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AIMS & SCOPE OF THE JOURNAL

The *Journal of Dredging* is published by the Western Dredging Association (WEDA) to provide dissemination of technical and project information on dredging engineering topics. The peer-reviewed papers in this practice-oriented journal will present engineering solutions to dredging and placement problems, which are not normally available from traditional journals. Topics of interest includes, but is not limited to, dredging techniques, hydrographic surveys, dredge automation, dredge safety a instrumentation, design aspects of dredging projects, dredged material placement, environment and beneficial uses, contaminated sediments, litigation, economic aspects and case studies.

DECONTAMINATION AND BENEFICIAL REUSE OF DREDGED MATERIAL USING EXISTING INFRASTRUCTURE FOR THE MANUFACTURE OF LIGHTWEIGHT AGGREGATE

J. D. Derman[1] and H. A. Schlieper[2]

ABSTRACT

The need to achieve an environmentally acceptable and economically beneficial reuse option for the management of dredged material is self-evident in order to retain and enhance the economic viability of America's waterways and harbors. A technological and commercial approach is needed that focuses on the utilization of dredged material as a feedstock in the manufacture of a value added building material, lightweight aggregate (LWA). Our approach, based on proven unit operations, is capable of yielding an "upcycled" product with a demonstrated market demand. Key to the success of the approach is the incorporation of existing infrastructure and capital assets. Beneficial reuse and thermal decontamination are accomplished employing a high temperature rotary kiln process traditionally used in the LWA manufacturing process at a plant that has been in continuous operation in the State of New York since the mid-1950's.

INTRODUCTION

In order to remain as viable port facilities, the harbors and waterways of the United States require periodic dredging to provide adequate draft for large ocean going vessels. Further, dredging is often required in order that draft can be maintained for barge movement. Historically, the disposal of dredged material has not posed a significant problem. Routinely, dredged material was hauled offshore and deposited in various open water options, e.g., open dumping at sea, in borrow pits or confined disposal facilities (CDFs) near shore or at sea. Alternately, dredged material was placed in upland CDFs near the site of the dredging activity. In recent times, the ability to utilize these management options has been significantly limited due to environmental concerns surrounding the potential impact of contaminants, both organic and inorganic, on the environment (Jones et al, 1998).

Disposal at sea continues to be the method used for dredged material that has been deemed "clean" from a contamination perspective. The remaining contaminated dredged material must be properly managed and disposed in accordance with environmental regulations. The disposal options for contaminated dredged material include: containment islands, sub-aqueous borrow pits, upland disposal in landfills, land placement following solidification and/or stabilization, or through decontamination technology.

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[1]Derman, J.D., JCI/UPCYCLE Associates, LLC, P. O. Box 11389, Loudonville, NY 12211-0389, USA.
[2]Schlieper, H.A., JCI/UPCYCLE Associates, LLC, 116 Gallinson Drive, New Providence, NJ 07974, USA.

A considerable effort has been undertaken by both public and private interests to develop a recycling approach, but to this point that effort has been unsuccessful either due to high operating/capital costs of the proposed method or lack of market for the resultant product.

The Port of New York/New Jersey (NY/NJ) serves as a prime example of this problem. While the Port would appear to be prosperous and growing, its rate of growth was substantially behind its major U.S. and international competitors. The world-wide trend for shipping is for increased containerization in larger ships. As other ports deepen their harbors to accommodate these new generation vessels, the Port of NY/NJ is faced with serious challenges to maintain the current depths of its channels and berthing areas, let alone to increase them.

The major obstacle facing the Port and potentially impacting its future viability is the lack of acceptable and reliable means of disposing of the millions of cubic yards of material that must be dredged to both maintain the current depth and provide additional depth for the new generation of container vessels.

The many years of industrial activity in the Port area have caused pollution and contamination of the sediment with the result being concern over the impact on the ecology of the New York Bight and its adjacent estuary. Due to the concern over these pollutants and their long-term potential degradation, the criteria for ocean disposal of dredged material were revised in 1992. These revisions include increased sensitivity in detection limits and more stringent criteria for assessing chronic impacts. Under this new testing regime, about 75% of the dredged material fails the ocean disposal test (Jones et al., 1998). The immediate result for the Port of NY/NJ is a situation where there is a lack of environmentally acceptable disposal sites for the vast majority of material requiring dredging.

Publicly available information shows that the Port Authority of NY/NJ recently paid $118 per cubic yard to stabilize dredge material, barge it to Texas and then rail the material to Utah for landfill cover. Material dredged from Port Newark Reach A was stabilized and used as a fill sub-base for a parking lot at a cost of $57 per cubic yard. The Pennsylvania Mine Reclamation Project has been reported at $84 per cubic yard. Other disposal options without the benefit of beneficial reuse range from $35 to $60 per cubic yard (BNL, 1999). With an estimated 4-5 million cubic yards per annum of dredged material needing proper handling, cost effective and environmentally acceptable management options are imperative if the Port of NY/NJ is to remain open and viable.

A technologically and economically viable approach for commercial quantities of dredged material, i.e., 500,000 cubic yards per year, is currently being developed in the Port of NY/NJ area that is highly competitive and offers an environmental benefit in the ability to reuse the dredged material and thus to conserving precious natural resources (JCI/UPCYCLE, 1999). This concept provides thermal decontamination and beneficial reuse of dredged material by producing an end product, lightweight aggregate, at a target price of $35 per cubic yard based on the processing of 500,000 cubic yards per annum of dredged material.

PROCESS OVERVIEW

Succinctly, the process technology encompasses dewatering, pelletizing and extrusion of the dredged material coupled with thermal treatment via a rotary kiln to achieve dredged material decontamination and coincidentally, beneficial reuse. After dredging, the pre-kiln processing steps including initial sizing and debris removal, dewatering and pelletizing are envisioned to occur at a central or "merchant" commercial facility. The dewatered pellets will then be transported to an existing lightweight aggregate plant where they will undergo extrusion prior to final processing in rotary kilns. Figure 1 depicts the process flow.

The lightweight aggregate manufacturing site is anchored by two 11 foot diameter by 175 foot long refractory lined rotary kilns supported by a full complement of monitored air and water pollution control systems. Ancillary equipment includes a full array of crushing, screening and sizing equipment.

The concept was developed after close examination of the mineralogical nature of dredged material within the Port of NY/NJ. This examination revealed that the mineralogical components are essentially the same as those in building materials produced and sold in commerce today. Table 1 presents a chemical analysis comparison of typical feedstock for lightweight aggregate production versus dredged material.

The beneficial reuse and decontamination technology being offered maximizes the contaminants that will be removed and destroyed while minimizing those that are left untreated. By exposing the extruded dredged material to the temperatures within the kiln's burning zone of 2100 - 2200° F, thermal desorption and destruction of organic constituents is obtained. The manufacture of lightweight aggregate is based on the conversion of the solids into a pyro-plastic (partially molten) state at the same temperature that the bloating gases begin to evolve. The plasticity of the substance is controlled by the amount and ratio of flux compounds (used to promote fusion) within the solids. These various flux compound oxides react with silica, SiO_2, (the predominant mineralogical component of dredged material) to form the complex compound matrix that further binds and immobilizes the various metal constituents and contaminants. The lightweight aggregate (LWA) product, with the millions of minute separated air cells, has a lighter bulk density, provides greatly enhanced thermal resistance and more than double the thermal insulation value to the final concrete end-product. Additionally, the LWA pyro-manufacturing process improves the fire resistance of the resulting concrete since any combustible components are removed within the kiln. Major traditional uses of LWA are in structural concrete, concrete masonry units and as geotechnical fill.

The dewatered dredged material pellets that will subsequently be thermally converted into LWA yield an end product in conformance with applicable American Society for Testing Materials (ASTM) and construction industry specifications with additional potential use in Brownfields' remediation and/or as landfill cover. From an environmental standpoint, dredged material provides a benefit from its ability to be reused and from conserving precious natural resources, e.g., shale or clay. From a commercial perspective, the markets for "upcycled" aggregate are well established and of such size that they can easily accommodate the introduction of additional

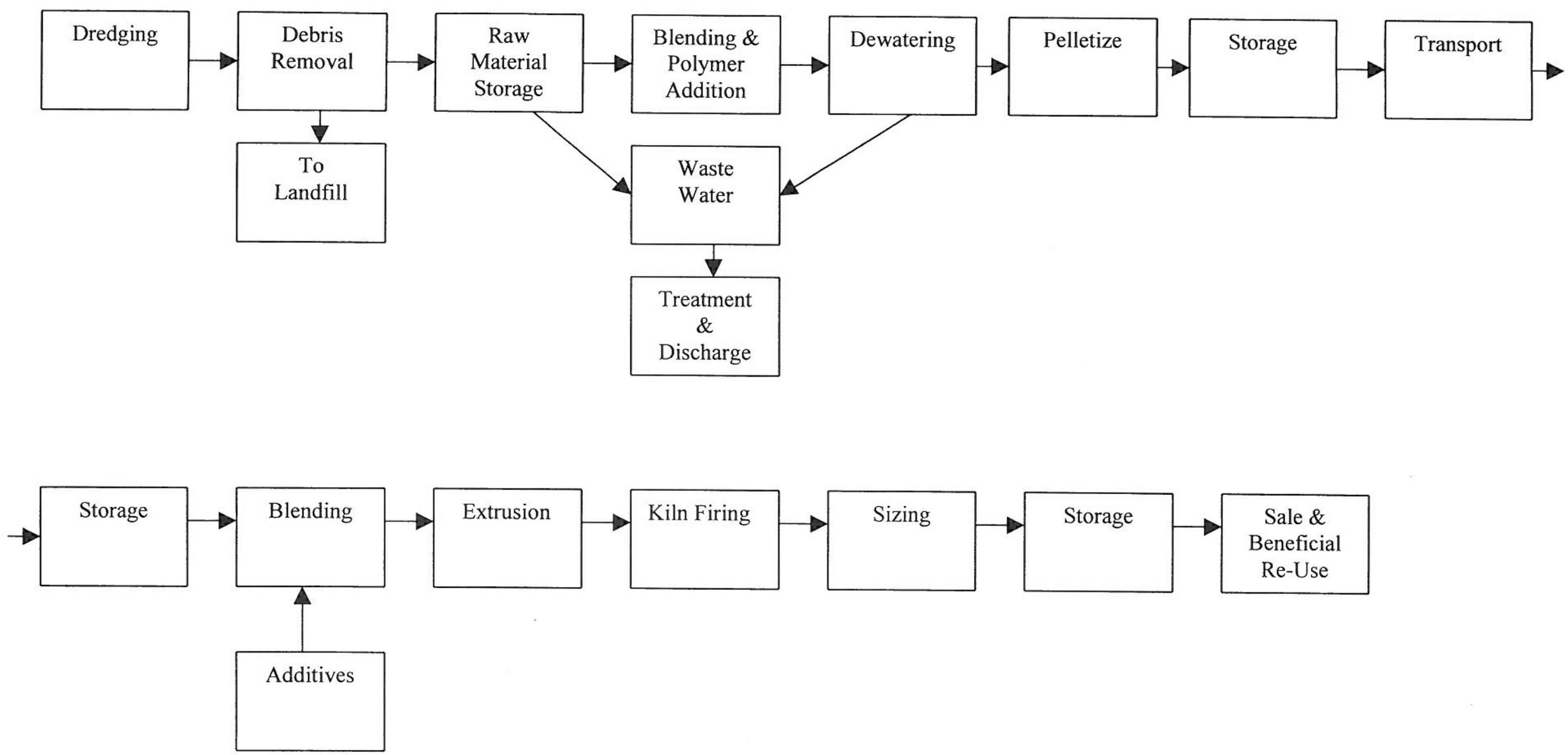

Figure 1. Dredged Material Decontamination: Beneficial Re-Use Process

Table 1. Chemical Oxide Analysis Comparisons (weight %)
LWA Raw Materials.

Chemical Compound	Typical LWA[1]	Norlite Shale[1] Fines	Upcycle DM[1]	Upcycle #5[1] Mix	Brookhaven DM[2]
SiO_2	50-80	59.51	53.56	53.13	75.23
Al_2O_3	10-25	16.40	12.66	13.06	10.25
Fe_2O_3	3-10	7.32	7.23	7.27	4.86
CaO	0-3	1.37	1.23	2.66	2.50
MgO	0-5	2.94	1.60	1.86	1.57
K_2O	1-10	3.55	2.19	2.51	2.19
Na_2O	0-5	1.24	1.87	1.83	2.30
P_2O_5		0.09	0.62	0.46	0.28
TiO_2		0.78	0.96	0.86	0.66
Mn_2O_3		0.18	0.12	0.13	0.061 (as MnO)
LOI @ 900°C	4-8	5.21	13.73	12.88	9.83

Notes:

1. Data from Fuller Company (1998)
2. Data from Spectrochemical Labs - Composite (1997)

sources. From an economic viewpoint, the process utilizes existing infrastructure, commercially available equipment and proven technology to create a viable dredged material management option.

OVERVIEW OF PROGRESS TO DATE

In conjunction with our team members, we self-funded a comprehensive pilot scale program to demonstrate the feasibility of this technology. The team comprised JCI/UPCYCLE, Norlite Corporation, Fuller Company, Solomon Technologies, Inc., Komline-Sanderson and GZA GeoEnvironmental, Inc.

We also conducted bench scale testing to confirm the suitability of dredged material to dewater and subsequently, to bloat and create lightweight aggregate. We used dredged material supplied by the USACE from the Arthur Kill for its preliminary analysis. While detailed analytical results are not available on the Arthur Kill material, these tests did produce actual quantities, albeit small amounts, of acceptable LWA. Most importantly, these "preliminary tests have indicated that the dredged material has very good potential for the production of lightweight aggregate" (Fuller Company, 1998).

Our ability to make the above conclusion is based on a variety of factors notwithstanding our team members 40 years experience in evaluating a multitude of potential raw materials for use in the manufacture of LWA. The first is the empirical relationships that predict the ability of a raw material to bloat based on its chemical analyses. The second is our team's knowledge and experience "that there is not much difference in producing LWA from dredged material, once it has been dried, then from conventional expandable clays or shales, particularly clays, which are a soil on land. Once dewatering is done on the dredge material, the material could be considered a sedimentary clay where it most likely originated from, based on the chemical analyses obtained in almost all cases."

With the understanding that LWA can be produced from dewatered dredged material and that high temperature treatment is effective at handling most commonly found contaminants, efforts were focused on consolidation/dewatering. In January, 1998, in conjunction with EPA and USACE representatives, we participated in a sampling program and obtained approximately 100 gallons of Category III material from Newark Bay. These samples were analyzed to determine and to verify the physical and chemical nature of the dredged material as compared to data available from both the EPA and the USACE's Waterways Experiment Station.

In March, 1998, a library search and bench scale testing on sediments were conducted to evaluate the effect of polymers to enhance water content reduction of dredged materials. The library research concluded that polymers can and do play a key role in the dewatering operation. Also, the right polymer for a specific application can enhance the engineering behavior of dredged materials with regards to both free and consolidated drainage. However, the library search identified that the state of knowledge and experiences were inadequate to engineer an off-the-shelf process for dewatering dredged material.

A second phase of laboratory testing on about 70 gallons of a homogeneous sample was proposed. This phase included the selection of specific polymers/conditioners, free drainage dewatering tests and consolidated dewatering tests utilizing pre-selected polymers.

The following conclusions have been excerpted from the test results. (GZA, 1998)

- The dredged soil can be dewatered to acceptable levels of water content by a one step consolidation dewatering process.

- Consolidation dewatering of this material without a polymer additive requires long dewatering times.

- The addition of polymers to the soil during the mixing of the soil simultaneously destroys the natural soil structures causing dramatic decreases in the time to consolidate the soil. The amounts of the decreases are systematically related to the concentration of the polymer. The equilibrium water contents of the soil at full consolidation are not significantly affected by the presence of the polymer.

- The processed data from the consolidation tests was used to develop design curves relating the time required for different amounts of consolidation as functions of drainage path distances, squeezing pressures and polymer concentrations.

In May, 1998, with this confirmatory information in hand, a laboratory test was undertaken to evaluate the effectiveness of a continuous belt filter press as a dewatering process for dredged material. The test program utilized bench scale filtration equipment and proprietary models to evaluate filtration properties, to define process relationships and to determine full scale equipment performance and sizing parameters. The technical goals of this test program included:

- Production of a friable cake suitable for transportation and further processing

- High processing rate

- Low operating and maintenance costs

- Small footprint

In summary, the test work confirmed that a belt filter press "will achieve significant volume reduction and produce a friable filter cake which easily passes the paint filter test." Additionally, it was determined that "operational costs are directly proportional to inlet concentration (rather than volume). Finally, the tests determined that the expected process efficiency, or solids capture rate, will range from 98.8% - 99.4% based on a total suspended solids mass balance and that filtrate and spent wash water are readily settleable at high processing rates." (K-S, 1998)

With this ever increasing level of knowledge, in August, 1998, we self funded a comprehensive pilot scale program. The pilot program utilized approximately 600 gallons (3 cubic yards) of dredged material from the Perth Amboy Marina to evaluate the rotary kiln production of lightweight aggregate. This work was performed utilizing the 1 ft diameter x 15 ft long pilot refractory lined rotary kiln system and was based on the previous successful laboratory study that demonstrated the feasibility of using dredged materials in the manufacture of lightweight aggregate. While the results from the pilot program are voluminous, the succinct outcome is that it is feasible to produce commercially acceptable lightweight aggregate from dredged materials. (Fuller Company, 1998) This conclusion is supported by the product analysis and by the demonstrated excellent compressive strength levels observed as compared to several commercial aggregate samples (Table 2). The implication of the compressive strength levels achieved is that the product will be suitable for use in lightweight aggregate structural concrete and concrete masonry units. Further, the composite feedstock and the resultant lightweight aggregate product were analyzed for total metal concentration and leachability via standard U.S. EPA analytical methods (SW-846 and Toxicity Characteristic Leaching Procedure, "TCLP"). The leachability of metals is at least one order of magnitude, and in most cases, several orders of magnitude below established regulatory limits (Table 3).

To further support our results, we subjected the pilot aggregate produced to an independent testing effort. (ATC, 1998) This program consisted of making a 3000 psi concrete mix design incorporating the pilot aggregate and testing the resulting concrete cylinders for compressive and tensile strengths after various time periods. Conclusions reached were completely validated in that the strengths achieved from the aggregate produced from dredged materials exceeded those obtained from a control mix using commercially available aggregate.

Based on the above success, the Port Authority of NY/NJ agreed to test our pilot aggregate to initiate and conduct its own material evaluation program. This work undertaken by the Port Authority's Materials Engineering Division at their Jersey City, NJ laboratories sought not only to replicate the evaluations already performed, but to subject the material to a battery of additional chemical and physical tests. The stated purpose of the Port Authority's efforts was to confirm the equivalence of lightweight aggregate manufactured from dredged material to that of commercially available aggregate in the concrete mixes routinely used by them, and of equal importance, to assure that there will not be adverse effects from the handling and use of dredged material produced LWA.

The Port Authority in their Laboratory Test Report on our aggregate (PANYNJ, 1999) concluded "... that the Upcycle aggregate exhibited physical characteristics desired for a construction grade lightweight aggregate" (Table 4). Moreover, the Port Authority has indicated an interest in utilizing a substantial quantity of "upcycled" material in a demonstration engineering application.

We have continued to pursue innovative technologies for the fluid-sediment separation, i.e., dewatering, required prior to the initial pelletization step of our process. Our team has successfully undertaken and completed several bench scale tests utilizing proprietary process equipment in conjunction with polymer chemistry and known mechanical means to produce a

Table 2. Compressive Strength Comparison Lightweight Aggregate Products[1]

Plant	Compression lbs.	Range lbs.	Coarse Bulk Density lb/ft^3	End Uses
A	131	103-169	55.0	Block & Limited Structural
B	177	138-236	50.7	Block
C	197	133-250+	41.0	Structural
D	128	70-180	34.1	Block
E	183	155-205	38.2	Block & Structural
F	165	110-205	35.0	Block
G	86	61-101	45.0	Fly Ash Block Product
UPCYCLE Mix #4	197+	175-230+	34.0	
UPCYCLE Mix #5	230+	230+	41.8	

[1]Data from Fuller Company (1998).

Table 3. Metal and TCLP Metal Results[1]

	Composite Feed			Product	
	Result			Result	
Metals	mg/kg			mg/kg	
Antimony	<2.89			<2.50	
Arsenic	46.4			43.1	
Barium	156			14.7	
Beryllium	1.27			<0.250	
Cadmium	<0.289			<0.250	
Chromium	98.7			7.75	
Copper	322			200	
Lead	194			11.8	
Mercury	3.46			<0.167	
Nickel	41.0			32.8	
Selenium	<2.89			<2.50	
Silver	<0.289			<0.250	
Thallium	<5.77			<5.00	
Zinc	311			26.1	
TCLP Metals	mg/l	Reg. Limit mg/l		mg/l	Reg. Limit mg/l
Arsenic	<0.050	5.0		0.102	5.0
Barium	0.364	100.0		0.208	100.0
Cadmium	<0.005	1.0		<0.005	1.0
Chromium	<0.010	5.0		<0.010	5.0
Lead	<0.050	5.0		<0.050	5.0
Mercury	<0.0002	0.2		<0.0002	0.2
Selenium	<0.050	1.0		<0.050	1.0
Silver	<0.005	5.0		<0.005	5.0

[1]Data from Fuller Company (1998)

Table 4. Laboratory Test Results - UPCYCLE Aggregate

(a) Absorption - Results are based on submerging the aggregate for 72 hours under 1/2 inch head of water at room temperature and atmospheric pressure.

Aggregate Type	Total Absorption (Minimum)
Control	11.3%
UPCYCLE	12.8%

(b) Bulk Specific Gravity SSD (Saturated Surface Dry) & Dry Rodded Unit Weight - Results are determined after submerging the aggregate for 72 hours under 1/2 inch head of water at laboratory temperature and atmospheric pressure. Aggregate for dry rodded unit weight was oven dried for 24 hours and tested in accordance with ASTM C-29.

Aggregate Type	Bulk Specific Gravity SSD	Dry Rodded Unit Weight
Control	1.25	44.8 lb/ft^3
UPCYCLE	1.34	54.4 lb/ft^3

(c) Soundness (ASTM C-88) - Indicates how well an aggregate will hold up to weathering action. Five soaking and drying cycles were performed using Sodium Sulfate.

Aggregate Type	Total Weighted Loss
Control	3.2%
UPCYCLE	1.3%

(d) Freeze & Thaw on Aggregate - Performed in accordance with AASHTO T-103 Procedure A with a total of ten freeze & thaw cycles.

Aggregate Type	Total Weighted Loss
Control	3.1%
UPCYCLE	0.7%

Note: Control material used was expanded shale lightweight aggregate.

"dry" filter cake in the range of 70+% weight solids. (ST, 1998) These most promising results have marked beneficial environmental as well as economic impacts on the overall process.

CONCLUSIONS

We have developed a concept capable of managing a minimum of 500,000 cubic yards per year of dredged material in a cost-effective and economically sound manner. This technological and commercial approach focuses on the utilization of dredged material as a feedstock in the manufacture of a value added building material, lightweight aggregate. A central factor in our approach is the utilization of existing infrastructure and capital assets coupled with the use of proven unit operations and readily available equipment. Beneficial reuse and decontamination of the dredged material is accomplished employing a high temperature rotary kiln process traditionally found in the LWA manufacturing process at a plant that has been in continuous operation in the State of New York since the mid-1950's.

We have self-funded extensive process pilot testing and coupled with thorough product testing conducted independently and by the Port Authority of NY/NJ that demonstrates that the aforementioned objective is achievable. Further, based on the Port Authority's test results, they have indicated an interest in utilizing "upcycled" aggregate in an upcoming engineering application. Our process offers a technologically and environmentally acceptable beneficial reuse and decontamination option for the management of dredged material that can serve to retain and enhance the economic viability of currently impaired waterways and harbors.

ACKNOWLEDGMENTS

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IDENTIFICATION AND EVALUATION OF REMEDIAL DREDGING DIFFICULTIES

Bradford S. Cushing[1]

ABSTRACT

The author has closely tracked projects at which remedial dredging has been implemented in order to identify techniques, cost, difficulties, and degree of success. This paper presents the author's findings, including an overview of remedial dredging methods used on 17 projects completed to-date in the U.S. (end of 1998), to provide insight into this specialized field. Only true dredging projects are presented, not dry excavation type projects from dewatered areas. The 17 projects resulted in removal of volumes of contaminated sediment ranging from 3,100 to 169,000 cubic yards. Key areas of difficulty that demand closer attention in future remedial dredging projects and represent challenges to the dredging industry are identified. These key areas of difficulty include: (a) rocks, vegetation, and debris; (b) free oil; (c) water management; (d) shallow water depths; (e) disposal issues; (f) low production rates; and (g) resuspension control (silt curtains).

Three related topics are also considered, which include: (a) a comparison of the methods and objectives of remedial dredging vs. those of traditional maintenance dredging; (b) an evaluation of the limitations and complexities of remedial dredging using conventional dredges; and (c) a discussion of reasons why production rates are low as compared to maintenance dredging. Low production rates realized during remedial dredging projects are generally not anticipated in the planning phase and have made the prediction of realistic cost and implementation times difficult and often optimistic for remedial dredging projects.

INTRODUCTION

The author has closely tracked projects in the U.S. at which full-scale sediment remediation by dredging ("remedial or environmental dredging") has been completed to identify techniques, cost, difficulties, and degree of success. Seventeen projects have been identified. The volumes of sediment removed have been exceedingly small by maintenance or navigational dredging standards but the difficulties encountered have been varied and formidable. Overcoming or efficiently dealing with these difficulties on future remedial dredging projects represent ongoing challenges to the dredging industry. Identification and discussion of these dredging difficulties, and possible corrective measures, are the focus of this paper. The subject was previously evaluated in (Cushing, 1998) and is now presented in an updated and more detailed form herein. Other authors recently addressing this subject and closely-related subjects include (Briot et al., 1999; Garbaciak et al., 1999; Mohan, 1998; and Priore et al., 1999.)

[1] Cushing, Bradford S., Principal and Vice President, Applied Environmental Management Inc., Malvern, PA 19355, USA.

Information Sources

Documentation of the outcome of remedial dredging projects to-date has, in varying degree, been inconsistent and incomplete. As a result, the author's firm, in conjunction with General Electric Company and Blasland, Bouck & Lee, Inc., has assembled a Database of major contaminated sediment projects in the U.S. (Database, 1999). Information assembled for each project in the Database is from a wide variety of sources, both written and oral. Much of the information in this paper is derived from the Database; citation of references, in every instance, is not practical. The Database and its reference citations are Internet accessible.

REMEDIAL DREDGING vs. MAINTENANCE/NAVIGATION DREDGING

Conventional maintenance/navigational dredging equipment and operational procedures are designed to maximize productivity. The procedural differences between maintenance dredging and remedial dredging are extensive; perhaps the only major similarity is the equipment itself. The foremost differences are that maintenance/navigational dredging often occurs in previously dredged areas and is aimed at achieving high removal rates and typically with few concerns regarding the disposition of the dredged sediments, whereas remedial dredging often occurs in pristine never-before-dredged areas and is aimed at removing a precise amount of contaminated sediment, and with strict handling procedures imposed on the movement and disposal of the contaminated sediment and the associated water.

FULL-SCALE REMEDIAL DREDGING PROJECTS

The project particulars for the 17 full-scale remedial dredging projects are summarized in Table 1 (located at the end of this paper). Only true dredging projects are presented, not dry excavation removal projects from dewatered areas. Project particulars include remedial target, type of dredge used, volume removed, total cost, and method of disposition of sediments. Volumes of material removed ranged from 3,100 to 169,000 cubic yards; overall unit costs ranged from $44 to $1,842 per cubic yard. Generally, the highest unit costs were realized for small volume pilot or interim hot spot removals (Grasse River; Sheboygan River; and New Bedford Harbor) and the lowest unit costs were associated with projects with minimal disposal costs (Cherry Farm and North Hollywood Dump). The median overall unit cost for the 17 projects is $212 per cubic yard.

REMEDIAL DREDGING DIFFICULTIES

Key, repetitive difficulties encountered in the 17 completed remedial dredging projects break down into the following seven categories:

- Rocks, Vegetation, and Debris
- Free Oil
- High Water Volumes and Water Treatment Capacity Limitations
- Shallow Water Depths

- Disposal Issues
- Low Production Rates (and, consequently, high cost)
- Resuspension Control (Silt Curtains)

Rocks, Vegetation, and Debris

One of the most common difficulties encountered in the types of areas targeted by remedial dredging is the presence of rocks, vegetation, and debris, all detrimental to a remedial dredging operation. At the General Motors (Massena, NY) facility which abuts the St. Lawrence River, an 11-acre nearshore area of the river was remedially dredged using a horizontal auger dredge. Before contaminated sediments could be removed, numerous rocks and boulders were removed, using a backhoe on a barge. The rocks were spray-washed to remove contamination and permanently placed along the shoreline. The rock quantities were not anticipated in advance. A further difficulty was the irregular, unstable, cratered bottom left by the removal of large rocks - - making efficient, precise dredging more difficult.

At the Grasse River (NY) project, rocks and cobbles made up 500 cubic yards of the total of 3,100 cubic yards removed. These were required to be landfilled along with the contaminated sediments. At the Marathon Battery (NY) Superfund site, extensive in-water vegetation was first removed by a weed harvester; at another area of the same project, a cove in the Lower Hudson River, hydraulic dredging was replaced in favor of a clamshell bucket due to the presence of rocks.

Prior to dredging at the United Heckathorn Superfund site near San Francisco Bay, a marine derrick raised two sunken barges, a used storage tank, caissons, cables, and other previously located and identified large debris from the targeted area. Remedial dredging was by mechanical bucket into scows which moved the material to a dock, for unloading into an adjacent dewatering cell. The "young bay mud" in the targeted area contained extensive amounts of metal debris, railroad spikes, metal cable, rope, and miscellaneous rubble. The debris "field" extended throughout the targeted channel. Due to both the size and volume of debris encountered, a metal grizzly was placed across the scow. The grizzly was only partially effective because a) the volume of debris filled the surface area quickly and b) the debris was so extensive that the grizzly would rapidly become blocked with material. Each dredging shift reportedly spent about 30% of its time positioning the grizzly and transferring debris from its surface. Also, the volume of debris often precluded pumping out the scow. Instead, unloading was typically done by bucket, followed by time-consuming separation of debris from sediment in the dewatering area. (CWM, 1997.)

At the Gould (Portland, OR) Superfund site, 3.1 acre East Doane Lake was hydraulically dredged. The lake contained extensive industrial debris, including cables, batteries, gas cylinders, concrete blocks, and tires. A bottom survey of the lake was done before dredging using an echo sounder, side scan sonar, magnetometer, and video. Debris was then tagged and mapped and most large items were removed by divers before the dredging began. The hydraulic dredge, however, continued to encounter objects throughout the project and experienced delays as a result. These objects were removed by a backhoe on a barge as dredging progressed. (IDR, 1999.)

A pre-removal underwater assessment for rocks, vegetation, and debris, preferably conducted by divers and documented by video, should be mandatory for most remedial dredging projects. Further, a decision should be made on whether to remove embedded rocks/boulders, or leave them in place and attempt to work around them. At the LTV Steel (IN) project, the latter approach was used.

Free Oil

Floating PCB oil plagued the hot spot dredging project at the New Bedford Harbor Superfund site. Volatilization of PCBs into the air during cutterhead dredging operations repeatedly caused human health risk-based air limits to be exceeded, requiring the dredging operation to shut down. Corrective dredging measures such as slowing speed of rotation of the cutter and increasing suction rate were implemented at the expense of production rate. (Otis, 1994.)

At the Bayou Bonfouca Superfund site in LA, a 4,000-foot turning basin contaminated with creosote was dredged by a custom-designed backhoe-on-a-barge. Floating oil was continuously present. The dredge operator was located in a sealed cabin, with controlled air filtration. A system of five tiers of silt curtains was used, two near the dredge and three placed in succession away from the dredge. Log booms were also deployed.

Sinking PCB oils at the Sheboygan River pilot project hampered removal activities, particularly at the hot spot areas with the highest PCB concentrations. Multiple passes were made to remove residual PCBs with varying degrees of success. For the 17 discrete sediment removal areas, post-removal residual PCB concentrations (after 2-4 dredge passes) ranged from 0.3 ppm to 295 ppm (vs. pre-removal concentrations of 0.1 to 4300 ppm). This ultimately led to 4 of the 17 areas being totally or partially capped/armored to sequester the elevated residual PCB concentrations. (BBL, 1995.)

High Water Volumes and Treatment Capacity Limitations

High water volumes are inherent in remedial dredging projects. All water removed must be managed (collected and typically treated). Water volumes treated have been identified for six of the 17 remedial dredging projects: Grasse River (12 million gallons); New Bedford Harbor (160 million gallons); GM (43 million gallons); Waukegan Harbor (95 million gallons); Bayou Bonfouca (171 million gallons); and Manistique River and Harbor (294 million gallons). The volumes are exceedingly large; the average percent solids in the dredged material for the five hydraulic dredging projects were low, as expected, ranging from 2.7% for New Bedford Harbor to 10% for GM (Massena). For Bayou Bonfouca, using mechanical removal, the percent solids averaged 25%. The average percent solids were calculated based on the total volume of sediments removed and the total water volumes.

All six projects were able to consistently meet or better the permitted water discharge limits, but at considerable expense, by using multi-component water treatment systems. Water treatment system components typically included, in sequence: (1) retention ponds, as settling basins, (2) filter presses, (3) clarifiers, (4) mixed-media filters, and (5) granular activated carbon filters.

The land-based water treatment system itself can also be limiting, and, when overloaded, causes the dredging operation to be shut down. At the New Bedford Harbor hot spot removal project, five to six hours of hydraulic dredging at 1,500 gpm "maxed-out" the 350 gpm wastewater treatment facility for 24 hours. At the LTV Steel project, the discharge pipe for the 12-inch cutterhead dredge was reduced to 8 inches to keep flows below 1,800 gpm because of wastewater treatment plant limitations. Wastewater treatment capacity was sometimes limiting at the Marathon Battery, Bayou Bonfouca, Pioneer Lake, and Manistique River and Harbor projects, also. At the Formosa Plastics project in Lavaca Bay, hydraulic dredging had to be abandoned after nine months of intermittent operation and replaced by mechanical (clamshell) dredging due to the greatly limited capacity of existing land-based wastewater treatment facilities.

Shallow Water Depths

Daily hours available for dredging for two of the projects were limited by tidally-influenced changes in water depth. At the New Bedford Harbor hot spot areas, dredging was limited to a four to six hour daytime window on either side of high tide to ensure sufficient water depth to float the cutterhead dredge. At the Marathon Battery site, adjacent to the tidally-influenced Lower Hudson River, the targeted cove and pond areas exhibited mud-flat conditions during periods of mean low water and dredging operations were timed to coincide with tidal cycles.

Disposal Issues

Sediment disposal can be a key bottleneck for a remedial dredging project, particularly for sizable volumes. The viability of offsite commercial disposal, or onsite treatment, diminishes as volumes increase (particularly if hundreds of thousands of cubic yards are involved). A dedicated onsite or local hazardous waste landfill then becomes one of the only viable options. Local opposition is invariably intense and often pivotal. Proposed onsite incineration of only 10,000 cubic yards of PCB-contaminated hot spot sediments from New Bedford Harbor was discontinued by EPA due to intense public opposition. The 14,000 cubic yards that were ultimately dredged were contained in a temporary nearshore confined disposal facility (CDF) pending a five-year EPA program to evaluate and select a suitable treatment technology. No efficient and cost-effective treatment technology was identified; the plan now is to dewater the material and dispose of the material at a commercial landfill (US EPA, 1999). Dredging of 60,000 cubic yards of contaminated sediments from two sectors of the Black River in Ohio was delayed for five years to identify a suitable disposal location. Ultimately, a dedicated landfill was built on the responsible industry's site about one mile upstream from the dredging location.

For the 17 projects discussed herein; disposal methods were (or will be) as follows:

- Onsite dedicated landfill or CDF: 6 projects (3,100 - 60,000 cy)

- Offsite commercial landfill: 8 projects (6,600 - 118,000 cy)
- Temporary on-land storage pending disposal decision: 1 project (3,800 cy)
- Disposal into an isolated oxbow: 1 project (40,000 cy)
- Onsite treatment (incineration): 1 project (169,000 cy)

Basic pre-treatment of the dewatered sediments has been implemented at five of the projects, by addition of cementitious agents to solidify/stabilize the material before disposal into a landfill (United Heckathorn, Marathon Battery, Ford Outfall, Pioneer Lake, and Formosa Plastics). However, it is interesting to note that, other than the one instance of onsite incineration, final treatment as a means of final disposition of contaminated sediments has not been implemented for these remedial dredging projects. Final treatment technologies have failed to make inroads as a component of remedial dredging projects, primarily due to (a) an inconsistent or non-existent track record at full-scale; (b) high unit costs; (c) the need for extensive land-based area for management of dredged material including for staging, size-reduction, dewatering, and treatment; and (d) concerns that regulatory-required low residual contaminant levels won't be able to be achieved.

Low Production Rates

The overall average production rates for the 17 remedial dredging projects are dramatically low in comparison to navigational or maintenance dredging, ranging from 5 (New Bedford Harbor) to about 80-100 (Outboard Marine and Ford Outfall) cubic yards per hour. These rates are averaged over the working hours available for active removal. Some of the reasons for low production rates (many of which have already been discussed) include: (1) the presence of obstructions such as rocks, vegetation, and debris; (2) operational controls imposed to minimize resuspension; (3) downtime during installation of sheetpiling or installation and relocation of silt curtains; (4) land-based water treatment capacity limitations; and (5) the need for precision in sediment removal to minimize the volume removed, leading to repeated, potentially inefficient passes with the dredgehead to achieve a targeted depth horizon or a targeted cleanup level.

One of the primary determinants of production rate is whether verification samples are periodically collected (and analyzed) from the dredged surface to ascertain progress toward achieving the targeted contaminant cleanup concentration, or whether only a natural depth horizon (e.g., bedrock, natural till layer), or a depth judged to be free of contamination, is targeted. In the first instance, the dredge often has to make repeated passes over already dredged surfaces in an attempt to reduce the contaminant surface concentration to progressively lower concentrations. Resuspended contaminants that fall back onto the dredged surface often make this task progressively more unproductive.

Two graphs plotting total dredged volume vs. total dredging time for 12 of the largest of the 17 dredging projects have been prepared, Figures 1 and 2. Dredge availability time for each project has been adjusted to a common basis for comparison purposes, i.e., equivalent to eight hours per day, five days per week. For each graph, a straight line through the origin ($x = 0$; $y = 0$) was then fit to these plotted points, the slope of which represents average monthly removal rate.

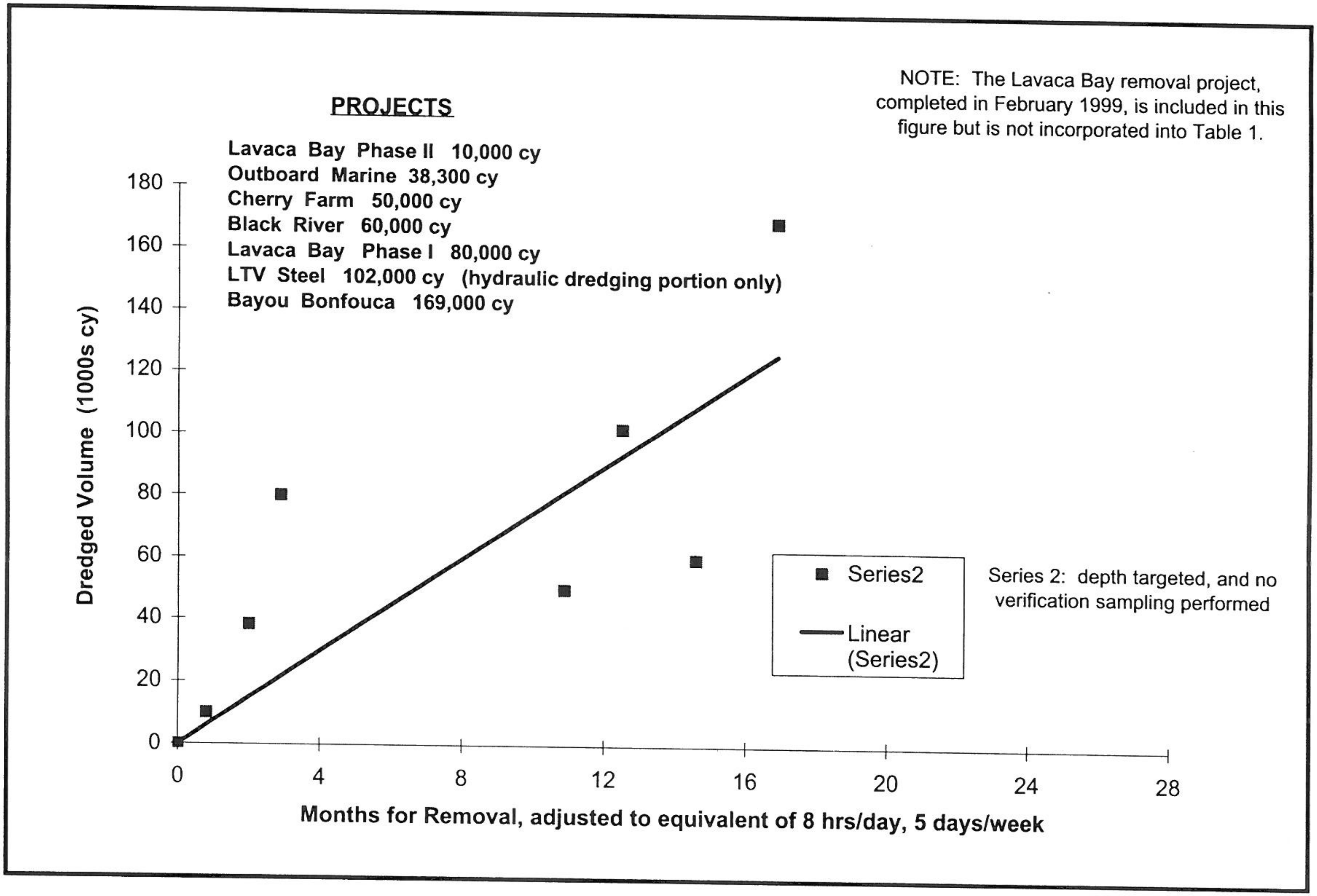

Figure 1. Sediment Volume Removed vs Time: Dredging Projects (Depth Targeted)

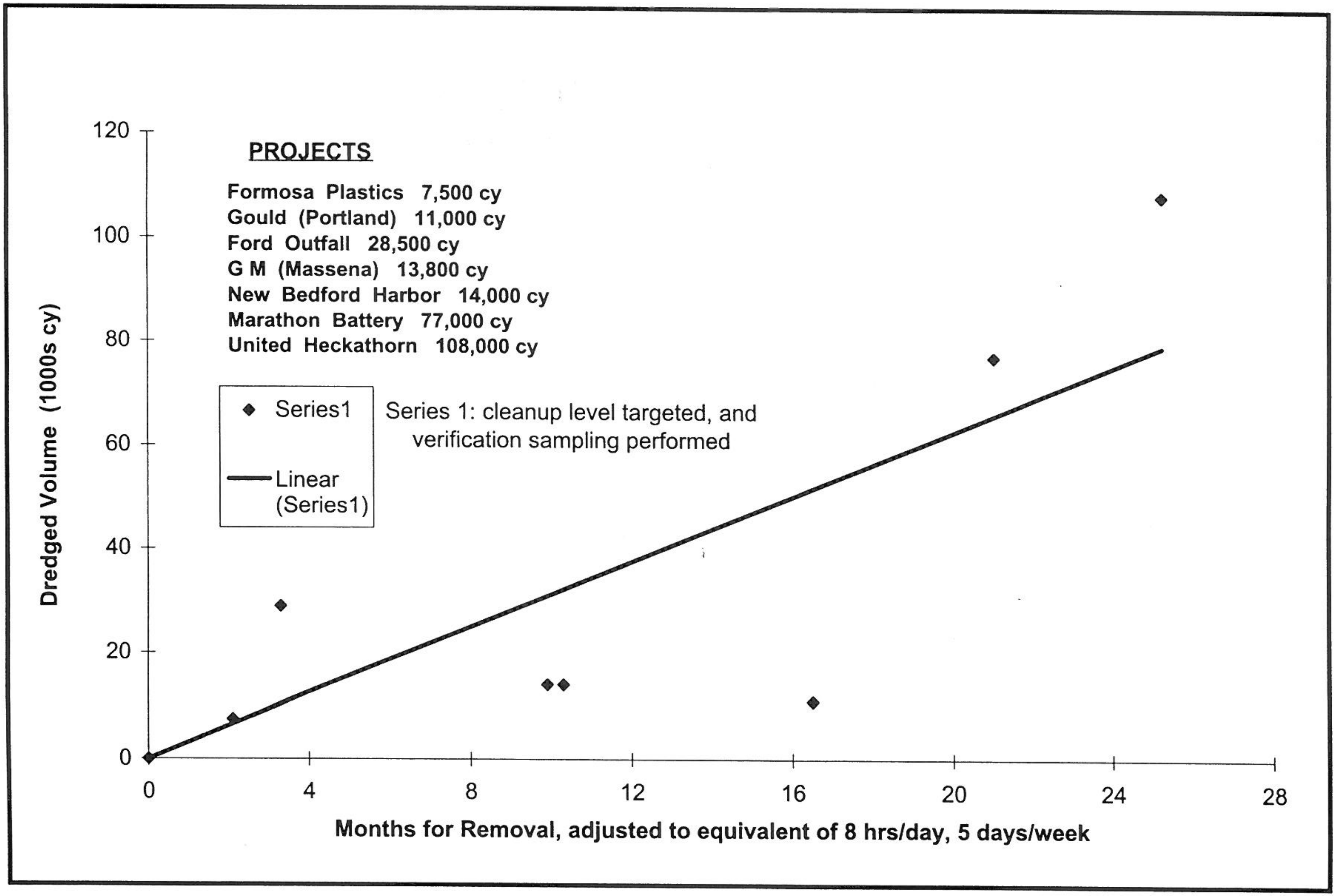

Figure 2. Sediment Volume Removed vs Time: Dredging Projects (Cleanup Level Targeted)

- For the seven plotted remedial dredging projects that targeted a depth only (Bayou Bonfouca, Black River, LTV Steel, Cherry Farm, Lavaca Bay Phases I and II, and Outboard Marine), the average monthly removal rate, adjusted to eight hours per day, five days per week, was in the range of 7,500-8,000 cy per month.

- For the other seven plotted projects, all of which targeted a cleanup level and performed verification sampling, the average monthly removal rate, adjusted to eight hours per day, five days per week, was in the range of 3,000 to 3,500 cy per month. These projects include United Heckathorn, Marathon Battery, Ford Outfall, New Bedford Harbor, GM Massena, Gould (Portland), and Formosa Plastics.

Of course, there are a large number of variables that will tend to skew proportionality when comparing projects, such as scale, locale (e.g., harbor vs. localized hot spots in fresh water vs. intake channel), type and size of dredge, and bottom conditions. Also, the actual work hours per day and days per week for each project were identified with difficulty and in most instances are approximate. Nonetheless, the average production rates identified are considered representative for remedial dredging projects, based on experience to-date.

These obviously low production rates are generally not anticipated in the planning phase and have made the prediction of realistic cost and implementation times difficult and often optimistic for remedial dredging projects.

Resuspension Control: Silt Curtains

Sediment lost to the water column during remedial dredging is called resuspended sediment, or resuspension. Containment of resuspended sediments and free oil, to prevent transport outside the area of dredging, is always a major consideration for a remedial dredging project. Resuspension is undesirable since the contaminants adsorbed onto the resuspended sediment particles, or desorbed from the sediment particles into the water, can potentially (a) be spread to downstream areas of the waterway, (b) resettle on the dredged surface (thereby recontaminating the surface), and (c) become bioavailable to aquatic biota. Further, contaminants tend to have a greater affinity for fine particles, which are also the particles most prone to resuspension. Thus, the resuspended sediment contaminant levels may exceed the sediment bed levels (Averett, 1995).

A variety of containment system arrangements were used to limit the downstream transport of resuspended sediments and floating materials at the 17 remedial dredging projects. These included geotextile and geomembrane silt curtains, floating booms, and in one instance, steel sheetpile. At 13 of the 17 projects, silt curtains were deployed with the primary objective of limiting transport of resuspended, contaminated sediment outside the immediate dredging area. At four of the sites (Bayou Bonfouca, Grasse River, Marathon Battery, Sheboygan River), two or more tiers of silt curtains as well as a floating boom were deployed; at Waukegan Harbor (Outboard Marine), one silt curtain was deployed at the lower part of the Upper Harbor and one at the entrance to a nearby operable boat slip; similarly, at United Heckathorn, a single silt curtain was installed across the mouth of the channel being dredged; a single silt curtain was deployed 360° around a targeted inner harbor dredging area at the Formosa Plastics project; at two other sites (described below), New Bedford Harbor and GM (Massena), the use of silt curtains was tried and judged infeasible due to site conditions, and abandoned.

A number of difficulties in the use of resuspension control barriers have been documented. At the GM (Massena) project, the outer boundary of the targeted 11-acre nearshore area was originally enclosed with silt curtains. This approach was abandoned in favor of sheetpile due to silt curtain installation difficulties and swift river currents. At the Sheboygan River hot spot removal project, high water and strong currents on numerous occasions damaged silt curtains causing construction delays for repairs. At the New Bedford Harbor hot spot removal project, silt curtains were deployed but were subsequently removed, since they continuously disturbed the bottom sediments (and contributed to PCB oil releases) in the shallow water of varying, tidally-influenced depth. On the Ford Outfall-River Raisin (MI) removal project, a 150-foot width of hot spot between the shore and the navigational channel was targeted. Three thousand linear feet of silt curtain were deployed. On at least one occasion, a ship passing in the navigational channel outside the silt curtain sent "mud waves" under the silt curtain, recoating the dredged surface.

At the United Heckathorn project, a tug boat destroyed the original silt curtain at the mouth of the targeted channel before the dredging operation commenced. The tug boat backed into the Lauritzen Channel and spun the silt curtain into its twin propellers. A new curtain was constructed and installed prior to initiating dredging. The dredging operation was delayed approximately one week due to the incident. An additional 14 days of delays were experienced during the project due to silt curtain management difficulties which included two days of extreme tides and propeller damage from tug boats moving vessels in the Santa Fe Channel. Removal operations adjacent to the curtain were performed last and on an outgoing tide to prevent tearing the curtain with the dredge bucket. The cumulative delays from the silt curtain maintenance in the targeted channel were 23 days over the course of the seven-month project.

Both the objective and degree of success of these containment measures are difficult to assess from available documentation, which, except for the Grasse River and Sheboygan River projects, is unavailable, extremely limited, or non-existent.

Extensive downstream sampling was conducted at New Bedford Harbor and at Bayou Bonfouca during dredging to assess the degree of downstream transport and compare measured results vs. upset limits. At New Bedford Harbor, during hot spot removal, downstream water samples were measured for PCBs and biological toxicity, and mussels were tested for PCB bioaccumulation. At Bayou Bonfouca, TSS was the primary parameter monitored. Reportedly, downstream limits were not exceeded at these two sites, however, documentation has not been identified and reviewed.

A 1995 report (BBL, 1995) provides an interesting summary of the use of and difficulties with two tiers of silt curtains positioned around hot spot areas on the Sheboygan River during pilot dredging in 1989 - 1991:

"Daily water-column samples were collected and analyzed for total suspended solids (TSS) and/or turbidity, with the latter providing a real-time measurement of construction-related disturbances outside the curtained areas . . . water samples were collected on a weekly basis to monitor any PCB transport resulting from construction activities . . ."

"The results of the daily water-column monitoring indicated that the siltation control system (used around the various sediment areas) appeared to contain substantial amounts of suspended material during construction operations, although other water column and fish monitoring results raise questions about the degree of effectiveness of the silt curtains. Factors which resulted in reduced effectiveness of the siltation control system are ice or high River flows which sometimes caused the curtains to be knocked down and/or damaged, disturbance of sediment during placement and removal, and difficulties in anchoring of the curtain bottoms."

"Based on the weekly PCB results, some transport of PCBs related to construction activities was noted. Due to disturbances caused by removal and armoring activities within the curtained areas, PCBs were detected (as expected) in the curtained water with concentrations ranging from <0.05 to 8.3 ppb."

At the Marathon Battery site near West Point, NY, the oversight contractor reported (Marano et al., 1994) somewhat more positive findings for the remedial dredging of 77,000 cy.

"The resuspension and resulting redistribution of sediment during dredging is not as far-reaching as initially believed. Resuspension appears to be very localized, to within a few feet of the original disturbance."

"Silt curtains are ineffective in flow velocities greater than 0.46 mps (1.5 fps) as documented in technical publications. Control of sediment dispersion at the source (i.e., controlling the speed and depth of cut and other dredging techniques) is more effective."

It is important to recognize that these Marathon Battery findings are for dredging in a relatively sheltered but tidally influenced inland cove and pond.

A different approach was used on the Outboard Marine project at Waukegan Harbor. Silt curtains were installed across the mouth of the nearby Slip No. 4 and across the south end of the Upper Harbor, but not around discrete areas of the 10-acre harbor area being dredged. Three silt curtain failures occurred, caused by wind or wind driven currents. Turbidity measurements were recorded daily during dredging activities from depths of 10 and 20 feet on either side of the silt curtain in the slip, and 500 feet south of the silt curtain positioned at the end of the Upper Harbor. Turbidity was measured in nephelometric turbidity units (NTU). The turbidity readings outside of each silt curtain were less than 17 NTU, which was well below the 50 NTU action level.

After completion of the Upper Harbor dredging, harbor water was sprayed with Nalcolyte, a potable coagulant, to aid in the settling of suspended particulates - - a procedure unique to this project. The silt curtains were then removed 48 hours after the application of the coagulant. (Canonie Env., 1996.)

At the Grasse River hot spot pilot removal project, a substantial effort went into controlling and measuring resuspension and downstream transport during dredging. Three tiers of silt curtains were used throughout the course of this project: an inner boulder zone curtain unfurled to the bottom, a secondary inner curtain aligned at the perimeter of the dredge area, and an outer primary curtain. The project documentation report (BBL, 1995) contains the following conclusions:

- Based on total suspended solids (TSS) measurements, and the obvious visual difference in the water's turbidity from inside to outside the curtain, the containment system appeared to be very effective in controlling the release of suspended sediment.

- Although the containment system performed well in controlling TSS, it was apparent that PCBs escaped the containment system and migrated downstream throughout the project. It appeared that, in addition to the sediment-bound PCBs, soluble PCBs were released from the curtains. The presence of soluble PCBs likely developed as a result of the mixing that occurred within the curtained area. On 13 occasions, PCBs greater than 2 ppb were detected at various monitoring locations at the perimeter to the containment system.

- Although the containment system was very effective in containing a majority of the suspended sediment within the removal area, some sediment did escape. Using local TSS monitoring data, an estimated total of 8 cy of sediment escaped from the curtained area. (NOTE: This represents 0.3% of the total sediment removed. This, however, is not a resuspension rate, which would have to be measured within the curtained area, but is simply a rough measure of effectiveness of the silt curtain system.)

The critical subject of resuspended contaminants during dredging, and their magnitude, fate, and controllability, is still poorly understood, measured, and documented, despite the fact that 13 of the 17 remedial dredging projects deployed one or more tiers of silt curtains. Often, measurements were infrequent and localized, and limited to TSS or turbidity measurements.

Remedial dredging projects and other collateral testing to-date have not provided substantive findings regarding such important concerns as:

- How effective are dredge operational controls in minimizing resuspension? What is the effect on dredge production rate?

- How effective are silt curtains in containing resuspended sediments? Which types of curtains and method of deployment are most effective vs. which site conditions?

- What percentage of the disturbed sediment will be captured by the dredge and what percent will be lost into the water column? How much *contamination* is associated with the resuspended material? How much of the resuspended *contamination* is associated with particulate and how much is dissolved? What percentage of the *contaminant* bypasses the silt curtain system?

Even an answer to the basic question of what percentage of sediments can be expected to be lost into the water column as a percentage of the total sediments removed by dredging, under specific site and operating conditions, is elusive. No estimates are available from the 17 completed remedial dredging projects. A sampling of values from seven separate references consulted by the author yielded estimates, none rigorously quantified, of from 0.1 to 5% of the dredged sediment lost to resuspension (BBL, 1994; Committee, 1997; Corps, 1989; Corps, 1990; Pirnie, 1978; NYSDEC, 1979; and van Oostrum et al., 1994).

SUMMARY

The purpose of this paper is to fill an information void regarding the outcome of remedial dredging projects, and promote an awareness of the difficulties experienced and highlight the need for innovation in the dredging industry in responding to these difficulties. Remedial dredging is a new field, greatly different from maintenance or navigational dredging, and dominated by relatively small projects constrained by a variety of difficulties. Seventeen projects are evaluated with sediment removal volumes ranging from 3,100 to 169,000 cubic yards and overall unit costs ranging from $44 to $1842 per cubic yard. Difficulties encountered on a frequent basis included (a) the presence of rocks, vegetation, and debris; (b) free oil; (c) high volumes of contaminated water from the dredging process which required treatment and sometimes exceeded the capacity of treatment equipment; (d) shallow water depths; (e) disposal limitations; (f) low production rates (and, consequently, high cost as compared to maintenance dredging); and (g) resuspension control equipment difficulties (silt curtains).

The low production rates realized during remedial dredging projects are generally not anticipated in the planning phase and have made the prediction of realistic cost and implementation times difficult and often optimistic for remedial dredging projects.

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Table 1. Completed Remedial Dredging Projects in the U.S.

Project	Remedial Target[1]	Remediation Method	Volume Removed (cy)	Total Cost (million $)	Unit Cost ($/cy)	Sediment Disposal
Bayou Bonfouca, LA	Depth horizon (1300 ppm PAHs)	Mechanical dredging	169,000	$115	$680	Onsite incineration
Manistique R., MI	10 ppm PCBs	Hydraulic dredging	118,000	$25	$212	Commercial landfill
LTV Steel, IN	Depth horizon (PAHs and oils)	Hydraulic dredging and diver assisted	114,000	$12	$105	Commercial landfill
United Heckathorn, CA	0.59 ppm DDT	Mechanical dredging	108,000	>$12	>$111	Commercial landfill
Marathon Battery, NY	10 ppm Cd	Hydraulic dredging and mechanical dredging; also, natural recovery	77,000	$9-11	$117-143	Commercial landfill
Black River, OH	Depth horizon (PAHs)	Hydraulic dredging and mechanical dredging	60,000	$5	$83	Onsite landfill
Cherry Farm, NY (Niagara River)	Depth horizon (20-50 ppm PAHs)	Hydraulic dredging	50,000	$2.2	$44	Onsite disposal pond
N. HollywoodDump, TN (40-acre lake)	Depth horizon (pesticides)	Hydraulic dredging	40,000	$2.4	$60	Burial in an oxbow

Table 1. Completed Remedial Dredging Projects in the U.S. (Cont'd)

Project	Remedial Target[1]	Remediation Method	Volume Removed (cy)	Total Cost (million $)	Unit Cost ($/cy)	Sediment Disposal
Waukegan Harbor (Outboard Marine), IL	Depth horizon (50 ppm PCBs)	Hydraulic dredging	38,300	$15	$392	Nearshore CDF
Ford Outfall, MI (River Raisin)	10 ppm PCBs	Mechanical dredging	28,500	$5.4	$190	Dedicated cell built in an onsite landfill
New Bedford Harbor, MA	4000 ppm PCBs	Hydraulic dredging	14,000	$20.1[2]	$1,436	Commercial landfill[2]
GM (Massena), NY	1 ppm PCBs	Hydraulic dredging, wet excavation, and capping	13,800	$10[2]	$725	Commercial landfill[2]
Gould (Portland), OR	PAHs	Hydraulic dredging	11,000	$3[2]	$273	Onsite landfill[2]
Formosa Plastics, TX	0.5 ppm ethylene dichloride	Mechanical dredging	7,000	$1.4	$200	Commercial landfill
Pioneer Lake, OH	Various for PAHs	Hydraulic dredging	6,600	$2.5	$379	Commercial landfill
Sheboygan River, WI	None[3]	Mechanical dredging, wet excavation, and capping	3,800	$7[2]	$1,842	Onsite storage (temporary)

Table 1. Completed Remedial Dredging Projects in the U.S. (Cont'd)

Project	Remedial Target[1]	Remediation Method	Volume Removed (cy)	Total Cost (million $)	Unit Cost ($/cy)	Sediment Disposal
Grasse River, NY	None[3]	Hydraulic dredging, wet excavation, and diver assisted	3,000	$4.9	$1,633	Onsite landfill
		TOTAL	862,000 cy			

1. "Depth horizon" means a depth only was targeted, designated (based on characterization data) either to remove "all" contaminated sediments or to reach a cleanup level, but no or only limited post-dredging sampling was performed to verify. PAHs are polyaromatic hydrocarbons.
2. Does not include disposal cost. Method of disposal has just recently been defined for New Bedford Harbor and GM (Massena) and has not yet been implemented. The onsite landfill at Gould has not yet been built.
3. No designated target was defined, since these were pilot (interim) removal programs; hot spots in the Sheboygan River were defined as areas > 686 ppm PCBs; in the Grasse River, the areal extent of the hot spot area targeted was defined by a 10 ppm PCB boundary.

NOTES FOR CONTRIBUTORS

GENERAL

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Keywords

Please provide 5 keywords that are not already contained in the title.

MANUSCRIPT PREPARATION

Order of contents

Title, author(s), affiliations, addresses, countries
Abstract (not to exceed 300 words).
5 keywords that are not already contained in the title.
Introduction, main body, and following text, conclusions, nomenclature (if necessary), and references.
Refer to a previous issue of the journal for general guidelines on format.

Preparation of the text

The text should be submitted on unlined white 8 1/2 in. x 11 in. paper with **single line spacing**, and top and side margins of 1 in. Use full justification. **The image area or block of text will then be 6.5 in. x 9.0 in.** The bottom margins should be 1.5 in. **Do not leave additional margins. Do not use company letterhead paper.**

Fonts

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Headings should be typed in bold capital letters centered and followed by a double space. Bold capitals and lower case letters should be used for subheadings, which should be preceded and followed by a double space as illustrated by these instructions. Sub-subheadings should use bold capitals and lower case letters and placed at the start of the paragraph.

Equations

All symbols must be defined in the nomenclature section that follows the conclusions. The SI system of units should be used. If units other than SI units are included, they should be given in parenthesis after the relevant SI unit. Equations should be indented and successively numbered (in parenthesis) flush with the right-hand margin (see example below).

$$y = a + b + cx^2 \tag{1}$$

References

References in the text should be given as: Smith (1988), (Smith, 1988) or (Jones et al., 1986). References should be listed alphabetically in the References section at the end of the paper. Give the names and initials of all authors, followed by the title of the article and publication, the publisher and the year of publication. References to conference papers or proceedings should include the name of the organizers. References to articles published in journals should also include the name of the journal, the number of the issue and page numbers (see example below). References to publications in a foreign language should give all details in the original language followed by a translation of the title.

Sample References

Hunt, J.B. (1995). *"Environmental Dredging"*. Smith & Sons, Inc., New York, NY., 120p.

Donegan, T.M., and Dinicola, W.J. (1986). *"Turbidity Associated With Dredging Operations"*. Technical Report, XYZ Consultants, Inc., Baltimore, MD., 60p.

Jones, F., Doe, E.J., and Next, J.P. (1986). *"The Design of Dredged Material Disposal Sites"*. Proceedings of the 15th World Dredging Congress, CEDA, Amsterdam, The Netherlands, pp. 350–368.

White, F.K., and Jone, J.M. (1991). *"The Analysis of Flow Fields Around Dragheads"*. Journal of Waterway, Port, Coastal & Ocean Engineering, Vol. 121, No. 5, ASCE, pp. 11-15.

Page numbers

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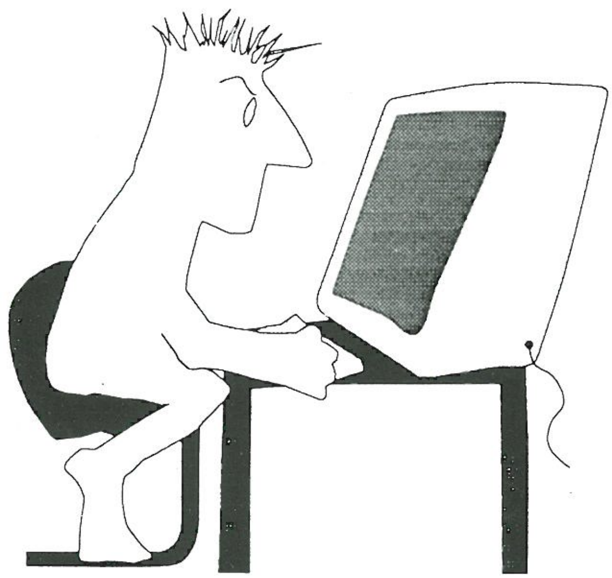

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