineration unit.

It is recommended that an expanded program be instituted that includes a study of several representative samples to determine if a satisfactory sands fraction can be obtained as well as determination of the economics of sludge dewatering prior to fluid bed incineration.

TABLE E1

CHEMICAL ANALYSES SUMMARY

Sample	Total p ppm	Soluble p ppm	BOD mg/l	COD mg/l
12" Cyclone Feed	629	4	20,000	81,000
Test #1 U'flow	728	3	-	-
Test #2 U'flow	793	3	-	-
Test #3 U'flow	813	3	-	-
50mm Cyclone Feed	567	-	-	-
#1 O'flow	786	-	-	-
#2 O'flow	536	-	-	-
#3 O'flow	561	-	-	-

BTU content of 30% solids thickener underflow is 1450 BTU/lb.

TABLE E2

12" CYCLONE SIZE ANALYSES

Tyler Mesh	% Cumulative Plus						
		Test #1		Test #2		Test #3	
	Feed	U'f	O'f	U'f	O'f	U'f	O'f
6	.158	.99	Tr	1.53	.29	.21	.17
8	.42	1.58	.36	1.95	.29	.55	.34
10	.63	2.36	.54	2.56	1.03	1.04	.52
14	1.05	3.30	1.25	3.17	1.17	1.52	1.20
20	1.58	4.82	1.43	4.15	1.77	2.56	1.38
28	2.64	7.65	1.97	5.60	2.50	3.94	1.90
35	3.70	12.5	3.04	8.05	3.24	5.67	2.42
48	5.17	23.2	3.58	13.5	4.12	9.13	3.10
65	7.3	43.5	4.83	24.6	4.70	16.6	3.80
100	10.2	64.5	6.8	42.8	6.18	29.0	4.83
150	13.6	74.0	9.8	58.6	8.54	43.6	5.70
200	17.1	79.1	13.7	67.3	12.0	55.8	8.28
325	25.6	82.9	20.9	74.6	20.9	67.7	15.5

Note: 1. Wet screening on 200 and end point on 325 plus 200 dried and RoTaped.
2. Coarse material contained in overflow is wood and light debris.

TABLE E3

MOISTURE ANALYSES

Sample	% Moisture	% Solids
12" Cyclone Feed	76.8	23.2
12" Cyclone Test #1 Overflow	77.7	22.3
12" Cyclone Test #1 Underflow	43.9	56.1
12" Cyclone Test #2 Overflow	78.0	22.0
12" Cyclone Test #2 Underflow	42.3	57.7
12" Cyclone Test #3 Overflow	79.5	20.5
12" Cyclone Test #3 Underflow	38.9	61.1
50 mm Cyclone Feed	77.6	22.4
50 mm Cyclone Test #1 Overflow	88.5	11.5
50 mm Cyclone Test #1 Underflow	49	51
50 mm Cyclone Test #2 Overflow	83.2	16.8
50 mm Cyclone Test #2 Underflow	41.3	58.7
50 mm Cyclone Test #3 Overflow	82.1	17.9
50 mm Cyclone Test #3 Underflow	42.3	57.7

TABLE E4

VOLATILE ANALYSES

	% Volatile Solids	
Sample	Dry Basis	Wet Basis
12" Cyclone Feed	14.05	3.24
12" Cyclone Test #1 Overflow	20.6	4.62
12" Cyclone Test #1 Underflow	8.85	4.99
12" Cyclone Test #2 Overflow	13.4	2.92
12" Cyclone Test #2 Underflow	10.85	4.5
12" Cyclone Test #3 Overflow	17.9	3.57
12" Cyclone Test #3 Underflow	9.15	2.94
50 mm Cyclone Feed	15.2	3.32
50 mm Test #1 Overflow	20.8	3.34
50 mm Test #1 Underflow	7.72	3.77
50 mm Test #2 Overflow	19.0	3.26
50 mm Test #2 Underflow	4.47	2.54
50 mm Test #3 Overflow	19.2	3.13
50 mm Test #3 Underflow	8.74	5.21

TABLE E5

DATA AND RESULTS OF 12" CYCLONE TESTS

Test No.	1	2	3
Diam. Unit (inches)	12	12	12
Apex Diam. (inches)	2	2	3
Vortex Diam. (inches)	5	5	5
Feed Pressure, psig	5	10	10
Feed Source	As Rec'd. Screened thru 1"	As Rec'd. Screened thru 1"	As Rec'd. Screened thru 1"
Additives	None	None	None
Input:			
Feed Conc. % Solids	23.2	23.2	23.2
Feed Rate gpm	180	262	262
Output:			
Overflow Conc, % Solids	22.3	22	21.5
Overflow Rate	175	253	246
Underflow Conc. % Solids	56.1	57.7	61.1
Underflow Rate gpm	5	9	16
% Recovery of Solids			
Underflow/Feed Solids	6.7	7.7	16.1
% Flow Split			
Underflow/Feed Rate	2.78	3.44	6.11

TABLE E6

DATA AND RESULTS OF 50 MM CYCLONE TESTS

Test No.	1	2	3
Type Unit	P-50	P-50	P-50
Diam. Unit (mm)	50	50	50
Apex Restrictions	None	Part	Maximum
Feed Pressure psig	35	35	35
Feed Source	12" Cyclone O'flow	12" Cyclone O'flow	12" Cyclone O'flow
Additives	None	None	None
Input:			
Feed Conc. % Solids	22.4	22.4	22.4
Feed Rate, gpm	17.57	16.5	16.4
Output:			
Overflow Conc. % Solids	3.7	16.8	17.9
Overflow Rate, gpm	16.25	15.75	15.9
Underflow Conc. % Solids	51	58.7	57.7
Underflow Rate gpm	1.32	.755	.496
% Recovery of Solids			
Underflow/Feed Solids	17.1	11.9	7.8
% Flow Split			
Underflow/Feed Rate	7.5	4.56	3.04

TABLE E7

LONG TUBE CLASSIFICATION TEST

325 Mesh Separation - 3 Decants

Settling	O'f Total Wt. gr.	O'f Solids gr.	O'f % Volatiles	Sediment Wt. Grams	U'f % Solids	Sediment % Volatiles
1	831	79.5	16.4	340	-	-
2	766	6.5	15.2	351.2	-	-
3	776	2.9	18.2	359.7	57.5	6.8

Feed material prepared by diluting 12" cyclone underflow with 1 part of water. Classification performed on a 2.7 specific gravity separation at 325 mesh.

TABLE E8

FILTRATION TEST RESULTS

1. Filtration Tests on thickener underflow:

   Drum Filter Basis

   Solids Rate - 10 lb/ft.^{2}/hr.
   Filtrate Rate - 2 gal./ft.^{2}/hr.
   Cake Moisture - 43%

2. Horizontal filtration tests on classifier underflow:

   Solids Rate - 1250 lb./ft.^{2}/hr.
   Cake Moisture - 8.5%

TABLE E9

CENTRIFUGE SPIN TEST RESULTS

1. Excessive flocculant requirements to obtain clear overflow.

2. Unflocculated test segregated badly with very turbid overflow.

FIGURE 10

THICKENING TEST RESULTS

12" cyclone overflow thickening requires plant unit area of 186 $ft.^2$/ton solids 24 hours underflow concentration 30.0% solids at 24 hours thickener detention time.

APPENDIX C7

DREDGINGS DISPOSAL IN SEWERAGE SYSTEMS

PREPARED BY

THE METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO

AND

U. S. ARMY CORPS OF ENGINEERS, CHICAGO DISTRICT

DEPARTMENT OF THE ARMY
CHICAGO DISTRICT, CORPS OF ENGINEERS
219 SOUTH DEARBORN STREET
CHICAGO, ILLINOIS 60604

NCCED-PH

DEC 3 0 1968

SUBJECT: Pilot Program, Great Lakes Dredging Disposal-Report on Feasibility of Disposing Dredged Material from Chicago River into Interceptor - Sewage Treatment Plant System of the Metropolitan Sanitary District of Greater Chicago

District Engineer, Buffalo District

1. There are inclosed copies of letter dated 12 November 1968 from the Metropolitan Sanitary District of Greater Chicago (Inclosure #1) and copies of the Sanitary District's report dated October 1968, titled "Cooperative Pilot Program to Determine Feasibility of Disposing of Dredge Spoil from Waterways in the Sanitary District Interceptor-Sewage Treatment Plant System." (Inclosure #2) Advance copies of the report were furnished you by letter dated 21 November 1968, subject: "Pilot Program, Great Lakes Dredging Disposal - Disposal of Dredged Material from North Branch, Chicago River in Local Sewers and Treatment in Municipal Sewage Treatment Plants."

2. In a general review of the Sanitary District's report, this office found certain errors or discrepancies which were called to the attention of the Sanitary District. It is understood that the Sanitary District intends to issue an errata sheet to its report but it is uncertain at this time when such issuance will be made. In addition to the general review this office has made a detailed study taking into consideration the information contained in the Sanitary District Report together with other information collected by this office. The results of this study, titled "Supplemental Study" are set forth in Inclosure 4. Attention is invited to the fact that the following paragraphs in this letter report are based on the Sanitary District's report and not on our Supplemental Study, as the latter should not affect to any major extent the general conclusions that can be reached from the Sanitary District's report.

3. Our letter of 21 November 1968, referred to in paragraph 1 above, stated that the Sanitary District's report was being reviewed in this office, and that the results of such review would be included in a Supplement to our report dated August 1968, titled "Study on Provision of Alternative Disposal Areas for Chicago Harbor and River, Illinois." During visit of Mr. Carl Fo^ley, Buffalo District on 26 November 1968 we were informed that our reports of studies of alternative disposal areas for various harbor projects will be included as appendices in the Pilot Study

Report, and that the study of the feasibility of disposing dredged material from the North Branch, Chicago River into the Sanitary District interceptor-sewage treatment plant system will be included as a separate appendix in the Pilot Study Report. Thus, our original intent to submit the latter study as a supplement to our report on provision of alternative disposal areas for Chicago Harbor and River is no longer applicable.

4. It was tentatively agreed with Mr. Foley on 26 November 1968 that the Chicago District would submit a letter report to the Buffalo District inclosing the Sanitary District's report on the feasibility of disposing the dredged material in the Sanitary District's interceptor-sewage treatment plant system, and thatthe Buffalo District will use it as considered appropriate in preparing the appendix on the subject matter for inclusion in the Pilot Study Report. This letter is the letter report on the subject.

5. The inclosed Sanitary District report states that dredged material was introduced into the interceptor-sewage treatment plant system, hereinafter referred to as the Sanitary District System, from two locations, i.e., on the South Fork of the South Branch of the Chicago River in the vicinity of the Racine Avenue Pumping Station, and on the North Branch, Chicago River just south of North Avenue. It is to be noted that the South Fork of the South Branch is often referred to locally as Bubbly Creek.

6. The first test or experiment was conducted at the Racine Avenue Pumping Station of the Sanitary District with material dredged from the South Fork of the South Branch by means of a mobile clam-shell crane operating on the river bank. The dredged material was carried by gravity through the Southwest Interceptor to the Southwest Treatment Plant located along the Chicago Sanitary and Ship Canal. The South Fork of the South Branch is not part of the Federal project. However, previous tests by FWPCA of bottom samples taken in the South Fork and in the North Branch, which is a part of the Federal project, indicated that the materials at both locations were somewhat similar (Inclosure 3). Thus, it was believed that the first test, which could be accomplished by use of a clam-shell crane at the Racine Avenue Pumping Station at comparatively low cost and with a minimum of difficulty, would probably produce results applicable to the North Branch and/or serve as a useful guide in planning additional tests that might be required.

SUBJECT: Pilot Program, Great Lakes, Dredging Disposal-Report on Feasibility of Disposing Dredged Material from Chicago River into Interceptor-Sewage Treatment Plant System of the Metropolitan Sanitary District of Greater Chicago

7. As indicated in the Sanitary District's report the first test at the Racine Avenue Pumping Station did not produce satisfactory results and showed the need for additional tests. Accordingly, on the basis of the first test, two additional tests were planned and conducted.

8. The second test was also conducted in the vicinity of the Racine Avenue Pumping Station with material dredged from the South Fork of the South Branch. However, in the second test a small hydraulic dredge was used in excavating the material in the South Fork instead of the clamshell crane. As in the first test, the material dredged in the second test was carried by gravity through the Southwest Interceptor to the Southwest Treatment Plant.

9. The third or final test was conducted in the North Branch of the Chicago River which is a part of the Federal project. As such, the material excavated was the same as would be excavated during normal maintenance dredging operations. Therefore, the third test was considered as being most representative and applicable with respect to maintenance dredging of the North Branch of the Chicago River. In the third test, the material was dredged from the North Branch by means of the small hydraulic dredge and was carried by gravity through the West Side Interceptor to the West Side Treatment Plant.

10. It is to be noted (see Figure 1 of the Sanitary District Report) that the Southwest and the West Side Treatment Plants are located in the same general area. Figures 2A and 2B of the Sanitary District's report are flow diagrams for the Southwest and West Side Treatment Plants. In connection therewith, attention is invited to the fact that the effluent from the Imhoff tanks of the West Side Treatment Plant receives secondary treatment at the Southwest Treatment Plant. Thus, the Southwest Treatment Plant performs secondary treatment for the flows carried in both the Southwest and West Interceptors.

11. Although not mentioned in the Sanitary District's report, the Southwest and West Side Treatment Plants have the following capacities.

Plant	Primary Treatment	Secondary Treatment
Southwest	300 mgd	800 mgd
West Side	500 mgd	none

SUBJECT: Pilot Program, Great Lakes Dredging Disposal-Report on Feasibility of Disposing Dredged Material from Chicago River into Interceptor-Sewage Treatment Plant System of the Metropolitan Sanitary District of Greater Chicago

12. In summary, the results of the tests indicated the following with respect to the feasibility of disposing dredged material from the North Branch of the Chicago River in the large interceptor-sewage treatment plant system of the Metropolitan Sanitary District of Chicago.

a. For the quantities of dredged material introduced into the system there was no adverse effect on the interceptor system when the material was excavated by hydraulic dredge. The cutter head was effective in breaking up the material to the extent that there was no noticeable deposition thereof in the gravity-flow interceptors. However, placement of large masses of material in the interceptors, such as would be excavated by clam-shell or similar type excavating equipment could ultimately adversely effect the flows in the interceptor by deposition of the material in the interceptors. This could more readily occur if the excavated material contained cohesive clay.

b. The quantities of dredged material, placed in the system did effect plant operation although the liquid quantity was only a very small fraction of the capacities of the treatment plants. This was due to the fact, that the dredged material passed through the grit chambers without settlement, thus causing an unusually high load in the primary and secondary treatment processes.

c. The estimated cost of disposing dredged material from the North Branch of the Chicago River into the Sanitary District interceptor-sewage treatment plant system is approximately $9.00 per cubic yard of dredged material, based on the results of the tests.

d. The capacities of the sewage treatment plants to handle the dredged material in the primary and secondary treatment processes or facilities are very limited. In view thereof an abnormally long period of time would be required to dispose of the dredged material from the North Branch of the Chicago River.

NCCED-PH DEC [illegible] 1968
SUBJECT: Pilot Program, Great Lakes Dredging Disposal-Report on Feasibility of Disposing Dredged Material from Chicago River into Interceptor-Sewage Treatment Plant System of the Metropolitan Sanitary District of Greater Chicago

13. In view of the high cost of handling the dredged material in the primary and secondary treatment facilities, and the very limited capacity of the plants which would prolong the dredging over an abnormal period of time and thus further add to the dredging costs, it is believed that disposal of dredged material from the North Branch of the Chicago River into the Sanitary District interceptor-sewage treatment plant system is not feasible from an economic viewpoint.

FOR THE DISTRICT ENGINEER:

R. M. Peach

R. M. PEACH
LTC, Corps of Engineers
Deputy District Engineer
for Civil Works

4 Incl (in quad)
1. Ltr dtd 11/12/68
2. Rpt dtd Oct 68
3. FWPCA Test Results
4. Supplemental Study
dtd Dec 1968 w/Exhibit A

Copies Furnished: (w/incls)
NCD

THE
METROPOLITAN SANITARY DISTRICT
OF GREATER CHICAGO
100 EAST ERIE ST., CHICAGO, ILLINOIS 60611 . . SUPERIOR 7-6900

November 12, 1968

Colonel Edward E. Bennett
U. S. Army, Chicago District
Corps of Engineers
219 South Dearborn Street
Chicago, Illinois

Dear Colonel Bennett:

You will find attached twelve copies of the report on "Cooperative Pilot Program to Determine Feasibility of Disposing of Dredge Spoil from Waterways in the Sanitary District Interceptor-Sewage Treatment Plant System."

Our major finding is that nearly all of the solids are handled in the primary and secondary phases of the treatment plant process. Unfortunately, we are very limited in our capacity to handle solids produced in these processes. This results in the subject method of dredge spoil disposal not being adaptable to large scale dredging operations. We feel it has definite potential to very limited projects, however.

Since dredge spoil disposal is an essential area within the pollution control picture, this basic method may be applicable in another form. It is not unrealistic to conceive of a plant specifically built to process and dispose of dredge spoil.

The Sanitary District feels satisfaction in having been part of this mutual endeavor. Deserving special recognition is the close cooperation between our two agencies. We feel this report will be informative in your further studies.

Very truly yours,

Vinton W. Bacon

Vinton W. Bacon
General Superintendent

INCLOSURE 1

THE METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO

Department of Maintenance and Operation

REPORT ON COOPERATIVE PILOT PROGRAM TO DETERMINE FEASIBILITY OF DISPOSING OF DREDGE SPOIL FROM WATERWAYS IN THE SANITARY DISTRICT INTERCEPTOR-SEWAGE TREATMENT PLANT SYSTEM

OCTOBER, 1968

INCLOSURE 2

TABLE OF CONTENTS

INCLOSURE 2

FINDINGS

A cooperative pilot program to study the feasibility of disposing the spoil from waterway dredging in the Sanitary District interceptor-treatment plant system has been concluded. It is found that the method is a practical one but is high in cost and would require long periods of time to dispose of large quantities of solids.

The high costs result because the material is fine in texture and must be handled by the more difficult methods of solids disposal. The long periods result because the Sanitary District does not have sufficient solids-handling capacity to process and dispose of this material, and it must be taken when excess capacity is available.

INTRODUCTION

At a meeting held on July 2, 1968 in the office of the Sanitary District, the Chicago District of the Corps of Engineers and the Metropolitan Sanitary District of Greater Chicago jointly agreed to conducting a pilot investigative program on the disposal of dredge spoil via the Sanitary District interceptor and treatment plant system. At the meeting, it was agreed that the Corps of Engineers would perform all necessary work in the conduct of dredging and putting the spoil into the Sanitary District system.

The Sanitary District would transport the spoil via the interceptor system and dispose of the spoil via its sewage treatment plant processes, collect samples of the dredge material, determine the effect upon the interceptor system and upon the treatment plant processes, and report the results of this program. This is a report on the conduct of this pilot program and a presentation of its effect upon the Sanitary District system and the proposed guidelines and estimated costs of full scale dredging operations.

CONDUCT OF DREDGING

The first phase of the dredging operations was undertaken at the Racine Avenue Pumping Station. Utilizing a clamshell bucket on a mobile crane, the Corps of Engineers dredged solids off the bottom of the South Fork of the South Branch of the Chicago River in the vicinity of the station and deposited this spoil into the north end of the discharge chamber of the station. The spoil material was sluiced through the discharge chamber by an amount of water taken in through a sluice gate. At the southern end of the discharge chamber, the mixture of spoil and sluicing water combined with the raw sewage being pumped at the station and was transported to the West-Southwest Sewage Treatment Plant via the Southwest Interceptor, a distance of some six miles.

Dredging in this manner occurred on July 26, 29 and 31, 1968. The amount of material introduced into the system was approximately 230 cubic yards. The clamshell operation experienced many difficulties which negated its performance as a reliable test program. Its most obvious deficiency was the inability to dredge a sufficient amount of material within a reasonable boom reach.

This phase of the program was concluded with a recognition that a better method of conduct of the pilot program was necessary.

Racine - Suction Dredge

The Corps of Engineers scheduled the use of an eight-inch suction dredge at the same site for the next phase of the pilot program. The dredge "Depoe Bay" was used and is a portable suction dredge having a nominal capacity of 100 cubic yards per hour capacity with a maximum digging depth of approximately seventeen feet. Its liquid discharge rate is approximately 4.5 cubic feet per second. This equipment was moved into the South Fork of the South Branch and dredging commenced on September 17 and concluded on September 26, 1968.

The dredge worked in the area to the north of the station across the full width of the river channel. Over this period of time, it moved a total of 6,788 cubic yards of material. This material has a dry solids equivalent of approximately

3070 tons. A list of daily output from the dredge may be observed on Table 1.

The liquid-solid slurry produced by this dredge was conducted via an eight-inch pipeline along the west side of the Racine Avenue Pumping Station to a manhole on the Southwest Interceptor No. 4 immediately to the southwest of the station. The slurry continued via the Southwest Interceptor to the West-Southwest Sewage Treatment Plant.

Within the Southwest Sewage Treatment Plant, the material passed through the coarse screens, was pumped at the main pumping station, passed through aerated grit chambers, through the primary settling tanks, the aerobic reactors, and the final clarifiers. See Figure 2A.

The solids from this slurry were largely removed in the primary and secondary processes at the plant. Very little solids were removed at the grit chambers. A breakdown of the proportions of removal within the treatment plant will be discussed later.

<u>North Branch - Suction Dredge</u>

The third phase of the pilot program consisted of dredging from the North Branch of the Chicago River with the same suction dredge previously used at Racine Avenue. This activity took place on September 30 and October 1 and 2, 1968. The dredging was accomplished in the turning basin located immediately south of North Avenue on the North Branch of the Chicago River.

The liquid-solid slurry from the dredge was conducted via the eight-inch pipeline to a manhole located on the west bank of the river at Blackhawk Street. This manhole is on the West Side Interceptor No. 9. The slurry was transported via the West Side Interceptor system to the West Side Sewage Treatment Plant.

The three-day operation on the North Branch resulted in the removal of 2,490 cubic yards of material which has a dry weight equivalent of approximately 604 tons. Daily detail on this operation is shown on Table 1.

Upon reaching the West Side Sewage Treatment Plant, the spoil material passed through the coarse screens and the pumping station, the grit chambers, and the imhoff plant. The effluent from the West Side Sewage Treatment Plant goes into the secondary process of the Southwest Sewage Treatment Plant. See Figure 2B.

Again, the solids were removed in the imhoff and secondary plants. No increase in grit production was evident. A breakdown of the proportions of removal is discussed later.

EFFECTS UPON INTERCEPTOR SYSTEM

During all phases of this pilot program and investigation, a surveillance of the interceptor system was kept to determine if any adverse effects were occurring. Prior, during and subsequent to the Racine-clamshell operations, inspections were made of the discharge chamber at the pumping station and the interceptor downstream for approximately 1.5 miles. These inspections revealed that there were no noticeable effects upon the interceptor; however, the discharge chamber did receive some deposits of dredged material. These deposits were found to be a result of the conduct of the dredging and of flow characteristics in the discharge chamber.

The clamshell operations produced large masses of cohesive clays which were not broken up in the dredging work. The discharge chamber has locations where flow is quiescent and would arrest the movement of these masses. Inspections prior to the clamshell dredging revealed deposits of loose grit material. However, subsequent to the dredging, these same deposits were found to be enlarged by the addition of masses of clay. In subsequent suction dredging, the operation of the cutter head broke up all materials and eliminated this problem.

During the suction dredge operations, both at Racine Avenue and at the North Branch, surveillance was made of the interceptor system. The surveillance was in the form of a

INCLOSURE 2

check on water level surfaces in the system at certain strategic locations. These observations indicated that during the dredging, there was no noticeable increase in water levels and thus no noticeable effect on deposition in the interceptor system. Furthermore, the examination of water level recorder charts from two recorders located in the West Side Interceptor indicated there was no trend or any other evidence which would indicate that deposition was occurring. Physical examination of these interceptors is extremely difficult because water depths range from 3.5 to 6.0 feet under normal flow conditions.

Dredging via a suction dredge or introduction into the system of dredge spoil via a pumped liquid-solid slurry would have no adverse effects upon the interceptor system. Transportation of the material via the interceptor system is feasible as long as the material is similar in nature to that material which was dredged in these operations. Velocities in the interceptor rarely fell below 2.5 feet per second.

EFFECT UPON PLANT OPERATIONS

The pilot program dredgings did have a significant effect upon plant operations. Prior to the start of the dredging, the material to be dredged was thought of as the type which would be largely removed in the grit chambers. After the first week of dredging at Racine Avenue site, the Southwest Sewage Treatment Plant personnel discovered an unusually heavy loading on the primary and secondary processes. It was at this time that the true character of the dredged material became evident.

Figures 3 and 4 present laboratory results of analyses made of samples of the dredged spoil. A composite sample of the dredged spoil was collected for each day of operation. The composite sample was made of half-hourly grab samples collected at the point where the dredged spoil enters the Sanitary District manhole from the dredge pipeline.

It is shown that the solids concentration for the two sites is higher on the average at Racine Avenue than at North Branch. Furthermore, the volatile portion of the total solids is higher in the material from the North Branch than that from the South Fork at Racine Avenue. This is probably due to the relative age of the dredged material. At Racine Avenue, the solids have accumulated to a greater depth over the years and the underlying material is of greater age. In contrast, on the North Branch the material is more in a flowing stream and large deposits are not allowed to accumulate.

The larger amount of volatile material would contribute to greater biological activity. This would cause an additional load on the treatment process as the biological activity must be reduced as well as the solids removed.

Figure 5 presents contrasting results of settleability tests made on samples taken from the same location. Prior to the conduct of the dredging in September, 1968, the consensus was that the material was largely of the grit type. This was in part due to the results of analysis of samples taken in November, 1967. The settleability tests made on a sample taken in July, 1968 present results which are quite the opposite. This sample was taken from the material as it was being dredged via the clamshell operation at Racine Ave.

Treatment plant operations indicated that very small amounts of this material were being deposited in the grit chambers and most was being handled in the primary and secondary phases of the plant process. A disposition of these solids was made to determine the relative proportions handled in the primary and secondary phases. It must be understood that this analysis is subject to some inaccuracies because of the complexity of the treatment process and the occurrence of rainfall during the conduct of the dredging operations. The information presented is based on the best available plant operating data and judgments of experienced treatment plant operating personnel.

During the suction dredge operations at Racine Avenue, an estimated total of 3070 tons of dry solids were introduced into the system and the treatment plant since no deposition in the interceptor was evident. On this total, thirty-five tons were handled in the grit chambers. This figure can be considered negligible since normal variations in plant operations could easily account for it.

The primary plant handled approximately 1700 tons or 55% and the secondary plant approximately 1370 tons or 45%. At our disposal costs, handling these solids would amount to $147,000 or $47.90 per ton of dry solids, or $21.70 per cubic yard of material as dredged.

During the dredging operations at the North Branch, an estimated total of 604 tons of dry solids were handled. Again, no deposition in the interceptor was evident, and we must assume this amount of material reached the treatment plant. There was no increase in production in grit material at the West Side Sewage Treatment Plant during this period.

The imhoff tanks at the West Side Sewage Treatment Plant handled approximately 351 tons or 58%, and the secondary plant at Southwest Plant handled approximately 253 tons or 42%. At our disposal costs, handling these solids would amount to $22,100 or $36.60 per ton of dry solids, or $8.90 per cubic yard of material as dredged.

The different unit costs on a dry-solids basis are due to the different disposition of solids within the plant. The different unit costs of the material as dredged also reflect the variation in solids concentration at the two dredging sites.

Disposal costs for primary solids are lower at the West Side imhoff plant as opposed to the Southwest primary plant. Imhoff solids are disposed of by sand drying beds and then dumping in a land fill, whereas the Southwest primary solids are handled in the Wet Air Oxidation process, a rather complex mechanical operation.

Disposal costs for secondary solids are similarly high since either digestion and land disposal or heat drying are employed. The solids from heat drying are sold at a large financial loss, as commercial fertilizer. The costs for these processes are summarized below:

PROCESS	COST
Imhoff, Drying Beds, Dump	$30 Per Ton
Wet Air Oxidation	$50 " "
Heat Drying	$48 " " Net
Digestion, Land Disposal	$35 " "

For comparison, grit solids are dewatered and dumped in a landfill at about $3.00 per ton.

Pilot program dredging at both sites resulted in a very similar disposition of solids within the whole treatment process. It can be assumed the dredging of this type of material would result in a disposition of 50% to 60% in the primary and 50% to 40% in the secondary. The one large cost variable is whether the dredge spoil receives primary treatment in the West Side or Southwest Plants. This variable is reflected in the unit figures given for the pilot program results.

COSTS AND CAPACITY FOR LARGE AMOUNTS OF SPOIL

An analysis of treatment plant records reveals that a combination of some rains and the Racine Avenue dredging contributed to high solids loading subsequent to September 21. These conditions would have resulted in a curtailment of the dredging operations had there been at that time more information as to how this dredging was affecting treatment plant operations. This information and this condition is typical of how the acceptance of dredge spoil would be handled in the event the Sanitary District were to process large amounts of this material on a production basis.

Solids loading and the quality of effluent being discharged into the canal system would be the prime factors in allowing receipt of this material. Because of the dependence of these factors upon weather and equipment availability within the treatment plant, it is apparent that we cannot allow the processing of dredged spoil on a continuous basis. It must be taken when conditions will allow and at other time be stored or otherwise withheld from our system.

When solids disposal equipment is at full capacity, there is the ability to dispose of 1100 tons of solids per day. Comparing this to an annual average of 800 to 850 tons of sewage solids removed and disposed of, there is an apparent excess of 250 to 300 tons per day of capacity. In reality, this excess is not available because of the erratic nature of the incoming solids loading and the need of equipment outage for normal or emergency maintenance.

Very infrequently, there is a period when there is an excess of solids disposal capacity. As a result, our plant is incapable of being committed to handling an extra load of solids. Periodically, some additional load could be accommodated. For this reason, the Sanitary District could engage in small maintenance dredging projects similar in volume to those of the pilot program.

During the pilot program, a total of approximately 3670 tons of solids were delivered to the plant within sixteen days. High solids content continued within the plant for at least two weeks subsequent to the end of the dredging. The plant is still recovering from this high input.

Based upon costs given above for the processing of the pilot program material from the North Branch, an estimate can be made of the cost of handling the estimated 120,000 cubic yards of material which the Corps of Engineers will remove as part of their maintenance dredging in the North Branch. These estimates assume that all deposits are similar to those already encountered. The estimated cost of handling this material for solids disposal alone is $1,100,000. Since it would take longer than one year to process this material, it would not be economical to engage dredge equipment for this period of time. Some form of temporary storage would be necessary to hold the material until the plant can handle it.

ACKNOWLEDGEMENT

This report is the result of many persons of the two agencies working closely together.

On behalf of the Corps of Engineers, Lieutenant Colonel Robert M. Peach, Deputy District Engineer for Civil Works, has served as overall program director; Mr. L. S. Kreger, Chief of the Operations Division, has directed the execution of the dredging work; and Mr. Fred Sullivan has served as technical liaison.

On behalf of the Sanitary District, the work of the program has been carried out within the Department of Maintenance and Operation, Mr. Ben Sosewitz, Acting Chief. The technical direction and preparation of report have been carried out by Mr. Richard Lanyon, Engineer of Waterways Control. Valuable assistance has been received from Mr. Bart Lynam, Assistant Chief Engineer; Mr. Leo R. Peller, Engineer of Treatment Plant Operations II; and Mr. Samuel Lokatz, Engineer of Treatment Plant Operations I. The laboratory analyses have been made by the Department of Research and Development.

TABLE I

THE METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO

Department of Maintenance and Operation

CONDUCT OF DREDGING OPERATIONS AND SOLIDS HANDLED

Date	Volume Removed (Cubic Yards)	Total Solids (% Per Day)	Solids Proportion (Per Cent)	Hours of Operation
SOUTH FORK OF SOUTH BRANCH OF CHICAGO RIVER				
9/17	648	3.64	159	8 AM - 4 PM
9/18	518	1.85	66	8 AM - 9 AM 9:30 AM-3PM
9/19	740	6.01	216	8 AM - 2:30PM
9/20	777	2.31	102	8 AM - 4 PM
9/21	770	7.21	320	8 AM - 4 PM
9/22	-	-	-	-
9/23	740	5.37	236	8 AM - 4 PM
9/24	900	11.03	720	8:30AM-9:45AM 1:30-Midnight
9/25	845	3.48	305	8AM-Midnight
9/26	850	3.34	294	Midnight-4PM
TOTAL	6,788	4.93 (Average)	3,066	
TURNING BASIN AT NORTH AVENUE - NORTH BRANCH OF CHICAGO RIVER				
9/30	555	2.30	93.2	8 AM - 4 PM
10/1	1,000	3.09	250.0	8AM-Midnight
10/2	935	3.22	261.0	Midnight-4PM
TOTAL	2,490	2.88 (Average)	604.2	

Volume removed determined from soundings made by Corps of Engineers.

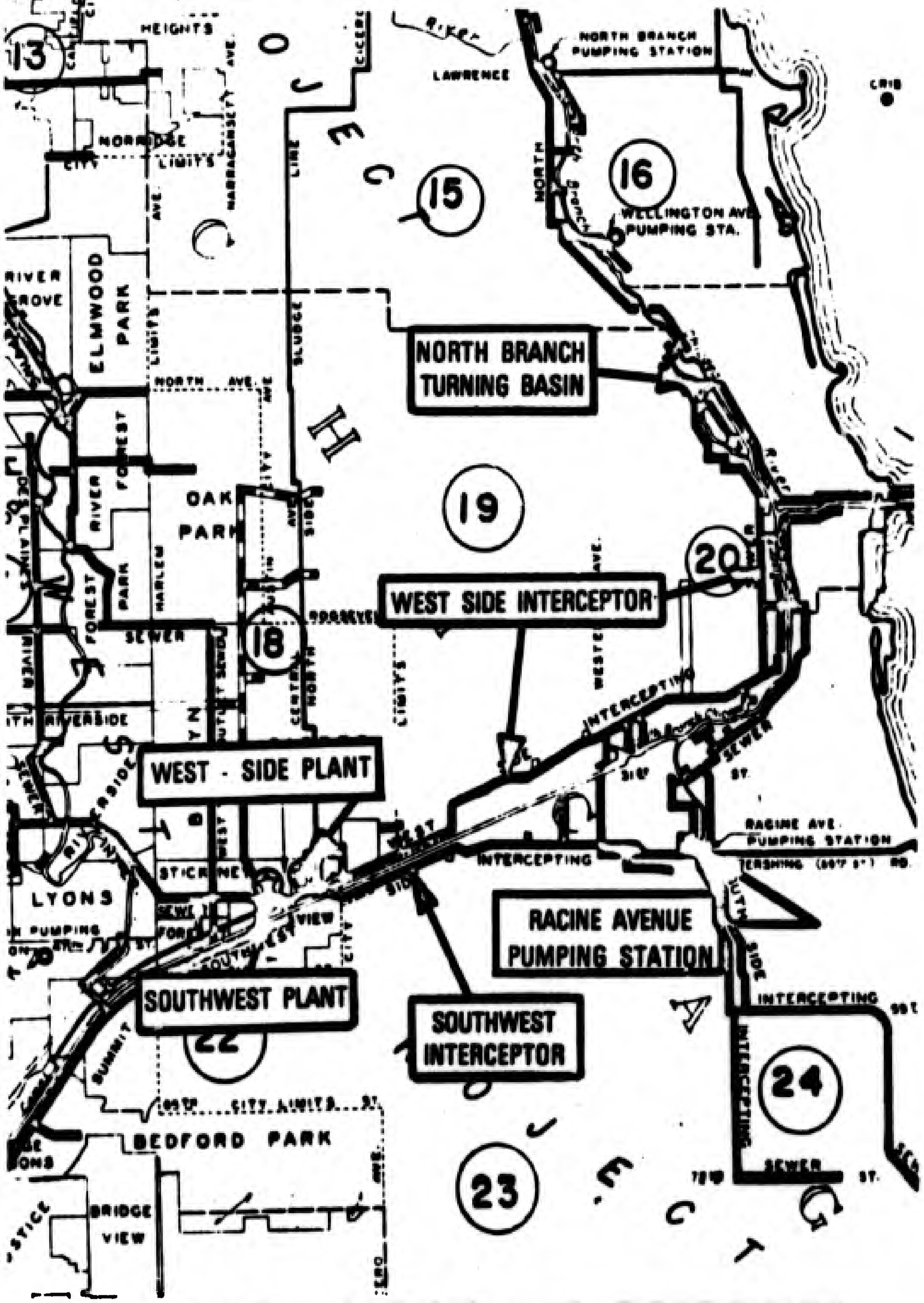
Solids processed determined from pumping rate and solids proportion.

Pumping rate determined as 4.9 cubic feet per second for Racine Avenue site and 4.5 cubic feet per second for North Branch site.

INCLOSURE 2

FIGURE 1

DREDGING AREAS & DISTANCES TO S. W. TREATMENT PLANT



6 MILES - RACINE AVE. DREDGINGS

11 MILES - TURNING BASIN DREDGINGS

INCLOSURE 2

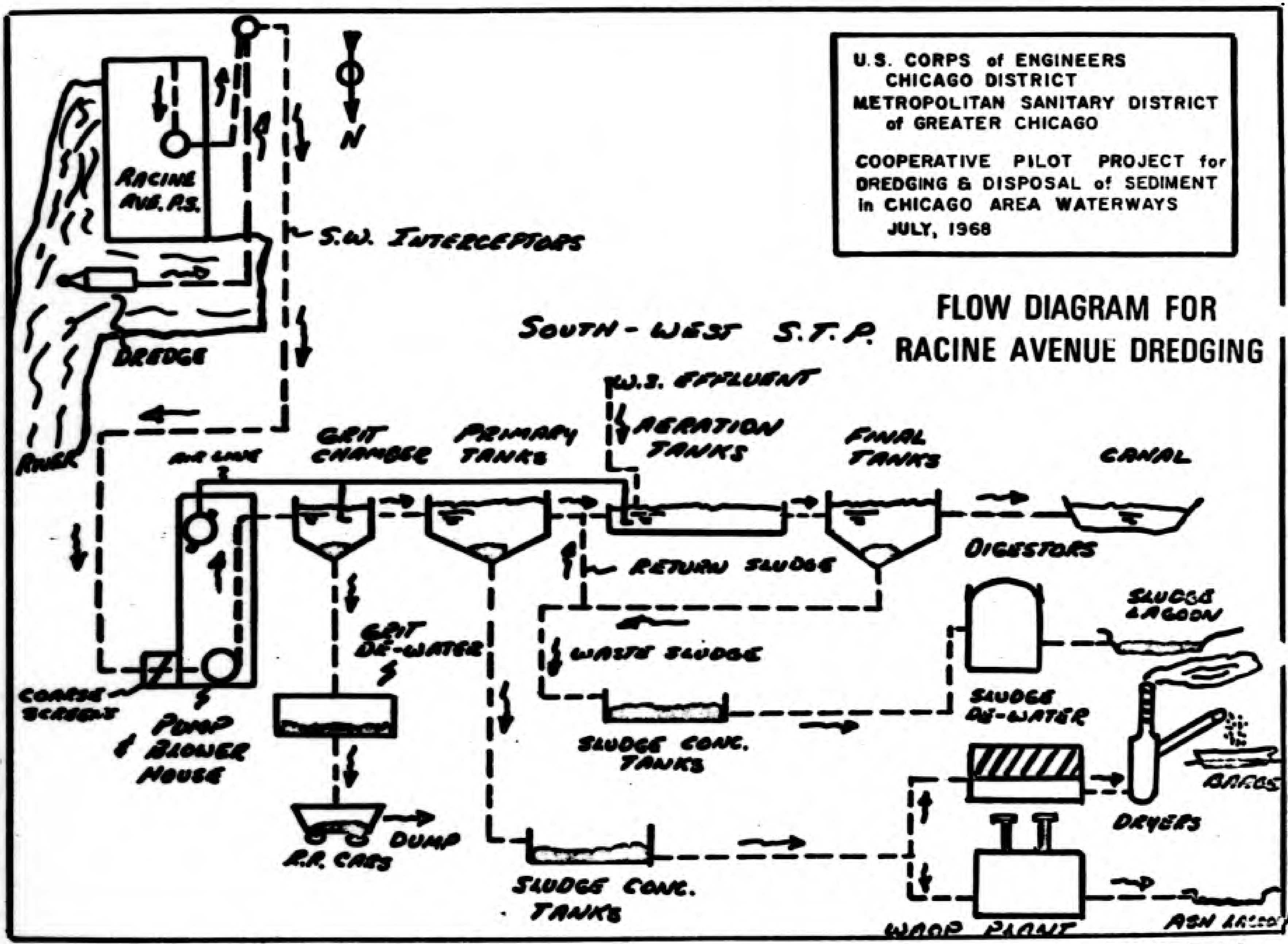


FIGURE 2A

INCLOSURE 2

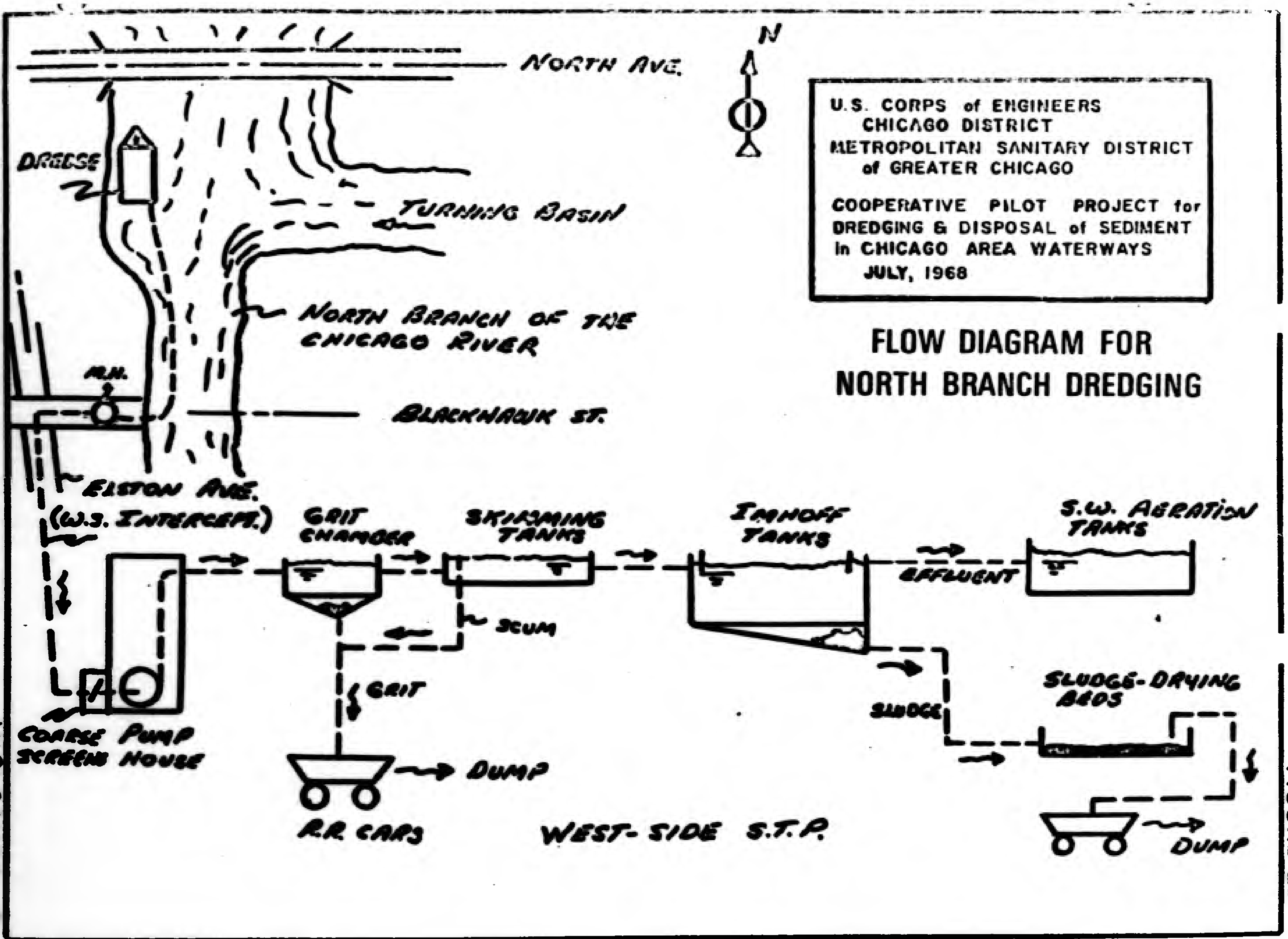


FIGURE 2B

INCLOSURE 2

FIGURE 2B

FIGURE 3

THE
METROPOLITAN SANITARY DISTRICT
OF GREATER CHICAGO
100 EAST ERIE ST., CHICAGO, ILLINOIS 60611 . . SUPERIOR 7-6500

Research & Development Laboratories
5901 West Pershing Road, Cicero, Illinois 60650

October 8, 1968

Project: Bubbly Creek Dredging
Sample Date: September 17 - 26, 1968
Type of Sample: Daily Composite of Dredging Material

PERCENT

DATE	TOTAL SOLIDS	VOLATILE TOTAL SOLIDS	GREASE*
9/17/68	3.64	37.94	5.85
9/18/68	1.85	35.25	3.04
9/19/68	6.01	31.99	4.13
9/20/68	2.31	36.12	4.66
9/21/68	7.21	21.89	1.94
9/23/68	5.37	32.98	4.82
9/24/68 -16 Hrs	11.03	18.64	5.90
9/25/68 -16 "	3.48	21.94	3.60
9/26/68	3.34	31.01	2.78
AVERAGES:	4.92	29.75	4.08

*Hexane soluble on dry basis

H. J. Baumert

H. J. Baumert
Sanitary Chemist III

HJB/dd
cc: Messrs. G. A. Ettelt
B. Lanyon
F. P. Loftus

INCLOSURE 2

FIGURE 4

THE
METROPOLITAN SANITARY DISTRICT
OF GREATER CHICAGO
100 EAST ERIE ST., CHICAGO, ILLINOIS 60611, SUPERIOR 7-8900

Research & Development Laboratories
5901 West Pershing Road, Cicero, Illinois 60650

October 8, 1968

DREDGING PROJECT
NORTH BRANCH OF THE CHICAGO RIVER (ELSTON & BLACKHAWK,

Reference: U. S. Corps of Engineers (August 8, 1968)

PERCENT

DATE	TOTAL SOLIDS	VOLATILE OF TOTAL SOLIDS	GREASE*
9-30-68	2.30	36.80	2.76
10-1-68	3.09	42.72	2.49
10-2-68	3.22	43.34	2.54
AVERAGES:	2.87	40.95	2.60

*Hexane soluble of dry basis

Howard J. Baumert
Howard J. Baumert
Sanitary Chemist III

HJB/dd
cc: Messrs. G. A. Ettelt
R. Lanyon
F. P. Loftus

INCLOSURE 2

Chicago Program Office, FWPCA　　　　　　　　　　　　　Date: 5/14/68

CHICAGO RIVER - BOTTOM SEDIMENTS
April 26, 1968
Results expressed in mg/kg - Dry basis*

Type of Sample	Bottom Sediments				
CPO No.	1600	1601	1602	1603	1604
Station (maps attached)	68-1	68-4	68-7	68-9	68-12
% Total Solids (of Sample)*	30.1	30.7	**(1) 34.6	**(2) 22.7	29.1
% Volatile Solids (of total solids)*	6.1	6.2	7.5	7.0	7.9
COD	269,000	296,000	378,000	616,000	559,000
BOD	12,000	11,700	11,100	> 18,000	> 14,000
pH*	6.90	6.95	7.10	7.20	6.95
Oil and Grease	7,100	31,372	35,547	68,948	52,821

* Solids results are based on wet sample and pH as explained below:

** 20 May 1968 - Specific gravity determinations of above samples (1) and (2) made by FWPCA on 20 May 1968 at request of Chicago District.

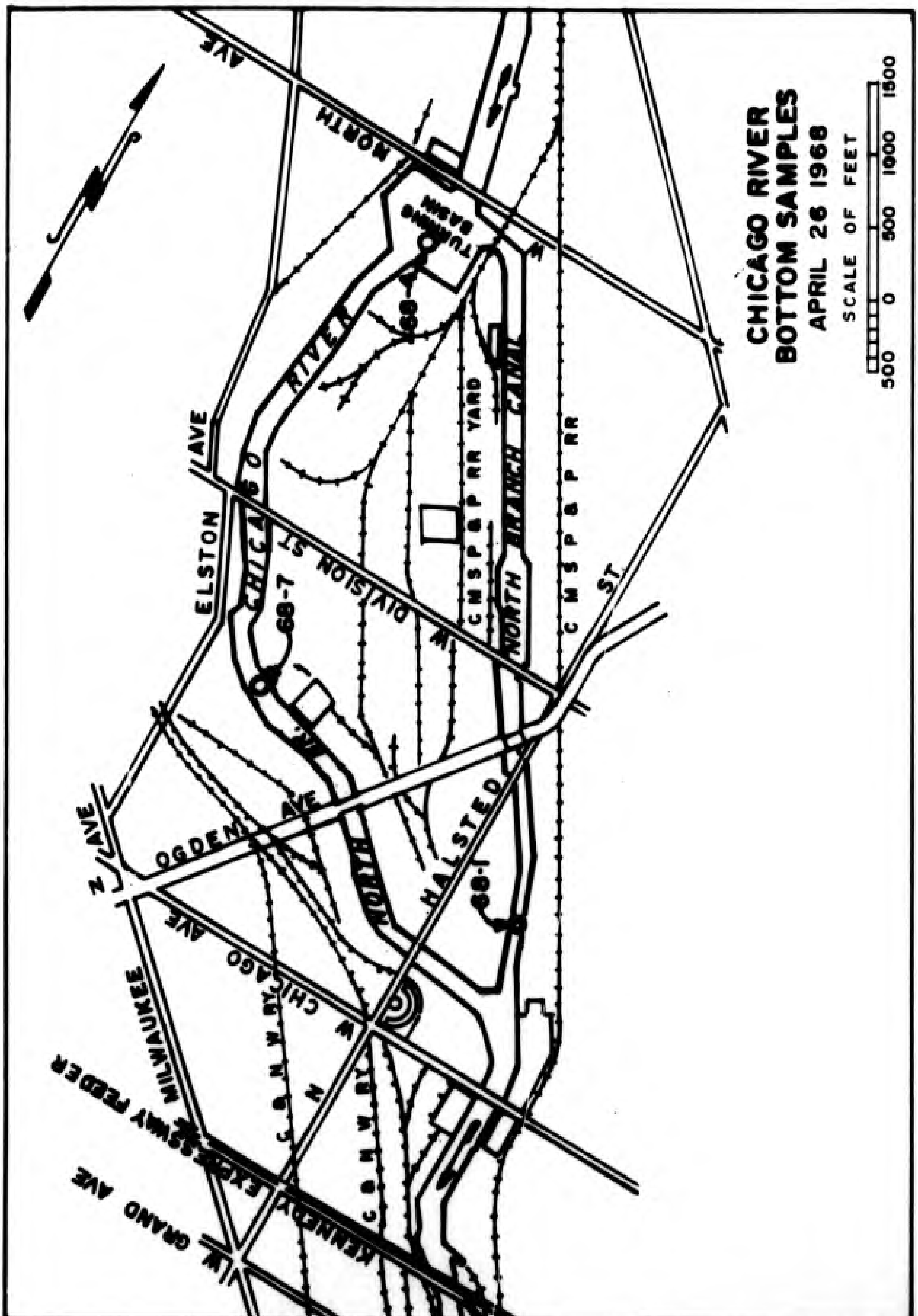
(1) Sp. gr. 1.2107　　　(2) Sp. gr. 1.1397

DISCUSSION

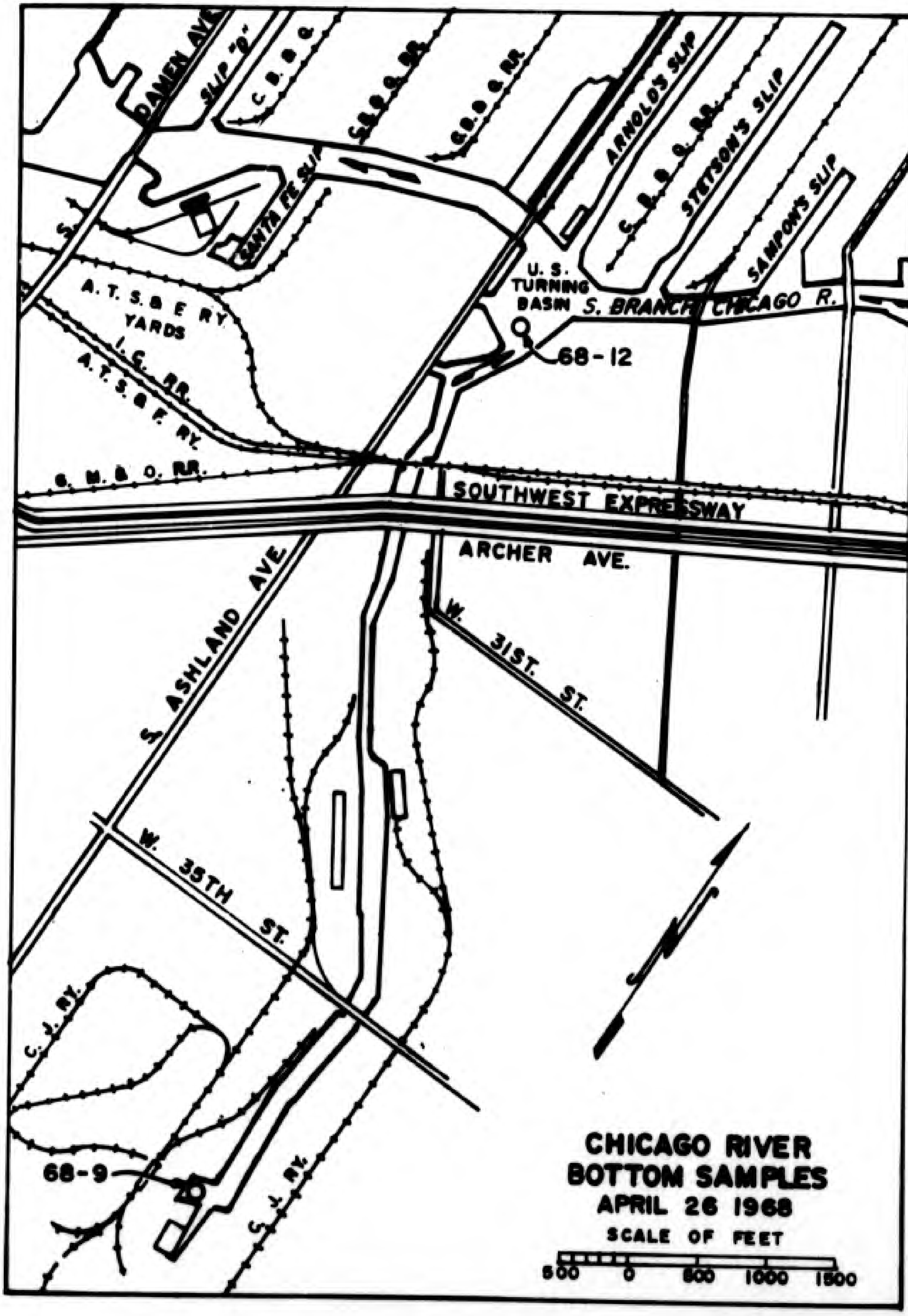
BOD's were tested by weighing designated amounts in BOD bottles, filling dilution water, shaking the mixture, and allowing to stand for 5 days.

The actual BOD values for Stations 68-9 and 68-12 are greater than the amounts listed in the above table since all oxygen was depleted before five days.

pH's were determined as on Page 46 (3-25) of "Soil Chemical Analysis" by Jackson. Twenty ml distilled water were added to a 20 gm sample and the mixture was stirred periodically for an hour; then pH was measured.


CHICAGO RIVER
BOTTOM SAMPLES
APRIL 26 1968
SCALE OF FEET
500 0 500 1000 1500
NORTH AVE
ELSTON AVE
W DIVISION ST
CHICAGO RIVER
NORTH BRANCH CANAL
TURNING BASIN
CMSP&P RR YARD
CMSP&P RR
68-7
68-1
HALSTED ST
OGDEN AVE
MILWAUKEE AVE
W CHICAGO AVE
C&NW RY
KENNEDY EXPRESSWAY FEEDER
W GRAND AVE
NORTH BRANCH

INCLOSURE 3


DAMEN AVE
SLIP "D"
C. B. & Q.
C.B.& Q. RR.
C.B.& Q. RR.
ARNOLD'S SLIP
C. B. & Q. RR.
STETSON'S SLIP
SAMPON'S SLIP
SANTA FE SLIP
U. S. TURNING BASIN
S. BRANCH CHICAGO R.
68-12
A. T. S. & F. RY. YARDS
I.C. RR.
A. T. S. & F. RY.
G. M. & O. RR.
SOUTHWEST EXPRESSWAY
ARCHER AVE.
S. ASHLAND AVE.
W. 31ST. ST.
W. 35TH ST.
C. J. RY.
C. J. RY.
68-9
CHICAGO RIVER
BOTTOM SAMPLES
APRIL 26 1968
SCALE OF FEET
500 0 500 1000 1500

INCLOSURE 3

December 1968

SUPPLEMENTAL STUDY BY CHICAGO DISTRICT IN CONNECTION WITH METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO REPORT DATED OCTOBER 1968, TITLED, "COOPERATIVE PILOT PROGRAM TO DETERMINE FEASIBILITY OF DISPOSING OF DREDGED SPOIL FROM WATERWAYS IN THE SANITARY DISTRICT INTERCEPTOR-SEWAGE TREATMENT PLANT"

1. With respect to Table I of the Sanitary District's report the following additions and/or corrections should be made:

a. The column heading "Solids Proportion (Per Cent)" should be changed to "Solids Portion-Tons."

b. The column heading "Hours of Operation" should read "Periods of Operation" as the time periods given in the column indicate the actual period of time the dredge was in operation and dredging into the interceptors.

c. An additional column "Actual Hours of Dredging" should be added.

d. The total in the fourth column for the South Fork is in error and should be changed from 3,066 to 2,418.

e. Information as to the average cubic yards dredged per hour should be added. This can be obtained by dividing the totals in the second column by the totals of the actual hours dredged (see subparagraph c above).

f. It would be useful to include information as to pumping rates in gpm as well as in cfs.

2. Exhibit A is a revised Table I incorporating the additions and/or corrections mentioned in paragraph 1 above.

3. The error mentioned in paragraph 1d above would require the following changes in the Sanitary District report.

a. In first line on page 4 change 3070 tons to 2418 tons.

b. In second line from bottom on page 9 change 3070 tons to 2418 tons.

c. The second paragraph on page 10 would read:

"The primary plant handled approximately 1050 tons or 43% and the secondary plant handled approximately 1370 tons or 57%. At our disposal costs, handling these solids would amount to $114,500 or $47.30 per ton of dry solids, or $16.90 per cubic yard of material as dredged."

The tonnages, percentages, and costs in the above quoted paragraph were furnished by the Sanitary District after it was informed that the 3066 tons in Table I was in error.

d. In the third paragraph on page 13, first line, change 3670 tons to 3022 tons.

4. It appears that in determining the tons of dry weight material handled in its system the Sanitary District applied the percentage of solids in the dredged material (combined liquids and solids) without considering the differences in densities. Apparently a density of 1.0 was taken for both the solids and liquid. In connection therewith the Sanitary District determined that on the North Branch the 2490 cubic yards of dredged material resulted in 604 tons of dry weight solids based on a dredge pumping rate of 4.5 c.f.s. and a 2.98 percent solids content. This equals approximately 485 lbs. of dry solids per cubic yard of dredged material or 4.12 cubic yards of dredged material is equal to about one ton of dry solids. However, using the results of FWPCA analyses of bottom material in the North Branch (see Inclosure 3), which indicated a 34.6 percent solids content and a specific gravity of 1.21 for the solids, (sample at station 68-7), a cubic yard of the river material prior to dredging would contain about 705 pounds of solids (dry weight or about 2.84 cubic yards of the material in the river would contain one ton of dry solids.).

5. The Sanitary District's report indicates that the introduction of dredged materials into its interceptor-sewage treatment plant system during the tests had a marked effect on the operation of the treatment plants but no apparent effect on the interceptors. On the South Fork, the hydraulic dredge discharged into interceptor at a rate of about 2200 gpm which is an equivalent rate of about 3.14 MGD. The discharge into the interceptor had about a 5 percent solids content (50,000 mg/kg). At the same time the pumps at the Racine Avenue Pumping Station were discharging sewage flow into the interceptor containing about 0.025 percent suspended solids (250 mg/l) at a rate of about 260 MGD. Although the pumps discharging sewage flow into the interceptor operated for only about 12 to 14 hours per day, and the discharge of dredged material into the interceptor was only for a limited period, the additional sewage flow entering the interceptor between the pumping station and the treatment plant resulted in a total flow at the Southwest Plant equal to about 300 million gallons in a 24-hour period. Thus, the flow in the interceptor attributable to the dredging operation was somewhat insignificant compared to raw sewage or sanitary flow.

6. On the North Branch where possible full-scale dredging operations might be feasible, the hydraulic dredge discharged into the interceptor at a rate of about 2,000 gpm which is equivalent to a daily rate of 2.86 MGD. Sewage or sanitary flow in the interceptor was estimated by the Sanitary District to be about 300 MGD. Additional sewage or sanitary flows discharging into the interceptor upstream of the West Side Sewage Treatment Plant resulted in a total flow in the interceptor at the plant of about 500 MGD. Thus, the flow in the interceptor attributable to dredging operation was almost negligible when compared to the sewage or sanitary flow.

7. The 300 MGD flow in the interceptor to the Southwest Side Treatment Plant plus the 500 MGD flow in the interceptor to the West Side Treatment Plant might reach peaks of one billion gallons per day which could provide a more favorable dilution factor. However, the total solids loading in the flow through the interceptors, while not adversely affecting the interceptors themselves would be such as to prohibit any additional discharge into the system from dredging operations.

8. The following tabulation summarizes the flows in the interceptors, both those resulting from hydraulic dredging operations and the normal sewage or sanitary flows.

TABLE I

SOLIDS HANDLED BY INTERCEPTORS
BEFORE AND DURING DREDGING OPERATIONS

2nd Test - South Fork - Racine Avenue Pumping Station

	Hydraulic Dredge Discharge Into Interceptor	Sanitary Flow in Interceptor
Pumping Rate	3.14 MGD	260 MGD
Suspended Solids	5%	0.0250%
Suspended Solids	50000 mg/kg	250 mg/l
Dry Solids handled per day at these rates	1,310,000 lbs.	542,000 lbs.

3rd Test - North Branch

	Hydraulic Dredge Discharge Into Interceptor	Sanitary Flow in Interceptor
Pumping Rate	2.86 MGD	300 MGD (estimated)
Suspended Solids	3%	0.0250%
Suspended Solids	30,000 mg/kg	250 mg/l
Dry Solids handled per day at these rates	715,500 lbs.	625,500 lbs.

INCLOSURE 4

Total Sewage Flow to West & Southwest Plants
Based on North Branch Operation

	Hydraulic Dredge Discharge Into Interceptor	Sanitary Flow in Interceptor
Flow Rate	2.86 MGD	800 MGD
Suspended Solids	3%	0.0250%
Suspended Solids	30,000 mg/kg	250 mg/l
Dry Solids handled per day at these rates	715,500 lbs.	1,668,000 lbs.

9. The quantities derived in the above tabulation were not based on the specific gravity of the solids in the dredged material as discussed in paragraph 4 above. It is to be noted that the computed 1,668,000 lbs. of dry solids to be carried in the interceptors to both the Southwest and West Side Sewage Treatment Plants corresponds closely with the 800 to 850 tons of dry solids given on page 13 of the Sanitary District's report as the annual average tons of solids removed at the two plants. As the maximum capacity for the two plants is about 1100 tons of solids removal per day, it is apparent that this capacity could be reached when the sanitary flow in the sewers approached 1,000 mgd, at which time there would not be plant capacity available to handle the solids from dredging operations.

10. It is also to be noted from the computed quantities given in the tabulation in paragraph 8 that:

a. The suspended solids in the sanitary flow in the interceptor at the Racine Avenue Pumping Station wereequal to about 250 mg/l which is equivalent to 542,000 lbs of dry solids based on a sanitary flow of 260 MGD. The dredged material introduced into the interceptor had suspended solids load equal to about 50,000 mg/kg which is equivalent to 1,310,000 lbs of dry solids based on dredged material flow of 3.14 MGD into the interceptor. Thus, the introduction of dredged material into the interceptor would increase the total solids in the flow in the interceptor from 542,000 lbs of sewage solids per day to a total of 1,842,000 lbs of combined sewage and dredging solids per day, although the rate of flow in the interceptor would be increased by only 3.14 MGD, i.e. from 260 MGD to 263.14 MGD per day. The concentration of solids would be increased from 250 mg/l of sewage solids to about 840 mg/l of combined sewage and dredging solids. Thus, it is apparent that introduction of dredged material, while causing only a negligible increase in the total flow in the interceptor, could more than triple the solids load carried in the interceptor. Although such increase in rate of solid load introduced into the system by dredging operations did not adversely affect the functioning of the interceptor, it did have a marked affect on the operation of the treatment plant.

INCLOSURE 4

b. The suspended solids in the sanitary flow in the interceptor near the North Branch of the Chicago River was equal to about 250 mg/l which is equivalent to some 625,500 lbs of dry solids based on a sanitary flow of about 300 MGD. The dredged material introduced into the interceptor had a suspended solids load of 30,000 mg/kg which is equivalent to 715,500 lbs of dry solids based on a dredged material flow of 2.86 MGD. Thus, the introduction of dredged material into the interceptor would increase the total solids in the flow in the interceptor from 625,500 lbs of sewage solids to a total of 1,341,000 lbs of combined sewage and dredging solids per day, although the rate of flow in the interceptor would be increased only 2.86 MGD i.e. from 300 MGD to 302.86 MGD. The concentration of solids would be increased from 250 mg/l of sewage solids to about 530 mg/l of combined sewage and dredging solids. Thus, it is apparent that while the introduction of dredged material results only in a very small increase in the total rate of flow in the interceptor, it could double the suspended solids load carried in the interceptor. While this did not have any apparent adverse effect on the functioning of the interceptor it did have a marked effect on the operation of the treatment plants.

11. The estimated costs to the Sanitary District for handling the solids from dredging operations on the North Branch of the Chicago River are about $9.00 per cubic yard of material as dredged. The estimated cost of operating the hydraulic dredge used in the tests is approximately $700 per day for one 8-hour shift per day, six days a week. Normally, the dredge operates three shifts a day, six days a week and has an output of about 2000 cubic yards per day. Assuming that the maximum dredged yardage that the Sanitary District system could handle might average about 400 cubic yards of dredged material, and that this dredging could be accomplished in one shift, which is a very inefficient use of the dredge, the cost of dredging would then be about $1.75 per cubic yard. Then, adding thereto the cost of about $9.00 per cubic yard for the handling of the dredged material in the Sanitary District system, the total cost per cubic yard approaches $11.00. This is based on the Sanitary District being able to handle 400 cubic yards per day every day. This is considered optimistic and there may be days when no dredged material can be introduced into the Sanitary District system. Under such conditions the total cost per cubic yard would be more than $11.00 per cubic yard. In view thereof, together with the fact that the dredging period would be exceptionably long, disposal of dredged material in the Sanitary District interceptor-sewage treatment plant system, while feasible, is considered to be uneconomical.

Revised Dec. 68

TABLE I

THE METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO

Department of Maintenance and Operation

CONDUCT OF DREDGING OPERATIONS AND SOLIDS HANDLED

SOUTH FORK OF SOUTH BRANCH OF CHICAGO RIVER

Date	Volume Removed (Cubic Yards)	Total Solids (% Per Day)	Solids Portion-Tons	Period of Operation	Actual Hrs. of Dredging
9/17	648	3.64	159	8 AM - 4 PM	6.75
9/18	518	1.85	66	(8 AM - 9 AM 9:30 AM-3 PM)	4.25
9/19	740	6.01	216	8 AM -2:30 PM	5.92
9/20	777	2.31	102	8 AM - 4 PM	7.25
9/21	770	7.21	320	8 AM - 4 PM	7.17
9/22	-	-	-	-	-
9/23	740	5.37	236	8 AM - 4 PM	7.25
9/24	900	11.03	720	(8:30AM-9:45AM 1:30-Midnight)	10.25
9/25	845	3.48	305	8AM - Midnight	13.50
9/26	850	3.34	294	Midnight-4 PM	7.08
TOTAL	6,783	4.96-Weighted Average Based on Original Period of Operation.	2,418	TOTAL	69.42

Average Cubic Yards Dredged per hour - 98

TURNING BASIN AT NORTH AVENUE - NORTH BRANCH OF CHICAGO RIVER

Date	Volume Removed (Cubic Yards)	Total Solids (% Per Day)	Solids Portion-Tons	Period of Operation	Actual Hrs. of Dredging
9/30	555	2.30	93.2	8 AM - 4 PM	5.92
10/1	1,000	3.09	250.0	8AM-Midnight	11.83
10/2	935	3.22	261.0	Midnight-4 PM	14.50
TOTAL	2,490	2.98-Weighted Average Based on Original Period of Operation.	604.2	TOTAL	32.33

Average Cubic Yards Dredged per hour - 77

Volume removed determined from soundings made by Corps of Engineers. Solids processed determined from pumping rate and solids portion. Pumping rate determined as 4.9 cubic feet per second for Racine Avenue site and 4.5 cubic feet per second for North Branch site.

Fluorescent dye used to determine pumping rate in the 8" pipe.

4.9 CFS = say 2200 gpm

4.5 CFS = say 2000 gpm

Exhibit A

INCLOSURE 4

APPENDIX C8

WRC SPECIAL REPORT NO. 2

FEASIBILITY OF EVALUATION OF BENEFITS FROM IMPROVED GREAT LAKES WATER QUALITY

Dr. Ben B. Ewing, Director
Dr. J. H. Austin
Dr. R. I. Dick
Dr. R. S. Malpass
Dr. D. D. Meredith
Dr. H. O. Nourse
Dr. E. B. Small
Dr. E. H. Storey
Mr. R. Aukerman
Mr. W. B. Betchart
Mr. A. R. Caskey
Mr. V. Kothandaraman
Mr. R. A. Lazarski

This report was prepared for the U.S. Army Corps of Engineers under Contract No. DACW23-68-C-0037.

Water Resources Center
University of Illinois
3220 Civil Engineering Building
Urbana, Illinois 61801

May 1968

SUMMARY

The objective of this study has been to determine the feasibility of evaluating the economic benefits which might accrue from improvement of Great Lakes water quality if dredged material were not disposed of in the open waters of the lakes. The assumption was made that the effect of changes in spoil disposal on the quality of water at points of use some distance from the disposal site could be estimated. Our purpose has been to develop a methodology for placing monetary values on these improvements. This information would be needed in a benefit-cost analysis of alternate dredging operations.

We have used the same basic approach for analysis of each beneficial water use, which involves following a change in water quality through a sequence of interrelationships to arrive at an estimate of the annual benefits. We have then developed a different proposed methodology for each of the important beneficial uses of the water resource in order to accommodate the specific technological, economic, social and aesthetic aspects of each use.

Assuming the water quality improvements can be identified, we have found that some of the benefits can be evaluated in monetary terms, if one is willing to accept some imprecise estimates. Other benefits cannot be estimated with any useful precision at this time because the interrelationships involved are not understood well enough.

TABLE OF CONTENTS

INTRODUCTION

Objective

The purpose of this study is to determine the feasibility of evaluating the economic benefits which might accrue from improvements in the quality of water in the Great Lakes. The motivation for the evaluation of benefits in this case stems from the desirability of a benefit-cost analysis of alternate dredging operations by the U.S. Army Corps of Engineers. Nevertheless, the methodologies developed herein should be applicable to water quality improvements resulting from other pollution abatement practices as well.

Background

The Corps of Engineers is charged with responsibility for maintaining the navigability of the Nation's harbors and inland waterways. Dredging is required for the construction and for the maintenance of harbors and channels. There are now 108 channel and harbor projects on the Great Lakes which the Corps of Engineers maintains. About 50 of these require dredging annually and most of the rest require dredging every few years. Approximately 10,000,000 cubic yards of material are removed from these harbors and channels in the Great Lakes annually. Usual practice has been to barge these materials out to designated disposal areas off-shore, selected to minimize effects on beaches and water intakes.

Predominantly the material which must be removed from river-mouth harbors is sediment carried by the flooded streams or littoral drift of sand along the shore. In some cases, however, the waters of the rivers and harbors have been polluted by sewage and industrial wastes. This is particularly true of the larger commercial harbors. The sediment which must be dredged to maintain the harbor is then polluted also. During the past three years the Corps of Engineers has been criticized for disposal of this polluted material in the open waters of the Great Lakes. Even though the dredging operation does not contribute polluting material, but simply moves it from one location to another, it is claimed that an additional area of pollution is created.

The Federal Water Pollution Control Administration of the Department of the Interior is responsible for pollution abatement enforcement and in connection with this activity has held conferences on the pollution of the Great Lakes. These conferences, particularly those concerned with pollution of the southern part of Lake Michigan, have attracted wide public attention. A pressing program for pollution abatement has been adopted which will require extensive expenditures by industries and municipalities. Executive Order No. 11288 issued by the President on 2 July 1966 directed the Heads of Federal Departments to provide leadership in the nationwide effort to improve water quality through prevention, control and abatement of water pollution from Federal Government activities.

Accordingly, the Corps of Engineers has been seeking alternatives to the disposal of dredged spoil in the open waters of the Great Lakes. Alternatives include disposal in diked areas along the shore, transport for inland disposal on land, and treatment to reduce objectionable effects of open water disposal.

The Chief of Engineers approved on February 3, 1967 establishment of a Pilot Project to develop the most economical methods for management of the pollution problem that may result from dredging operations on the Great Lakes. Under direction of the Buffalo District, alternative techniques for disposal of spoil are being studied at seven sites. The Lake Survey District and the FWPCA laboratories are participating in collection and analysis of samples. The Corps has engaged a Board of Consultants to advise and guide in the study. The objective of the project is to assess the effect of various alternatives on the quality of the water and shore and evaluate the economics of each alternative.

The accepted basis for economic evaluation of water resources projects, which has been used so extensively by the Corps of Engineers, is the benefit-cost ratio. Federal policy, as outlined in Senate Document 97, provides that water resources planning should be formulated to provide the maximum net benefit from each project provided the project has a benefit-cost ratio which exceeds unity. Benefit-cost analyses have not generally been attempted for water pollution abatement projects heretofore. The Bureau of the Budget has requested such an analysis to evaluate a request for appropriation of additional funds for the increased cost of dredging operations that might eliminate their alledged adverse effects on water quality.

The Corps of Engineers has the experience and the information to make estimates of the cost of various alternative dredging and spoil disposal techniques. The Corps is also evaluating the benefits which might accrue from alternative methods of spoil disposal, including the value of made-land and the value of by-products which might be recoverable. The evaluation of benefits which accrue from improvements in water quality has not been accomplished before and it is not known whether the evaluation of such benefits is feasible. The objective of this study has been to determine the feasibility of evaluating the economic benefits which might accrue from water quality improvements associated with the dredging operation.

Benefit Evaluation

The study reported here is considered the first phase of a possible two-phase program to evaluate the economic benefits of water quality improvements. Phase I is the feasibility study while Phase II will be the definitive evaluation of economic benefits, if feasible. The goal of Phase I is to determine for each beneficial use of water whether the benefit resulting from an improvement in water quality can be evaluated in monetary terms; if so, how; and if not, why. A methodology could hopefully be developed which could be used at any given dredging site to determine the dollar-value of the benefit involved.

The plan was that the Feasibility Study should identify and designate an array of water quality parameters or constituents which are considered germane to each of the beneficial uses. A reasonable range of values which might conceivably result from various alternate methods of disposal would then be established. The feasibility of determining the monetary benefits which result from variations in these water quality parameters within the designated range would be studied and methods and procedures for determination of the benefits were to be developed where feasible.

It was considered that the most appropriate course of investigation for the feasibility study would be (1) to inventory the data pertaining to the problem available from various Federal, State and local agencies and private sources, (2) to review the literature pertaining to water resources benefit evaluation as a means of establishing the state-of-the-art, (3) to organize free discussion by a team of qualified experts in various pertinent disciplines in an effort to expose all the questions which must be answered in determining the benefits involved and (4) to work out methods for answering these questions. Within the limits of the time and staff available, this is what was done.

This study considered the benefits which result from changes in certain water quality parameters at points of use; i.e., water intakes, beaches, marinas, etc. We have not attempted to evaluate the changes in water quality which result from the various alternative methods of disposal; that is the responsibility of others associated with the Pilot Project. This feasibility study is based, therefore, on the assumption that the changes in water quality at points of use which result from changes in operations at the point of disposal can be predicted. It is clear that this assumption may not always be valid. Many of the changes may be so small or so uncertain that they cannot be distinguished from variations in water quality due to other factors.

It is important to recognize, therefore, that determination of the effect of changes in dredged spoil disposal practices upon quality of water at some distant point-of-use is a very important first-step in the economic benefit evaluation. This determination, and its limitations, may be the major determining factor in the feasibility of the economic benefit evaluation. Its not being considered in this report is due to the fact that it has been considered to be beyond the scope of the study, not because it is unimportant.

A second assumption, which simplifies in many ways the evaluation of benefits, is that the changes in water quality which result from new dredging practices will be small and will be by way of improvement. Hence, the conditions will not move so far from present conditions that certain values which are measured under present conditions cannot be applied also to the new slightly improved condition. For example, it is assumed that the raw water will not be improved so greatly that municipal water treatment plants will no longer require filtration.

Senate Document 97 proscribes the following standard for measurements of water quality control benefits:

> "The net contribution to public health, safety, economy, and effectiveness in use and enjoyment of water for all purposes which are subject to detriment or betterment by virtue of change in water quality. The net contribution may be evaluated in terms of avoidance of adverse effects which would accrue in the absence of water quality control, including such damages and restrictions as preclusion of economic activities, corrosion of fixed and floating plant, loss or downgrading of recreational opportunities, increased municipal and industrial water treatment costs, loss of industrial and agricultural production, impairment of health and welfare, damage to fish and wildlife, siltation, salinity intrusion, and degradation of the esthetics of enjoyment of unpolluted surface waters, or, conversely, in terms of the advantageous effects of water quality control with respect to such items. Effects such as these may be composited roughly into tangible and intangible categories, and used to evaluate water quality control activities. In situations where no adequate means can be devised to evaluate directly the economic effects of water quality improvement, the cost of achieving the same results by the most likely alternative may be used as an approximation of value."

The last statement offers an enticing alternative means of benefit evaluation. It would certainly be easier to estimate the cost of construction and operation of a municipal waste treatment plant which would substitute for modified dredging operations in bringing about the desired water quality improvements. This alternative was not selected for three reasons:

a. No alternative means of water quality control could possibly produce "the same results."

b. There is no assurance, if cost of an alternative were used as an estimate of benefits, that either of the two methods of improving water quality have benefits in excess of the costs. This would only indicate which method has the lesser cost.

c. An alternate method of preventing pollution by polluted dredged material is to prevent pollution of the harbor sediment in the first place. This is expected to occur due to more stringent enforcement of water pollution laws. Several years will be required to achieve this improvement, however. Because this alternative cannot be implemented immediately, it is not comparable.

Hence, the net contribution must be evaluated in terms of the advantageous effects of water quality improvements with respect to the various beneficial uses. The beneficial uses listed in Senate Document 97 include municipal and industrial water supply, irrigation, water quality control, navigation, electric power, flood control, land stabilization, drainage, recreation, and fish and wildlife. It is our considered opinion that the only benefits of significance which would accrue from water quality improvements associated with dredging would accrue to municipal and industrial water treatment plants, to recreation activities, to commercial fishing, and to esthetic enjoyment. The remaining activities are not likely to be affected perceptibly by any water quality improvements associated with dredging practices.

There are other economic factors which must be considered in the evaluation of benefits. The period of analysis is assumed to be 10 years. This period is the expected life of a diked landfill facility. It is also a period during which one might expect pollution abatement measures to improve the conditions in the polluted harbors sufficiently to obviate the necessity of more expensive disposal techniques. The practice of open-water dumping could be reinstituted as the benefits would have dwindled. At any rate, re-evaluation of the benefit-cost ratio at 10-year intervals is reasonable and prudent. Interest rate used for discounting future benefits should be based on average rate of interest payable by the Federal Government on recently issued securities, as proscribed by Senate Document No. 97. Price levels should reflect the exchange values expected to prevail at the time the benefits accrue.

Organization of Study

The feasibility study reported here is the product of the following staff members at the University of Illinois:

Project Director - Dr. Ben B. Ewing, Professor of Sanitary Engineering and Director, Water Resources Center

Biology - Dr. Eugene B. Small, Asst. Prof. of Zoology

Civil Engineering - Dr. John H. Austin, Assoc. Prof. of Sanitary Engineering

Dr. Richard I. Dick, Asst. Prof. of Sanitary Engineering

Dr. Dale D. Meredith, Instructor in Civil Engineering

Mr. Will B. Betchart, Research Assistant

Mr. V. Kothandaraman, Research Assistant

Economics - Dr. Hugh O. Nourse, Assoc. Prof. of Economics

Mr. Rich Lazarski, Research Assistant

Psychology - Dr. Roy S. Malpass, Asst. Prof. of Psychology

Recreation - Dr. E. H. Storey, Professor of Recreation

Mr. Robert Aukerman, Research Assistant

Mr. Al Caskey, Research Assistant

Secretary - Mrs. Cathryn Johnson

Mrs. Virginia Loftus

The project staff contributed in two ways. Each contributed within his own discipline on the literature review, in the regular discussion sessions and in the preparation of the report. In addition, each served as a critic of the others. Each of the fifteen discussion sessions was attended almost unanimously by the staff.

We would like to acknowledge the consultation and advice provided by the following individuals who were contacted in the course of the study:

Dr. A. M. Beeton, University of Wisconsin, Milwaukee

Mr. J. C. Vaughn, City of Chicago Water Department

Mr. H. L. Plowman, Gary-Hobart Water Corporation

Mr. F. A. Underwood, City of Milwaukee Water Department

Dr. David Chandler, University of Michigan, Ann Arbor

Mr. R. W. Saalfeld, Great Lakes Fishery Commission

This report is organized according to the various beneficial uses of water. Each section presents a short discussion of the effects of water quality on the subject benefit. This is followed by a methodology in outline form for the use of those who will apply the methodology to evaluation of this type benefit. The detailed discussion of the methodology follows immediately behind the outline, and the reader is cautioned that the detailed discussion is necessary to the understanding of the methodology.

SYSTEMS APPROACH

The many beneficial uses of water in the Great Lakes represent an extremely complex system. It is a system comprised of many different uses even in a single subregion of a given lake. It is a system which involves many different water quality characteristics with a multitude of influences on those characteristics. Furthermore many of the uses are affected by a number of extraneous influences not related to water quality. Economic evaluation of the benefits accruing from an improvement in water quality can only be determined by use of a systematic analysis.

Systems analysis is characterized by (1) being organized to take full advantage of a spectrum of resources, (2) being empirical to rely on extensive use of data, (3) being theoretical to make maximum use of theories of all relevant sciences, and (4) being systematic to efficiently deal with complex interrelationships. There are five steps to a systems analysis of a water-resource system. They are:

1. conceptually identify the system under examination, identifying and describing the boundaries of the system with as much detail as is available;

2. describe the elements of the system and delineate to the fullest extent possible their interrelationships and interactions;

3. define the system objectives and establish the criteria for optimum performance of the system in achieving the objectives;

4. develop alternative approaches for achieving system objectives and evaluate them in terms of criteria established in step 3; and

5. present the alternatives for achieving the system objectives to the decision makers who then select the best course of action.

One technique for evaluating an approach is to develop a mathematical model of the system identified in step 1 which incorporates the interrelationships and interactions of step 2 and the constraints imposed in step 3 and which can be solved to determine the results of the approach. In order to apply this technique, the interrelations and interactions for each water quality characteristic for each use must be determined for each area of each lake that is affected by dredging operations.

A mathematical model is presented in the appendix which can be solved to determine the benefits for a change in water quality when the level of water quality before and after improvement is known. Use of the model requires an understanding of the interrelationships and interactions of each water quality characteristic for each use in each area of each lake affected by dredging operations.

The model is applicable to all water uses. The methodologies presented in this report are intended to provide a means of obtaining the interrelationships and interactions necessary for applying the model to particular water uses. For instance, the relationship between chemical dose and raw water quality or the relationship between recreation use and water quality, or the relationship between the value of commercially valuable fish and the fish species population are examples of the interrelationships which the methodologies seek to define.

Block diagrams for the methodologies are presented in Figure 1. In each case the horizontal pathway represents the interrelationships which the methodology must define in order to evaluate the benefit of water quality improvements. Changes in water quality are reflected by a sequence of changes across this horizontal pathway. The external factors which are considered essentially independent of water quality changes are shown as vertical inputs. In the case of water supply and recreation, the methodology outlined in this report begins with water quality changes at point of use. In the case of commercial fishery, the methodology begins with fish species population. In the case of aesthetic benefits, the dotted lines represent that portion of the evaluation which is not feasible.

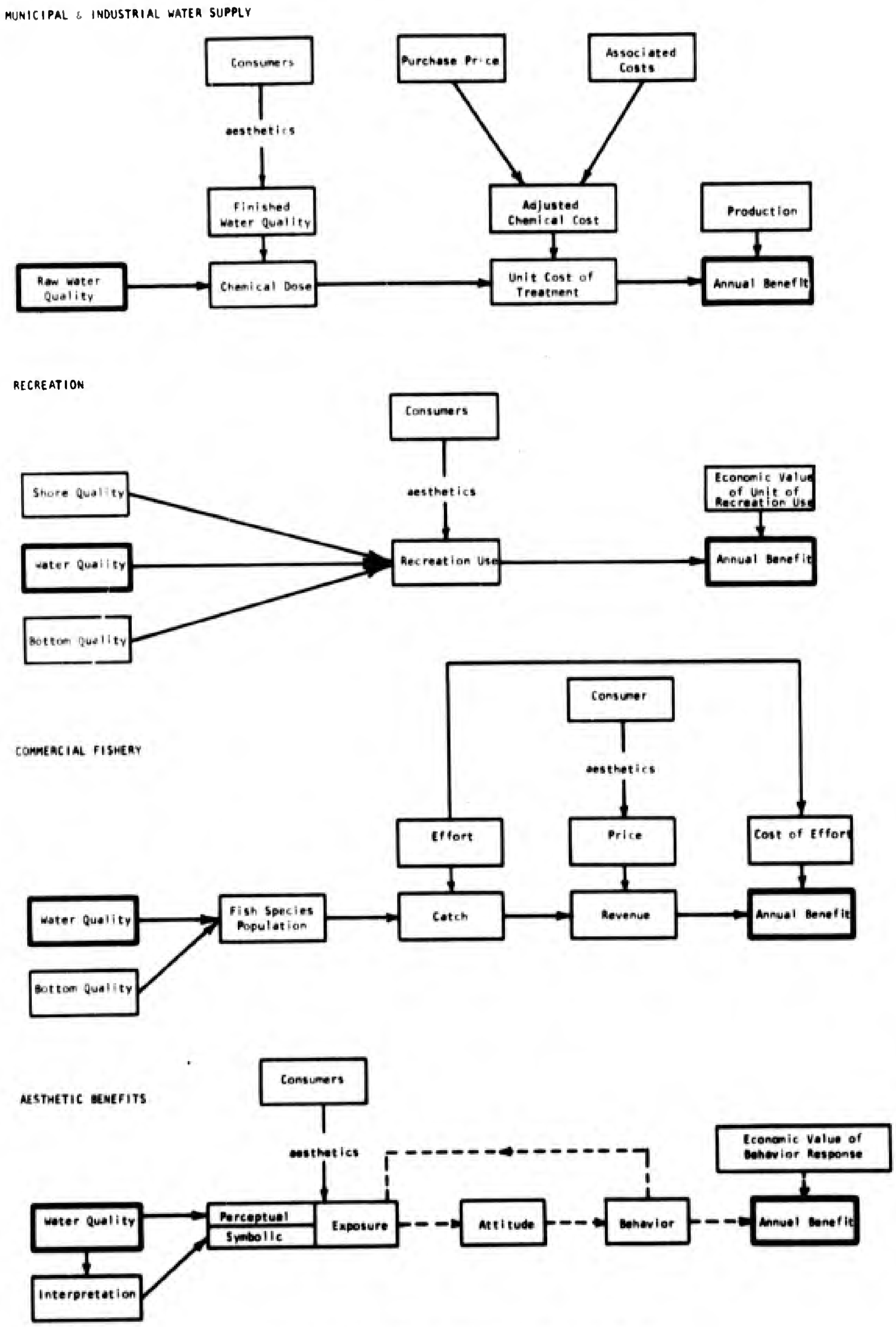


FIGURE 1. BLOCK DIAGRAM OF BENEFIT EVALUATION METHODOLOGIES

MUNICIPAL WATER SUPPLY

Effects of Quality

For many years the primary concern of municipal water supply systems was procuring and supplying sufficient quantities of water. In recent times, however, higher standards of living have led to greater concern for the quality of the water supplied. Although the early consideration for quality was primarily in regard to preventing the transmission of communicable diseases, technological improvements, continuing degradation of supplies, and society's growing affluence have led to present concern for virtually every physical, chemical, and biological aspect of the water supplied.

The quality of a finished municipal water can affect the benefit derived from its use in two ways. First, the amount of benefit to be derived from the use of water changes as water quality changes and second, the quantity of a water of different quality which is used is also different. If there were no expense involved in increasing the quality of the finished water, both the benefit of its use and the amount used would increase as the quality improved.

Unfortunately, however, expense is incurred in improving municipal finished water quality and the expense occurs in one of two ways; the use of treatment facilities to adjust the quality of water or steps taken to protect or improve the quality of the water supply source. Logically, the more a municipality relies on one of these means, the less money it needs to spend on the other.

Ideally man would be capable of rationally analyzing the effects and interrelationships of these four types of benefits and costs, but at the present time he has not succeeded. This section is concerned with the interrelationships of, or the trade-offs between, beneficial use and municipal water treatment costs on one hand and a particular type of source improvement on the other. The source improvement in question is the modification of disposal techniques in the Corps of Engineers' dredging operations. In this discussion it is assumed that small but significant improvements in the water quality at the treatment plant intake will prove to be detectable. The assumption is necessary since the Corps of Engineers has undertaken that part of the analysis. The objective is to arrive at a feasible methodology for accurately assessing the benefits which accrue from the plant intake on, that is the savings in treatment costs and the increased benefits to the users.

Methodology

A. Assume finished water quality is the same before and after improvement in the raw water quality.

B. Identify each municipal treatment plant which uses lake water from the affected area. Determine what treatment processes they use and what factors control the operation of those processes. Choose one of these plants for completion of the following steps.

C. Correlate doses of each chemical with changes in selected raw water quality variables in the plant being considered.

D. Assume capital costs are unaffected and that elements of the operating costs are fixed, that is, that changes in costs of treatment are completely reflected in chemical and associated costs. Determine the magnitude of the associated chemical costs in the plant being considered.

E. Determine the probability that each possible combination of unimproved values of the raw water quality variables used in the correlations with chemical doses will occur during the affected season of the year.

F. Determine the improvement which is predicted to be realized in each of the above water quality variables from a specific change in the dredging disposal practices.

G. Select one of the combinations of raw water quality variables from step E.

H. Determine the improved level of concentration of each of the raw water quality variables in the combination by subtracting its change as determined in step F from its original value.

I. For each chemical, determine the change in dose by taking the difference between the doses for the improved and unimproved raw water quality levels. Each of these doses should be determined from the correlations derived in step C.

J. Determine the benefits per unit volume of water treated for this selected raw water by multiplying the adjusted cost of the chemical per pound by the change in dose times the probability of occurrence and summing th.s product over all the chemicals.

K. Repeat steps G through J for each combination of unimproved values of raw water quality variables which has a finite probability of occurrence during the affected time period.

L. The total annual benefits at this plant are then equal to the volume of water treated during the affected time of the year times the sum of the benefits per unit volume for each of the probable combinations of raw water quality variables.

M. Repeat steps C through L for each plant in the affected area.

N. To determine the total annual benefits of this change in dredging practices in the affected area, sum the values of annual benefits found for each plant.

O. Repeat process for other changes in dredging disposal practices provided that the water quality improvements due to these changes in practice are known.

Discussion of Methodology

In studying benefits from increased raw water quality one must consider both the two means in which benefits from use of treated water occur and cost of treating the raw water. Techniques for the evaluation or prediction of the benefits of water use are lacking and the prospect for their development in the near future is dim. Man has, as an alternative, resorted to educated guesses and rules-of-thumb which have subsequently resulted in standards of treated water quality. Since the standards demand such low levels of impurities in finished municipal water that they are, in many cases, scarcely detectable, it was assumed that the quality of the finished water would be the same before and after the improvement in the quality of the raw water. This assumption is supported by Koenig who states that for most municipal water treatment plants that he studied[12] "finished water quality standards are so strict and the performance with respect to them is so uniformly high that in the parameters of interest there is very little variation from plant to plant or from month to month in their values in finished water. For components which are expected to be removed by the treatment process, that is for turbidity, for color, for taste and odor, and for coliform organisms, the amounts remaining in the finished water are extremely low and, in any case, the intended goals in these measurements are extremely low ... they are all close to zero that statistically the value of the raw water parameter cannot be distinguished from the change in parameter on treatment."

In summary, the three types of benefits that can be realized from raw water quality improvement are

(1) that due to the change in benefit per unit of use which can be totaled by multiplying the change in benefit per unit of use (ΔB) by the amount used (N), or $(\Delta B)(N)$,

(2) that due to the change in amount of use which can be approximated by multiplying the old benefit per unit of use (B) minus the old cost of treatment per unit of use (C) plus the change in benefit per unit of use (ΔB) by the change in volume of use (ΔN),

$$(B - C + \Delta B)(\Delta N), \text{ and}$$

(3) that due to the change in the unit cost of treatment which can be represented by $\Delta C(N + \Delta N)$ where ΔC is the change in the unit cost of treatment.

In assuming that the finished water quality will be the same before and after the raw water quality improvement, we are elminating the evaluation of the first two types of benefits; that is, $\Delta B = \Delta N = 0$.

The next step in the evaluation of benefits from improved raw water quality used for municipal purposes would be to identify each municipality which withdraws water from the area in which the water quality will improve. This step is necessary to avoid the obvious waste of effort which would be involved from completing the following steps for plants at which no benefit would be felt.

It is now necessary to determine the relationship of the costs of treatment to raw water quality at each of the plants identified above. Since the change in dredging practices should result in higher quality raw water it is proposed to assume that the change will not result in a different level of capital costs for municipal water treatment nor in a different level of fixed operating costs (e.g., secretaries, lights, administration, etc.). These costs should already be fixed by the design of the treatment plant and should not depend on raw water quality. A possible case in which capital cost would be affected by a change in raw water quality is in the design of a new water treatment plant or in the design of an addition to or remodeling of an old plant. A treatment plant must be designed to handle the worst raw water conditions which will occur. Since these conditions will usually result from the violence of a storm (runoff or turbulence) or from a slug of especially bad pollution, the changes in raw water quality due to different dredging disposal practices are not likely to permit a relaxation in design criteria. Also the Corps is considering the dredgings disposal project to have a life of only ten years and intends to reevaluate the whole situation at that time. This very short period adds support to the assumption of static capital costs. Changes in technology and required capital investment could be accurately evaluated at that time for inclusion in the next period of analysis, an opportunity not often encountered in water resources planning.

There is a further portion of the costs of operating a water treatment plant that should be independent of the raw water quality. Pumping cost, with the exception of that needed for wash water, many maintenance costs and a large portion of the labor costs will be proportional to the amount of water which is treated, and their value per unit volume treated will be unchanged. Since we have assumed that the volume of water treated will not change due to a change in raw water quality these costs can also be ignored in our study.

The remaining costs of treatment, which are dependent on raw water quality to some degree, may be divided into two categories. The first is the cost of the chemicals used in treatment and the second is the costs that can be associated with the use of chemicals.

The "associated chemical costs" would include such expenses as labor for handling and feeding chemicals, interest on the value of the necessary inventory, maintenance of the chemical feeding machinery and power for operation of the feeding and mixing equipment. For the purpose of this analysis wash water used in backwashing filters and in cleaning sedimentation basins will be defined as a chemical and thus its costs can be easily incorporated into the analysis.

Thus the next step in the proposed methodology is to determine the cost per pound of each chemical for each treatment plant. The determination of unit chemical costs is relatively straightforward, but the necessity to determine these figures for each plant must be emphasized. There will be a considerable variation in the unit prices paid for chemicals between plants, especially between large and small plants, and it will therefore be necessary to develop considerable experience with the figures before judgment can be incorporated to reduce the magnitude of the task.

Next a relationship between the required dose of each chemical and the quality of the raw water must be developed. The correlation of chemical dose with raw water quality is perhaps the most crucial step in the entire analysis of the benefits of improved raw water quality to municipal water supply.

In a comprehensive article dealing with the cost of water treatment, Louis Koenig[12] described the results of a "cost engineering audit" made on thirty water treatment plants in 1965. He studied which elements, differentiable from the available plant data, make up the cost of water treatment, the relative magnitude of their respective contributions, and the distribution of these statistics among the different plants. His study was limited to plants employing coagulation, sedimentation and rapid sand filtration of two principal size ranges, namely 0.3-0.5 million gallons per day (approximately the median size of plant in the U.S.) and 6-13 million gallons per day (approximately the size of the plant from which the median gallon of water in the U.S. would come). Among the variables which Koenig has considered are the fraction of plant capacity used, capital costs, manpower costs, energy, chemical cost, maintenance and replacement costs, treating costs, and miscellaneous costs. The greatest contributions to treatment costs (excluding costs of raw water and of distribution of treated water) were capital costs, manpower costs, and energy costs. These three elements were responsible for 85 to 90 percent of the treatment cost, while chemicals were generally responsible for only 5 to 10 percent of the total treatment cost. Typical total costs of treatment ranged from five to twenty-five cents per thousand gallons. No correlation between raw water quality and treatment costs was derived.

Young, Popowchak and Burk[27] correlated yearly chemical costs for fourteen plants with average values of various raw water quality parameters.

Both simple linear regression (one raw water quality variable) and multiple linear regression (several raw water quality variables) analyses were completed. Although reasonably good correlations were achieved, the sample size was small, the quality data consisted of only yearly averages, and the trends noted depended on rather wide ranges of variation in values of the water quality variables. It was thought that a more precise method would be needed to consider the smaller ranges of quality variation found in the Great Lakes.

Another significant attempt to associate improvements in raw water quality with savings in municipal water treatment is a recent study by Frankel[5, 6]. As a part of his study concerning the economics of providing municipal waste treatment he found linear correlations between biochemical oxygen demand (BOD) and chlorine demand, between BOD and coagulant demand and between detergent concentration and activated carbon requirements in effluents from secondary treatment plants. However, since the concentration of BOD is infrequently measured in most raw waters and the differences between concentrations in secondary effluents and the Great Lakes would be large, it was doubted that these correlations would prove to be useful in the present problem.

Baxter[2] in 1964 found no clear relationship between chemical costs and some standard indices of pollution including turbidity and coliform densities.

The one area of water treatment in which significant work has been completed relating treatment costs to variables of raw water quality is that of softening[9, 18]. The applicability of this work to the present problem is limited, however. Because of the moderate levels of hardness in the great Lakes, few municipal plants conduct softening operations.

In the above articles some allusions were made to research which might still be in progress. Koenig[12] stated that the FWPCA was currently conducting a study of the effect of raw water quality on cost in a single treatment plant. Baxter[2] mentioned that the Delaware River Basin Commission was in the process of authorizing a similar study. Volume II of the Water Resources Research Catalog (Office of Water Resources Research, 1966), U.S. Department of the Interior lists a project of this type sponsored by the City of Philadelphia. Inquiries concerning these projects have been made, but time has not permitted additional efforts to obtain their results.

From this brief survey of the current state-of-the-art, the only possible conclusion was that a feasible methodology, if one exists, would have to include engineering studies to determine whether a significant correlation between the costs of water treatment and the quality of the raw water exists. Although Young et al. and Frankel have had limited success there is no indication in the literature that a detailed study has been completed.

In order to obtain relationships between raw water quality and chemical doses it is necessary to make simplifications which render the procedure manageable. The following assumptions are noted:

1. The quality of the treated water remains the same after the improvement in raw water quality.
2. The effect of the change in raw water qaulity in one plant is being considered.
3. The effect of the change in raw water quality on the required dose of one chemical in this plant is being analyzed.

If only one raw water quality parameter were changed by the new method of disposal of dredgings it should be possible to develop the curve shown in Figure 2. This curve shows the dose of the one chemical we are studying that would be required at any level of the one raw water quality parameter ($L1_{j=1}$) which has been changed. All other raw water quality variables are assumed to remain constant. The change in dose (ΔD) can be easily computed by taking the difference between the dose required at the current level and the level which will exist after the improvement of raw water quality.

Now, however, suppose that two raw water quality variables are changed. This makes it necessary to develop a family of curves such as the group shown in Figure 3. These curves show the dose of the one chemical which we are studying which would be required at any level of the first raw water quality variable when the second has various constant values (P_1, P_2, ... P_5). All other raw water quality variables ($L1_{j>2}$) are assumed to remain constant.

If we now assume that a third raw water quality variable were changed by the different means of dredging disposal it would be necessary to develop a set of curves like Figure 3 for each of several (assume 5) values of the third water quality variable ($L1_{j=3}$). In this case the change in chemical dose would be computed by finding the current dose from the graph for the current value of the third water quality variable ($L1_{j=3}$) and finding the dose required under improved conditions from the graph for the new value of the third water quality variable. The change in dose would be determined by taking the difference between the two values.

A fourth water quality variable which was changed would require us to develop a set of five graphs like Figure 3 (one for each of five values

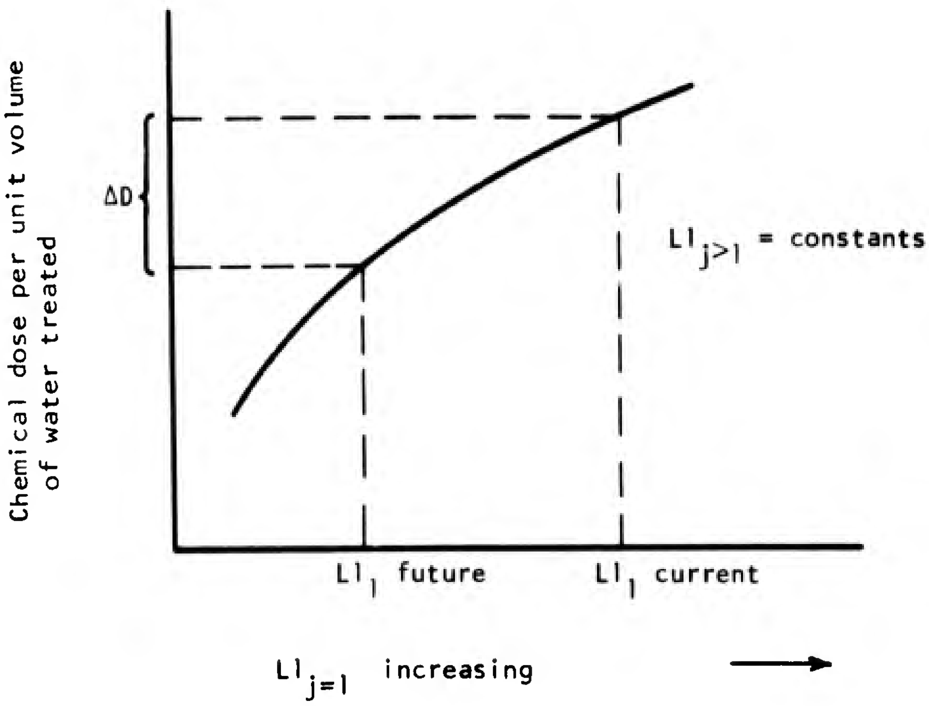


FIGURE 2. Change of chemical dose with change in level of one water quality variable

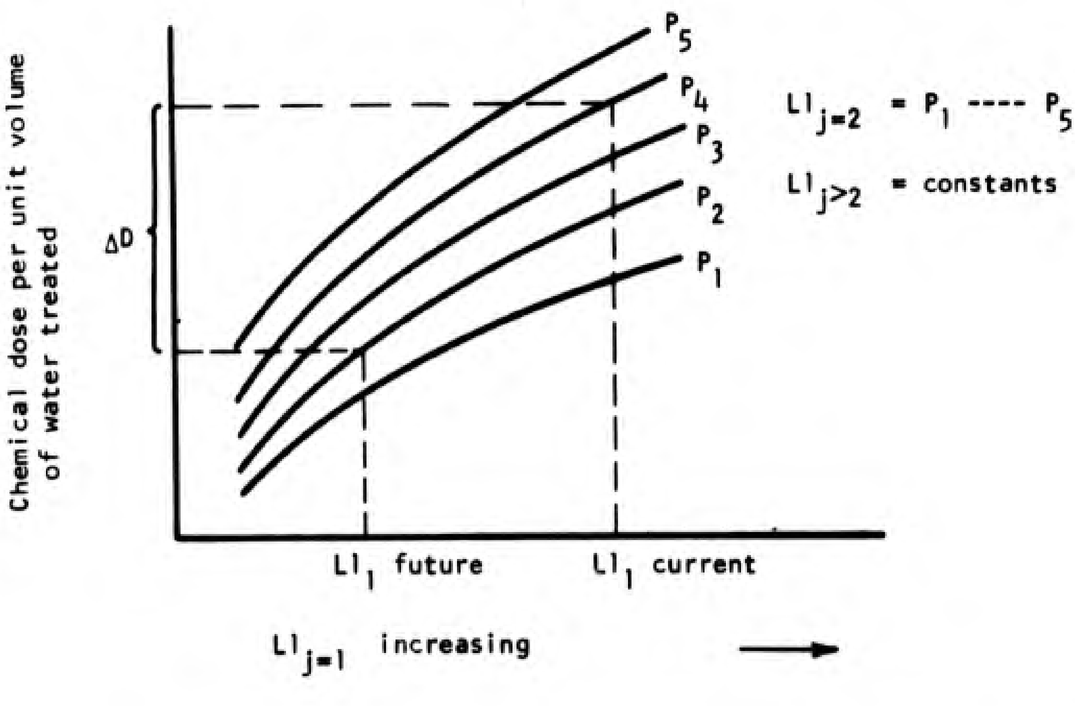


FIGURE 3. Change of chemical dose with change in levels of two water quality variables

of the fourth water quality variable ($L1_{j=4}$) for each of the five graphs for values of the third water quality variable ($L1_{j=3}$). The problem is growing quite rapidly. If it is assumed that five values of a raw water quality variable were used to define its effect on chemical dose, and if n raw water quality variables were changed it would be necessary to develop $5^{(n-2)}$ graphs like Figure 3 with a total of $5^{(n-1)}$ curves. And this is just to determine the effect on the dose of one chemical. Since the requirements of this method of analysis become so great, we must try to select a limited number of water quality variables with which to describe the effect of raw water quality on chemical doses.

To assess the effect of water quality changes in the Great Lakes it is necessary to compare present levels of various constituents of the Great Lakes waters with standards which have been promulgated for drinking waters. Table I is a compilation of some standards which have been applied to drinking water. It should not be considered as a complete compilation. Tables II, III, and IV show some Great Lakes water quality data and indicate the general range of values to be expected.

On the basis of these tables it was felt that the following variables would deserve first attention in the proposed evaluation:

1. chlorine demand
2. turbidity
3. algae
4. coliform organisms
5. hardness, total
6. hardness, noncarbonate
7. extractable organic matter

With the probable exception of coliform organisms, all of these variable would be expected to influence the required dose of one or more chemicals.

The following table shows the water treatment chemicals which have

TABLE I

Water Quality Variables for Municipal Water Supply
(Concentrations are in milligrams per liter unless otherwise indicated)

Constituent	Maximum Concentration an "Ideal Water" (Elwood Bean)[a]	USPHS 1962 Drinking Water Standards[b]		Ranges of Maximum Concentration Standards Promulgated for Raw Water Sources in the U.S. (McKee & Wolf)[c]			Proposed Criteria for Max. Concentrations in Surface Sources of Public Water Supply (Interim Report)[d]	
	(1)	Recommended Maximum Level (2)	Maximum Permissible Level (3)	Excellent source (disinfection only) (4)	Good source (filtration & disinfection) (5)	Poor source (special treatment) (6)	Permissible criteria (treatable with assumed plant)[e] (7)	Desirable criteria (easily treatable) (8)
Physical Characteristics								
Color (color units)	(true) 3	15.		0-20	20-150	>150	75	<10
Odor & Taste	No change on Carbon Contact	TON3.					Removable	Virtually Absent[i]
*Solids, Dissolved (filterable residue)	200.0	500.					500	<200
Solids, Suspended (nonfilterable residue)	0.1							
*Temperature							Unobjectionable	
Turbidity (Jackson units)	0.1	5.		0-10	10-250	>250	Nonvariable & removable types & concentrations	Virtually Absent
Biological Characteristics								
Coliforms /100ml	0.1		1.	50-100[f] <5%>100[g]	50-5000[f] <20%>5000[g]	>5000[f] <5%>20000[g]	10,000	<100
Fecal Coliforms/100ml							2,000	<20
Macroscopic and Nuisance Organisms	None							

Chemical Characteristics	(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)
(Inorganic)									
Alkalinity (as $CaCO_3$)								Constant 30<alk<500	Normal Nonscaling Noncorrosive
Aluminum	0.05								
Ammonia (as N)									
*Arsenic	0.01	0.01		0.05				0.5	<0.01
*Barium	0.5			1.0				0.05	Absent[j]
*Boron								1.0	Absent
*Cadmium	0.01			0.01				1.0	Absent
*Chloride		250.			<50	50-250	>250	0.01	Absent
*Chromium (+6)	0.01			0.05				250	<25
*Copper	0.2	1.						0.05	Absent
								1.0	Virtually Absent
*Fluoride Five year average of maximum daily air temperature in ^oF		Minimum	Optimum		<1.5	1.5-3.0	>3.0		
50.0-53.7	1.2	0.9	1.2	1.7				1.7	
53.8-58.3	1.1	0.8	1.1	1.5				1.5	
58.4-63.8	1.0	0.8	1.0	1.3				1.3	
63.9-70.6	0.9	0.7	0.9	1.2				1.2	
70.7-79.2	0.8	0.7	0.8	1.0				1.0	
79.3-90.5	0.7	0.6	0.7	0.8				0.8	
*Hardness (Calcium & Magnesium as $CaCO_3$)	80.0							constant	<60-120
Iron	0.05	0.3						(filterable) 0.3	(filterable) Virtually Absent
*Lead	0.03			0.05					
*Manganese	0.01	0.05						0.05	Absent
								(filterable) 0.05	(filterable) Absent

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
*Nitrates	(N)5.0	(NO_3)45.					(+ Nitrites) (N) 10	(+ Nitrites) Virtually Absent
Oxygen Dissolved (in streams as indicator of pollution)				>4.0-7.5[f] >75%[h]	>4.0-6.5[f] >60%[h]	>4.0[f]	>4.0[f] >3.0[g]	Near Saturation
pH (range)				6.0-8.5	5.0-9.0	3.8-10.5	6.0-8.5	
*Phosphorus (total as P)							0.05	
*Selenium	0.01		0.01				0.01	Absent
*Silver	0.02		0.05				0.05	Absent
*Sulfate		250.					250	<50
*Uranyl Ion (UO_2)							5	Absent
*Zinc	1.0	5.					5	Virtually Absent
(Organic)								
BOD (5 day)				0.75-1.5[f] 1.0-3.0[g]	1.5-2.5[f] 3.0-4.0[g]	>2.5[f] >4.0[g]		
*Carbon Alcohol Extract	0.10							
*Carbon Chloroform Extract	0.04	0.2					(tentative) 0.15	<0.04
*Cyanide	0.01	0.01	0.2				0.20	Absent
*Grease & Oil							Virtually Absent	Absent
*Methaline Blue Active Substances (detergents)	(ABS)0.20	(ABS)0.5					0.5	Virtually Absent
*Pesticides & Herbicides	No appreciable effect on test fish						Virtually Absent[k]	Absent
*Phenols	0.0005	0.001		(maximum) None	(maximum) 0.005	(maximum) >0.005	0.001	Absent

(Radioactive)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	pc/l	pc/l	pc/l				pc/l	pc/l
*Gross Beta Emmiters	100		1000				1000	100
*Radium (Ra^{226})	3		3				3	< 1
*Strontium (Sr^{90})	5		10				10	< 2

FOOTNOTES FOR TABLE I

[*] Denotes variables which are relatively unaffected by the assumed treatment (see footnotes d and e.)

[a] Bean, Elwood L., "This is Ideal Water", Water Works Engineering, 115:10:825, (October 1962); see also "Progress Report on Water Quality Criteria", Journal AWWA, 54:1313, (November, 1962).

[b] U.S. Department of Health, Education, and Welfare Public Health Service, Public Health Service Drinking Water Standards 1962, Public Health Service Publication No. 956, U.S. Govt. Printing Office, Washington, 1962, pp. 3-9.

[c] McKee, Jack Edward, and Wolf, Harold W., Water Quality Criteria Second Edition, The Resources Agency of California - State Water Quality Control Board, Publication No. 3A, Sacramento, 1963, p. 93.

[d] U.S. Department of the Interior's National Technical Advisory Committee to the Federal Water Pollution Control Administration on Water Quality Criteria, Interim Report, Washington, D.C., June 1967, Section on Public Water Supplies.

[e] The assumed treatment plant is the combination of "the most common processes in use in this country in their simplest form for treatment of surface waters." Specifically this includes the following:

1. Coagulation - up to 50 ppm coagulant plus alkalinity but no coagulant aids
2. Sedimentation - six hours or less
3. Filtration - three gallons per minute per square foot or less
4. Chlorination

[f] Monthly Average Value

[g] Allowable Daily or Sample Value

[h] Percent of Saturation

[i] Virtually Absent - detectable but of very low concentration

[j] Absent - not detectable by most sensitive analytical method in Standard Methods for the Examination of Water and Waste Water.

[k] Criteria for permissible concentrations of several pesticides and herbicides are given.

TABLE II

SUMMARY OF WATER QUALITY DATA FOR LAKE ERIE (in mg/ℓ unit except where indicated)

CONSTITUENT	Buffalo, New York[a] Oct. 1958-Sept. 1959			Buffalo, New York[b] Oct. 1962-Sept. 1963			Buffalo, New York[c]	Lake Erie-Open Water[d]			Environmental and Biota Changes[e]	
	Low	Mean	High	Low	Mean	High	Mean	Min	Mean	Max	1900	1965
PHYSICAL CHARACTERISTICS												
Chlorine Demand (1 hr)	0.	0.8	1.8	0.1	0.8	2.6						
Chlorine Demand (24 hr)	0.2	2.3	3.7	1.1	1.9	4.0						
Color (units)	0.	0.1	10.	0.	0.	0.	0.					
Solids, Dissolved	121.	186.	264.	156.	201.	254.	204.				145.	200.
Specific Conductance (micro mhos @ 25°C)							306.	-	325.	-		
Temperature (indicate °F or °C)	1.5°C	15.9°C	25.8°C	0.0°C	12.2°C	26.0°C	75.0°F					
Turbidity (units-Jackson)	1.	3.	12.	0.0	12.	40.	12.					
BIOLOGICAL CHARACTERISTICS												
Algae, Total #/mℓ	30.	350.	850.	0.	233.	600.						
Coliform #/100mℓ	1.	18.	180.	4.	34.	230.						
CHEMICAL CHARACTERISTICS												
(INORGANIC)												
Alkalinity, Total (as $CaCO_3$)	49.	86.	98.	72.	86.	92.	95.	82.	115.	160.		
Ammonia (as N)	0.0	0.04	0.3	0.0	0.004	2.0						
Calcium							38.	30.	40.	71.	32.	38.
Chlorides	18.	27.	45.	18.	23.	25.	22.	7.	30.	130.	7.	24.
Hardness, Noncarbonate (as $CaCO_3$)							40.					
Hardness, Total (as $CaCO_3$)	110.	123.	136.	120.	134.	142.	127.					
Iron							0.03	0.01	0.04	0.12		
Magnesium							8.6	5.	9.	13.		
Nitrate							0.2	0.1	2.	10.		
Oxygen, Dissolved	8.0	11.7	15.	7.8	11.3	14.0						
pH (units)	7.4	8.1	8.5	7.9	8.2	8.6	8.1	6.28	8.0	8.77		
Phosphate (PO_4)				0.0	0.1	0.4	0.8					
Potassium							1.4	1.	5.	10.		
Silica							2.	0.2	2.	6.9		
Sodium							9.5	3.	10.	16.	6.	12.
Sulfates	17.	23.	27.	19.	24.	28.	23.	14.	35.	71.	13.	25.
(ORGANIC)												
BOD	0.1	0.8	2.3	0.7	1.7	3.9						
Carbon Alcohol Extract	0.107	0.140	0.206	0.098	0.118	0.173						
Carbon Chloroform Extract	0.025	0.049	0.064	0.028	0.049	0.066						
COD	0.3	6.	27.	4.	15.	141.						
(RADIOACTIVE)												
Total Alpha (pc/ℓ)	0.0	0.5	2.	0.0	0.3	2.						
Total Beta (pc/ℓ)	0.0	26.	69.	9.	25.	53.						

TABLE III

SUMMARY OF WATER QUALITY DATA FOR SOUTHERN LAKE MICHIGAN (in mg/ℓ units except where indicated)

CONSTITUENT	Gary, Indiana[a] Oct. 1958-Sept. 1959			Gary, Indiana[b] Oct. 1962-Sept. 1963			Gary, Indiana[c]	Mouth of Indiana Harbor Ship Canal[d] Nov.-Dec. 1967			Environmental and Biota Changes[e]	
	Low	Mean	High	Low	Mean	High	Mean	Min	Mean	Max	1900	1965
PHYSICAL CHARACTERISTICS												
Chlorine Demand (1 hr)	0.4	1.0	2.6	0.4	1.2	3.2						
Chlorine Demand (24 hr)	0.0	2.7	5.6	2.2	3.0	4.9						
Color (units)	5.	10.	25.	0.	8.	30.						
Solids, Dissolved	151.	169.	197.	144.	153.	186.		111.	181.	278.	132.	154.
Solids Suspended								3.	10.	28.		
Temperature °C	1.4	11.9	21.1	1.4	10.3	21.6						
Turbidity (units)	1.	5.	18.	7.	12.	40.	16.					
BIOLOGICAL CHARACTERISTICS												
Algae, Total #/mℓ	450.	2340.	9740.	300.	1436.	3400.						
Coliform #/100 mℓ	4.	354.	2400.	1.	576.	7000.						
CHEMICAL CHARACTERISTICS (INORGANIC)												
Alkalinity, Total	102.	114.	130.	110.	119.	138.	122.					
Ammonia (as N)				0.0	0.2	0.4		0.01	0.49	1.8		
Calcium											34.	34.
Chlorides	6.	6.4	8.	4.	6.6	9.					3.9	7.5
Hardness, Total	130.	135.	147.	125.	132.	160.	142.					
Oxygen, Dissolved	6.7	11.	15.6	7.	10.6	14.9						
pH (units)	7.6	8.1	8.4	7.8	7.6	8.3	8.1	7.	8.	8.7		
Phosphate (PO_4)				0.	0.01	0.3		0.011	0.037	0.102		
Sulfates				21.	29.	45.					9.	18.
(ORGANIC)												
BOD	0.2	2.1	7.	0.1	0.8	3.						
Carbon Alcohol Extract	0.034	0.096	0.14	0.067	0.089	0.1						
Carbon Chloroform Extract	0.029	0.043	0.063	0.017	0.036	0.071						
COD	0.3	7.	26.	12.	28.	57.		1.3	11.6	50.		
(RADIOACTIVE)												
Total Alpha (pc/ℓ)	0.	0.4	2.	0.	0.5	4.						
Total Beta (pc/ℓ)	1.	25.	109.	3.	14.	30.						

TABLE IV

SUMMARY OF WATER QUALITY DATA FOR LAKE SUPERIOR (in mg/ℓ units except where indicated)

CONSTITUENT	Duluth, Minnesota[a] Oct. 1958-Sept. 1959			Duluth, Minnesota[b] Oct. 1962-Sept. 1963			Environmental and Biota Changes[e]	
	Low	Mean	High	Low	Mean	High	1900	1965
PHYSICAL CHARACTERISTICS								
Chlorine Demand (1 hr)	0.7	1.0	1.8	0.5	0.7	1.		
Chlorine Demand (24 hr)	1.3	2.4	3.4	1.1	1.4	2.2		
Color (units)	0.	2.3	15.	0.	0.8	5.		
Solids, Dissolved	35.	54.	76.	49.	56.	64.	59.	55.
Temperature °C	0.6	5.5	17.2	1.1	5.8	20.		
Turbidity	0.	0.7	6.	0.	1.	25.		
BIOLOGICAL CHARACTERISTICS								
Algae, Total #/mℓ	50.	240.	780.	0.	118.	500.		
Coliform #/100 mℓ	1.	12.	68.	1.	54.	830.		
CHEMICAL CHARACTERISTICS (INORGANIC)								
Alkalinity, Total (as $CaCO_3$)	39.	43.	45.	42.	43.	44.		
Ammonia	0.1	0.06	0.3	0.	0.	0.		
Calcium							13.	12.
Chlorides	1.	1.8	2.	2.	2.	2.	2.	2.
Hardness, Total (as $CaCO_3$)	37.	41.	45.	42.	44.	45.		
Oxygen, Dissolved	9.4	12.5	14.	9.8	12.3	14.		
pH (units)	7.5	7.7	8.	7.4	7.5	7.8		
Phosphate (PO_4)				0.	0.	0.		
Sodium							3.	2.
Sulfates	1.	3.7	5.	2.	2.5	4.	4.	3.
(ORGANIC)								
BOD	0.3	0.5	1.	0.2	0.4	1.		
Carbon Alcohol Extract	0.063	0.094	0.116	0.033	0.067	0.081		
Carbon Chloroform Extract	0.021	0.026	0.034	0.014	0.022	0.033		
COD	2.	4.3	8.8	5.	8.6	12.		
(RADIOACTIVE)								
Total Alpha (pc/ℓ)	0.	0.09	1.	0.	0.	0.		
Total Beta (pc/ℓ)	0.	18.	148.	3.	17.	28.		

FOOTNOTES FOR TABLES II, III, & IV

(a) U.S. Dept. of Health, Education, and Welfare. Public Health Service. National Water Quality Network: Annual Compilation of Data, October 1, 1958 - September 30, 1959. Public Health Service Publication No. 663, (1959).

(b) ___. Water Pollution Surveillance System: Annual Compilation of Data, October 1, 1962 - September 30, 1963. Public Health Service Publication No. 663, Vol. 1 and 4, (1963 revised edition).

(c) Durfor, Charles N. and Edith Becker. Public Water Supplies of the 100 Largest Cities in the United States, 1962. Geological Survey Water-Supply Paper 1812. U.S. Government Printing Office, Washington, D.C. (1964).

(d) Department of the Army. Lake Survey District, Corps of Engineers. Personal communication. Detroit, Michigan (April 1968).

(e) Beeton, A. M. Changes in the Environment and Biota of the Great Lakes. Contribution No. 7, Center for Great Lakes Studies, University of Wisconsin, Milwaukee, Wis. (1968).

been selected as the important ones and the raw water quality variables which might be correlated with each.

Chemical Dose	Raw Water Quality Variable
chlorine	chlorine demand
coagulant	turbidity & total algae
activated carbon	extractable organic matter (or TON) (or phenols)
wash water	turbidity & total plankton
lime	total hardness
soda ash	noncarbonate hardness

A large expenditure of effort will be necessary to determine if the desired correlations exist. However, it is felt that sufficient raw water data exists in any of the large treatment plants of the Great Lakes so that this study could proceed. In fact, all of the raw water quality variables suggested here have been measured weekly for practically ten years by various Great Lakes water treatment plants in conjunction with the U.S. Public Health Service National Water Quality Network. The cities include Buffalo, Detroit, Gary, Milwaukee, Duluth, Port Huron, and Saulte Ste. Marie. It is expected that the large treatment plants might measure these and other raw water quality variables even more frequently than this and thus provide a large amount of data with which to work. It is quite likely that if relationships were developed in a few plants they might form patterns in a region or might be used for generalization over a wide area. However, it must be emphasized that because of the magnitude of the interdependencies, the study should begin in individual plants.

The use of a small number of raw water quality variables for correlation with the required dose of a chemical necessarily assumes that the dose is independent of all other raw water quality variables. It assumes that each chemical is always responsible for accomplishing the same fraction of the removal of its variables in relation to the fraction removed by other chemicals and other unit operations at any specific level of the chemical's raw water quality variables.

A situation more representative of the actual workings of a treatment plant would be to use, instead of the raw water concentration of the particular variable(s), the concentration of the variable(s) immediately before the unit operation in which the chemical is employed. Examples of this would be correlation of wash water use with turbidity and total plankton concentration as the water being processed entered the filters. Unfortunately these data are not available and changes in their values would be hard to predict from change in dredging practice if they were.

Another assumption which is implicit in the development of the above relationships is that the plant is operating at a constant capacity. If the rate of production were to be changed, a significant shift in the required dose at any raw water quality level might occur. For example, if the rate of treatment were increased, water would have less time in the settling basin and this could result in a higher dependence on the filters to remove suspended material. This in turn might cause a significant increase in the wash water required at a particular raw water quality level.

There is one alternative to the detailed study of chemical doses versus raw water quality which deserves mention. If a water treatment plant were controlled by a set of operating rules which stated that for certain levels of raw water quality, the operator should add so much of certain chemicals, the development of correlations would be unnecessary. They would in fact be replaced by the operating rules. However, it is thought that the existence of firm enough rules to provide a continuous indication of the effect of raw water quality is rare, and statistical analysis will be necessary.

The next step in the municipal water supply methodology is to determine, for each plant identified above, the costs of treatment which can be associated with the amount of chemicals used per unit volume of water treated. The determination of this association in each plant is especially important when considering plants of different sizes since the magnitude of the associated costs is likely to vary considerably. After developing considerable experience with plants of various sizes, it is anticipated that more judgment will be utilized especially in studying "associated chemical costs" in small plants.

The incorporation of the "associated chemical costs" into the analysis will probably be most easily accomplished in one of the following ways. If the associated chemical costs are found to be constant amounts per pound for each chemical added, their change with a change in water quality will be easily considered by adding the associated chemical cost per pound (A_1) to the unit purchase price of each chemical (C_1) and multiplying each of these sums by their respective changes in chemical doses (ΔD). In symbolic notation this operation would be expressed by the formula:

$$\Delta C = \Delta D(C_1 + A_1)$$

The "associated chemical cost" per pound could in this case be different for each chemical or it could be nearly the same for all chemicals. It is thought that the latter case might be likely, and this could lead to considerable simplification.

Another way in which associated chemical costs might be incorporated is if they are found to be a constant fraction of the purchase price for each chemical. In this case, the change in cost due to one chemical will be computed by determining the product of the change in dose (ΔD), the unit purchase price (C_1) and one plus the term (A_2) presenting the associated chemical costs per dollar spent on the chemical. Symbolically this operation would be expressed by the following formula:

$$\Delta C = \Delta D(C_1)(1 + A_2)$$

The "associated chemical cost" per dollar of chemical cost (A_2) could in this case be different for each chemical or it could be nearly the same for all chemicals. It is thought to be more likely that it would be different.

It is also possible that one of the above procedures would be found to work well for some of the chemicals while the other procedure would be found to give more accurate results for other chemicals. If this situation presents itself, the applicable method should be used for each chemical. The total change in the unit cost of water treatment would still be easily obtainable by summing the contributions of all the respective chemicals.

The last and most complicated method could incorporate both of the first two procedures in computing the savings in cost for one chemical. It might be found that the contribution to the change in the unit cost of water treatment by each chemical was accurately represented by a formula such as the following:

$$\Delta C = \Delta D[(C_1)(1 + A_2) + A_1]$$

This formula simplifies to each of the above methods when the appropriate conditions exist. If difficulty is encountered in determining the associated costs, the change in chemical costs could be used as a minimum estimate of the benefits of an improvement in raw water quality.

Now that the means are available to compute the effects of changes in quality on costs, the remainder of the procedure becomes more straightforward. It is necessary, however, since the changes in chemical doses may in many cases be nonlinear, to allow for the variability which will occur in raw water quality. To do this, for each possible combination of values of raw water quality variables, the probability that that variable will occur during the affected period must be determined. It is visualized that the process which would be used in this determination would utilize only data from the past few years since water quality is changing due to other causes. Thus one would take a specific combination of values of the raw water quality variable being used and determine the number of times this specific raw water quality occurred in, for example, the last four years. The probability that the same combination of values would occur in the future would then be assumed to equal the number of times it had occurred during the affected season of the years being used divided by the total number of times that analyses had been made during these time periods.

It is then necessary to determine the improved level of water quality. The Corps is conducting, in another part of the Pilot Program, a study of what effect various changes in dredging practices will have on raw water quality at municipal intakes. They are hopeful of being able to determine, for each alternate dredging disposal method, the improvement which will occur in each important raw water quality variable.

We now select one of the specific combinations of values of the raw water quality variables and use the above determined improvements to obtain the new level of each raw water quality variable. The process should require only subtracting the changes from the unimproved values.

The correlations of chemical doses with raw water quality which were developed earlier are now utilized to determine the doses of each chemical required under both the unimproved and improved conditions. The change in each chemical dose is easily found by taking the differences between their two doses.

The benefits per unit volume of water treated for the selected unimproved raw water quality which has a probability of occurrence (P) equal the summation over all chem cals of the following expression:

$$\Delta D[C_1(1 + A_2) + A_1]P$$

The above procedure is repeated for each combination of raw water quality variables which has a finite probability of existence under unimproved conditions. By summing the benefits per unit of water treated for all the probable levels of unimproved raw water quality and multiplying by the volume of water (N) which is treated by this one plant during the affected time of the year, we are able to obtain the total annual benefit to the plant.

The entire process now needs to be repeated for each plant which is located in the affected area. Thus the total benefits which accrue to municipal water supply in one year (TAB) in the area affected by a certain change in dredging disposal practices would be expressed by the following formula:

$$TAB = \sum_{\text{plants}} N \sum_{\substack{\text{unimproved} \\ \text{conditions}}} \left[\sum_{\text{chemicals}} \Delta D[C_1(1 + A_2) + A_1]P \right]$$

The methodology, once the various costs versus quality relationships were developed, could be easily repeated for any other change in dredging disposal practices which it was desired to evaluate. It is visualized that any anticipated change in water use due to population increase or increased per capita use of water could be applied to the annual benefit figure computed above without considerable error, especially since the period of analysis is only ten years.

Conclusion on Feasibility

The above methodology is quite detailed and completion would require large expenditures of time and money. It is anticipated, however, that once detailed analysis was under way, methods of considerable short-cut might develop. It is necessary, however, to obtain a vast increase in our present knowledge of the interrelationships of treatment costs and raw water quality before any assumptions can be justified. Until those advances are realized it is very necessary to make our analyses as specific as possible so that relationships of importance are not distorted by the fluctuations of variables which have been ignored.

It is again noted that the applicability of the above procedure to the present problem of evaluating water quality improvement benefits accruing to municipal water supply from changes in the methods of disposal of dredged materials is dependent on the following:

1. the success in finding improvements in raw water quality resulting from dredging operations and specifying the time and length of their occurrence.
2. completion of successful engineering studies correlating changes in chemical doses with the values of various raw

water quality variables and sufficient independence of these relationships from other variables in raw water quality.

3. the development of estimates of the costs of water treatment which are associated with the amounts of chemicals added.
4. the assumption that finished water quality will remain unchanged.
5. the assumption that chemical costs and costs which can be associated with them adequately reflect the benefit of improvement to the municipal treatment plant.

INDUSTRIAL WATER SUPPLY

Effect of Water Quality

As with municipal water supply, increasing concern has developed recently for the quality of industrial water as well as for the quantity available. Industrial water supply is also comparable to municipal water supply in that benefits of improved raw water quality would accrue in the same three ways, that is by increased benefit per unit of use, by increased use, and by decreased cost of treatment. Techniques of evaluating these benefits also appear to be relatively scarce.

There are, however, some very distinct differences between industrial supplies and municipal supplies. Perhaps the most important is that industrial waters are used in three principal ways; as cooling water, as process water, and as boiler feed water. To present some concept of the relative importance of these uses the Interim Report of the National Technical Advisory Committee on Water Quality Criteria[a] indicates that in 1964, United States industry used 121 billion gallons per day for cooling, 10.1 billion gallons per day for processes and 2.6 billion gallons per day for boiler feed. These figures include that portion of industrial water purchased from municipal supplies. A total of approximately 24 billion gallons per day would be withdrawn for municipal purposes. Thus it is seen that each use is quite significant.

---

[a] Interim Report, National Technical Advisory Committee to the Federal Water Pollution Control Administration on Water Quality Criteria, U.S. Department of the Interior (1967), p. 8.

Quality considerations vary, of course, for each of the above industrial uses. Since the quality requirements are greatest for the small volume used for boiler feed, and least for the great volume used for cooling, each use might realize significant benefits. Thus, it is unlikely that any can be ignored in the evaluation.

Points which are most frequently made in discussions of water quality requirements are that a successful treatment process can be established for raw water of virtually any quality to satisfy the needs of any production requirements. Once this process has been established, raw water degradation can result in significiant increases in treatment cost. Subsequent raw water quality improvement, on the other hand, provides a much less significant decrease in costs of treatment because part of the investment cannot be recovered. Most important, however, is the avoidance of marked variability in raw water quality which might require constant adjustment of treatment processes.

It was concluded that reductions in treatment costs were the only possibly feasible means of evaluating benefits from water quality improvements. A literature review was therefore undertaken and emphasis on economics of hardness removal was again found.

There were, however, publications which discussed additional parameters in considering industrial quality. Eliassen and Rowland[4] found that economic benefits to industry from improved water in the Contra Costa Canal would be equivalent to \$0.281 per mg/ℓ reduction of chloride ion per ion per acre foot of water used. The found benefits would accrue until the chloride concentration was reduced to 100 mg/ℓ. Rambow[17] converted this figure to a benefit of 4.2 cents per mg/ℓ of dissolved solids reduction per acre foot of use, but did not set a lower limit to the existence of the benefit.

In a study by the Stanford Research Institute for the State of California[20] it was found that when comparing Colorado River water with a northern California source a benefit of 3.6 cents per mg/ℓ of dissolved solids reduction per acre foot used would result from employing the California source. Rambow averaged these two results and advocated use of a value of 4 cents per mg/ℓ of dissolved solids reduction after reviewing other earlier studies. He also found basis for use of a figure of 2.2 cents per mg/ℓ of hardness reduction for both municipal and industrial sources. Unfortunately (or fortunately) neither dissolved solids nor hardness concentrations are high enough in the Great Lakes to make use of these figures. Rambow also warned that they were based on very limited data.

Thus the situation for evaluation of industrial water supply benefits is very much the same as that for municipal water supply. Again a feasible methodology, if one exists, would have to include investigation to determine correlations between costs of water treatment and raw water quality. It was again felt that capital costs were likely to be unaffected and that changes in treatment costs would be most successfully determined by correlation of chemical doses with the levels of certain raw water quality variables. In this case, however, the three different goals of water treatment must be remembered.

The search for a methodology was begun by comparison of water quality criteria for the various industrial uses (see Table V) with the available data on general water quality levels in the Great Lakes. (Tables II, III, & IV)

The major considerations which determine the suitability of cooling

TABLE V

INDUSTRIAL WATER QUALITY CRITERIA[a]

(Unless otherwise indicated, units are mg/ℓ and values are ranges of recommended threshold or limiting values at the points of use.)

CONSTITUENT	Boiler Feed Waters[b]		Cooling Waters	Process Waters							Steel Manuf.
	Low Pressure	High Pressure		Brewing	Carbonated Beverages	Dairy Industry	Food Industry: Canning & Freezing	Food Industry: Equip. Washing	Pulp & Paper Indust: Unbleached Kraft Paper	Pulp & Paper Indust: Fine Paper	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
PHYSICAL CHARACTERISTICS											
Color (units)	40			0-10	5.0-10.0	None		5-20	100	5	
Corrosiveness			Low						Low	Low	Low
Gases, Dissolved			Low								
Odors & Tastes				None-Low	None-Low	None	None-Low	None			
Solids, Dissolved				500-1500	850		850	850	500	200	
Solids, Suspended			Low						Low	Low	25
Solids, Total	2500-500[c]	0.5[c]				500					
Temperature (°F)			Low								75
Turbidity (units)			50	0-10	1.0-2.0		1.0-10	1.0	100	10	
BIOLOGICAL CHARACTERISTICS											
Algae					None *[m]		*[n]				
Bacteria #/100 mℓ						<25=Very Good 25-100=Good 100-500=Passable					
Coliform #/100 mℓ				*[i]	*[i]		*[i]	*[i]			
Microorganisms (General)				*[j]	*[m]				Low	Low	
Protozoa					None *[m]						
Slime Growths			Low								
CHEMICAL CHARACTERISTICS (INORGANIC)											
Alkalinity (as $CaCO_3$)				75-80[k] 80-150[l]	50-128		30-250		150	75	
Aluminum	*[d]	*[d]									
Aluminum Oxide	0.5									8	
Ammonia	*[e]	*[e]				Traces	0.5				
Bicarbonate	30										

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Calcium				100-200[k] 200-500[l]						(as $CaCO_3$)	
Calcium Chloride				100-200							
Calcium Sulfate				100-500							
Carbon Dioxide									10	10	
Carbonate	100		Low	50-68							
Chloride				60-100	250	30		250	200		175
Chlorine										.3-2.0	
Copper				None			Low[o]				
Fluoride				1.0	0.2-1.0		1.0	1.0			
Hardness (as $CaCO_3$)	40	0.	50		200-250	180	50-85[p]	10	200	100	50
Hydrogen Sulfide	3			0.2	0-0.2		1.0				
Hydroxide	40										
Iron			0.5	0.1-1.0	0.1-0.2	0.1-0.3	0.2		1.0	0.1	
Iron plus Manganese			0.5	0.1	0.1-0.5		0.2-0.3	0.2			
Magnesium				30							
Magnesium Chloride				50-200							
Magnesium Sulfate				50-200							
Manganese			0.5	0.1	0.2	0.03-0.1	0.2		0.03	0.0	
Nitrate				10		(as N_2O_5) 30	(as N_2O_5) 15				
Nitrite				0.0		None					
Oxygen, Dissolved	0.14	0.05	Low								
pH (range)	>8.4			6.5-7.0			>7.5			7.8-8.3	6.8-7.0
Silica	20	0.2		50					100	20	
Sodium and/or Potassium	*[f]	*[f]									
Sodium Carbonate			Low[h]	100							
Sodium Chloride				275-500			1000-1500				
Sodium Sulfate				100							
Sulfate					250	60					
Sulfate: Carbonate (ratio)	2:1										
(ORGANIC)											
Chemical Oxygen Demand	10				1.5	12					
Grease & Oil			Low								
Organic Matter (General)			Low		Infinitesimal			Infinitesimal	Low	Low	Low
Sugar	*[g]	*[g]									

FOOTNOTES FOR TABLE V

(a) McKee, Jack Edward, and Wolf, Harold W. Water Quality Criteria, Second Edition, The Resources Agency of California - State Water Quality Control Board, Publication No. 3A, Sacramento (1963), pp. 93-106.

(b) Primarily from the "Progress Report of the Committee on Water Quality Tolerances for Industrial Uses," Journal of the New England Water Works Association, 54:261 (1940).

(c) Depends on design and use of the boiler.

(d) Aluminum is troublesome since it tends to form a scale.

(e) Ideally, no ammonia should be present since it is very damaging to copper parts.

(f) Excessive sodium and/or potassium may contribute to foaming.

(g) The presence of sugar in boiler feed waters, which is sometimes a problem in sugar refineries, can cause foaming and also can result in production of corrosive organic acids.

(h) Sodium Carbonate has been found to be responsible for delignification of wood cooling towers.

(i) Should meet Public Health Service Drinking Water Standards.

(j) Water used for brewing should not contain microorganisms which affect the germination process.

(k) In production of light beer.

(l) In production of dark beer.

(m) Microorganisms must be almost completely elminated since many would grow rapidly in the beverages, particularly in fruit juice beverages.

(o) Copper has been found to decrease the shelf life of some foods.

(p) This range of maximum values for hardness applies to canning and freezing in general. Special cases include: legumes 25-75; fruits & vegetables 100-200; peas 200-400.

water include temperature (thought to be little affected by dredging), the presence of material which might clog pipes such as suspended matter, slime forming microorganisms, or scale forming compounds and the corrosiveness of the water. Process water on the other hand will usually warrant the same criteria as were used in consideration of municipal water supply together with study of additional parameters in specific industries. Preparation of boiler feed water will require consideration of removing dissolved solids in addition to the conventional treatment given to municipal or process water. The usual treatment scheme might be a two-step process consisting of pretreatment in a manner similar to municipal water treatment prior to demineralization to reduce dissolved solids. The effect of raw water quality changes on chemical dose in the pretreatment would be very similar to the municipal water use. The quality of the finished product of this pretreatment would be essentially the same regardless of raw water quality. Hence it is not expected that improvement in raw water would carry over to the demineralization step, unless changes in dredging practices significantly reduce dissolved solids such as silica which are important in preparation of boiler waters. The additional "chemicals" which must be considered in establishing use relationships with raw water quality might include:

1. inhibitors of slime growths
2. vacuum or chemicals for degasification
3. other chemicals to control scaling and corrosion
4. demineralization resins.

Methodology

The methodology to be used would proceed according to the following scheme:

A. Assume that finished water quality is the same before and after the raw water quality improvement.

B. Identify the industries which use lake water from the affected area. Determine what uses are made of the water and which treatment processes are employed to prepare the water for these uses. Choose one use (cooling, process, or boiler feed) in one of these plants for completion of the following steps.

C. Correlate doses of each chemical with changes in selected raw water quality for the use being considered.

D. Assume capital costs are unaffected and that elements of the operating costs are fixed, that is, that changes in costs of treatment are completely reflected in chemical and associated costs. Determine the magnitude of the associated chemical costs for the use being considered.

E. Determine the probability that each possible combination of unimproved values of the raw water quality variables used in the correlations with chemical doses will occur during the affected season of the year.

F. Determine the improvement which is predicted to be realized in each of the above water quality variables from a specific change in the dredging disposal practices.

G. Select one of the combinations of raw water quality variables from step E.

H. Determine the improved level of concentration of each of the raw water quality variables in the combination by subtracting its change as determined in step F from its original value.

I. For each chemical, determine the change in dose by taking the difference between the doses for the improved and unimproved raw water quality levels. Each of these doses should be determined from the correlations derived in step C.

J. Determine the benefits per unit volume of water treated for this selected raw water by multiplying the adjusted cost of the chemical per pound by the change in dose times the probability of occurrence and summing this product over all the chemicals.

K. Repeat steps G through J for each combination of unimproved values of raw water quality variables which has a finite probability of occurrence during the affected time period.

L. The total annual benefit to this use is then equal to the volume of water treated during the affected time of the year times the sum of the benefits per unit volume for each of the probable combinations of raw water quality variables.

M. Repeat steps C through L for each use in the industry being considered. The sum of the annual benefits to each use equals the annual benefit to the industry.

N. Repeat steps C through M for each industry withdrawing lake water from the area affected by the change in dredging disposal practices.

O. To determine the total annual benefits of this change in practices in the affected area, sum the values of annual benefits found for each industry.

P. Repeat process for other changes in dredging disposal practices provided that the water quality improvements due to these changes in practice are known.

RECREATION

Effect of Water Quality

The evaluation of economic benefits attributable to recreational use of water resource areas is a complex problem. While it has received increased study in recent years, as yet no method of evaluation has been developed that enables precise measurement of either the demand for outdoor recreation, or the monetary benefits attributable to outdoor recreation participation.

Recreational use is the most rapidly growing demand on water.** But pollution of public waters, from a variety of sources, is reducing the capacity of these waters to support such use. Indicators at public recreation areas that substantiate this viewpoint are high bacteria counts, large masses of algae and aquatic plants, mass die-off of fish, oil slicks, debris, offensive odors, scum, and turbidity problems[50].

The extent to which recreational use of water is deleteriously affected by pollution (or conversely, the extent to which recreational use of water is increased by improvement in the quality of polluted waters) has not been well-identified because of many variables which are difficult to measure, either singly or as an interacting group.

That recreational use of water resources does result in economic benefit is an unquestionable fact. The problem lies not in the lack of economic benefit, but in the measurement of it[39]. The methodology proposed herein deals only with the measurement of tangible benefits. It

---

**Kneese, Allen V. and Stephen C. Smith (ed.) Water Research, "Major Research Problems in Water Quality" by Earnest F. Gloyna. John Hopkins Press, Baltimore, Md., 1966.

is recognized that there are intangible benefits of importance to society which will result from any improvement in water quality. The quality of the recreation experience afforded according to water quality characteristics is one such important intangible which is not directly measurable at this time.

The method proposed in this report is admittedly crude and cumbersome. Its use is recommended as a temporary means of economic evaluation pending the development of more refined techniques.

A thirteen-step method is presented herein. However, the study group feels that only a limited number of cases will require action beyond step 4 because it is believed that the amount of pollutants identified in the dredged materials may have such small effect at recreation sites that the monetary value attributable to water quality improvement for that purpose may be zero. Steps 5 through 13, while cumbersome, appear to provide a feasible means of estimating monetary value of water quality improvement for recreation where increased recreation participation can be shown to be generated.

Methodology

1. Establish water quality parameters to describe the suitability of water, to support specific recreation uses.
2. Determine the different recreation uses (activities) and potential uses in the water resource area, and locate the existing and potential recreation use sites in the area.
3. Determine the water quality at each recreation site.
4. Compare the water quality levels so determined with the water quality parameters established for each activity.

5. Estimate the effect of different levels of water quality on recreation participation at each site. (Figure 4)
6. Determine the improved water quality level that would be attained if harbor dredgings were not dumped in the area.
7. Identify the recreational carrying capacity of the site at the existing water quality level.
8. Identify the recreational carrying capacity of the site at the improved water quality level.
9. Determine the increase in participation attributable to improving the water quality.
10. Calculate the number of recreation days attributable to improved water quality.
11. Establish a monetary value attributable to increased participation in a given activity at a given site as a direct outcome of water quality improvement.
12. For each site within a sector, sum the monetary values attributable to each recreation activity.
13. For each sector, sum the monetary values attributable to each site.

Discussion of Methodology

1. Establish water quality parameters to describe the suitability of water, to support specific recreation uses.

These water quality parameters will fall within two ranges which are established according to threshold levels:

Effective Range

The range of water quality which is not polluted sufficiently to

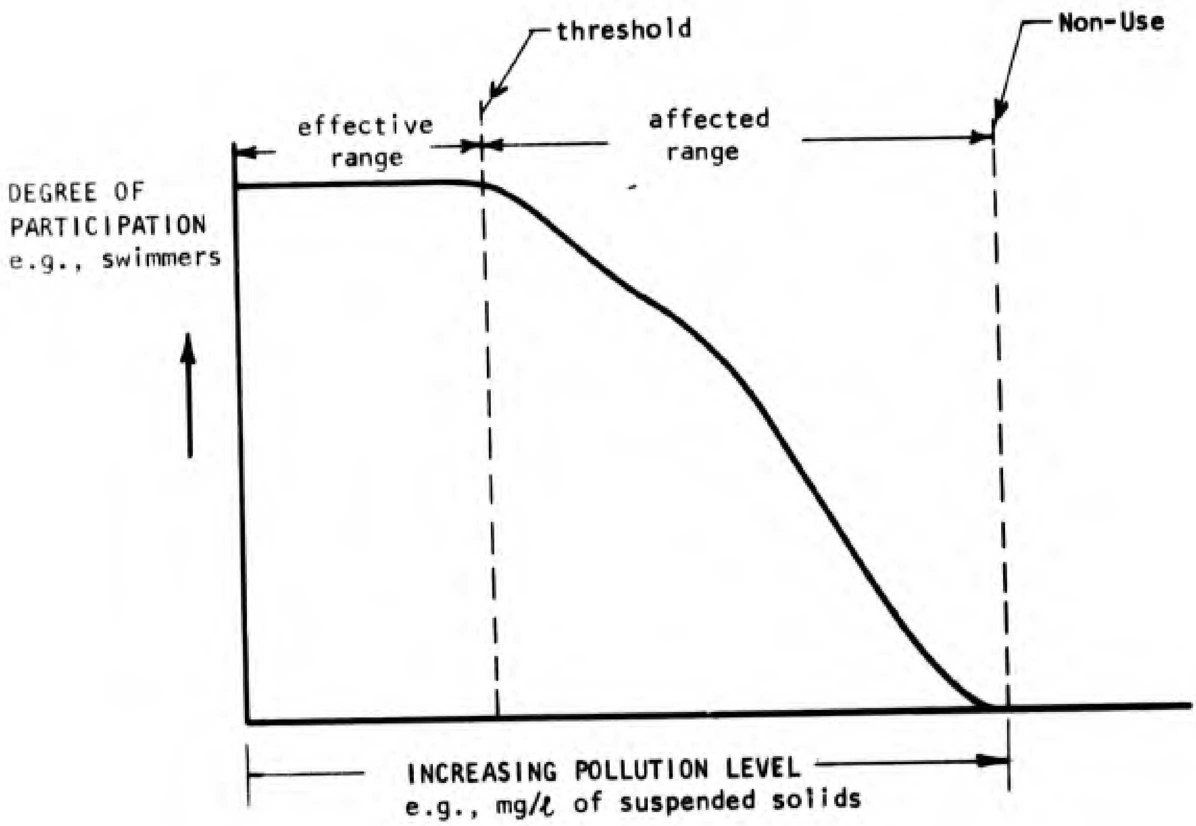

threshold
Non-Use
effective
range
affected
range
DEGREE OF
PARTICIPATION
e.g., swimmers
INCREASING POLLUTION LEVEL
e.g., mg/ℓ of suspended solids

FIGURE 4

affect the suitability of the water for recreation use.

Threshold

The minimum level of water quality necessary to support recreation use without affecting its suitability for such use.

Affected Range

The range of water quality within which the suitability of the water for recreation use is deleteriously affected.

Technique

A technique for establishing water quality parameters for recreation is currently being developed at the Water Resources Center of the University of Illinois by Robert Aukerman, John T. O'Connor and Edward H. Storey. This study is scheduled for completion in August 1969.

Pending completion of this study, a reasonably satisfactory substitute technique would be to use a jury of qualified recreation specialists such as park administrators, marina operators, beach managers, and campground supervisors. The jury's task would be to (a) establish threshold levels for selected recreation activities, thus defining the effective range, and (b) estimate the effect of water quality changes on participation rates within the affected range.

In the case of some pollutants, such as coliform bacteria, threshold levels are established by law, and require no judgment by the jury. In other instances, recommendations of the U.S. Department of the Interior may be used. Where such standards would be the basis for regulated use; i.e., closing a beach, the effect on recreation use would be more drastic than shown in Figure 4.

The pertinent pollutants are listed in Table VI.

2. Determine the different recreation uses (activities) and potential uses in the water resource area, and locate the existing and

TABLE VI

WATER QUALITY VARIABLES AFFECTING RECREATION ACTIVITIES

VARIABLES	ACTIVITIES		
	Direct Body Contact (1)	Indirect Body Contact (2)	Non-Body Contact (3)
	Swimming, Skin Diving, Water Skiing	Boating, Hunting, Fishing, Nature Study	Camping, Sight-seeing, Picnicking, Vacation Cottaging
AESTHETIC AND PHYSICAL			
Color			
Turbidity	*	*	*
Odor	*	*	*
Taste	*	*	
Floating Materials			
Oil, Grease, and other scum			
Foam			
Gas Bubbles			
Brush			
Driftwood			
Human Litter	*	*	*
Plant and Animal Pests (See Biological Section)			
Suspended and Settleable Solids	*	*	*
Obstructions			
Bottom Quality	*	*	
Temperature			

*(Indicates possible relevance to dredged materials in the Great Lakes)

	(1)	(2)	(3)
BIOLOGICAL			
Bacteriological Indicators			
Coliform	*	*	
Streptococcus Faecalis			
BOD Exerting Materials		*	
Plant Pests			
Algae f (N, P)	*	*	*
Floating Scums (Plankton Algae)			
Suspended Matter			
Attached Filaments			
Bottom Dwelling			
Higher Aquatic Plants		*	
Submergent	*		
Emergent			
Floating			
Animal Pests			
Dead Fish	*	*	*
Midges			
Mosquitoes		*	*
Flies and Other Insects	*	*	*
Leeches	*	*	
Trematode Worms (Schistosome cercariae)			
Sludge Worms, Maggots	*	*	
Nutrients - Entrophication	*	*	
Phosphorus	*		
Nitrogen	*		

	(1)	(2)	(3)
CHEMICAL			
pH	*		
Heavy Metals	*	*	
Gases		*	
NH_3			
O_2 (DO) F (t)		*	
H_2S	*		*
Cl_2			
Organic Poisons		*	
Pesticides and Herbicides		*	
Arsenicals			
Chlorinated Hydrocarbons		*	
Salinity		*	
RADIOACTIVITY			
Gross α			
Gross β and γ			

potential affect the suitability of the water for recreation use.

Technique

A. Use Bureau of Outdoor Recreation inventories to locate existing sites.

B. Use mailed questionnaire to public park and recreation agencies to determine existing and potential recreation uses and to supplement the site inventory. Agency names and addresses can be obtained through the National Recreation and Park Association, 1700 Pennsylvania Avenue, N.W., Washington, D.C.

C. Use mailed questionnaire to private and commercial recreation groups to locate nonpublic sites. Obtain names and addresses frcm local Chambers of Commerce. Use of questionnaires may require approval of the Bureau of the Budget, in accordance with the Federal Reports Act.

A classified listing of water oriented recreation activities which should be included in the survey is presented in Table VII.

3. Determine the water quality at each recreation site for each pollutant listed in Table VI.

4. Compare the water quality levels so determined with the water quality parameters established for each activity.

A. If the water quality level falls within the effective range for that activity, the pollutant has no effect on the activity, and the economic benefit attributable to water quality improvement for that activity would be zero.

B. If the water quality level falls within the affected range, it will be necessary to determine the extent to which participation is affected, as an economic benefit will likely accrue through water quality improvement.

5. In order to estimate the effect of different levels of water

TABLE VII

WATER ORIENTED RECREATION ACTIVITIES

DIRECT BODY CONTACT

- Swimming
- Skin Diving
- Water Skiing

INDIRECT BODY CONTACT

- Boating
  - Motor
  - Sail
  - Canoe
  - Row
- Fishing
- Hunting
- Outdoor Education and Nature Study

NON-BODY CONTACT

- Camping
- Picnicking
- Sightseeing
  - Riding for pleasure
  - Walking for pleasure
- Vacation Cottaging

quality on recreation participation at each site, some assumptions must be made, as follows:

A. It will be assumed that the demand for recreation in metropolitan areas exceeds the supply, and that water-oriented recreation areas are particularly in short supply. This rationale is well-documented in the 1962 publications of the Outdoor Recreation Resources Review Commission[90, 104].

B. It will be assumed that each recreation site has an identifiable optimum annual carrying capacity. Optimum carrying capacity is defined as the highest desirable level of use (in recreation days)** for each type of recreation area. This is determined according to two factors:

(1) the ability of the resource to sustain recreation traffic without deterioration of the resource;

(2) the density (people per area ratio) that can be accommodated without detracting from the quality of the recreation experience.

Carrying capacity is a management concept which is now being applied in some state and national parks for campgrounds, and in some public park and recreation systems on such areas and facilities as picnic grounds and swimming pools.

Carrying capacity studies for recreation use areas are currently being conducted by the San Antonio District Office of the Corps of Engineers

---

**A recreation day is defined as a standard unit of use consisting of a visit by one individual to a recreation development or area for recreation purposes during any reasonable portion or all of a 24-hour period. (P.3, Supplement No. 1, Senate Document No. 97, President's Water Resources Council).

in cooperation with Texas Technological College through the Corps of Engineers Graduate Associate Program.

Pending establishment of carrying capacities which are pertinent to each region, the task of estimating annual carrying capacities could be assigned to the same jury described in step 1.

C. It will be assumed that each recreation site will operate at optimum annual carrying capacity if water quality is maintained within the effective range. The jury will be required to estimate the effect upon carrying capacity of decreasing levels of water quality. The task of the jury will be to estimate the following:

(1) the optimum carrying capacity of the site at the effective range of water quality;

(2) the drop-off in carrying capacity of the site at successively decreasing levels of water quality in the affected range.

These varying levels of carrying capacity can be shown on a scale depicting the percent of carrying capacity estimated at each water quality level.

6. Determine the improved water quality level that would be attained if harbor dredgings were not dumped in the area. This is being worked on by the Corps of Engineers.

7. Identify, on the jury percent scales, the percent of carrying capacity of the site at the existing water quality level.

8. Identify, on the jury percent scale, the percent of carrying capacity of the site at the improved water quality level.

9. Subtract the carrying capacity percent at the existing water quality level from the carrying capacity percent at the improved water level. The difference is the percent increase in participation attributable

to improving the water quality (see Figure 5). If more than one pollutant has an identifiable effect, the calculation should be based on the pollutant which has the most restrictive effect on recreation participation, since it would be impossible to identify the multiple effects of more than one pollutant. The possible permutations and combinations would be too numerous to handle in any reasonable way. This procedure will necessarily result in a conservative estimate of monetary benefits attributable to increased recreation participation.

10. Calculate the number of recreation days attributable to improved water quality by multiplying the carrying capacity of the site by the percent difference identified in step 8.

11. To establish a monetary value attributable to increased participation in a given activity at a given site as a direct outcome of water quality improvement, multiply the increase in recreation days identified in step 10, by a monetary value per recreation day as authorized in Supplement No. 1, Senate Document 97.

12. For each site within a sector, sum the monetary values attributed to each recreation activity as established in step 11.

13. For each sector, sum the monetary values attributable to each site as established in step 12.

Conclusion

It is feasible to estimate the monetary values attributable to increased recreational use of the Great Lakes as a result of water quality improvement through nondumping of harbor dredgings. The estimates will, at best, be approximations because of the lack of precise methods of (a) projecting recreation demand and (b) allocating accurate monetary values

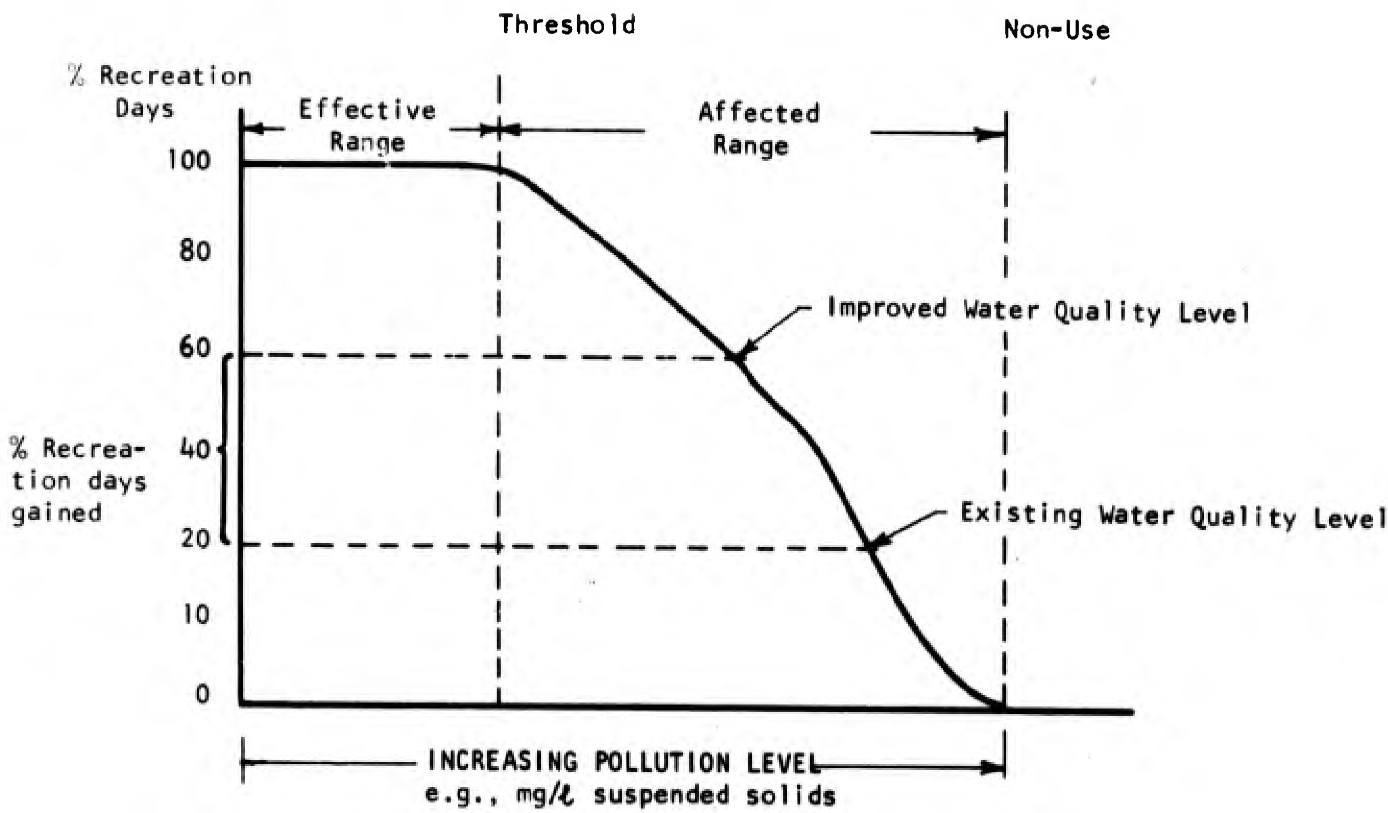

Threshold
Non-Use
% Recreation Days
Effective Range
Affected Range
100
80
60
40
20
10
0
% Recreation days gained
Improved Water Quality Level
Existing Water Quality Level
INCREASING POLLUTION LEVEL
e.g., mg/ℓ suspended solids

FIGURE 5

to recreation activity days. Use of an approximate value is justified, however, since allocating a zero value, when a positive value is known to exist, would be a disservice to the public interest as it seeks satisfaction of recreation needs.

Recommendations

Three specific areas of recreation research should be supported to enable more efficient methodology in studies of this kind:

1. Intensive research is needed on water quality parameters for recreation, and particularly upon the effect on recreation participation of multiple pollutants acting at the same time in the same location.

2. Research to identify the recreational carrying capacity of water resources under varying quality conditions is essential to sound planning and management practices for water resources.

3. Studies to identify realistic monetary values attributable to recreation activity days are essential to the development of valid economic evaluation procedures.

COMMERCIAL FISHERIES

Effect of Water Quality

The economic benefits attributable to commercial fishing as a result of changes in dredging operations are difficult to evaluate. Beeton has summarized the series of chemical-physical changes occurring in the Great Lakes.* According to Beeton, these eutrophic changes have been accelerated due to man's activity[115]. Gradual decline in the numbers of prime commercial fish species (e.g., white fish, Coregonis Clupeaformis) can be attributed to pollution of the lake environment[114]. Beeton has shown that overall changes in the lakes can be measured by a number of chemical parameters from data taken at lake water plant intakes. Gradual changes, generally increases, in a few measured factors taken at a few specific sites where data are available correlate well with the decrease in numbers and kinds of prime fish species. "Relatively little information is available on past conditions in most areas of the Lakes, since extensive limnological studies have been undertaken only within the past 15 years."[114] Dredging operations are on the one hand likely to bring about immediate, grossly noticeable changes at the dredging and disposal sites; but on the other hand the overall net affect of the open water disposal of dredged material might be a general impairment to the overall lake benefits. Thus, any methodology for estimating effects of change in quality on numbers of each fish species is dependent on identifying and studying the effect of quality parameters, as Beeton so succinctly outlined

*A. F. Beeton, Indices of Great Lakes Eutrophication (Pub. No. 15, Great Lakes Research Division, The University of Michigan, 1966).

in his cited papers. But the measurement of these parameters, as they affect each fish species in different areas of the Lakes, have yet to be made.

Methodology

1. Estimate effect of change in quality on the number of each species of fish.
2. Assume percentage change in catch equals the percentage change in population of each species.
3. Multiply the change in catch by the weighted average market price less the additional cost of catching the fish.

Discussion of Methodology

A recent study by the Great Lakes Fishery Commission suggested an approach to calculating net benefits to commercial fishing in Lake Superior from the lamprey control program[116]. The Commission obtained data on the costs and revenues of the U.S. and Canadian fishing fleets operating in Lake Superior during 1965 and 1966. There were 85 U.S. vessels in Lake Superior in 1965. They made 7,069 units of effort. A unit of effort is 1,000 feet of gill net lifted once. The average cost per unit of effort for the two most efficient vessels was $4.77. This information from the Commission report can be used to illustrate an approach to calculating the net benefits from improvement in water quality. The numbers used are hypothetical and are for illustrative purposes only. The size of changes are exaggerated to simplify understanding.

If the impact on the fish population from changing the dredging operation would be slight, the net gain to commercial fishing from the change would be the increased receipts from the catch because no additional effort would be required. For example, if the catch before the change was 10 pounds per unit of effort and the average market price of the catch was 50 cents per pound, the sales would have been $5 per unit of effort. If water quality improves and the catch increases to 12 pounds per unit of effort, and there is no change in total units of effort, or in the price per pound of fish, the net benefit to the economy is the increase in value of the catch. That is,

$0.50 x 2 pounds = $1 per unit of effort

7,069 units of effort x $1 = $7,069 total net benefits.

Another possibility, of course, is that the catch changes in value because of a change in the species caught. A greater percentage of more desirable species such as Lake Trout would increase the average value of the catch per unit of effort. In the above hypothetical illustration, an increase in the value of the catch to an average of $0.60 per pound would increase the sales to $7.20 and thus increase benefits to $2.20 per unit of effort, or a total of $15,552.

The Commission's study of the Canadian fishing fleet was not reported in a manner comparable to that of the U.S. fleet. They obtained a sample of thiry vessels and reported on the average costs of operating the ten most efficient vessels. They did not, however, report these costs per unit of effort, as was done for the U.S. fishing fleet. The Canadian study recognized an additional difficulty in assessing the cost of fishing enterprise. Costs may vary not only with the units of effort, but with the value of the catch. Wages may be based partly on the value of the catch. The crew may receive a percentage share of the value. The Canadian study considered this to be an increased cost, lumping crew's shares together with wages. Current Federal policy, however, would consider all benefits, whomsoever they may accrue. Therefore, if the crew receives a share of the cooperative venture, their share would be part of the profit and would be included in the benefit. The opportunity cost of the crew's labor must be deducted, however, if their wages are not already deducted.

Wages and earnings of fishermen and owners may be less than they could earn in alternative occupations. In calculating the net benefits of a public investment it might seem appropriate to include in the costs of operation of the fishing enterprises the loss to other production in the community because these men are fishing. Consider the following example. If a fisherman is making $4,000 per year, while in another occupation he could be making $5,000 per year, it might seem appropriate to include an additional $1,000 in the cost of the fishing operation. One could argue, however, that these men prefer this occupation, and are willing to earn less and stay in the business, rather than earn more in another occupation. Thus, to society as a whole, including these men, this is not a cost. It is offset by the intangible benefits of fishing to these men. Therefore, it would not appear appropriate to include these opportunity costs in the costs of the fishing operation.

If there is expected to be a major change in the value of the fish catch, profits of existing enterprises would rise. The existing enterprises would increase their fishing effort, and new enterprises would find it worthwhile to enter the business. This is assuming that quotas or other governmental restrictions would allow more fish to be caught. The increased effort might affect the pounds of fish caught per unit of effort. Thus, the above illustration might be changed in the following way. With no additional units of effort the fishing catch would increase from 10 pounds to 20 pounds per unit of effort. This might so increase profits that additional units of effort would be encouraged. This increased effort might cause the catch per unit of effort to be reduced to 15 pounds. The net benefit from the change in water quality would then be the increase in value of the 5 pounds of catch for each of the original 7,069 units of effort plus the net profit on the additional units of effort. The net profit on these additional units would be the value of 15 pounds of fish less the total costs of each unit of effort times the additional number of units of effort.

Conclusion on Feasibility

The calculations for estimating the net benefits to commercial fishing can not be undertaken until much more is known about the ecology of the Great Lakes. Perhaps some information will be made available in the report of the Board of Consultants that is to be completed around December 1968. If it is possible to estimate a change in the fish population resulting from changing dredging operations, then it is feasible to estimate the net benefits. The cost studies by the Great Lakes Fishery Commission might make it unnecessary to conduct another survey of the fishing industry in Lake Superior. The industry in the other lakes where they would be affected would have to be surveyed. A sample survey rather than a complete census would be adequate to determine the nature of costs in the industry. Consideration of the ecology of the Great Lakes, however, would make us think that the impact of changes in quality on the fish population resulting from changing dredging operations is not going to be feasible for several years.

AESTHETIC RESPONSES AND VALUES

Effect of Quality

The problem of aesthetic responses to variations in water quality leads to consideration of the following: exposure to water conditions, aesthetic and evaluative responses to the exposure, behavioral outcomes subsequent to exposure, and the economic impact of the behavior.

Exposure: There are two subconsiderations. a) characteristics of persons making contact with Great Lakes water, for example, their income, property ownership, purpose of contact, frequency of contact, periodicity of contact, age, etc. b) the mode of perceptual contact, e.g., visual, olfactory, gustatory, tactual, and auditory, or the mode of symbolic contact, e.g., verbal, newspaper, magazine, and other media.

Measurement of the first of these would employ standard survey techniques and would be relatively expensive. While feasible, unless such information is of specific utility for other reasons, it could be neglected as it does not relate directly to the question of the determinants of aesthetic response to water quality variation. Questions would be of the following types: What proportion of the population come into direct perceptual contact with Great Lakes water? What proportion of the population come into contact with symbolic descriptions of Great Lakes water? What is the distribution of contact across person and purpose types and across water quality variables? Answers to these questions are not considered as important as other classes of data to be presented in this chapter.

Laboratory study of modes of perceptual contact other than the visual mode is difficult. The control of olfactory, gustatory, tactual and even auditory stimuli such that they are of known composition and magnitude and are perceived to represent states of the natural environment is at the very best difficult. Visual contact would seem to predominate and seems the most obvious first place to look for relations of water quality variation to aesthetics and values.

Modes of symbolic contact with water quality variation is an important source of information concerning water quality and will be considered as an antecedent of aesthetic response.

Aesthetic and evaluative responses to exposure: The aesthetic responses are relatively "pure" evaluative responses. These are measured by a response device (the Semantic Differential) using bipolar adjectives representing the evaluative component of connotative meaning as described by Osgood, *et al*.[127]. Examples of these bipolar adjective scales are good-bad, beautiful-ugly.

Another class of evaluative responses has denotative content, as opposed to the connotative meaning of the aesthetic responses. This class is a set of inclusive values such as "freedom", "the good life", "continued security for our species", etc. Four distinctions can be made within this class of values: personal values, societal values, natural environmental values, and values specifically related to water quality in the Great Lakes.

We can determine the relation of water quality variables to variation in a) aesthetic responses, and b) the degree to which people view their values as being promoted by or blocked by a given level or change in a water quality variable. This reflects the extent to which they "value" the level or change. This "value" is theoretically related to satisfaction or apprehension, and related to behavioral and economic outcomes.

Behavioral and economic outcomes: It does not seem useful to speculate here about the possible effects that aesthetic responses or other values related to water quality might have on behavior, either in the market place or in the ballot box. Such effects do occur and are implicitly reflected in other chapters of this report. For example, aesthetic factors are present in recreation (in site preference and in the effects of water quality on recreational use), in municipal water quality (in demands of taste, smell and clarity characteristics), and in commercial fisheries (in market choice of species). The economic value of the aesthetic component is thereby represented even if it is not specifically identifiable or directly estimated. Separate and specific aesthetic studies could be designed to determine the aesthetic component of decisions such as those mentioned above. Such studies would necessarily be exploratory. Behavioral and economic outcomes such as those mentioned above are not considered in this chapter.

The concern of this chapter: Typically we ask questions about specific antecedents of phenomena, not about a mushrooming set of phenomena caused by a treatment. The phenomena of concern here are levels of aesthetic and valuational responses. The antecedents are variations in perceptible water quality and reported water quality. Changes in levels of aesthetic and valuational responses are considered intangible benefits. The category of aesthetic and valuational responses related to water quality is a residual one: it contains those responses to water quality that have an unpleasant or pleasant "feel", but that do not have any obvious relation to overt behavior. By our present definition, aesthetics are for the most part noneconomic. Economic outcomes of aesthetic response have been taken account of elsewhere, as indicated above. A benefit-cost analysis in dollar terms is not possible for the aesthetic values defined here. There are, however, some areas in which aesthetic values relate to economic considerations in ways not covered elsewhere in this report. These will be noted briefly at the end of this chapter.

Social policy should not always be based solely on economic considerations. It is clear, however, that many issues are ignored until either enough persons with economic power act on the issue, or the issue shows up in the costs of society. The economics and aesthetics of the present may not be an adequate basis for determining social policy. We may legitimately concern outselves, however, with ways in which aesthetic responses may enter the public domain. If they do, the first thing we want to know is the determinants of the responses. If they do not, and rational decisions are made on other than economic criteria, we will want to know the determinants of aesthetic responses and their social correlates. It is the relation of aesthetic and valuational responses to variation in water quality variables that is the focus of this chapter.

Methodology

1. Relation of perceptual water quality variation to variation in aesthetic response.
   a) Identify relevent water quality variables
   b) Select photographs for use as stimuli

c) Obtain aesthetic responses (Semantic Differential) and plot relation to water quality variation

d) Judge importance of water quality variables

e) Determine relative importance of water quality variables

2. Relation of symbolic water quality variation to variation in aesthetic response.

   a) Sample and identify symbolic water quality variables

   b) Obtain aesthetic responses (Semantic Differential) and plot relation to symbolic water quality variation.

   c) Judge importance of symbolic water quality variables

   d) Determine relative importance of symbolic water quality variables.

3. Means-value analysis

   a) Obtain lists of values

      (1) personal values

      (2) societal values

      (3) natural environment values

      (4) Great Lakes water quality values

   b) Reduce the lists

   c) Obtain means-value responses to perceptual water quality variation

   d) Obtain means-value responses to symbolic water quality variation.

Discussion of Methodology

1. Relation of perceptual water quality variation to variation in aesthetic response.

   a) Water quality variables: The following should be examined -- color, turbidity, oil, blue-green algae, filamentous algal species, floating refuse, alewives, and others potentially related.

b) Selection of stimuli. The levels of natural occurrence of these water quality variables should be determined and color photographs taken representative of specific levels of each variable. More than 10 photographs should be taken to represent levels evenly covering the entire range of variation on each variable. The photographs should "abstract" the levels of the variables. That is, no photo should show a "beautiful shore scene", since the context would then become another variable to be eliminated in the research design. The photographs should, however, be identifiable without introducing extraneous variables. A picture of scum shouldn't be a picture of scum clinging to higher aquatic plants, clinging to a baby's legs, nor should it be unidentifiable as scum in lake water. If it can be discovered that dredging disposal practices contemplated will not change a given water quality variable, that variable can be eliminated for purposes of the present study.

c) Obtaining Aesthetic Responses. The Semantic Differential (SD) is an instrument developed in connection with the study of connotative meaning, and has been widely used in the psychological study of aesthetics. It consists of scales of bipolar adjective (e.g., good-bad, ugly-beautiful, hard-soft) that have known factor loadings on various factors, most importantly an evaluative factor. An SD could be constructed from the scales loading heavily on the evaluative factor of connotative meaning, and should be limited to 10 scales. Consult Osgood, et al.[140] for further details and for administration procedures. In addition to the SD scales, add

"Polluted-unpolluted". The SD is scored on a seven-point scale, from -3, through 0, to +3, equivalent in the evaluative context of positive, neutral and negative evaluations.

Using the SD as a response device, and using the method of serial exploration[126] evaluative responses to photgraphs of all levels of all relevant water quality variables can be gathered, and the relation between level of the variable and evaluative (aesthetic) response for each water quality variable plotted.

d) A variable can be judged important if dredging disposal alternatives will affect some water quality variable such that (1) SD responses enter or leave the negative region of the scale, (2) a large change in SD ratings occurs, or (3) if the change in water quality variable will cause the condition to be labeled, or cease to be labeled "polluted". Only "important" variables need to be considered beyond this point.

e) Determining relative importance of Water Quality Variables. Peterson[130] used factor analysis and multiple regression techniques to discover the dimensionality and relative importance of dimensions for photographs of residential neighborhoods. His problem was to discover the variables relevant to preference. Our problem is much simpler. We already know (presumably) the variables. We have no need to seek the equivalence information given by factor analysis, and there are simpler if less elegant methods for determining relative importance. One such method is based on the method of paired comparisons discussed by Edwards[118]. In this technique, all photographs are paired with all others and for each pair a judgment is made of which member is the more preferable. This technique yields a matrix whose values represent the frequency with which each stimulus photograph is preferred over each other photograph. From the values in this matrix the water quality variables can be ranked in terms of their importance for judgments of preference. The photographs chosen for this purpose should be four in number for each water quality variable: two from those with positive SD averages, two from those with negative SD averages. These should be of comparable levels of deviation from the SD neutral point across water quality variables investigated. The paired comparison judgments should be done separately for photographs having positive SD averages and again for those having negative SD averages. It is possible that one water quality variable will be effective in determining preference in the positively evaluated group, and another in the negatively evaluated group. Care must be taken so that the photos used on the positive side of the variables do not all look alike; i.e., represent the total absence of the variable, each being a photograph of "cool, clear, water".

2. Relation of symbolic water quality variation to variation in aesthetic response.

Much contact with information concerning water quality is obtained through symbolic sources, as opposed to direct perceptual contact with the Lakes. Many people will have aesthetic judgments concerning variation in water quality in the absence of direct perceptual experience with the actual appearance of water qualities being described. The problem here is to (i) determine the water quality variables available to the public of this symbolic type, (ii) select the frequently recurring ones, and (iii) determine the relation between symbolic expressions of water quality variables and aesthetic judgments on the SD. Given this information, one can infer equivalence between points on the perceptual-aesthetic scale of water quality variables and the symbolic-aesthetic. That is, a certain level of a perceptual water quality variable will be equivalent to a given level of a symbolic water quality variable insofar as determining aesthetic judgments is concerned. What is not known, which would complete the picture, is the relation between perceptual water quality variation and symbolic variation. This would require studying members of the Press, and does not seem to be feasible.

a) Sampling Symbolic water quality variables. For a period of three years, 1965-1967 inclusive, survey articles from popular magazines, major newspapers of Great Lakes cities, and if possible transcripts of radio and television programs on the issue. Record each instance of mention of water quality, water quality variables, and descriptions of water conditions in the Great Lakes. For each water quality variable mentioned with high frequency, descriptions representing varying levels of the variable should be obtained. Semantic Differential judgments are then gathered for each description, as outlined above. Once the symbolic stimuli are chose, the procedures follow those outlined for perceptual-aesthetic judgments discussed above.

When this phase is completed, information will be available concerning the impact of varying descriptions of lake conditions in the public communications media on public aesthetic response. The relation of actual water quality change to variation in information concerning water quality in the public media is not known. Neither is the relation between public policy concerning water quality and the dissemination of information concerning water quality to the public. These relations seem important in determining the aesthetic feelings concerning water quality in the Great Lakes held by persons who contact the lakes primarily (though not exclusively) via symbolic media. They may be in the majority.

3. Means-value analysis.

Improvement in certain qualities of the natural environment, among them water qualities, can be seen as leading to some values or valued states, and blocking others. Similarly, degradation of these qualities can also be placed in a means relation to values or valued states. Numerical indices can be constructed that will take account of the general facilitating or blocking effect attributed to changes in water quality variables. This can be done for particular water quality variables, or for composites, and various ranges of variation on the water quality can be used: if a general relation is sought, the entire range observable can be examined; if consequences of change from one level of a variable to another are of interest, the two levels only can be focused upon.

The technique is described by White[138] and used by Rosenberg[132, 133].

Briefly, values are placed on a 21 point "value importance" scale (from "gives me maximum satisfaction" to "gives me maximum dissatisfaction"). A social policy or other event (reducing turbidity of water to the point shown in a particular photograph) is then given a "degree of instrumentality" on an 11 category scale according to the degree of attainment (+5) or blocking (-5) caused by the policy for each value. The value importance score is then weighted by the "degree of instrumentality" rating, and summed across all values. The index has a range of -50 to +50. Negative scores indicate negative values, positive scores positive values. Note that blocking of a negative value yields a positive score, indicating that for the individual it's a positive, or good, thing.

Four types of value lists should be gathered: personal values, societal values, values related to pollution of the natural environment in general, and values related to pollution of the Great Lakes in particular.

i. Personal values can be gathered in response to a question such as "What are the five most important personal values or personal goals that you have in life?".

ii. Societal values can be gathered in response to a question such as "What are the five most important values or goals that our country has for itself as a human society?".

iii. Values related to pollution of the natural environment can be gathered in response to a question such as "What important things or values in your life would follow (would be prevented by) cleaning up our natural environment (forests, parks, lakes, air, etc.) and stopping pollution of them (continuing pollution of the natural environment; e.g., forests, parks, lakes, air, etc.). There are really four separate questions here.

iv. Values specifically related to the Great Lakes can be gathered by an adaptation of each of the four forms of the question in iii.

Once, values have been gathered, the list can be reduced to a few values of each type, perhaps 5. Factor analysis could be applied to the frequency scores for values, separately for each type of value, to discover important value clusters to be represented.

When a final list of approximately 20-30 values has been prepared, the means value analysis can and should be approached in two ways. Firstly, the relation of changes in important water quality variables (either single or in composite) to values can be determined using photographs that represent an anticipated or contemplated variation on water quality variables within a perhaps narrow range, or represent the entire range of possible variation so that the more general relation between water quality variation and value is determined.

Secondly, verbal descriptions obtained from public media can also be used as stimuli, as described in part 2) above. These descriptions should be used in a way similar to that proposed above in 3.c. for the photographs, and for the reasons stated in Part 2).

This data will give information about the "value" of changes in water quality variables in the Great Lakes in the four value areas. In addition, it will provide a rough estimate of the impact of such change on important values, from perceptual contact with the water quality variables through photographs, and from symbolic contact through public media descriptions. It is then possible to relate photographs to the stimulus for the description and derive an estimate of the relative impact of the two sources of contact with water quality information.

4. Subject population from whom judgments are elicited.

The subjects should be sampled from the geographical area surrounding the location of proposed changes in dredging practice. The number of subjects per set of judgments should be on the order of 150 total. A different set of subjects should be used in the Semantic Differential tasks and the paired comparison judgment tasks. Each subject group should number about 150.

There are a number of distinctions between groups of subjects (persons) that would be potentially interesting; e.g., rural-urban, socio-economic status, geographical mobility, occupation type, prior utilization of water resources, especially for aesthetic-recreational purposes. See also distinction made on page 72. It does seem, however, that the first and more important steps do not involve distinctions of this type: general responses of people are what are required. Finer breakdowns are more expensive and reflect a more intense interest in the sociology of aesthetics than seems appropriate in the present context. These finer breakdowns are potentially interesting, however, and perhaps are along the directions further investigation in this area will follow.

Subjects for the studies discussed here should therefore be representative of the general population in the area of the studies. Data of the types suggested above could certainly be collected, and the analyses suggested here could be done separately for different subject groups for purposes of comparisons between them. We make no proposals or analytic suggestions along these lines at present except to note the possibility.

5. Some additional outcroppings of aesthetics into economic behavior.

The relation of aesthetic qualities to economic values and economic behavior will continue to be an important if problematic issue. A systematic interdisciplinary study of the relationship is in order. Some potential outcroppings of the relationship are listed below. It seems possible to obtain relative values (compared with other social issues) from these sources, and absolute values from some. There are problems in obtaining real dollar values from these indices because they are not exhaustive of the class of economic effects.

a) costs of radio and TV time given over to discussion of aesthetic aspects of natural environments.

b) costs per word for newspapers and popular magazines, weighted by the number of words concerning aesthetic response to natural environments. This index can be used to gain a comparative index of economic contribution of different social issue . This contribution can be taken as an index of importance.

c) value of volunteer time spent in advancing aesthetic considerations in public policy.

d) costs of environmental research, journal space, and editorial time, enter into the valuational system.

e) premiums paid for lake side apartments, vista views, park views, and surrounding trees and bodies of water. Real estate holders would be good subjects in estimating the relation between variation in perceived water quality and anticipation of falling real estate values.

Feasibility

The gathering of data concerning the relation of aesthetic response to both perceptual contact with water quality variables and symbolic contact with water quality variables is feasible. It will yield no information about economic outcomes of change in water quality variables. Other data mentioned in this chapter is either not feasible to gather, is not of primary importance, or are (to our knowledge) unexplored avenues of data bearing upon the aesthetic issue and therefore not proposed. Which of these is true in any given instance is discussed above.

The study of economic outcomes of psychological responses to the aesthetics of the natural environment is not presently feasible. Persons concerned with specific classes of such outcomes may be able to estimate the magnitude of the aesthetic component in the phenomena they study, and a methodology similar to the one proposed here might form the basis for investigating the relation between aesthetic judgments and economic behavior.

When public policy decisions are made solely on the basis of economic considerations, the aesthetics of the matter cannot be included. If policy decisions will be made in part on aesthetic and valuational basis there will be no numbers to guide, nor formulas to follow. There never has been in the question of the values of a society.

CONCLUSIONS AND RECOMMENDATIONS

We believe our studies support the following conclusions:

1. The first step in evaluating the economic benefits which might accrue from modifications in the disposal practices for dredged material is to determine the effect of the change on certain water quality characteristics at points of use. The feasibility of determining monetary values of the benefits will depend largely upon the success in identifying the changes in water quality, bottom quality and shore quality at points of use. This step is beyond the scope of our study, but is important to the feasibility of benefit evaluation.

2. The benefits of the many uses of water involve an extremely complex system. Systems analysis presents an orderly method of considering the many components in the system.

3. The tangible benefits which will be important are those which accrue to municipal and industrial water treatment plants, to recreation activities, and to the commercial fishery. Aesthetic aspects will be important, but will be intangible and cannot be measured in monetary terms.

4. Determination of the benefits to municipal water treatment plants is feasible provided the changes in quality of raw water at the intake can be evaluated and provided a reasonable correlation can be developed between chemical dose and a few water quality characteristics for each treatment plant.

5. The important characteristics of raw water quality for municipal water supplies, in this case, are believed to be turbidity chlorine demand,

total extractable organic matter (or perhaps threshold odor number), total plankton mass, and hardness. The Pilot Project should seek to determine the relation between these characteristics and dredging operations at each of the study sites.

6. The same general methodology which is proposed for evaluating municipal water supply benefits can be used for industrial water supplies. The same limitations in the feasibility apply and the same raw water characteristics are important. In addition, dissolved solids, dissolved gases, and presence of slime forming organisms may be important at industrial water intakes.

7. It is feasible to obtain a conservative estimate of the monetary value of increased recreational use of the Great Lakes as a result of water quality improvements provided the water quality improvements can be identified. The estimates will be approximations because of lack of precise methods of projecting recreation demand and allocating accurate monetary values to recreation activity days.

8. Further research is needed to identify water quality parameters for recreation uses, carrying capacity of recreation facilities and monetary values attributable to recreation activity days.

9. If it is possible to estimate a change in fish species population resulting from a change in dredging operations, then it is feasible to estimate the net benefits. Consideration of the ecology of the Great Lakes, however, would make us think that the determination of the impact of changes in quality on the population of commercially important fish species resulting from dredging operations is not going to be feasible for several years.

10. Determination of economic outcomes of psychological responses

to the aesthetic character of the natural environment is not presently feasible. Some quantitative measures of the extent of exposure of people, both perceptually and symbolically, could be made if sufficient funds for a rather expensive survey were available. We do not recommend it in this case.

11. The gathering of data concerning the relation of aesthetic response to both perceptual and symbolic contact with water quality variables is feasible. Methodologies have been proposed for this.

12. Behavioral response and the economic valuation of it are not sufficiently understood to indicate that they could be determined by sampling a reasonable number of people. Because it is not feasible to study the entire population and the entire universe of behavior, these cannot be determined.

The following recommendations are appropriate:

1. The Corps of Engineers should continue long-term studies of the effects of dredging operations on water quality.

2. If these effects can be determined, then a definitive evaluation of water supply and recreation benefits should be undertaken for an area affected by one dredging site as a test of the methodologies presented here.

3. When understanding of the ecology of the Great Lakes has progressed to the point that the effect of dredging disposal operations on fish populations can be determined, then the benefit to the commercial fishery should be included in the analysis.

4. Research is badly needed to develop the interrelationships between the many components of the water resource system so that the

evaluation of benefits which cannot now be accomplished will become feasible, and the precision of the evaluation of benefits which can now be evaluated will be greatly improved.

APPENDIX A

A CONCEPTUAL WATER QUALITY MODEL FOR BENEFIT-COST ANALYSIS

Conceptual Model for Evaluation of Benefits due to Improved Water Quality

Let a lake be divided into any number of sectors such as Lake A in Figure 1. These sectors are areas in which strong water quality interrelationships exist and in which the water quality is influenced more by what occurs in the sector than by neighboring sectors. Sectors may be defined by the water uses.

Some of the major water uses and water quality parameters are given in Table 1.

Table 1

USES

Commercial fishing	Irrigation
Cooling water	Recreation:
Domestic waste carrier	Swimming
Domestic water supplies	Wading
Industrial waste carrier	Fishing
Industrial water supplies	Boating
	Sightseeing

WATER QUALITY PARAMETERS

Bacteriological indicator tests (coliform, enterococci, etc.)	Organic material
Carbon dioxide	Phenols
Color	Phosphorous compounds
Dissolved oxygen	Plankton (number, diversity)
Dissolved solids	Suspended solids
Hardness	Tastes
Nitrogen compounds	Temperature
Odor	Toxic substances
	Turbidity

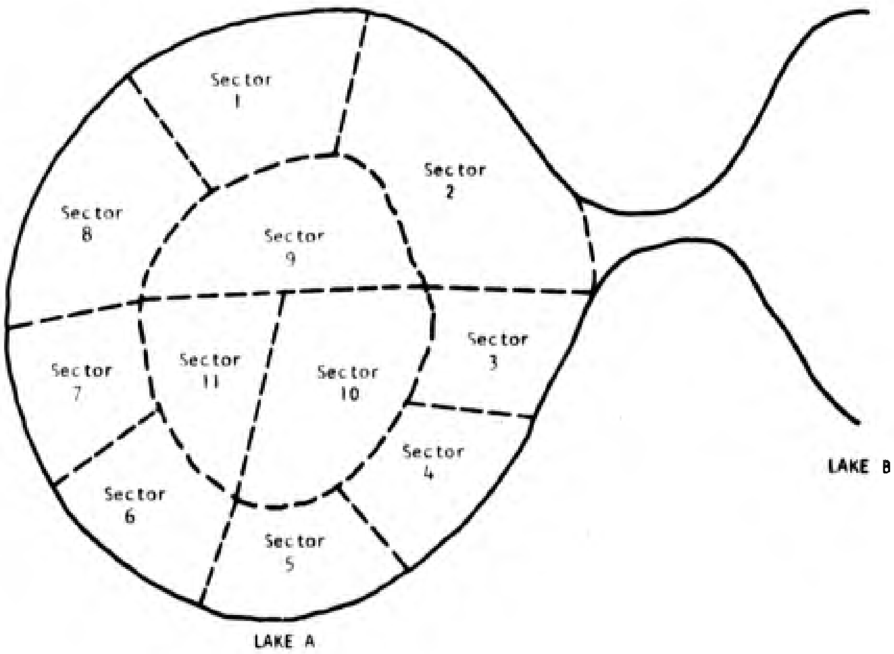


Figure 1
Division of lake into sectors.

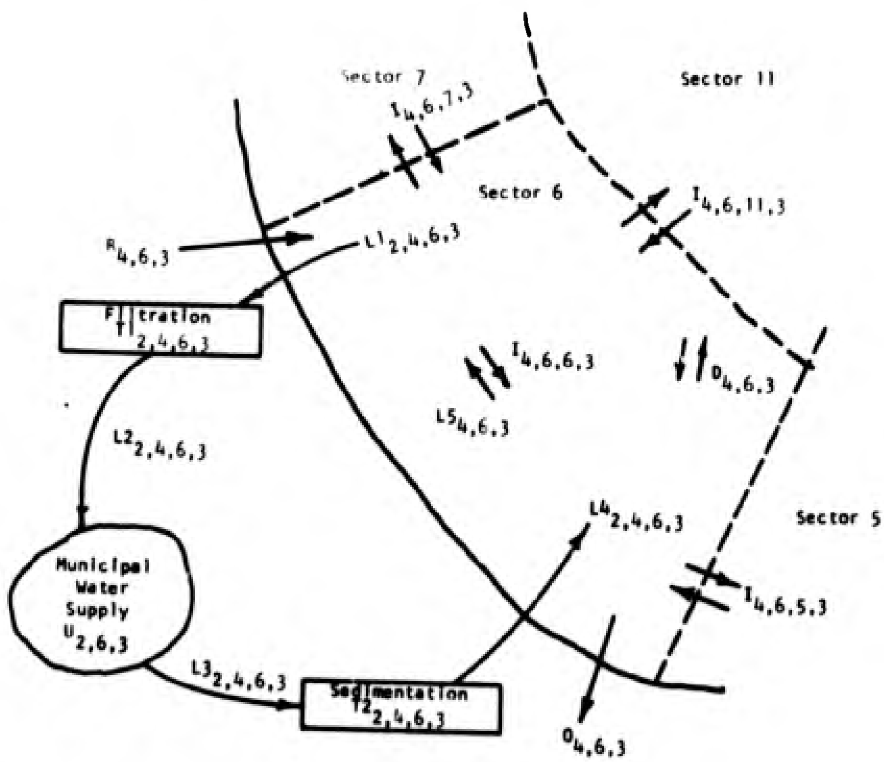


Figure 2
Sector 6 of Lake 3 showing municipal water supply as Use 2 influenced by water quality parameter 4.

The variables used in the water quality model for benefit-cost analysis are defined below. The first column contains the variables, the second column defines the variables in general terms, and the third column defines the variables for a specific problem shown in the example which is for evaluating benefits due to a reduction of suspended solids in the raw water at the intake for municipal water supply.

Table 2

Definition of variables used in water quality model for benefit-cost analysis.

Variable	Variable Definition	Example Variable
Subscripts:		
i	identifies the use	municipal water supply = 2
j	identifies the water quality	suspended solids = 4
k	identifies the lake sector	the area of water included in lines 30 miles north, 30 miles south and 30 miles east of Milwaukee = 6
l	identifies the lake	Lake Michigan = 3
m	identifies the sectors adjoining to sector k	
t	identifies the season or time	
ni	total number of different uses	total number of water uses in the series of lakes
nj	total number of different water quality parameters used for all uses	the total number of water quality parameters felt to be significant for all uses
nk	maximum number of sectors in any lake	the maximum number of sectors any lake in the system is divided into

Variable	Variable Definition	Example Variable
nl	total number of lakes in the system	for Great Lakes; nl = 5
U_{ikl}	the i-th specific use of the water in the k-th sector of the l-th lake	municipal water supply for Milwaukee
$T1_{ijkl}$	the treatment, management, or enforcement controls for the j-th water quality parameter on the influent water to the i-th use from the k-th sector of the l-th lake	filtration to remove the suspended material from water used from this sector for municipal water supply
$T2_{ijkl}$	the treatment, management, or enforcement controls for the j-th water quality parameter on the effluent water from the i-th use to the k-th sector of the l-th lake	filtration to remove some of the suspended solids added to water as a result of municipal use before it is returned to this sector of the lake
$L1_{ijkl}$	level of the j-th water quality parameter in the k-th sector of l-th lake at the point where the water is collected for the i-th use	the concentration of suspended solids at the location of Milwaukee's water supply intake, mg/l
$L2_{ijkl}$	level of the j-th water quality parameter after treatment and before i-th use in k-th sector of l-th lake	the concentration of suspended solids in the water used as Milwaukee's city water, mg/l
$L3_{ijkl}$	the level of the j-th water quality parameter after the i-th use and before treatment and returning to the k-th sector of l-th lake	the concentration of suspended solids in the water after being used in Milwaukee's distribution system, mg/l
$L4_{ijkl}$	the level of the j-th water quality parameter after treatment following i-th use as it is returned to the k-th sector of the l-th lake	the concentration of suspended solids at the location where the return flow from Milwaukee's water supply is put into the lake, mg/l

Variable	Variable Definition	Example Variable
$L5_{jkl}$	the average level of the j-th water quality parameter in the k-th sector of l-th lake	the average concentration of suspended solids in the water zone described above, mg/l
$LI1_{ijkl}$	the level of the j-th water quality parameter in the k-th sector of l-th lake at the point where the water is collected for the i-th use after the water quality in the lake has been improved	the concentration of suspended solids at Milwaukee's water supply intake after the concentration has been reduced by some means, mg/l
$LI2_{ijkl}$	the level of the j-th water quality parameter in the k-th sector of l-th lake after treatment and before use after a reduction in $L1_{ijkl}$	$LI2_{ijkl} = L2_{ijkl}$
I_{jkml}	the relationship which describes the extent to which the level of the j-th water quality parameter in the m-th sector affects the level of the j-th water quality parameter in the k-th sector of l-th lake. When m = k this is the relationship which describes the effect of biota and other objects in the k-th sector on the level of the j-th water quality parameter in the k-th sector of l-th lake	the relationship which describes the extent to which the concentration of suspended solids in a neighboring sector affects the concentration of suspended solids in the sector of Milwaukee's water supply
D_{jkl}	the interaction between the sediments and the overlying lake water in the k-th sector of l-th lake involving the j-th water quality parameter	the relationship which describes the effect of sediment deposition and uptake on the level of suspended solids in the sector adjacent to Milwaukee

Variable	Variable Definition	Example Variable
R_{jkl}	water discharging into the k-th sector of l-th lake, which was not taken from this sector, and which involves the j-th water quality parameter	the extent to which untreated urban storm drainage affects the concentration of suspended solids in the sector adjacent to Milwaukee
O_{jkl}	diversion of water from k-th sector of l-th lake involving the j-th water quality parameter	the exportation of water from the sector adjacent to Milwaukee to another sector or drainage basin which affects the concentration of suspended solids in the sector adjacent to Milwaukee
$C1_{ijkl}$	cost of treatment to remove one unit of the j-th water quality parameter per unit of the i-th use in the k-th sector of l-th lake	cost to reduce the suspended solids one mg/l per million gallons of water use by Milwaukee, ($/(mg/l))/million gallons
$C2_{ijkl}$	cost of treatment to remove one unit of the j-th water quality parameter per unit of water treated after i-th use in the k-th sector of l-th lake	cost of reducing the suspended solids one mg/l per million gallons of water treated after being used for Milwaukee's water supply ($/(mg/l))/million gallons
$CU1_{ikl}$	total cost of treatment for all water quality parameters for the i-th use in the k-th sector of l-th lake	cost of treating all water for municipal water supply taken from this sector, $
$CU2_{ikl}$	total cost of treatment for all water quality parameters after the i-th use in the k-th sector of l-th lake	cost of treating all municipal water supply return flow before it is returned to lake, $
TC1	total cost of treatment for all water quality parameters for all uses in the lake system before use	

Variable	Variable Definition	Example Variable
TC2	total cost of treatment for all water quality parameters after use and before it is returned to lake for all uses	
TCL	total cost of water treatment in the lake system for all water quality parameters for all uses	
N_{ikl}	number of units of the i-th use in the k-th sector of l-th lake	number of million of gallons of water supply taken from this sector
B_{ikl}	benefits from one unit of the i-th use in k-th sector of l-th lake	amount of benefits for one unit of water supply in Milwaukee, $/million gal.
TB	total benefits for all uses in the lake system	
ΔB_{ikl}	increase in value of one unit of i-th use in k-th sector of l-th lake due to a reduction in Ll_{ijkl}	increase in value per million gallons of municipal water supply due to a decrease in suspended solids at intake not including reduced cost of treatment, zero in example
ΔN_{ikl}	the number of units of increase in i-th use in k-th sector of l-th lake due to a reduction in Ll_{ijkl}	
BT_t	total benefits attributed to a reduction in Ll_{ijkl}'s for all uses in the lake system for the t-th period	
NB	net benefits for all uses in the lake system under initial conditions	

Variable	Variable Definition	Example Variable
$LI4_{ijkl}$	an effluent standard for the level of the j-th water quality parameter for the i-th use in the k-th sector of the l-th lake	
UK	intangibles	may be the aesthetic value of reducing the level of suspended solids in drinking water to a level below the value set by standards
AC	total added cost to all uses in the lake system due to new effluent standards on users	
E	administration and enforcement cost to cause users to meet new effluent quality standards	

Figure 2 shows an enlarged view of one sector of the lake with one use of the water in that sector. The water is withdrawn from the lake, treated, used, treated, and returned to the lake in this sector. Also indicated are the interactions between the various lake sectors and interactions within the sector. Associated with each water use are benefits attributed to that use and there are costs attributed to the treating of the water before and after use.

Figure 2 may be converted into a box diagram, Figure 3, to show the general network of the model. The model is based on the identification of degree of water quality based on a specific use and the benefits and costs associated with that use. Figure 4 then illustrates the modular arrangement that can be used to extend the model to represent the interaction between uses within a sector and adjoining lake sectors.

This discussion is not concerned with the relationships for the I's, O's, R's, and D's and their influence on the LI's of the model. It will be assumed that these are known, since they are to be determined by a different study and used as inputs to this model.

Cost of treatment before water is used in i-th use in k-th sector of l-th lake = the sum for all water quality parameters of ((the cost of removing the j-th water quality parameter per unit of parameter removed per unit of use) x (number of units used) x (level of the j-th water quality parameter at raw water intake - the level at which the j-th water quality parameter that can be used) all for i-th use in k-th sector of l-th lake)

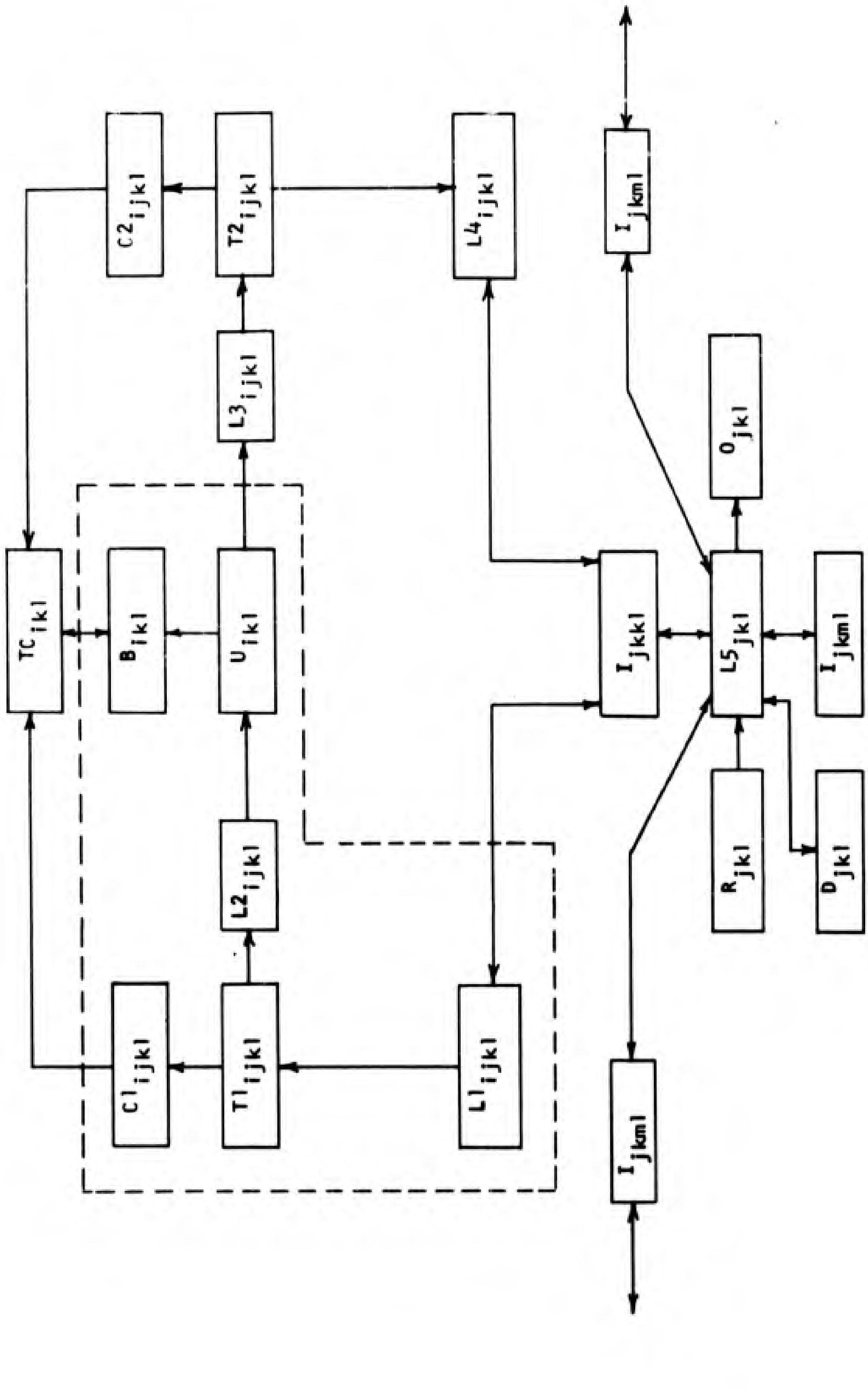


Figure 3
Box Diagram

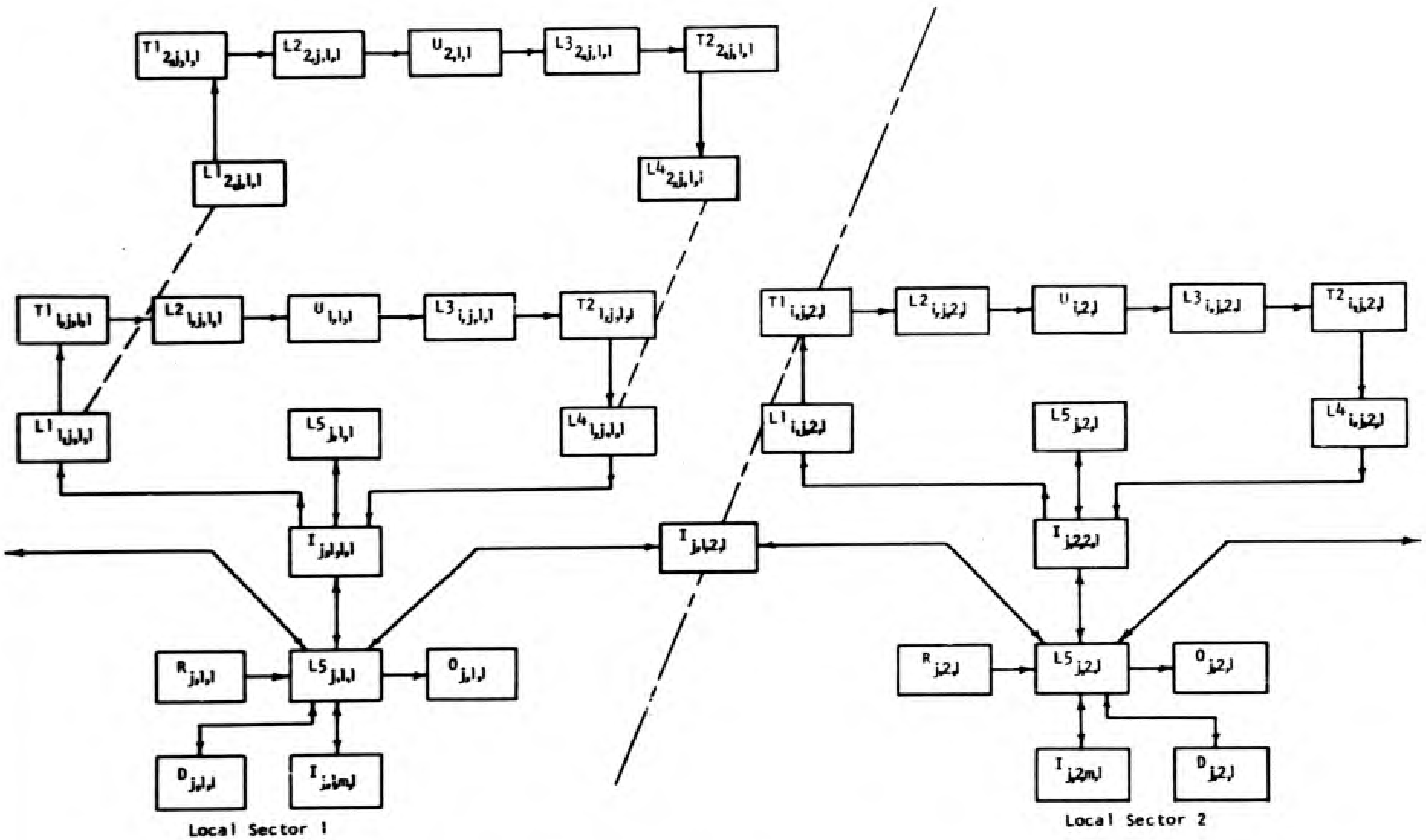


Figure 4

Box diagram showing modular nature of model with uses 1 and 2 in Sector 1 and Use i in Sector 2.

$$CU1_{ikl} = \sum_{j=1}^{nj} (C1_{ijkl} \times N_{ikl} \times (L1_{ijkl} - L2_{ijkl})) \qquad \text{Eq. 1}$$

Total cost of treatment for all uses in the lake system before use = the sum for all lakes of the sum for all sectors of the sum for all uses the cost of treatment for each use in each sector of each lake.

$$TC1 = \sum_{l=1}^{nl} (\sum_{k=1}^{nk} (\sum_{i=1}^{ni} (\sum_{j=1}^{nj} (C1_{ijkl} \times N_{ikl} \times (L1_{ijkl} - L2_{ijkl}))))) \qquad \text{Eq. 2}$$

Eq. 2 can be rewritten as

$$TC1 = \sum_{l=1}^{nl} (\sum_{k=1}^{nk} (\sum_{i=1}^{ni} (CU1_{ikl}))) \qquad \text{Eq. 3}$$

Similarly the cost after treatment can be written as

$$TC2 = \sum_{l=1}^{nl} (\sum_{k=1}^{nk} (\sum_{i=1}^{ni} (\sum_{j=1}^{nj} (C2_{ijkl} \times N_{ikl} \times (L3_{ijkl} - L4_{ijkl}))))) \qquad \text{Eq. 4}$$

where $C2_{ijkl}$ is the cost of treatment for removing the j-th water quality parameter per unit removed per unit of use. $L3_{ijkl}$ and $L4_{ijkl}$ are the level of the j-th water quality parameter after use and the level of the j-th water quality parameter at point of return flow into the lake.

The total cost of treating water in the lake system for all uses is the sum of treatment costs before and after use for all uses in the lake system.

$$TCL = TC1 + TC2 \qquad \text{Eq. 5}$$

The total benefits from all uses in the lakes is given by Eq. 6.

Total benefits for all uses in the lakes = the sum of (the benefit per unit of each use in each sector of each lake x the number of units of each use in each sector of each lake) for all uses, all sectors, and all lakes.

$$TB = \sum_{l=1}^{nl} \left(\sum_{k=1}^{nk} \left(\sum_{i=1}^{ni} (B_{ikl} \times N_{ikl}) \right) \right) \qquad \text{Eq. 6}$$

The total benefits and total costs for use of the water in the lake system can now be compared by using equations 5 and 6 if the terms $L1_{ijkl}$, $L2_{ijkl}$, $C1_{ijkl}$, $L3_{ijkl}$, $L4_{ijkl}$, $C2_{ijkl}$, B_{ikl}, and N_{ikl} are known for i, j, k, and l. The lakes do not necessarily need to have the same number of sectors, the sectors need not contain the same number of uses, and uses need not be influenced by the same number of water quality parameters.

The net benefits for all uses in the lake system is given by Eq. 7.

Net benefits = Benefits - treatment costs

$$NB = TB - TCL \qquad \text{Eq. 7}$$

Up until now the development has been for a general solution. Since any change in water quality which is likely to occur at the raw water intakes is not likely to affect the treatment of water after use for any uses, this study is now limited to that portion of the model enclosed in the dashed box in Figure 3 and Eqs. 2 and 6 are left to be evaluated.

It should be noted that if one were interested in determining the costs and benefits due to changing effluent standards for the users then Eq. 4 would be included. The added cost to meet a new effluent standard would be given by $(L4_{ijkl} - LI4_{ijkl}) \times C2_{ijkl} \times N_{ikl}$, where $LI4_{ijkl}$ is the new standard.

For a given change in water quality at the raw water intakes the net benefits, NB, may also change. This change in net benefits is the amount of benefits which can be attributed to the change in water quality. It is assumed that the change in water quality is toward an improved quality and thus the change in NB is positive and thus the benefits attributed to the water quality are positive.

The problem is now to determine the benefits which accrue due to an improvement in the water quality at the raw water intakes, i.e. lower Ll_{ijkl}'s. There are three ways in which benefits can occur because of a reduction in the Ll_{ijkl}'s. One way that benefits can occur is through a reduction in treatment cost. A second way in which benefits can occur is through an increase in the value of some uses per unit of use. The third way in which benefits can occur is through an increase in the number of units of use due to a decrease in Ll_{ijkl}'s.

Total benefits from water quality improvement at raw water intakes = decrease in treatment cost + increase in value of use + value of increase use.

Total benefits due to improved raw water quality = [(number of units of water quality parameter to be removed before improvement − number of units of water quality parameter to be removed after improvement)

$$BT_t = \sum_{l=1}^{nl} \left(\sum_{k=1}^{nk} \left(\sum_{i=1}^{ni} \left(\sum_{j=1}^{nj} \left(\left(\left(L1_{ijkl} - L2_{ijkl} \right) - \left(LI1_{ijkl} - LI2_{ijkl} \right) \right) \right.\right.\right.\right.$$

× cost per unit of removal per unit of use × number of units of use] + [increase in value per unit of use

$$\left.\left.\left.\left. \times\ C_{ijkl} \times N_{ikl} \right)\right)\right)\right) + \sum_{l=1}^{nl} \left(\sum_{k=1}^{nk} \left(\sum_{i=1}^{ni} \left(\sum_{j=1}^{nj} \left(\Delta B_{ijkl} \right.\right.\right.\right.$$

× number of units of use] + [(value + increase in value per unit of use)

$$\left.\left.\left.\left. \times\ N_{ikl} \right)\right)\right)\right) + \sum_{l=1}^{nl} \left(\sum_{k=1}^{nk} \left(\sum_{i=1}^{ni} \left(\sum_{j=1}^{nj} \left(\left(\left(B_{ijkl} + \Delta B_{ijkl} \right.\right.\right.\right.\right.\right.$$

− (units of water quality parameter to be removed per unit of addition use × cost per unit of removal per unit used)] × increase in number of units used

$$\left. - \left(\left(LI1_{ijkl} - LI2_{ijkl} \right) \times C1_{ijkl} \right) \right) \times \Delta N_{ikl} \Big)\Big)\Big)\Big) \qquad \text{Eq. 8}$$

where $L1_{ijkl}$ is the original level of water quality at the intake and $LI1_{ijkl}$ is the improved level of water quality at the intake. The value $(L1_{ijkl} - LI1_{ijkl})$ is the amount it has been improved.

The first step toward solution of Equation 8 is to identify the water uses in each sector along with the limiting levels of the parameters of water quality associated with each use. Next determine the number of units of each use in each sector, N_{ikl}; the reduction to be made in number of units of water quality parameter removed per unit of use, $((L1_{ijkl} - L2_{ijkl}) - (LI1_{ijkl} - LI2_{ijkl}))$; the value per unit of use, B_{ijkl}; the cost of treatment, $C1_{ijkl}$; the increase in value per unit of use, ΔB_{ijkl}; and the increase in use, ΔN_{ikl}.

Simplified Example.

This is a simplified example to show the concept of the model and is not intended to represent any actual condition. Let municipal water supply be the 2nd use for water in sector 6 of Lake A in Figure 2 and let suspended solids be the 4th water quality parameter. Let Lake A be the 3rd lake in the system. Therefore

$$\begin{aligned} i &= 2 \\ j &= 4 \\ k &= 6 \\ l &= 3 \end{aligned} \qquad \text{Eq. 9}$$

The average level of suspended solids in this sector is given by $L5_{2,4,6,3}$ in mg/l. At the raw water intake the level of suspended solids is given by $L1_{2,4,6,3}$. This raw water is then treated by some process $T1_{2,4,6,3}$, such as filtration, to reduce the suspended solids concentration to a level $L2_{2,4,6,3}$ such that it can be used for municipal water supply. After use the water contains a concentration of suspended solids $L3_{2,4,6,3}$ and must be treated by a process $T2_{2,4,6,3}$, such as sedimentation, to reduce the suspended solids to level $L4_{2,4,6,3}$ which is then returned to the lake. There is occurring during this time an interaction, $D_{4,6,3}$ between the sediments in this sector and the amount of suspended solids through the processes of deposition and entrainment. Also the concentration of suspended solids is being influenced by neighboring sectors represented by interactions $I_{4,6,5,3}$, sector 5 influencing sector 6; $I_{4,6,7,3}$, sector 7 influencing sector 6; $I_{4,6,11,3}$, sector 11 influencing sector 6; and $I_{4,6,6,3}$, the influence within sector 6 of biota and other objects or mechanisms.

With the treatment $T1_{2,4,6,3}$ there is associated a cost $C1_{2,4,6,3}$ per unit of municipal water supply treated per unit of suspended solids removed. Similarly there is a $C2_{2,4,6,3}$ associated with $T2_{2,4,6,3}$. There is a benefit $B_{2,6,3}$ associated with each unit of municipal water supply used in this sector. There are $N_{2,6,3}$ units of municipal water supply used in this sector from the lake.

Let the assumption be made that municipal water supply is the only use which has any benefit attributed to it and the only water quality parameter which must be treated for water supply is suspended solids. Further let it be assumed that municipal water supply is only taken from the lake system in sector 6 of lake 3. This means that

$$B_{ikl} = 0 \quad \text{for} \quad i \neq 2,\ k \neq 6,\ l \neq 3 \qquad \text{Eq. 10}$$

$$C1_{ijkl} = 0 \quad \text{for} \quad i \neq 2,\ j \neq 4,\ k \neq 6,\ l \neq 3 \qquad \text{Eq. 11}$$

$$C2_{ijkl} = 0 \quad \text{for} \quad i \neq 2,\ j \neq 4,\ k \neq 6,\ l \neq 3 \qquad \text{Eq. 12}$$

Then the total benefit for all uses on the lakes is

total benefits = benefit per unit of use x number of units of use

$$TB = B_{2,6,3} \times N_{2,6,3} \qquad \text{Eq. 13}$$

from Eq. 6 and the total cost of treating all water in the lake system for all uses is

$$\text{total cost} = \text{cost per unit of removal per unit of use} \times \text{units of use} \times \text{units removed per unit of use before use}$$

$$TCL = C1_{2,4,6,3} \times N_{2,6,3} \times (L1_{2,4,6,3} - L2_{2,4,6,3})$$

$$+ \text{cost per unit of removal per unit of use after use} \times \text{units of use} \times \text{units removed per unit of use after use}$$

$$+ C2_{2,4,6,3} \times N_{2,6,3} \times (L3_{2,4,6,3} - L4_{2,4,6,3}) \qquad \text{Eq. 14}$$

from Eqs. 2, 4, and 5. This then allows a comparison of the benefits and costs of the uses in this simplified example.

If by some means the suspended solids concentration were reduced at the raw water intake there would be a reduction in treatment cost to meet the same quality of treated water. If there is no increase in the value of a unit of water supply and there is no increase in the number of units of water used, the only benefit due to an improvement in the raw water quality will be this savings in treatment cost. This means

$$\Delta B_{2,6,3} = 0 \qquad \text{Eq. 15}$$

$$\Delta N_{2,6,3} = 0 \qquad \text{Eq. 16}$$

and if the effluent standards remain the same then Eq. 8 reduces to

total benefit due to improved raw water quality per time interval t	=	reduction in units of water quality parameters to be removed per unit of use	x	cost of removing one unit of the water quality parameter per unit of use	x	number of units of use

$$BT_t = (L1_{2,4,6,3} - LI1_{2,4,6,3}) \times C1_{2,4,6,3} \times N_{2,6,3} \qquad \text{Eq. 17}$$

where $LI1_{2,4,6,3}$ is the new level of suspended solids at the raw water intake.

If the assumptions of Eqs. 10, 11, and 12 are now removed, the benefits for the reduction in the level of the other water quality parameters for water supply could be found for sector 6 in lake 3 similar to that in Eq. 17 and the benefits for all uses could be found in this sector and then for all sectors on all lakes. The sum of these benefits are then the value obtained by Eq. 8 with ΔB_{ikl} and ΔN_{ikl} equal to zero.

Discussion.

It may not be necessary to determine the value of each variable in Eq. 8. For water supply only the first term may be important, since the improved water quality at the intake will result in lower treatment costs to produce the same level of treated water. The lower value for $LI1_{ijkl}$ is the value of the water quality at the use, $L2_{ijkl}$. Any value of $LI1_{ijkl}$ below $L2_{ijkl}$ does not decrease treatment cost.

For recreation the second term may be the important term plus the third term simplified. In recreational use there is no treatment so that the third term in Eq. 8 becomes

$$\sum_{l=1}^{nl} \left(\sum_{k=1}^{nk} \left(\sum_{i=1}^{ni} \left(\sum_{j=1}^{nj} \left(\left(B_{ijkl} + \Delta B_{ijkl}\right) \times \Delta N_{ikl} \right)\right)\right)\right).$$

$C1_{ijkl}$ may depend on the value of $L1_{ijkl}$, $L2_{ijkl}$, N_{ikl}, the value of other $C1_{ijkl}$'s as well as season of the year and will be zero if no treatment is needed for that parameter.

$$C1_{ijkl} = f(L1_{ijkl}, L2_{ijkl}, N_{ikl}, C1_{ijkl}\text{'s}, t) \qquad \text{Eq. 18}$$

B_{ikl} may be zero unless $L1_{ijkl}$ is below some threshold value and then is dependent on $L1_{ijkl}$, season of the year, amount of this use available, plus many intangible and unknown factors.

$$B_{ikl} = f(L1_{ijkl}, t, N_{ikl}, UK) \qquad \text{Eq. 19}$$

ΔB_{ikl} would then be a function of the same factors as B_{ikl} plus $LI1_{ijkl}$.

If one were interested in doing a study of the benefits and costs for the lake system for different effluent standards for the various users this model can also be used provided the I's, and D's are known. If $LI4_{ijkl}$ is the new effluent standard and $LI4_{ijkl}$ is less than $L4_{ijkl}$ then the added cost to the user is

$$AC = \sum_{l=1}^{nl} \left(\sum_{k=1}^{nk} \left(\sum_{i=1}^{ni} \left(\sum_{j=1}^{nj} \left(\left(L4_{ijkl} - LI4_{ijkl}\right) \times C2_{ijkl} \times N_{ikl}\right)\right)\right)\right) + E \qquad \text{Eq. 20}$$

The new $LI4_{ijkl}$ influence the L1's through the I's and thus the L1's become $LI1_{ijkl}$ an improved raw water quality such the benefits can be evaluated by Eq. 8. Thus the benefits and costs due to different effluent standards on the various users can be used. Here E is the administration and enforcement cost to cause the users to meet the new standards.

Conclusions.

If the values of LI_{ijkl}, LII_{ijkl}, CI_{ijkl}, N_{ikl}, B_{ijkl}, ΔB_{ijkl}, and ΔN_{ikl} can be determined then Eq. 8 will allow one to determine the benefits attributed to improved water quality in a lake system. It may be impossible to evaluate some of these variables and therefore only an approximation of the benefits can be obtained.

This evaluates the benefits for a given period and assumes that the values of the variables are constant during this period. The computations and evaluations would have to be repeated for each period for which it is desired to determine the benefits. It is necessary only to solve Eq. 8 to determine the benefits. The results of Eqs. 13 and 14 are shown in the example only for purposes of illustration and explanation.

BIBLIOGRAPHY

I. WATER SUPPLY

1. Aultman, W. W. "Synthetic Detergents as a Factor in Water Softening Economics." Journal of American Water Works Association, Vol. 50, No. 10, (October 1959), pp. 1353-1370.

2. Baxter, S. S. "Determination of Stream Use." JAWWA, Vol. 56, No. 10, (October 1964), p. 1285.

3. DeBoer, L. M. and T. E. Larson. "Water Hardness and Domestic Use of Detergents." JAWWA, Vol. 53, No. 7, (July 1961), p. 809.

4. Eliassen, R. and W. F. Rowland. Industrial Benefits Derived from Improved Raw Water Quality in the Contra Costa Canal. Institute in Engineering-Economic Systems, Stanford University, Stanford, Calif., (1962).

5. Frankel, R. J. Economic Evaluation of Water Qaulity: An Engineering-Economic Model for Water Quality Management. University of California, Berkeley. SERL Report No. 65-3 (1965).

6. ___. "Water Quality Management: Engineering Economic Factors in Municipal Waste Disposal." Water Resources Research, Vol. 1, No. 2, (Second Quarter, 1965), pp. 173-186.

7. Gamet, M. B. and J. M. Rademacher. "Study of Short Filter Runs with Lake Michigan Water." JAWWA, Vol. 52, No. 1, (January 1960), pp. 137-152.

8. Harwood, R. M. "Plant Experiences at Flint, Michigan." JAWWA, Vol. 58, No. 9, (September 1966), pp. 1137-1144.

9. Howson, L. R. "Economics of Water Softening." JAWWA, Vol. 54, No. 2, (February 1962), pp. 161-166.

10. Johnson, E. L. "A Study in the Economics of Water Quality Management." Water Resources Research, Vol. 3, No. 2, (Second Quarter, 1967), pp. 291-305.

11. Kneese, A. V. "Water Management in the Ruhr - A Case Study of the Genossenshaften." The Economics of Regional Water Quality Management, Johns Hopkins Press, Baltimore, (1964).

12. Koenig, L. "The Cost of Water Treatment by Coagulation, Sedimentation and Rapid Sand Filtration." JAWWA, Vol. 59, No. 3, (March 1967), pp. 290-336.

13. Langdon, P. E., Jr. "Economic Aspects of Iron Removal and Ion Exchange Softening." Proceedings, Eighth Sanitary Engineering Conf., University of Illinois, Urbana, Ill., (1966).

14. Larson, T. E. "Interpretation of Soap Savings Data." JAWWA, Vol. 40, No. 3, (March 1948), p. 291.

15. Muss, D. L. "Relationship Between Water Quality and Deaths from Cardiovascular Disease." JAWWA, Vol. 54, No. 2, (February 1962), pp. 1371-1378.

16. Orlob, G. T. and M. R. Lindorf. "Cost of Water Treatment in California." JAWWA, Vol. 50, No. 1, (January 1958), pp. 45-55.

17. Rambow, C. A. "Evaluating Water Quality." JAWWA, Vol. 60, No. 1, (January 1968), pp. 10-14.

18. Rohm, L. F. and W. H. Plautz. "Various Costs of Clarification, Filtration, and Lime Softening." Proceedings,Eighth Sanitary Engineering Conf., University of Illinois, Urbana, Ill., (1966).

19. Ritter, R. H. "Design of Treatment Plants for Low Turbidity Water." Proceedings, Journal of the American Society of Civil Engineers, (January 1955), pp. 591-1 to 591-16.

20. State of California, Dept. of Water Resources. Effects of Differences in Water Quality, Upper Santa Anna Valley and Coastal San Diego County. Bulletin No. 78, (January 1959), Appendix B.

21. Stevens, J. B. "Recreation Benefits from Water Pollution Control." Water Resources Research, Vol. 2, No. 2., (Second Quarter, 1966), pp. 167-182.

22. Stoevener, H. H. "Water Use Relationships as Affected by Water Quality on the Yaquina Bay." Papers of the Western Resources Conf., 1964. The University of Colorado Press, Boulder, Colo. pp. 87-99.

23. U.S. Congress Senate. Select Committee for National Water Resources. Methods of Approximating Water Requirements as a Supplemental Measure for Control of Water Quality in Rivers. Government Printing Office, Washington, D.C. 86th Congress, 2nd Session, Committee Print No. 29, (1960).

24. Vaughn, J. C. Effect of Water Quality Determination on the Operation of Chicago South Water Filtration Plant. Presented at the Four-State Pollution Conf. held in Chicago, January 31, 1968, City of Chicago, Dept. of Water and Sewers.

25. Weyermuller, G. "Water Supply Points Way to $84,000/yr Savings." Chemical Processing for Operating Management. (January 28, 1963), p. 56.

26. Whipple, W., Jr. "The Economics of Water Quality." American Water Resources Association Proceedings, 1965. Urbana: American Water Resources Association, (December 1965), pp. 225-242.

27. Young, K., Jr., T. Popowchak, and G. W. Burke, Jr. "Correlation of Degree of Pollution with Chemical Costs." JAWWA, Vol. 57, No. 3, (March 1965), pp. 293-297.

II. RECREATION

28. Beeton, A. M. Changes in the Environment and Biota of the Great Lakes. Milwaukee, Wisconsin: University of Wisconsin, Center for the Great Lakes Study.

29. ___. Eutrophication of the St. Lawrence Great Lakes. Ann Arbor, Michigan: U.S. Bureau of Commercial Fisheries.

30. Brewer, M. F. "Incorporating Recreational Values into Benefit Cost Analysis." Economics in Outdoor Recreational Policy. Conference Proceedings, Committee on the Economics of Water Resources Development of the Western Agricultural Economics Research Council at the University of Nevada, Reno, Nevada. Report No. 11, (August 1962), pp. 85-96.

31. Brinser, Ayers and Fry, E.E.J. and Smith, L. L., and Frick, H. C. "Report of the Economic Study Groups to the Great Lakes Fishery Commission Annual Meeting." (1967).

32. Brown, William G., Ajmer Singh, and Emery N. Castle. An Economic Evaluation of the Oregon Salmon and Steelhead Sport Fishery. Agricultural Experiment Station, Technical Bulletin 78. Corvallis, Oregon: Oregon State University, (September 1964), 48 pp.

33. Camp, Thomas R. Water and its Impurities. New York: Reinhold Publishing Corp., (1963).

34. Castle, Emery N. and William G. Brown. "The Economic Value of a Recreational Resource: A Case Study of the Oregon Salmon-Steelhead Sport Fishery." Water Resources and Economic Development of the West. Conference Proceedings Committee on the Economics of Water Resources Development of the Western Agricultural Economics Research Council. Report No. 13. San Francisco, California, (December 9-11, 1964), pp. 1-12.

35. Ciriacy-Wantrup, S. V. "Benefit-Cost Analysis and Public Resource Development." Journal of Farm Economics. (November 1947), pp. 1181-1196.

36. Clawson, Marion. How Much Leisure, Now and in the Future. Washington: Resources for the Future, Inc., Reprint No. 45, (May 1964), 20 pp.

37. ___. "Issues of Public Policy in Outdoor Recreation." New Horizons for Resources Research: Issues and Methodology. Western Resources Conference, Boulder, Colorado: University of Colorado Press, (1964), pp. 3-8.

38. ___. Methods of Measuring the Demand for and the Value of Outdoor Recreation. Washington, D.C.: Resources for the Future, Inc., Reprint No. 10 (February 1959).

39. Clawson, Marion and Jack L. Knetsch. Economics of Outdoor Recreation. Baltimore: Johns Hopkins Press. Published for Resources for the Future, Inc., (1966).

40. ___. "Outdoor Recreation Research: Some Concepts and Suggested Areas of Study." Natural Resources Journal, Vol. 3, No. 2, (October 1963), pp. 250-275.

41. Crutchfield, James A. "Valuation of Fishery Resources." Land Economics. Vol. XXXVIII (1962), pp. 145-154.

42. Davis, Robert K. "Recreation Planning as an Economic Problem." Natural Resources Journal, Vol. III, No. 2, (October 1963), pp. 239-249.

43. ___. The Value of Outdoor Recreation: An Economic Study of the Maine Woods. Unpublished dissertation presented to the Economics Faculty. Cambridge, Massachusetts: Harvard University, (April 1963).

44. Eckstein, Otto. Water Resource Development, The Economics of Project Evaluation. Cambridge, Massachusetts: Harvard University Press, (1958).

45. Eckstein, Otto and John V. Krutilla. Multiple Purpose River Development. Baltimore, Maryland: Johns Hopkins Press, (1958).

46. Fox, Irving K. "New Horizons in Water Resources Administration." Public Administration Review, Vol. XXV, No. 6, (March 1965), pp. 61-69.

47. Geuther, Carl E. "Compendium of Water Pollution Laws." Manual Sheet W-5 of Water Pollution Abatement Manual. Washington, D.C.: Manufacturing Chemists Assn., (1959).

48. Gordon, Seth. "Impacts of Pollution on Fish and Wildlife, Recreation and Esthetic Values," National Conference on Water Pollution Proceedings. Washington, D.C.: Dept. of Health, Education and Welfare, U.S. Government Printing Office, (1961).

49. Hammond, R. J. Benefit-Cost Analysis and Water Pollution Control. Stanford: Stanford University Food Research Institute, (1960).

50. Henley, Robert J. Water Quality Influences on Outdoor Recreation in the Lake Ontario Basin. Ann Arbor, Michigan: U.S. Bureau of Outdoor Recreation.

51. Hines, Lawrence G. "Measurement of Recreation Benefits: A Reply." Land Economics. Vol. XXXIV, pp. 365-367.

52. Illinois. Sanitary Water Board. Rules and Regulations Establishing Water Quality Criteria. Pamphlets. Springfield, Illinois: Sanitary Water Board.

53. Illinois. Department of Public Works and Buildings. Kankakee River Basin Study. Springfield, Illinois: State of Illinois, (1967), p. 40.

54. Indiana. Department of Natural Resources. Northwest Recreation Area Site Selection Study in Indiana. State of Indiana: Dept. of Natural Resources, (August 1967).

55. Kneese, Allen V. The Economics of Regional Water Quality. Baltimore: Johns Hopkins Press, (1964).

56. ___. Economic and Related Problems in Contemporary Water Resources Management. Washington, D.C.: Resources for the Future, Inc., Reprint No. 55, (1965).

57. Klein, Louis. River Pollution-2: Causes and Effects. London: Butterworth, (1962).

58. Knetsch, Jack L. "Economics of Including Recreation as a Purpose of Eastern Water Projects." Journal of Farm Economics. Vol. 46, (December 1964), pp. 1148-1157.

59. ___. "The Influence of Reservoir Projects on Land Values." Journal of Farm Economics. Vol. 46, No. 1, (February 1964), pp. 231-243.

60. ___. "Outdoor Recreation Demands and Benefits." Land Economics. Vol. XXXIX, No. 4, (November 1963), pp. 387-396.

61. ___. "Problems of Appraised Recreation Demand." Water Resources and Economic Development of the West. Conference Proceedings Committee on the Economics of Water Resources Development of the Western Agricultural Economics Research Council, Report No. 13, San Franscisco, Calif. (December 9-11, 1964), pp. 41-50.

62. Krutilla, John V. Welfare Aspects of Benefit-Cost Analysis. Washington: Resources for the Future, Inc., Reprint No. 29, (June 1961).

63. Lee, Ivan M. "Economic Analysis Bearing upon Outdoor Recreation." Economic Studies of Outdoor Recreation. Reports to the Outdoor Recreation Resources Review Commission, ORRRC Study Report 24. Washington, D.C.: U.S. Government Printing Office, (1962), pp. 1-44.

64. Lerner, Lionel. "Quantitative Indices of Recreational Values." Economics in Outdoor Recreational Policy. Conference Proceedings, Committee on the Economics of Water Resources Development of the Western Agricultural Economics Research Council at the University of Nevada, Reno, Nevada. Report No. 11, (August 1962), pp. 55-80.

65. ___. "The Demand-Value Structure of Recreation." New Horizons for Resources Research: Issues and Methodology. Western Resources Conference. Boulder, Colorado: University of Colorado Press, (1964), pp. 21-28.

66. Lessinger, Jack. "Measurement of Recreation Benefits: A Reply." Land Economics. Vol. XXIV, pp. 369-370.

67. Lifton, Fred B. "Trends in Small Boating and Its Impact on Water Resources Development." Proceedings of the Second Annual American Water Resources Conference. Bowden, Kenneth L., Editor. Urbana, Illinois: The American Water Resources Association, (1966), pp. 182-186.

68. Mackenthun, Kenneth M. and Ingram, William M. and Porges, Ralph. Limnological Aspects of Recreational Lakes. Washington, D.C.: U.S. Department of Health, Education, and Welfare, Public Health Service, (1964).

69. McKean, Ronald N. Efficiency in Government Through Systems Analysis with Emphasis on Water Resources Development. New York: John Wiley and Sons, (1958), 336 pp.

70. McKee, Jack E., and Harold W. Wolf. Water Quality Criteria. California: The Resources Agency of California, State Water Quality Control Board, (1963).

71. Maas, Arthur. "Benefit-Cost Analysis: Its Relevance to Public Investment Decisions." The Quarterly Journal of Economics. (May 1966), pp. 208-226.

72. Margolis, Julius A. "The Economic Evaluation of Federal Water Resource Development." The American Economic Review. Vol. 49, (March 1959), pp. 96-111.

73. Merewitz, Leonard. Recreational Benefits of Water Resource Development. Unpublished paper of the Harvard Water Program. Cambridge: Harvard University, (June 1964).

74. ___. "Recreational Benefits of Water Resources Development." Water Resources Research. Vol. 2, No. 4, (4th Quarter, 1966), pp. 625-640.

75. Minnesota Outdoor Recreation Resources Commission. User Fees. Staff Report No. 1, St. Paul, Minnesota: MORRC, (1964).

76. Murphree, Clyde E. Resource Use and Income Implications of Outdoor Recreation. Agricultural Experiment Station, Bulletin 690. Gainesville, Florida: University of Florida, (1965).

77. New York State Health Dept., Pure Waters Guide, New York, N.Y., (November 16, 1965).

78. Prewitt, Roy A. The Economics of Public Recreation. An Economic Study of the Monetary Evaluation of Recreation in the National Parks. Washington, D.C.: Land and Recreational Planning Division, National Park Service, U.S. Department of the Interior, (1949).

79. Price, R. C. "The Increasing Impact of Recreation on Water Resource Planning." Proceedings of the Second Annual American Water Resources Conference. Bowden, Kennth L., Editor. Urbana, Illinois: The American Water Resources Association, (1966), pp. 187-192.

80. Rasmussen, David. Investment Criteria: The Relationship of Benefit-Cost and Rate-of-Return Analysis. St. Louis, Missouri: Washington University, Institute for Urban and Regional Studies, (1966).

81. "Report of the Joint Committee on Bathing Places - Conference of State Sanitary Engineers and American Public Health Association." Tenth Ed., New York: American Public Health Assn., (1957).

82. Sewell, W.R.D., John Davis, A. D. Scott, and D. W. Ross. Guide to Benefit-Cost Analysis. Ottawa, Canada: Queen's Printer and Controller of Stationery, (1965).

83. Steiner, Peter O. "The Role of Alternative Cost in Project Design and Selection." Quarterly Journal of Economics. (August 1965), pp. 417-430.

84. Stevens, Joe B. "Recreation Benefits from Water Pollution Control." Water Resources Research. Vol. II, No. 2, (2nd Quarter, 1966), pp. 167-182.

85. Stott, Charles C. Criteria for Evaluating the Quality of Water Based Recreation Facilities. Report No. I, Raleigh, North Carolina: University of North Carolina.

86. ___. "Evaluating Water Based Recreation Facilities and Areas," Management Aids Bulletin No. 70. Washington, D.C.: National Recreation and Park Association, (1967).

87. Tolley, George S. and Cleon Harrell. "Extensions of Benefit-Cost Analysis." The American Economic Review, (May 1962), pp. 459-468.

88. Trice, Albert M. and Samuel E. Wood. "Measurement of Recreation Benefits." Land Economics. Vol. XXXIV, No. 3, (August 1958), pp. 195-207.

89. U.S. Bureau of Outdoor Recreation. Federal Agencies in Outdoor Recreation, Washington, D.C.: U.S. Government Printing Office, (1962).

90. ___. Outdoor Recreation for America. Washington, D.C.: U.S. Government Printing Office, (1962).

91. ___. Outdoor Recreation Trends. Washington, D.C.: U.S. Bureau of Outdoor Recreation, (April 1967).

92. ___. Recreation Land Price Escalation. Washington, D.C.: U.S. Government Printing Office, (1967).

93. ___. Water Oriented Outdoor Recreation-Lake Ontario Basin. Ann Arbor, Michigan: USBOR

94. U.S. Bureau of the Budget. Executive Office of the President. "Reports and Budget Estimates Relating to Federal Programs and Projects for Conservation, Development, or use of Water and Related Land Resources." Bureau of the Budget Circular A-47. Washington: Bureau of the Budget. (December 31, 1952).

95. U.S. Congress Senate. Evaluation Standards for Primary Outdoor Recreation Benefits. 87th Congress, 2d Session. Senate Document No. 97, Supplement No. 1, Washington, D.C.: U.S. Government Printing Office, (June 4, 1964).

96. ___. Policies, Standards, and Procedures in the Formulation, Evaluation and Review of Plans for Use and Development of Water and Related Land Resources. 87th Congress, 2d Session. Senate Document No. 97. Washington, D.C.: U.S. Government Printing Office, (1962).

97. U.S. Department of Agriculture. Soil Conservation Service. Economics Guide for Watershed Protection and Flood Prevention. Washington, D.C.: U.S. Government Printing Office, (March 1964).

98. U.S. Department of the Interior. Water Oriented Outdoor Recreation in the Lake Michigan Basin, (1965).

99. U.S. Department of the Interior, Great Lakes Region. Water Pollution Problems of Lake Michigan Tributaries. Chicago, Illinois: U.S. Department of the Interior, Federal Water Pollution Control Administration, (January 1968).

100. U.S. Inter-Agency Committee on Water Resources. Subcommittee on Evaluation Standards. Proposed Practices for Economic Analysis of River Basin Projects. Washington, D.C.: U.S. Government Printing Office, Revised May 1958.

101. U.S. Outdoor Recreation Resources Review Commission. Economic Studies of Outdoor Recreation. ORRRC Study Report No. 24, Washington, D.C.: U.S. Government Printing Office, (1962).

102. ___. Participation in Outdoor Recreation: Factors Affecting Demand Among American Adults. ORRRC Study Report No. 20. Washington, D.C.: U.S. Government Printing Office, (1962).

103. ___. Prospective Demand for Outdoor Recreation. ORRRC Study Report No. 26. Washington, D.C.: U.S. Government Printing Office, (1962).

104. ___. Water for Recreation - Values and Opportunities. ORRRC Study Report No. 10. Washington, D.C.: U.S. Government Printing Office, (1962).

105. ___. Library of Congress. Outdoor Recreation Literature: A Survey. ORRRC Study Report No. 27. Washington, D.C.: U.S. Government Printing Office, (1962).

106. U.S. Statutes at Large. Federal Water Project Recreation Act. Public Law 89-72. Vol. 79, Washington (July 9, 1965), p. 213.

107. "Water Quality Criteria." ASTM Special Technical Publication No. 416. Philadelphia, Pennsylvania: American Society for Testing & Materials, (1964).

108. Weiss, Marvin D. Industrial Water Pollution. New York: Chemonomics Inc., (1951).

109. Wennergren, E. Boyd. "Recreational Resource Values: Some Empirical Estimates." Water Resources and Economic Development of the West. Conference Proceedings Committee on the Economics of Water Resources Development of the Western Agricultural Economics Research Council. Report No. 13. San Francisco: December 9-11, 1964. pp. 13-28.

110. ___. "Valuing Non-Market Priced Recreational Resources." Land Economics. Vol. XXXX (1964), pp. 303-314.

111. Wisconsin, University. Bureau of Business Research and Service, Wisconsin Vacation - Recreation Papers, Vol. I - No. I to Vol. I - No. II. Madison, Wisconsin: Bureau of Business Research and Service, (1960).

112. Wollman, Nathaniel, et al. The Value of Water in Alternative Uses. Albuquerque: The University of New Mexico Press, (1962), 426 pp.

113. World Health Organization. Aspects of Water Pollution Control, Geneva, Switzerland, (1962).

III. COMMERCIAL FISHERIES

114. Beeton, A. M. Changes in the Environment and Biota of the Great Lakes. Center for Great Lakes Studies, University of Wisconsin, Milwaukee, Wis. Contribution No. 7, (1968).

115. ___. Eutrophication of the St. Lawrence Great Lakes. Presented at the Symposium on "Recent Trends in Ecological Research in the Great Lakes," sponsored by the Ecological Society of America, American Association for Advancement of Science Meetings, Cleveland, Ohio, (December 27, 1963), pp. 240-254.

116. Brinser, Dr. Ayers, et al. Report of the Economic Study Group to Great Lakes Fishery Commission. Presented at the Annual Meeting June 20-22, 1967.

117. Kneese, A. V. The Economics of Regional Water Quality Management. Baltimore: Johns Hopkins Press, (1964).

IV. AESTHETICS

118. Edwards, A. Techniques of Attitude Scale Construction. New York: Appleton, Century, crofts, (1957).

119. Craik, K. H. n.d. The Comprehension of the Everyday Physical Environment. Inst. of Personality Assessment & Research, Univ. of Calif., Berkeley. (Mimeo.) 29 pp.

120. ___. The Prospects for an Environmental Psychology. Inst. of Personality Assessment & Research, Univ. of Calif., Berkeley. (Mimeo.) 18 pp.

121. Kates, R. W. "The Pursuit of Beauty in the Environment." Landscape, 16(2), (1966-67), pp. 21-25.

122. Kates, R. W. and Wohlwill, J. F. (Eds.) "Man's Response to the Physical Environment." J. Social Issues, 22(4). (Entire issue), (1966).

123. Litton, R. B. and Twiss, R. H. "The Forest Landscape: Some Elements of Visual Analysis." Proc., Soc. of Amer. Foresters, (1966), pp. 212-214.

124. Lowenthal, D. "Not Every Prospect Pleases." Landscape, 12(2), (1962), pp. 19-24.

125. ___. Environmental Perception and Behavior. Chicago: Geog. Dept., Univ. of Chicago, (1967).

126. Osgood, C. E. Method and Theory in Experimental Psychology, New York: Oxford, (1953).

127. Osgood, C. E., Suci, G. and Tannenbaum, P. The Measurement of Meaning. Urbana, Illinois: University of Illinois Press, (1957).

128. Parr, A. E. "Environmental Design and Psychology." Landscape, 14(2), (1964-65), pp. 15-18.

129. Peterson, G. L. "Complete Value Analysis: Highway Beautification and Environmental Quality." Highway Research Board Record, No. 182, pp. 9-17.

130. ___. "Measuring Visual Preferences of Residential Neighborhoods." Chicago: Northwestern University. Ekistics, 25, (1967), pp. 169-173.

131. ___. "A Model of Preference: Quantitative Analysis of the Perception of the Visual Appearance of Residential Neighborhoods." J. of Regional Science, 7(1), (1967), pp. 19-31.

132. Rosenberg, M. The Experimental Investigation of a Value Theory of Attitude Structure. Unpublished doctoral dissertation, Univ. of Michigan, (1953).

133. ___. "Cognitive Structure and Attitudinal Affect." Journal of Abnormal and Social Psychology, (1956), 53, pp. 367-372.

134. Stipe, R. E. (Ed.). Perception and Environment: Foundations of Urban Design. Chapel Hill: Inst. of Govt., Univ. N. Carolina, (1966).

135. Twiss, R. H. "Science and the Regional Landscape," Proc., 16th Alaska Science Conf., (1966), pp. 284-295.

136. Twiss, R. H., and Litton, R. B. "Research on Forest Environmental Design." Proc., Soc. of Amer. Foresters, (1966), pp. 209-210.

137. ___. "Resource Use in the Regional Landscape." Nat. Res. J., 6, (1966), pp. 76-81.

138. White, R. K. Value Analysis: The Nature and Use of the Method. Society for the Psychological Study of Social Issues, (1951).

APPENDIX C9

UNITED STATES ARMY CORPS OF ENGINEERS

Study for Determination of Benefits From Improved Great Lakes Water Quality

November 1968

U.S. Army Engineer District, Chicago

Contract No. DACW23-69-C-0006

Greeley and Hansen, Engineers
14 East Jackson Boulevard
Chicago, Illinois 60604

UNITED STATES ARMY CORPS OF ENGINEERS

Study for Determination of Benefits From Improved Great Lakes Water Quality

November 1968

Greeley and Hansen, Engineers
14 East Jackson Boulevard
Chicago, Illinois 60604

UNITED STATES ARMY CORPS OF ENGINEERS

Study for Determination of Benefits From Improved Great Lakes Water Quality

November 1968

TABLE OF CONTENTS

UNITED STATES ARMY CORPS OF ENGINEERS

Study for Determination of Benefits From Improved Great Lakes Water Quality

November 1968

LIST OF TABLES

LIST OF FIGURES

GREELEY AND HANSEN

ENGINEERS

14 EAST JACKSON BOULEVARD • CHICAGO, ILLINOIS 60604

TELEPHONE (312) 939 5850

November 25, 1968

District Engineer
U. S. Army Engineer District, Chicago
219 South Dearborn Street
Chicago, Illinois 60604

Dear Sir:

In accordance with our Contract No. DACW23-69-C-0006, we are pleased to submit our Study for Determination of Benefits from Improved Great Lakes Water Quality.

We concentrated our initial efforts toward a determination of benefits that would accrue to the Chicago municipal water supply, the largest treatment facility on the Great Lakes. Our findings are as follows:

1. Improvements in water quality would have no discernible effect on coagulant dosage.

2. Annual savings in chlorine and activated carbon would be not more than $7,500 for Chicago and in our judgment would probably be less than $1,000.

3. As Chicago's supply is of the magnitude of one-third of the total for all Great Lakes municipalities, the possible overall savings are of such minor significance as to warrant no further studies.

4. We recommend that analyses of possible savings at other plants not be made and that the study be terminated at this time.

The detailed findings on which the foregoing are based will be found in the main body of the report, which follows.

Yours sincerely,

GREELEY AND HANSEN

Thomas M. Niles

TMN:MG

U.S. ARMY CORPS OF ENGINEERS

Study for Determination of Benefits From Improved Great Lakes Water Quality

November, 1968

I. Introduction

The U.S. Army Corps of Engineers has authorized Greeley and Hansen to determine, if possible, the monetary benefits that would result from an improved Great Lakes water quality due to a cessation of lake disposal of polluted harbor dredgings. The results of the investigation and studies are summarized herein.

II. Procedures

In May, 1968, the University of Illinois Water Resources Center reported to the Corps on the Feasibility of Evaluation of Benefits from Improved Great Lakes Water Quality. On page 15 of that report is outlined a proposed method for assessing the benefits to a municipal supply which accrue as savings in treatment costs, as follows:

"Methodology

"A. Assume finished water quality is the same before and after improvement in the raw water quality.

"B. Identify each municipal treatment plant which uses lake water from the affected area. Determine what treatment processes they use and what factors control the operation of those processes. Choose one of these plants for completion of the following steps.

"C. Correlate doses of each chemical with changes in selected raw water quality variables in the plant being considered.

"D. Assume capital costs are unaffected and that elements of the operating costs are fixed, that is, that changes in costs of treatment are completely reflected in chemical and associated costs. Determine the magnitude of the associated chemical costs in the plant being considered.

"E. Determine the probability that each possible combination of unimproved values of the raw water quality variable used in the correlations with chemical costs will occur during the affected season of the year.

"F. Determine the improvement which is predicted to be realized in each of the above water quality variables from a specific change in the dredging disposal practices.

"G. Select one of the combinations of raw water quality variables from step E.

"H. Determine the improved level of concentration of each of the raw water quality variables in the combination by subtracting its change as determined in step F from its original value.

"I. For each chemical, determine the change in dose by taking the difference between the doses for the improved and unimproved raw water quality levels. Each of these doses should be determined from the correlations derived in step C.

"J. Determine the benefits per unit volume of water treated for this selected raw water by multiplying the adjusted cost of the chemical per pound by the change in dose times the probability of occurrence and summing this product over all the chemicals.

"K. Repeat steps G through J for each combination of unimproved values of raw water quality variables which has a finite probability of occurrence during the affected time period.

"L. The total annual benefits at this plant are then equal to the volume of water treated during the affected time of the year times the sum of the benefits per unit volume for each of the probable combinations of raw water quality variables.

"M. Repeat steps C through L for each plant in the affected area.

"N. To determine the total annual benefits of this change in dredging practices in the affected area, sum the values of annual benefits found for each plant.

"O. Repeat process for other changes in dredging disposal practices provided that the water quality improvements due to these changes in practice are known."

The report also suggests one alternative to the detailed study of chemical doses versus raw water quality. This is in the event the dosage is controlled by a set of operating rules which state that for certain levels of raw water quality the operator should add a specific amount of a particular chemical. The development of a correlation would be unnecessary because of the existence of the operating rule.

On page 26 of the University of Illinois report, it is suggested that the following variables would deserve first attention in evaluation:

1. Chlorine demand	5. Hardness, total
2. Turbidity	6. Hardness, noncarbonate
3. Algae	7. Extractable organic matter
3. Coliform organisms	

The report also selects the following chemicals as the important ones to be considered and the corresponding raw water quality variable(s) with which they might be correlated, as follows:

Chemical Dose	Raw Water Quality Variable(s)
Chlorine	Chlorine demand
Coagulant	Turbidity and total algae
Activated carbon	Extractable organic matter (or TON*) (or phenols)
Wash water	Turbidity and total plankton
Lime	Total hardness
Soda ash	Noncarbonate hardness

*Threshold Odor Number.

The methodology for industrial water supplies is similar to that outlined above for municipal supplies. It is pointed out in the report that the most important difference between municipal and industrial supplies is that industrial waters are used in the following principal ways:

1. As cooling water

2. As process water

3. As boiler feedwater

The report further states that

"The major considerations which determine the suitability of cooling water include temperature (thought to be little affected by dredging), the presence of material which might clog pipes such as suspended matter, slime forming microorganisms, or scale forming compounds and the corrosiveness of the water. Process water on the other hand will usually warrant the same criteria as were used in consideration of municipal water supply together with study of additional parameters in specific industries. Preparation of boiler feedwater will require consideration of removing dissolved solids in addition to the conventional treatment given to municipal or process water. The usual treatment scheme might be a two-step process consisting of pretreatment in a manner similar to municipal water treatment prior to demineralization to reduce dissolved solids. The effect of raw water quality changes on chemical dose in the pretreatment would be essentially the same regardless of raw water quality. Hence it is not expected that improvement in raw water would carry over to the demineralization step, unless changes in dredging practices significantly reduce dissolved solids such as silica which are important in preparation of boiler water. The additional 'chemicals' which must be considered in establishing use relationships with raw water quality might include:

"1. inhibitors of slime growths

"2. vacuum or chemicals for degasification

"3. other chemicals to control scaling and corrosion

"4. demineralization resins."

III. Changes in Qualities to be Considered

In the memorandum, subject: Determinations of Benefits for Disposal of Dredged Materials Through Alternatives to Present Practices, which accompanied their letter of October 10, 1968 to Greeley and Hansen the Corps of Engineers supplied results obtained by the Great Lakes Research Center, U.S. Lake Survey, evaluating the effects of dredging and disposal on Lake Erie at Toledo, Ohio. A comparison was made between the contribution of pollutants from the Toledo area dredging project and from the estimated discharge from the Maumee River during the same 51-day period. These data are listed in Table 1.

Also included in the memorandum were the basic data regarding the Corps' estimates of the effects on changes in water quality due to lake disposal of dredged spoil. The Corps obtained these changes by calculating the percentage buildup of the particular water quality characteristics listed in the University of Illinois report over the period of years for which records were available, dividing by the number of years to obtain the annual average increase, and taking 10 percent of this annual increase as the portion attributable to dredgings disposal. The Corps has assumed that a cessation of lake

TABLE 1

River Versus Spoil Contribution to Lake Erie at Toledo, Ohio, During Dredging Period

1967

Parameter	Contribution to Lake (Lbs.) by River	by Dredge	Dredge/ River %
Chloride	54,023,500	3,500	.0065
Phosphate	3,608,000	200	.0061
Nitrate	22,610,000	1,300	.0056
Sulfate	177,513,000	15,100	.0085
Calcium	54,841,300	4,900	.0089
Magnesium	27,661,200	1,500	.0053
Sodium	65,905,800	2,500	.0037
Potassium	7,456,600	700	.0088
Silica	6,734,900	400	.0061

TABLE 2

Estimated Impairment in Raw Water Quality Due to Lake Disposal of Dredged Spoil

Characteristics	Increase %
A. Municipal and Industrial Supplies	
Turbidity	0.04
Chlorine Demand	0.5
Total Extractable Organic Matter (or Threshold Odor Number)	0.8 TON
Total Plankton Mass	1.0
Hardness	0.05
B. Industrial Supplies Only	
Dissolved Solids	0.06
Dissolved Gases	0 (No data available)
Slime Forming Organisms	0.4 (No data available)

disposal of dredged spoil would result in an improvement in water quality by the same percentages. Table 2 indicates their estimated changes in the various water quality characteristics due to lake disposal of dredgings.

It is our understanding that the Corps has arbitrarily overstated the quantitative changes in water quality so that calculated benefits (reduced water treatment costs) which might result from reversing such changes will be readily recognized as exaggerated and, in all probability, beyond those attainable or measurable in actual practice. There are no data available on changes of characteristics such as turbidity, plankton, chlorine demand, etc., that can be ascribed definitely and directly to disposal of dredged material. The quantitative tests performed on chloride, phosphate, nitrate, etc., shown in Table 1, may be taken as indications of the magnitude of the effect of dumping. We recognize that this information is limited and covers a very short period of time, but it remains the best available at this time.

Among the harbors of the Great Lakes, the average annual quantity of maintenance dredging at Toledo is second only to that dredged at Cleveland, and the bottom sediments which must be removed at Toledo are among the most highly polluted. The most severe contribution from dumping in the 51-day period covered by the data in Table 1 is for calcium in the amount of 0.0089 percent. The Corps' estimates given in Table 2 are greater than the results shown in Table 1, the smallest estimate in Table 2 being four times greater, and the largest estimate being about 100 times greater than the value for calcium in Table 1 (obtained by dividing 0.0089 into 0.04 and 1.0 respectively).

From the preceding, it becomes apparent that judgment must be used when arriving at the estimated changes in raw water quality. We believe the impairment percentages listed in Table 2 are much higher than might reasonably be expected. It must be kept in mind that they are four to 100 times greater than indicated by the limited average information on quantitative changes due to disposal of dredgings at Toledo.

The Corps of Engineers has requested that we calculate monetary benefits using two times and five times their estimates, but seeing that the estimates could be liberally overstated we believe the pursuance of these calculations would further exaggerate the results and would not be realistic or consistent with the known facts.

IV. Study Plan

It was proposed that the investigation would cover at least two municipal water supplies and three industrial water supplies on each of Lake Michigan and Lake Erie for a total of ten water supplies. Letters of inquiry enlisting cooperation were sent to the following on August 27, 1968:

American Oil Company
Buffalo Water Department
Chicago Water Department
Cleveland Water Department
Commonwealth Edison Company
Gary-Hobart Water Corporation
Hammond Water Department
Milwaukee Water Department
Toledo Water Department

The responses indicated an interest in the subject and a willingness to participate in the study.

It was planned to obtain the local data (City of Chicago) and follow the methodology outlined in the University of Illinois report. If the correlations existed and benefits could be calculated, an evaluation would be made of the results. Sizable dollar benefits would warrant a continuation of the investigation and gathering of data would be expanded to include the out-of-town sources. Accordingly, we obtained data from the City of Chicago Water Filtration Plants.

V. Correlation of Data

In the attempt to determine correlations between water quality characteristics and chemical dosages, the records at the Chicago South Water Filtration Plant (SWFP) were used since they were more complete than those at the relatively new Central Water Filtration Plant. The period of study selected was from January, 1964, through August, 1968.

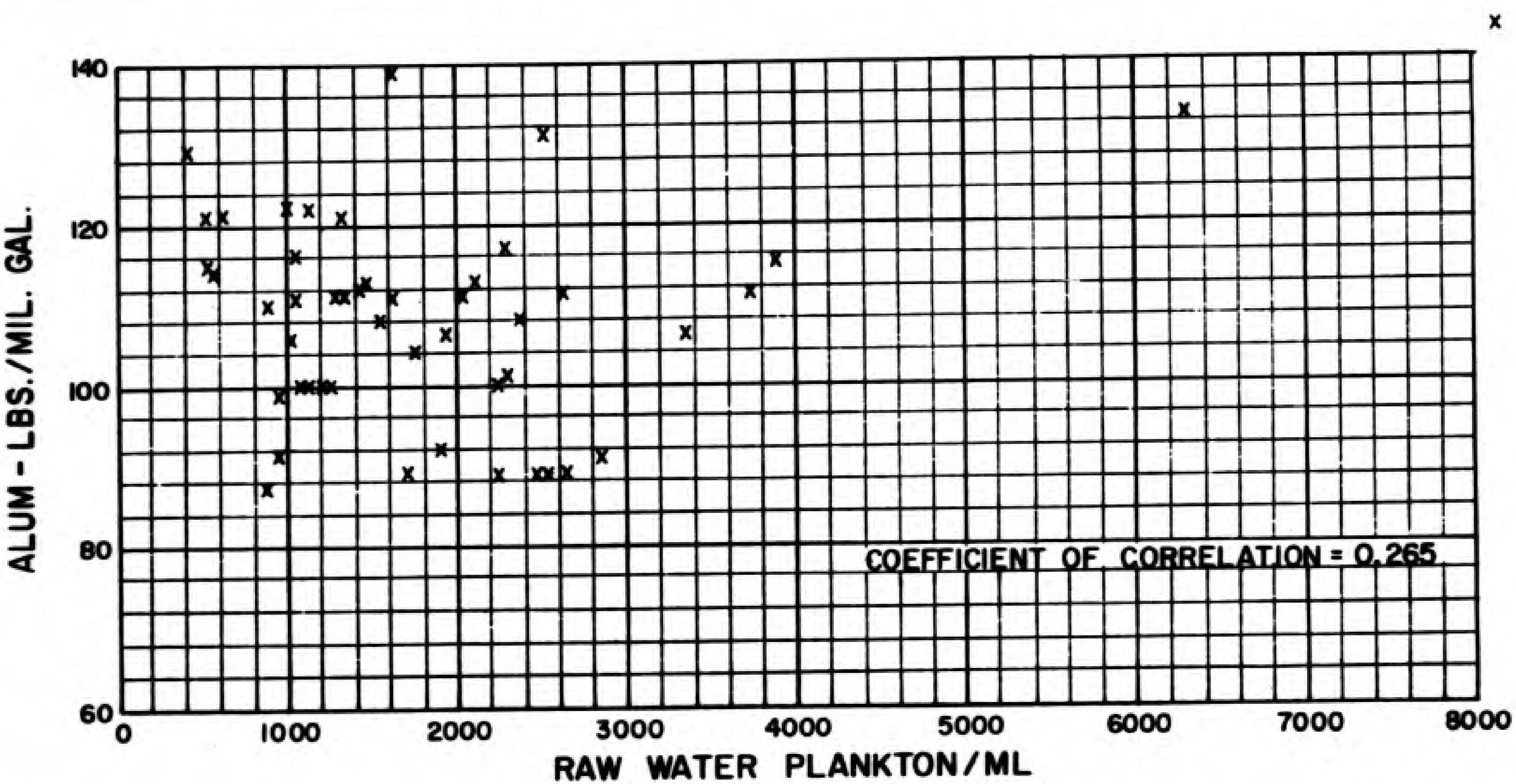
The data assembled and used were the monthly average rates of dosage. It is our opinion that these provide more reliable information than the hour-to-hour or daily dosages, which are more subjected to operator's errors in judgment. The long-term effects and trends are better reflected in the monthly averages.

Hardness. In view of the relatively constant hardness of Lake Michigan water coupled with the fact that softening is not a part of the treatment process, variables numbers 5 and 6 (page 4: Total and Noncarbonate Hardness) were eliminated from the evaluations, with the corresponding elimination of an attempt to establish the correlation between lime and total hardness and between soda ash and noncarbonate hardness.

Plankton. As the plankton laboratory test results have a time lag of about 24 hours from the time of sampling, they are used primarily as general information to establish patterns of occurrence. The plant operators make dosage changes based on judgment founded on such factors as season of year, water current direction and duration, wind direction and duration, water temperature and knowledge of the types and life cycles of various aquatic organisms.

Attempts were made to establish relationships between the number of plankton in the raw water and the alum and ferrous sulfate dosages and the amount of wash water used at the SWFP. Figures 1, 2 and 3, indicating the average monthly plankton/ml versus the alum dosage, ferrous sulfate dosage, and percent wash water used respectively, were plotted to establish relationships by inspection. As can be seen from these figures, however, no consistent or significant relationships are discernible.

A statistical analysis by the least squares method was conducted to establish a linear correlation on these graphs. The coefficient of correlation for each graph



X = MONTHLY AVERAGE

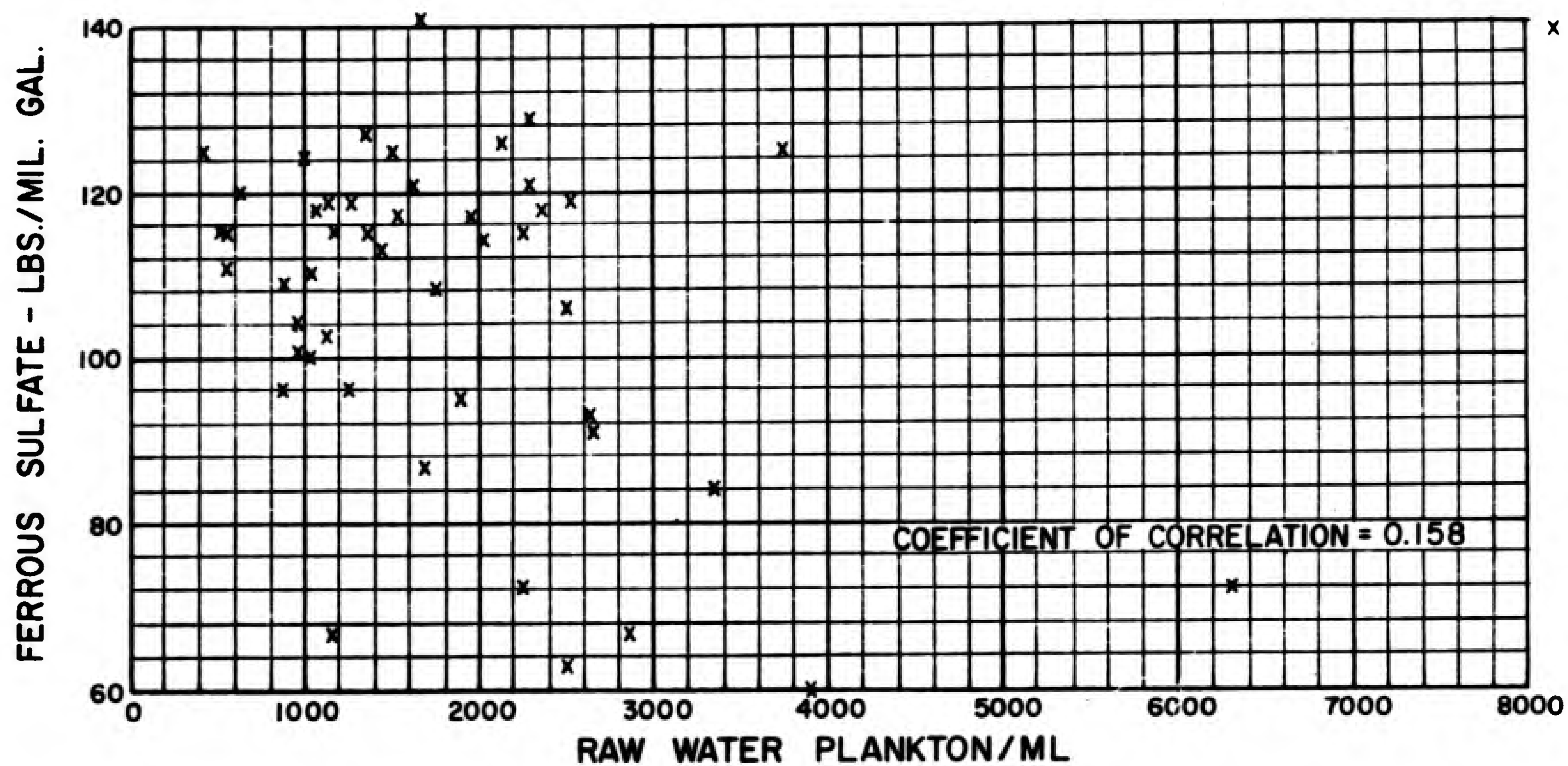
U.S. ARMY CORPS OF ENGINEERS
REPORT ON THE DETERMINATION OF BENEFITS
FROM AN IMPROVED GREAT LAKES WATER QUALITY

ALUM DOSAGE VS. RAW WATER PLANKTON/ML AT CHICAGO SOUTH WATER FILTRATION PLANT, 1964 THROUGH 1967

NOVEMBER, 1968

FIGURE 1

GREELEY AND HANSEN
ENGINEERS



X = MONTHLY AVERAGE

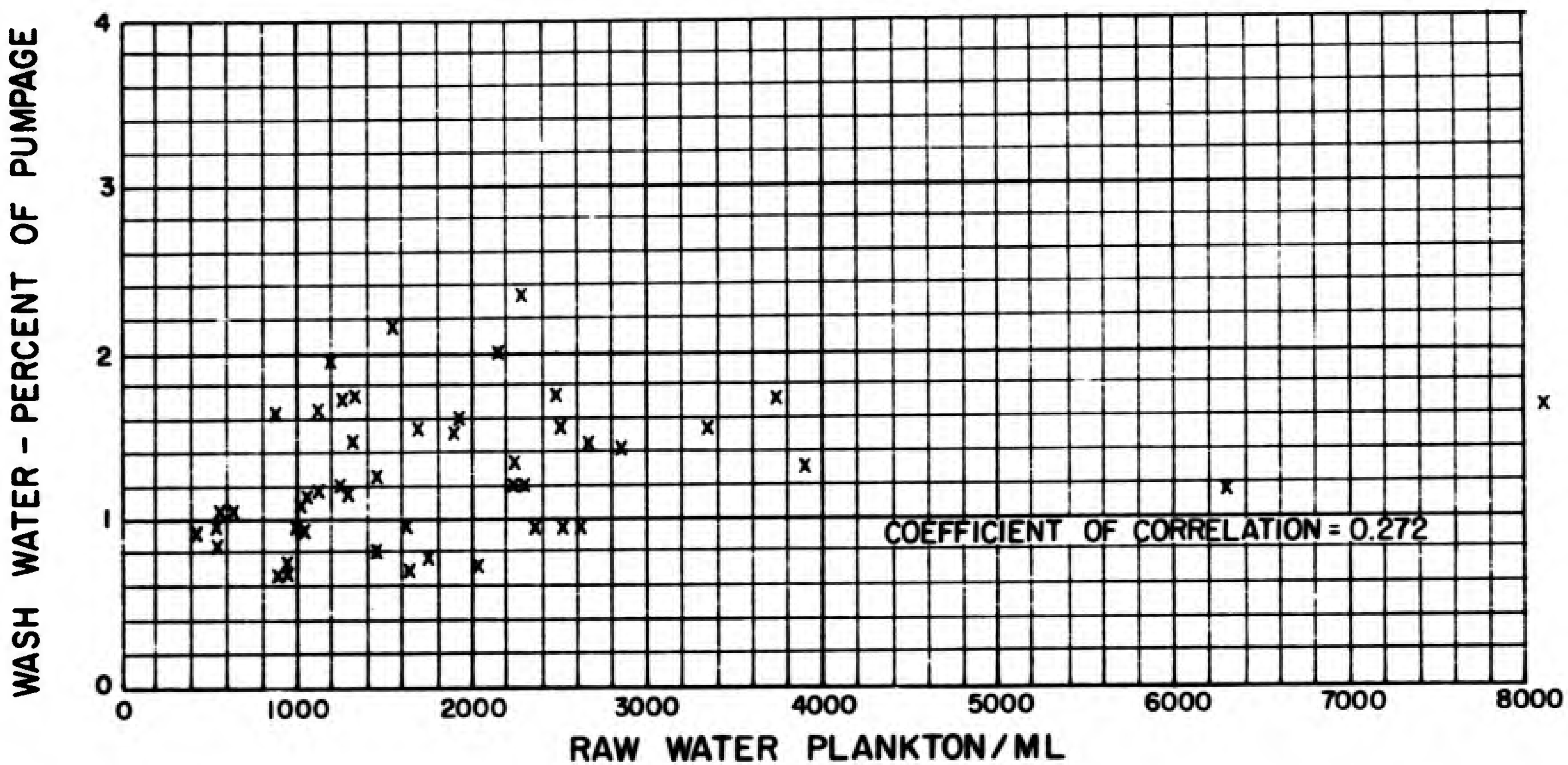
U.S. ARMY CORPS OF ENGINEERS
REPORT ON THE DETERMINATION OF BENEFITS
FROM AN IMPROVED GREAT LAKES WATER QUALITY

FERROUS SULFATE DOSAGE VS. RAW WATER PLANKTON/ML AT CHICAGO SOUTH WATER FILTRATION PLANT, 1964 THROUGH 1967

NOVEMBER, 1968

FIGURE 2

GREELEY AND HANSEN
ENGINEERS



U.S. ARMY CORPS OF ENGINEERS
REPORT ON THE DETERMINATION OF BENEFITS
FROM AN IMPROVED GREAT LAKES WATER QUALITY

WASH WATER VS. RAW WATER PLANKTON/ML
AT CHICAGO SOUTH WATER FILTRATION PLANT,
1964 THROUGH 1967

NOVEMBER, 1968

FIGURE 3

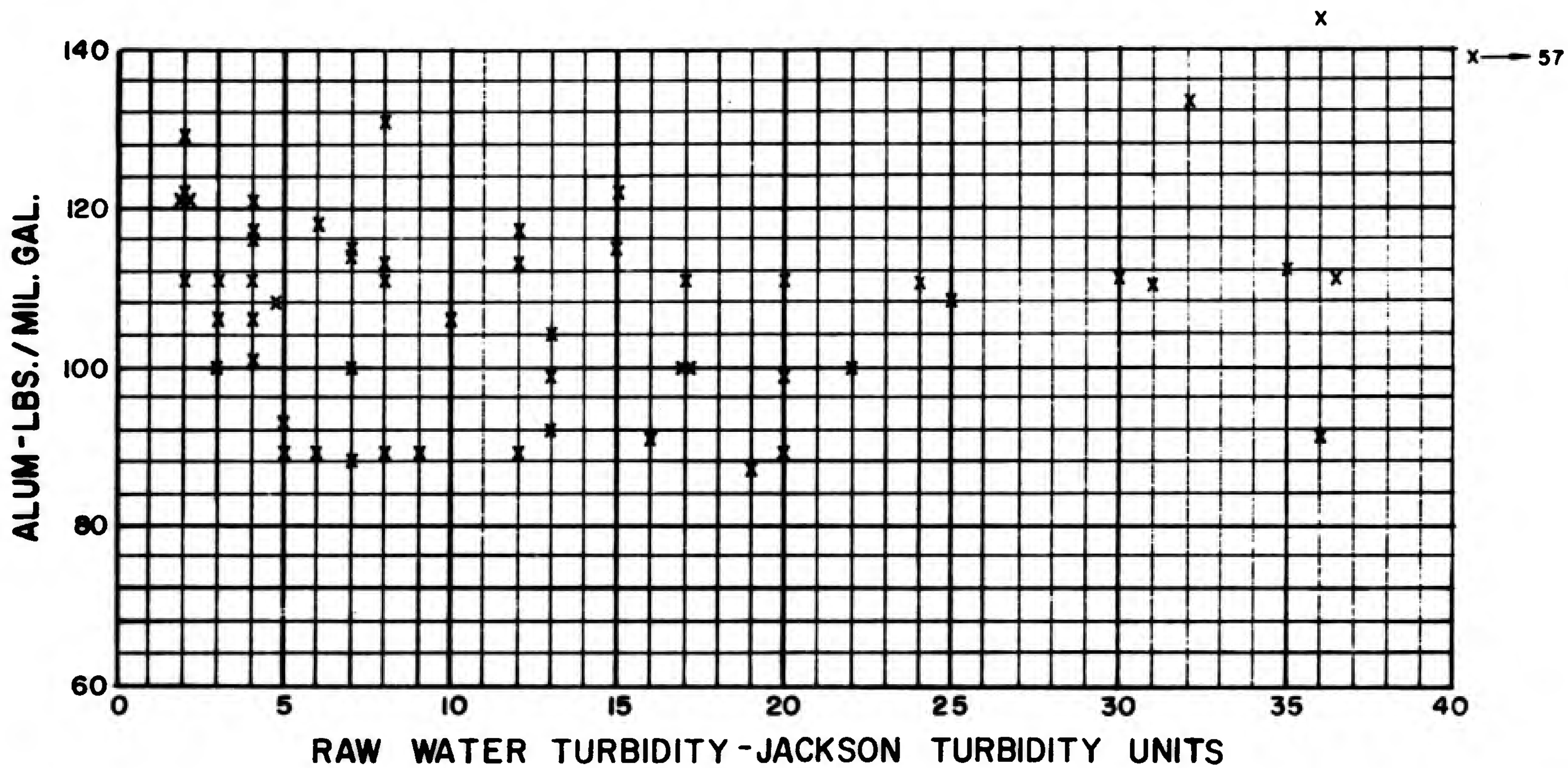
GREELEY AND HANSEN
ENGINEERS

was so small, however, that no fit could be made. A perfect coefficient of correlation is 1.000, but, as can be noted from the graphs, the actual coefficients ranged from 0.158 to 0.272. It was therefore concluded that no relationship between the number of plankton/ml in the raw water and the dosages of alum, ferrous sulfate, and wash water could be established, and thus no monetary benefit could be calculated for an improvement in this water quality characteristic.

Turbidity. Turbidity in water is caused by the presence of suspended matter such as clay, silt, finely divided organic matter, plankton, and other microscopic organisms. Turbidity is an expression of the optical property of the sample which causes light to be scattered and absorbed. It is not a direct equivalent of the amount of suspended matter, as the size, shape, and refractive index of the particulate materials are of most importance optically, but bear little direct relationship to the concentration and specific gravity of the suspended matter. Therefore, the magnitude of turbidity cannot be directly related to coagulant dosage. The nature or character of the turbidity is a major factor influencing the difficulty of its removal and has a greater effect on the chemical dosage. For example, a very finely divided suspended matter is usually more difficult to coagulate than coarse particles. Other factors, such as the cation-exchange capacity of the particles of turbidity and the detention time in the mixing tanks, affect the coagulant dosage and further inhibit the establishment of a relationship.

We did, however, attempt to establish relationships between the raw water turbidity and alum, ferrous sulfate, and wash water. Figures 4, 5 and 6 indicate the results of these attempts. Since the points on these graphs were at least as greatly scattered as those in the case of plankton, it was our judgment that a statistical analysis on these graphs was not warranted. We concluded that no correlation could be established and that benefits could not be calculated.

Chlorine Demand. The prechlorine dosage varies in direct proportion with the raw water chlorine demand. The postchlorine dosage is provided to maintain the proper residual as the finished water leaves the plant and is a nearly constant dosage rate, entirely independent of the prechlorine requirement. We have separated the post from prechlorine, and applied the benefits to the prechlorine total costs as a straight percentage savings.



X = MONTHLY AVERAGE

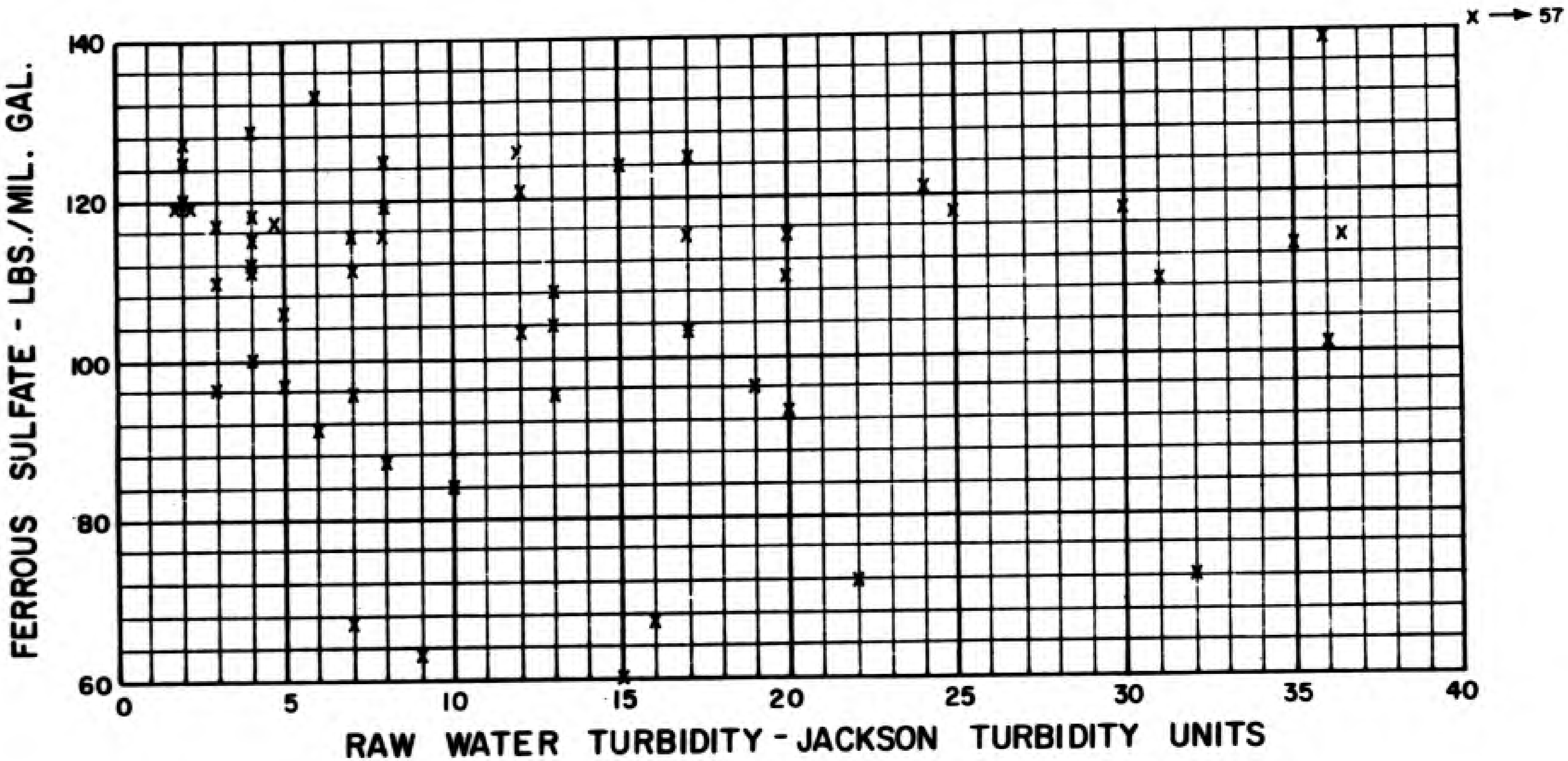
U.S. ARMY CORPS OF ENGINEERS
REPORT ON THE DETERMINATION OF BENEFITS
FROM AN IMPROVED GREAT LAKES WATER QUALITY

ALUM DOSAGE VS. RAW WATER TURBIDITY AT CHICAGO SOUTH WATER FILTRATION PLANT, 1964 THROUGH AUGUST, 1968

NOVEMBER, 1968

FIGURE 4

GREELEY AND HANSEN
ENGINEERS



X = MONTHLY AVERAGE

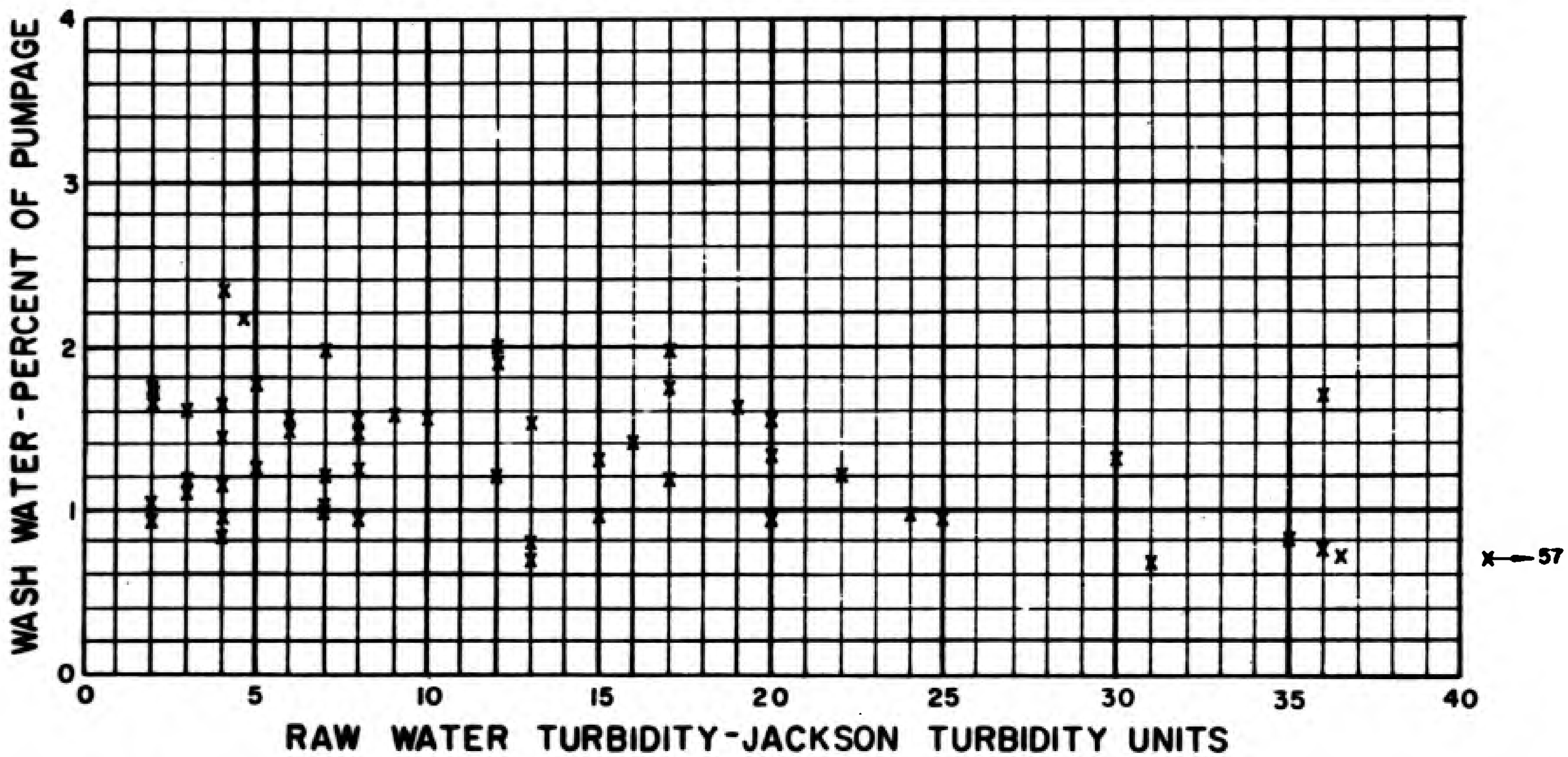
U.S. ARMY CORPS OF ENGINEERS
REPORT ON THE DETERMINATION OF BENEFITS
FROM AN IMPROVED GREAT LAKES WATER QUALITY

FERROUS SULFATE DOSAGE VS. RAW WATER TURBIDITY
AT CHICAGO SOUTH WATER FILTRATION PLANT,
1964 THROUGH AUGUST, 1968

NOVEMBER, 1968

FIGURE 5

GREELEY AND HANSEN
ENGINEERS



U.S. ARMY CORPS OF ENGINEERS
REPORT ON THE DETERMINATION OF BENEFITS
FROM AN IMPROVED GREAT LAKES WATER QUALITY

WASH WATER VS. RAW WATER TURBIDITY
AT CHICAGO SOUTH WATER FILTRATION PLANT,
1964 THROUGH AUGUST, 1968

NOVEMBER, 1968

FIGURE 6

GREELEY AND HANSEN
ENGINEERS

<u>Threshold Odor Number</u>. Standard operating rules for the correlation of threshold odor numbers (TON) and activated carbon dosage are used at the Chicago Filtration plants, as follows:

1. Minimum carbon dosage, regardless of type of odor, is 10 lbs./mil.gal. of water treated whenever there is a TON of 1.
2. Nonhydrocarbon odors in any threshold odor number range require 10 lbs./TON/mil.gal.
3. Hydrocarbon odors from 1 to 5 TON require 100 lbs./mil.gal.
4. Hydrocarbon odors from 5 to 10 TON require 100 lbs./mil.gal. plus 15 lbs./TON/mil.gal. for TON numbers above 5 and less than 10.
5. Hydrocarbon odors above 10 TON require 175 lbs./mil.gal. plus 10 lbs./TON/mil.gal. above 10 TON.

The annual reports of the past four years contain comments on the frequency and magnitude of hydrocarbon threshold odor numbers to the effect that they mainly occur in winter months (November, December, January, February). This coincides with periods in which dredged materials are not being dumped in the lake, so we used the nonhydrocarbon rules in calculating monetary benefits. It was also noted that the maximum TON are usually the hydrocarbon type, especially at the SWFP.

VI. Calculation of Benefits

From the preceding section, it is seen that there is no correlation between wash water or coagulant and plankton or raw water turbidity. It is not feasible to calculate a benefit due to improvement in water quality through reduction in raw water turbidity and plankton.

In 1967, chlorine costs (pre and post) for the Chicago water supply were $457,812, of which approximately $286,400 was the cost of prechlorine dosage. A reduction of 0.5 percent chlorine demand would have resulted in savings of $1,432 for the year.

The carbon costs for the same year were $759,000, so a reduction of 0.8 percent threshold odor number would have resulted in a direct savings of $6,072 for 1967.

The total benefit for chlorine and carbon is $7,504, based on 1967 figures, while the total chemical costs for the Chicago water supply in 1967 was $2,466,347, or $6.27 per million gallons. A reduction in chemical costs of $7,504 amounts to an increment equal to 0.304 percent of the annual chemical costs, or about two cents per million gallons. As previously stated, this calculated benefit could be overstated from four to 100 times, making the amount of dollars negligible in the overall picture. If this is true for the largest treated municipal water supply on the Great Lakes, we believe the total benefits to all water supplies cannot be significant. Of the total of Great Lakes municipal water supplies, the Chicago supply is roughly estimated to represent one-third.

VII. Conclusions

A. The state of the art is not sufficiently advanced to the place where testing and sampling procedures permit the establishment of relationships between turbidity and plankton characteristics and chemical dosage or wash water quantity.

B. Based on the improvements in raw water quality characteristics stated in Table 2, and present knowledge of the effects of chemical dosages on these characteristics, the benefits to the City of Chicago water in reduced chemical costs would have been about $7,500 in the year 1967 had the Corps of Engineers curtailed disposal of dredgings in Lake Michigan.

C. Based on the measured effects of disposal of dredgings elsewhere, the benefit in Conclusion "B" may be overstated by a factor of four to 100 as previously discussed, i.e., the amount may be $75 to $1,900.

D. It is our opinion that the costs of pursuing this study in further detail would exceed the calculable water supply benefits gained annually from the curtailment or termination of disposal of dredgings.

VIII. Recommendations

1. We recommend that the study be terminated at this point.

2. In view of the limited information on which the benefits are based and the amount of judgment required in estimating the improvements in water quality, we recommend that extreme care be exercised when using the conclusions contained herein.

APPENDIX A

U.S. Corps of Engineers' letter of October 10, 1968,
with enclosure

DEPARTMENT OF THE ARMY
NORTH CENTRAL DIVISION, CORPS OF ENGINEERS
536 SOUTH CLARK STREET
CHICAGO, ILLINOIS 60605

IN REPLY REFER TO

NCDED

10 October 1968

Greeley & Hansen
14 East Jackson Street
Chicago, Illinois

ATTENTION: Mr. Robert Hall

Dear Mr. Hall:

This is in regard to your study on the evaluation of water supply benefits that would result from a cessation of lake disposal of harbor dredgings. The contract for the study specifies that the Corps of Engineers is to furnish the effects on raw water quality of the Corps' present practice of dumping dredgings in open-water lake-disposal areas.

The effect on water quality parameters is certainly very small and can only be estimated from arbitrary assumptions. However, such assumptions are required for the study.

The inclosed memorandum, subject: Determinations of Benefits for Disposal of Dredged Materials through Alternatives to Present Practices, presents our estimates of the effects, which are tabulated on page 6 of the memorandum. (Effects are considered the same as water quality improvement due to alternative methods of disposal of polluted dredged material.)

It is desired that your evaluation of benefits be based on these estimates of the effects. It is suggested that your study also include evaluations with the effects twice and five times the values shown in the table.

In view of the uncertain nature of the estimates that we have made, we would appreciate any comments or suggestions that you may have.

Sincerely yours,

Charles F. MacNish

CHARLES F. MacNISH
Authorized Representative of
Contracting Officer, Alternate

1 Incl.
Memo.

SUBJECT: Arbitrary Estimates of Effects on Raw Water Quality of Open-Lake Disposal of Harbor Dredgings

REFERENCE: Feasibility of Evaluation of Benefits from Improved Great Lakes Water Quality, Special Report No. 2, University of Illinois, Water Resources Center, May 1968

1. Background Information. The University of Illinois report is based on the assumption that evaluation of benefits is feasible and that the first step in evaluating benefits is to determine the effect of the change on certain water quality characteristics at points of use. The feasibility of determining benefits will depend upon the success in identifying the changes in water quality due to dredge disposal at points of use.

2. Suggested raw water quality parameters as listed in the University of Illinois report are shown in Table No. 1. Parameters normally recorded at the Chicago Water Filtration plant and the Wyandotte, Michigan Water Filtration plant are also shown for purposes of comparison.

3. A small amount of historical data regarding raw water quality has been collected for the Chicago, Cleveland, and Wyandotte, Michigan areas; also some data from the FWPCA for Lake Erie. Certain data show a buildup of chlorides, sulfates, dissolved solids and coliform numbers. None of the data presents any information regarding the effects of open lake disposal of dredged material.

UNIVERSITY OF ILLINOIS REPORT		CHICAGO SOUTH WATER FILTRATION PLANT	WYANDOTTE MICHIGAN WATER TREATMENT PLANT
MUNICIPAL SUPPLY	INDUSTRIAL SUPPLY	residual chlorine	pre chlorine
		Hydrogen - Ion Concentration(PH)	turbidity
turbidity	turbidity	flouride	odor
chlorine demand	chlorine demand	ammonia nitrogen	temperature
total extractable organic matter (or perhaps threshold odor number)	total extractable organic matter (or perhaps threshold odor number)	turbidity	PH
		odor tests	chlorides
			alkalinity
total plankton mass	total plankton mass	temperature	hardness
hardness	hardness	alkalinity (94 tests)	coliform
	dissolved solids	hardness (86 tests)	flourides
	dissolved gases	coliform	
	slime forming organisms	plankton	

TABLE NO.1

4. The Great Lakes Research Center, U. S. Lake Survey has prepared a preliminary report on Effects of Spoil Disposal at Toledo, Ohio. To illustrate the complexities in determining the effects of open lake dredge disposal on water quality of the Great Lakes, the following excerpts from the conclusions of this report have been tabulated as follows:

a. The Maumee River as a major tributary and contributor of suspended solids in Lake Erie dominates. . .

b. The extent of flow and composition of the river tended to mask the dredging and dumping effect. Turbidity is one parameter which should be prominent in the area of dredging. However, the turbidity levels in the river and bay were sufficiently high to mask most of the effect.

c. Concentrations of the other ions measured in the disposal areas showed disposal effects in varying degrees. However, in all cases the effects were rapidly dissipated in the areas not strongly influenced by contributions from the river.

d. There was little evidence, if any, of dredging effects on the adjacent stations in the river. Dumping effects were noted at the open-lake disposal area but were often minor when compared with contributions made by the river. In some instances it was difficult to separate the river effects from the effects of dumping.

e. In an attempt to evaluate effects of dredging and disposal on Lake Erie a comparison was made between that project in the Toledo area and the estimated discharge from the Maumee River during the same

51-day period. Data is listed in the following table (Table No. 2):

Table No. 2 River Versus Spoil Contribution to Lake Erie at Toledo, Ohio During Dredging Period - 1967

Parameter	Contribution to Lake (lbs.) by River	by Dredge	Dredge/River
Chloride	54,023,500	3,500	.0065%
Phosphate	3,608,000	200	.0061%
Nitrate	22,610,000	1,300	.0056%
Sulfate	177,513,600	15,100	.0085%
Calcium	54,841,300	4,900	.0089%
Magnesium	27,661,200	1,500	.0053%
Sodium	65,905,800	2,500	.0037%
Potassium	7,456,500	700	.0088%
Silica	6,734,900	400	.0061%

5. Personal observations from persons familiar with water quality at various locations in the Great Lakes have also been obtained. The consensus was that, although certain water-quality parameters have deteriorated over the years, no changes have been noted that could be specifically attributed to open-lake disposal of dredged material.

6. Based on the preceding paragraphs it is apparent that lake disposal of dredged material has little effect on Great Lakes water quality at points of use such as municipal water intakes. Effects from dilution in the lakes, inflow of pollutants from sources other than dredge disposal, and the inadequacy of present day testing procedures are sufficient to mask any effects at water intakes, caused by present methods of dredgings disposal.

7. Arbitrary Estimates of Effects. As previously noted, the first step in evaluating water-supply benefits that may accrue from a cessation of open-water disposal of dredgings in the Great Lakes, is the determination of effects on raw water quality at points of use. The complexity of determining the effects of open-water disposal and the lack of data for a detailed study have been pointed out.

8. It is considered, however, that arbitrary estimates of the effects are possible, such that the estimates would encompass (be greater than) any possible actual effects and thus provide a basis for determining water-supply benefits that would be on the liberal side but would be useful in considerations of the dredgings-disposal problem.

9. For the arbitrary estimates, the parameters used are those listed in the University of Illinois report. Estimates for change are based on data pertaining to the water intakes of Chicago and Cleveland, and on some data obtained from the FWPCA regarding Lake Erie. The data, in general, show a buildup over the years for such parameters as sulfates, chlorides, chlorine dosage, and odor periods at Chicago; and coliform, dissolved solids and calcium for Lake Erie.

10. Gross assumptions had to be made regarding the influence of open-lake dredgings disposal on raw-water quality at water intakes. The major portion of the historical data used for calculating changes in raw-water quality, pertains to the municipal water intakes of Chicago, Illinois and Cleveland, Ohio. It is recognized that indicated changes in raw-water quality at Chicago are not representative of changes at other intakes on Lake Michigan;

that indicated changes at Cleveland are not representative of changes at other intakes on Lake Erie; and further that changes on the two lakes are not the same. For purposes of the arbitrary estimates herein, however, data from the Chicago and Cleveland intakes were composited to arrive at values which are considered to represent changes that would be among the most severe to be found at any intakes in the Great Lakes.

11. Arbitrarily percentage changes for the raw-water quality parameters listed in the University of Illinois report are tabulated in Table No. 3.

Tabel No. 3 - Water Quality Parameters and Percent Increase Due to Lake Disposal of Dredge Spoil

Municipal Water Supplies:		
Turbidity	.04%	
Chlorine Demand	.5%	
Total Extractable Organic Matter (or perhaps TON)	.8% TON	
Total Plankton Mass	1.0%	
Hardness	.05%	
Industrial: (Same as municipal plus the following:)		
Dissolved solids	.06%	
Dissolved gases	0%	(No data available)
Slime forming organisms	.4%	" " "

12. In general the preceding parameter percentage changes were obtained by calculating the percentage buildup of that certain parameter over the period of years for which records were available, dividing by the number

of years and arbitrarily taking 10% of this as the portion attributable to disposal of dredgings. Where no data was available for such as slime organisms, this percentage change was based on per cent change in coliforms.