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Environmental Effects of Dredging

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Section 03—Wetland/Estuarine Disposal
EEDP-03-1 through EEDP-03-7

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Environmental Effects of Dredging Technical Notes

WETLAND ANIMAL BIOASSAY OF SALTWATER DREDGED MATERIAL

PURPOSE: This note introduces the concept of using a wetland animal as an indicator of the contaminants in dredged material proposed for disposal in a wetland environment. An example of the application of an animal bioassay procedure to saltwater dredged material in a wetland creation environment was reported in a paper entitled "Application of a Wetland Animal Bioassay for Determining Toxic Metal Uptake from Dredged Material," which was presented at the International Symposium of Ecotoxicological Testing for the Marine Environment (Simmers, Rhett, and Lee 1984). The text of this note was taken from the paper.

BACKGROUND: Animal bioassay test procedures are being evaluated and field tested and verified under the "Interagency Field Verification of Testing and Predictive Methodologies for Dredged Material Disposal Alternatives," called the Field Verification Program (FVP). The FVP research is being conducted in conjunction with a scheduled dredging project in Black Rock Harbor near Bridgeport, Connecticut. The procedures are relatively simple and can provide information that may be required in the ecological evaluation and environmental assessment of dredged material disposal. Based on laboratory results and limted field testing, the procedures can be applied to saltwater sediment (dredged material) that requires placement in a wetland environment. The concept presented in this note is the result of ongoing research under the FVP. Draft final guidance will be completed in September 1987.

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Introduction

The Clean Water Act requires that the environmental evaluation of dredged material prior to discharge or impacting the waters of the United States include the effects of disposal on contaminant concentrations through biological processes. This resulted in a need for Corps of Engineers

Districts to be able to predict the potential contamination of animals that may be associated with each of these potential disposal alternatives: open-water disposal, upland disposal, and/or wetland creation. The following is a summary of a wetland animal solid-phase bioassay test applied to sediment collected from the waterway at Black Rock Harbor (BRH), Bridgeport, Connecticut. This test procedure was designed to evaluate the potential movement of toxic heavy metals and other contaminants from dredged material placed in a wetland (reduced) environment into sediment-dwelling intertidal invertebrates as a first step that may be used to evaluate contaminant mobility to animals that may colonize the dredged material. No inference on the movement of contaminants through the wetland food web is offered at this time.

Methodology

The sandworm *Nereis virens* was selected as the test animal. A stock of the worms was obtained from supplier in Maine and held in tanks of 22 ppt salinity seawater (Instant Ocean) with a sand substrate.

The contaminated sediment used in the tests was collected from an area of BRH that was scheduled to be dredged. Sediment near the mouth of the harbor (an area of lesser contamination) was collected for use as a reference material. Both types of sediment were kept flooded (i.e., in a reduced condition) while in storage and throughout the test procedure. The sand used as a third test medium was the same used in the holding tanks. Results of bioassay tests of animals from aquaria with the sand substrate provided information on background levels of the contaminants of interest.

Preliminary screening tests were used to determine if dilution of the contaminated sediment would be necessary to ensure the survival of all test animals for the maximum exposure period of 14 days. The same sand as that used in the holding-tank was used as a dilution medium. Based on the results of the screening tests, a mixture of 75 percent sand and 25 percent BRH sediment was selected for use as the contaminated sediment substrate. The reference control sediment or the sand was used as the substrate in the other aquaria.

Twelve sandworms (26 g total wet weight) were placed in 3.2 ℓ of each substrate in aquaria. The medium was kept under 15 cm of seawater and aerated. All of the aquaria were placed in a constant temperature bath at 17° C.

At the end of the 7- and 14-day test periods, the worms were harvested, counted, weighed, and allowed to depurate in clean sand for 24 hr. The worms were then killed in boiling water and homogenized in a stainless steel Sorvall omni-mixer (DuPont Co., Newton, CT 06470). A portion of the homogenized tissue was frozen for future needs, and the remainder was oven-dried prior to analysis for arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc.

Results

The preliminary screening tests indicated that the BRH sediment was toxic to the sandworms. This toxicity did not occur in the reference sediment. The screening tests indicated that survival for up to 14 days could be obtained if the sediment was diluted with 75 percent sand. Sand of the same kind used in the maintenance cultures of the test animals was used as a dilution medium.

The weights and number of worms surviving in the three treatment groups at 14 days is shown in the following tabulation. There was some weight loss

Substrate	Numbers ($\bar{X}$) and Mean Weight of Worms, g (wet wt) Initial	Final	14-day Weight Loss, %
Sand	$\bar{X}$ = 10.5 27.07 ± 0.3	$\bar{X}$ = 10.25 21.84 ± 2.4	19
75% sand/25% BRH sediment	$\bar{X}$ = 12.5 26.86 ± 0.8	$\bar{X}$ = 12 21.51 ± 2.0	20
Reference sediment	$\bar{X}$ = 11.5 26.71 ± 0.7	$\bar{X}$ = 9.75 19.17 ± 2.4	27

Note: Data represents composite of four replications.

in all three groups and a slight decrease in worm numbers. Since none of the worms in any treatment group were fed, the weight loss may have been due to starvation: the worms in the sand medium lost about the same weight as those in the reference and contaminated sediments. Based on the weight comparisons, the worms in the contaminated sediment did not appear to be stressed more than those in the reference sediment or the sand.

The tests using the sand substrate differed from the maintenance culture only in that the worms were not fed. This treatment represented the background levels after 7 and 14 days depuration in clean sand (Table 1). These data indicate the levels of heavy metals that would be retained in worms

Table 1

Contaminant Concentrations in Substrate and Animal Tissue

Substrate	Contaminant	Contaminant Concentration, µg/g (dry wt)* Substrate	Tissue 7 Days	Tissue 14 Days
Sand	Arsenic	<0.49	0.80 ± 0.13	<1.20
	Cadmium	0.1	0.63 ± 0.05	0.20 ± 0.04
	Chromium	0.9	3.15 ± 0.34	4.56 ± 1.10
	Copper	<4.9	14.1 ± 2.6	17.9 ± 1.5
	Lead	13.3	2.95 ± 0.45	5.47 ± 1.17
	Nickel	0.2	4.15 ± 1.75	11.22 ± 4.18
	Zinc	<4.9	193 ± 58	176.2 ± 16
75% sand/25% BRH sediment	Arsenic	0.47	1.40 ± 0.42	1.07 ± 0.13
	Cadmium	0.4	1.08 ± 0.35	2.95 ± 0.26
	Chromium	92.3	3.15 ± 1.42	10.96 ± 3.51
	Copper	153.0	13.9 ± 1.4	168.0 ± 28
	Lead	22.4	3.06 ± 0.30	5.67 ± 3.17
	Nickel	12.9	9.32 ± 1.70	11.55 ± 6.69
	Zinc	83.6	270.6 ± 95.6	206.4 ± 40.3
Reference sediment	Arsenic	4.9	0.64 ± 0.17	1.20
	Cadmium	0.3	0.48 ± 0.12	1.42 ± 0.10
	Chromium	230.5	6.98 ± 4.51	4.42 ± 2.39
	Copper	326.5	13.4 ± 1.3	28.1 ± 6.2
	Lead	75.2	2.95 ± 0.17	3.06 ± 1.15
	Nickel	36.2	3.07 ± 0.65	6.33 ± 1.28
	Zinc	256.5	190 ± 38	353.2 ± 163.8

* Each value is mean of 4 replicates.
All mercury concentrations at or below detection limit (0.1 µg/g).

caught in an area of naturally occurring sediment and maintained for 30 days in clean sand prior to the depuration and analysis. The analyses of the worms in the BRH sediment/sand mixture and the reference medium are shown in Table 1.

In all the test media and tissue samples, mercury concentrations were near or below detection limits of 0.1 µg/g. The sediment concentrations varied for arsenic, chromium, lead, and zinc, although the animal tissue levels remained much the same. Cadmium remained relatively constant with the exception of the 14-day tissue samples from the BRH sediment/sand medium. The observed levels of nickel were quite variable in both the sediment and animal tissue samples. Only copper showed a marked increase in animal tissues exposed to the diluted BRH sediment test medium.

Discussion

The apparent levels of arsenic, cadmium, copper, and zinc are above sediment levels and deserve some note. Arsenic accumulation by *Nereis* has been investigated by Bryan and Gibbs (1983). From exposure to sediment containing 2520 μg/g, these authors found 87 μg/g in the tissues of *N. diversicolor* in comparison to 7 μg/g tissue arsenic in normal sediments containing 13 μg/g arsenic. The values appearing in Table 1 indicate that the arsenic levels both in the diluted BRH sediment and in the animals exposed to it are very low in comparison to those of Bryan and Gibbs (1983). The very low sediment arsenic content initially would explain the insignificant uptake by the sandworms.

Due to ecotoxicological significance of cadmium, any indication of accumulation of this metal is highly significant. Although the movement of cadmium to *Nereis* appears to be through the interstitial water shown by Ray et al. (1980), the availability of the cadmium from the sediment is of concern.

A review of the literature indicates that the tissue levels of cadmium after exposure to contaminated sediments as shown in Table 1 are generally higher than other reported values. Luoma and Bryan (1982) found levels of 0.20-3.10 μg/g in *N. diversicolor* from sediments containing 0.1-10.8 μg/g cadmium. Bryan and Hummerstone (1973) found cadmium levels in *N. diversicolor* of 0.12-0.56 μg/g (dry weight) from sediments with cadmium levels similar to that of the diluted BRH sediment. This may indicate that the cadmium in the BRH material is more available to *N. virens* and/or may represent species differences within *Nereis*.

Copper appeared to be accumulated in the bioassay animals placed in the diluted BRH sediment (Table 1). Bryan and Hummerstone (1973) found that in sediment containing 17-3052 μg/g of copper, the copper content of *N. diversicolor* did not exceed 68 percent of the sediment concentration. This suggests that the copper in the diluted BRH material is quite available and is taken up by *Nereis*.

The accumulation of zinc in *Nereis* is relatively uniform across the three sediments. Bryan (1976) indicated that in *N. diversicolor*, zinc is actively accumulated and controlled as a metabolite. The zinc levels found in these bioassay organisms tend to substantiate the concept of physiological regulation of zinc by *Nereis* and suggest that at the sediment concentrations studied, zinc is not of concern to *Nereis*.

Conclusions

The sandworm screening test demonstrated that the BRH sediment is toxic to intertidal annelids when maintained in a reduced condition. The bioassay showed that of the heavy metals present in the sediment, only copper and, to a lesser extent, cadmium are bioaccumulated. If the BRH sediment were mixed with uncontaminated sediment and used to create a wetland, there is a possibility of copper and cadmium accumulation in *N. virens*, and, as Ray et al. (1980) suggested, cadmium may accumulate to elevated levels in *Nereis* living full 5- to 6-year life spans. The comparison of the levels of metals in the three test substrates (Table 1) suggests that the toxicity observed in the initial screening portion of the test was not due to the uptake of toxic heavy metals but to something else.

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Environmental Effects of Dredging Technical Notes

WETLAND ANIMAL BIOASSAYS/BIOMONITORING

PURPOSE: This note follows Technical Note EEDP-03-1 and adds support to the concept of using wetland animals as indicators of bioavailable contaminants in dredged material used to create intertidal wetlands. The text of this tech note was taken from a paper by Kay, Marquenie, and Simmers (1986).

BACKGROUND: Animal bioassay test procedures are being evaluated (field tested) and verified under the "Interagency Field Verification of Testing and Predictive Methodologies for Dredged Material Disposal Alternatives," called the Field Verification Program (FVP). Bioassays have been shown to be a relatively simple tool for ecological evaluation and environmental assessment of potential contaminant movement within permanent or temporary wetlands, and with field verification, it will be a useful biomonitoring tool as well.

One objective of the FVP was to verify laboratory wetland animal bioassay test results in the field. Lab tests using sediment from Bridgeport Harbor indicated highly toxic effects on the sandworm, *Nereis virens*. Field test results also indicated toxicity. However, the concept of direct verification of laboratory test results in the field proved to be an oversimplification. The goal of confining the sandworm at the FVP wetland site or a reference site and ensuring adequate survival during the field test was not attained. The application of an effective and realistic field test procedure required additional studies to relate the laboratory test species to species actually colonizing the site during the early stages of the wetlands ecological succession.

Current research in the wetland animal bioassay work unit of the FVP suggests that a suite of species occupying different ecological niches in the wetland may be more valuable in bioassay and biomonitoring procedures than a single index species. Different species often bioaccumulate and react to the contaminants in the environment differently; therefore, the usefulness of a bioassay and biomonitoring species may best be evaluated by its capability as an indicator. Some common marine wetland species accumulate metals readily while others tend to accumulate organic contaminants. Literature indicates that a contaminated wetland, such as the FVP wetland site at Bridgeport, Conn., would have a great availability of organic contaminants for the biota and that bioassay/biomonitor species should indicate the potential bioavailability of these contaminants to native species. The mud snail found on the New England intertidal mud flats has been found to be a good indicator of bioavailable polyaromatic hydrocarbons (PAHs), as reported by Kay, Marquenie, and Simmers (1986).

The information herein supports the selection of the mud snail as a complementary bioassay/biomonitor for use in the laboratory and the field. Additional verification of the wetland animal bioassay and biomonitoring procedures will be reported later. The concept presented in this note is the result of ongoing research under the FVP. Draft FVP final guidance on wetland animal bioassay and biomonitoring will be completed in September 1987.

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Introduction

Field verification of the results of laboratory studies is necessary to accurately predict the impact of disposal of dredged material containing complex mixtures of organic and inorganic contaminants (Chapman and Long 1983). Field studies encounter many difficulties that do not exist in the laboratory, including seasonal climatic fluctuations, temporary and extended abnormal weather conditions, predation, and human activities.

The native mud snail, *Ilyanassa obsoleta (Nassarius obsoletus)*, was selected as a potential bioassay animal because of its abundance on the intertidal mud flats of New England. It is one of the dominant invertebrate species found in the Connecticut salt marshes (Brousseau 1981, Fell et al. 1982). It is able to withstand anoxia up to nine days and can partially regulate its oxygen consumption either metabolically or through the formation of oxygen-containing gas bubbles within the mantle cavity (Kushins and Mangum 1971). Mud snails are common on the surface and burrowing within the surficial sediments at low tide in midsummer, thereby demonstrating the ability to withstand the high ambient temperatures of the intertidal mud flat. Therefore, this species is well suited to the prevailing environmental conditions of an intertidal (wetland creation) disposal facility.

Since the mud snail had not been previously used in any bioassay or bioaccumulation studies, it was necessary to determine its suitability as an indicator species by conducting bioaccumulation studies under controlled laboratory conditions. The objective was to assess the potential of the mud snail as an intertidal invertebrate bioassay organism to complement the existing bioassay organism (sandworm) in bioassay and bioaccumulation tests of approximately one month duration.

Materials and Methods

Test sediment was collected from Black Rock Harbor, and mud snails were collected from Tongue Point, both near Bridgeport, Conn. The snails were held in artificial seawater at 20° C and 22 ppt salinity and fed a commercial invertebrate diet.

Laboratory intertidal simulation chambers, 19 × 41 × 12 cm (depth × width × length), were constructed to simulate the effects of exposure to contaminated sediment under conditions of a 12-hr tidal cycle. Each chamber contained 20 ℓ of sediment and was stocked initially with approximately 350 mud snails. Peristaltic pumps gradually inundated the sediment with artificial seawater at 22 ppt salinity over a 6-hr period and drained the sediment in the subsequent 6-hr period. Temperature was maintained constant at 20° ± 1° C throughout the study, and aeration was provided.

In this preliminary study, samples of 50 mud snails each were taken for analysis prior to exposure and at intervals of 4, 8, 16, and 32 days. At the end of each time period, the snails were placed in aerated artificial seawater overnight to purge the gut contents and then were frozen. Sediment and tissue samples were homogenized and extracted, and PAHs were determined by high performance liquid chromatography. Subsamples of about 0.5 g of each tissue homogenate and sediment were used to determine dry (sediment) and ash-free dry (tissue) weights. Due to the preliminary nature of the study, analyses were conducted on only a single sample from each time period.

Results and Discussion

As indicated, the bioaccumulation of specific PAHs either appeared to plateau during the first 8 to 16 days or continued to increase throughout the study (Figure 1). After 32 days, benzo(a)pyrene and benzo(k)fluoranthene continued to increase. Chrysene uptake had plateaued by day 16. Pyrene, fluoranthene, and benzo(a)anthracene declined after an initial period of accumulation. The uptake of pyrene, fluoranthene, chrysene, and benzo(a)anthracene was rapid during the first 8 days; whereas uptake of benzo(a)pyrene and benzo(k)fluoranthene appeared to be slow and continuous throughout the study. This preliminary time-series experiment with the mud snails suggested that a 1-month exposure would be adequate to attain the steady state for some lower and intermediate molecular weight PAHs desired in the bioassay. The initial rapid increase of several PAHs followed by a sharp decline after 16 days was similar to that demonstrated previously for phenanthrene in a detritus-feeding clam, *Macoma balthica*, and in a burrowing polychaete, *Abarenicola pacifica* (Augenfeld et al. 1982). The relatively high concentrations of some PAHs in the snails may be the result of a relatively poorly developed mixed-function oxidase (MFO) enzyme system in the snails, as only recently have MFO enzyme systems been detected in gastropods (Payne and May 1979).

Those PAHs that accumulated to the highest concentrations in the snails were the lower molecular weight compounds, both more water soluble and more easily degraded metabolically than the higher molecular weight compounds. This agrees with one report (Mix and Schaffer 1983) that the low molecular weight unsubstituted PAHs bioaccumulate to higher levels than the higher molecular weight compounds. The sampling technique used in the study disturbed the sediment each time snails were collected, thus mixing the deeper strata with the top 1 to 2 cm of sediment. Each disturbance possibly released a pulse of contaminants, causing a shift toward a new steady state. The concentrations of the more soluble PAHs increased rapidly following each disturbance of the sediment. When the time between sampling periods was constant, uptake of the more soluble PAHs was rapid and essentially linear. As the time between sampling periods lengthened, the more labile PAHs apparently were lost rapidly through metabolic activity and passive elimination. These results agree with the statement of Kveseth, Sortland, and Bokin (1982) that the lower molecular weight compounds may depurate more readily than the higher molecular weight compounds.

The more persistent PAHs such as benzo(a)pyrene continued to bioaccumulate for a much longer time, but more slowly than compounds such as pyrene and

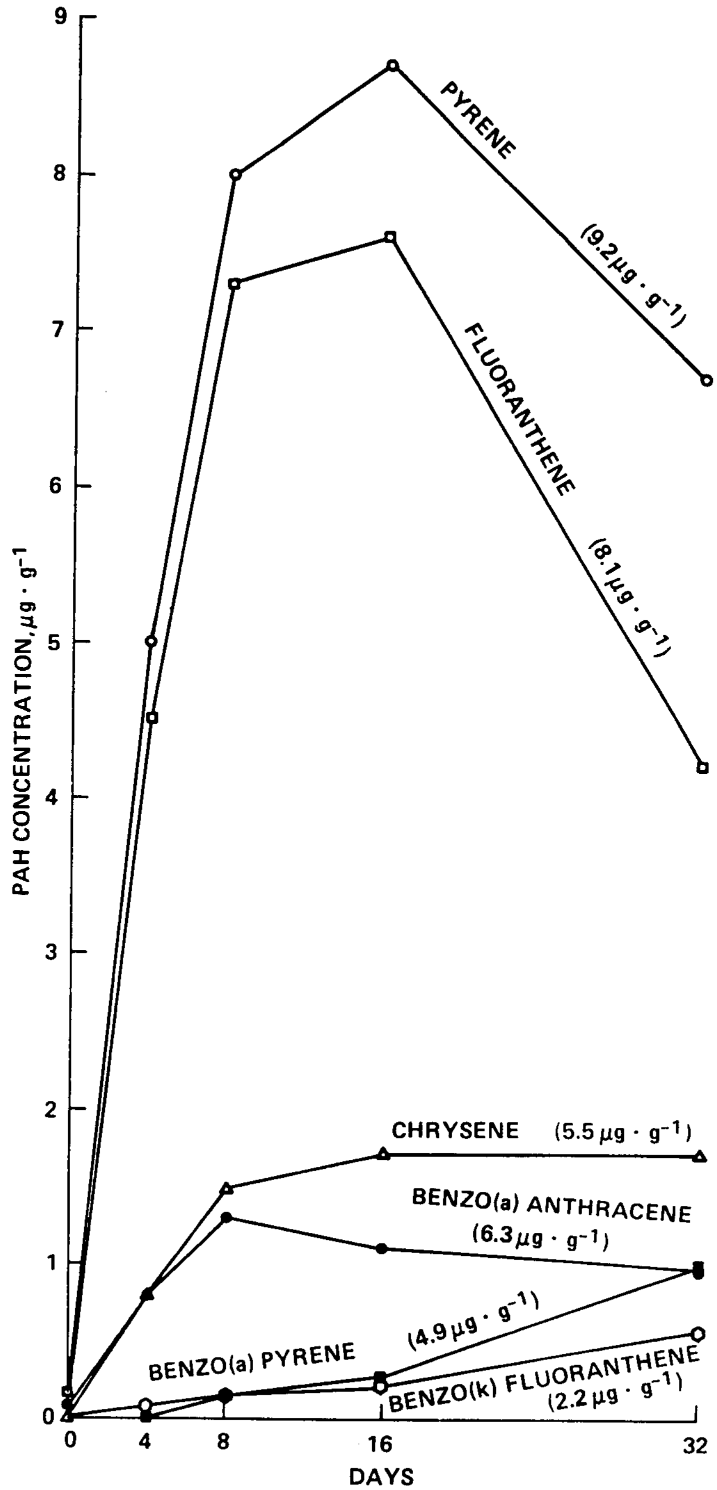

Figure 1. Time-dependent uptake of PAH by mud snails. Values in parentheses are PAH concentrations in the sediment

fluoranthene. The net result of the competing processes of bioaccumulation and elimination ultimately would be greater accumulation of the less soluble, higher molecular weight PAHs over a longer period of time. Consequently, under field conditions, the higher molecular weight PAHs could bioaccumulate to higher concentrations than the lower molecular weight PAHs. This factor must also be considered in the interpretation of bioassay test results.

This preliminary study suggests that the mud snail may be a good indicator of long-term bioaccumulation of many PAHs, especially those that are more persistent. The use of this species to assess bioaccumulation of the more water-soluble PAHs may be limited due to the possible rapid elimination of these compounds. These results also demonstrate the necessity for extreme care in the design of time-course studies involving bioaccumulation of contaminants from sediment. The mud snail is well suited as a biomonitor/bioassay animal, although further research is needed before the mud snail bioassay can be applied beyond the New England area to predict accurately the potential steady-state conditions in an intertidal disposal site.

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Environmental Effects of Dredging
Technical Notes

FIELD VERIFICATION OF THE ESTUARINE PLANT BIOASSAY PROCEDURE

PURPOSE: This note summarizes results of field testing and verification of plant bioassay procedures developed under the Long-Term Effects of Dredging Operations (LEDO) Program. The verification work was conducted as part of the Interagency Field Verification of Testing and Predictive Methodologies for Dredged Material Disposal Alternatives, called the Field Verification Program (FVP).

BACKGROUND: The FVP is a multiyear research project initiated in 1982. The objectives of the program are to field test and verify laboratory predictive methods for assessing the effects of disposal of contaminated dredged material and to evaluate findings of these objectives for aquatic, intertidal (wetland creation), and confined upland disposal alternatives.

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The FVP used contaminated sediment dredged from a project in Black Rock Harbor (BRH), Bridgeport, Conn. Use of a single highly contaminated dredged material afforded a unique opportunity to evaluate results of disposal under three different disposal alternatives: open water, intertidal (wetland), and upland.

Upland and wetland sites were designed to meet surface area, elevation, and operational requirements for FVP contaminant mobility studies. Designs for sedimentation and storage followed recently developed Corps procedures, and the resulting site performance fulfilled design objectives. Provisions were made to ensure that essentially the same dredged material was placed in the open-water, upland, and wetland sites. The upland and wetland sites, constructed within protected areas using conventional construction techniques, were filled hydraulically from barges. The filling operation provided conditions typical of confined dredged material disposal operations. Following filling, the weirs at both sites were managed to allow free drainage of surface water as the fill stabilized through consolidation. Within approximately 9 months, the upland and wetland substrates had stabilized at the desired surface elevations.

Prior to dredging, sediment samples were collected from 25 locations along the BRH channel. These samples were mixed together into a composite sample to simulate the mixing that usually occurs during confined disposal. The composite material was used in laboratory tests to predict uptake of selected metals by plants grown in the wetland creation site and the upland confined disposal site.

The estuarine plant bioassay procedure was used in the laboratory to evaluate heavy metals uptake from BRH sediment. The estuarine index plants *Spartina alterniflora* and *Sporobolus virginicus* were grown on the sediment and then were analyzed for selected metals. Sediment samples were subjected to total and Diethylenetriaminepentacetic acid (DTPA) metal extraction (Lee, Folsom, and Bates 1983). Some of the other factors known to affect plant uptake of heavy metals were also determined. These included organic matter, wet-dry pH and calcium carbonate equivalent, salinity, etc.

Chemical analysis of the BRH sediment (Table 1) indicated that the sediment would eventually become extremely acidic (dry pH < wet pH) and highly saline upon air-drying (high electrical conductivity); thus, under upland disposal conditions, the dredged material would become a harsh environment for

Table 1

Selected Physical and Chemical Parameters of Black Rock Harbor Sediment

Organic matter, %	19.5
Salinity, parts per thousand	28.0
Electrical conductivity, dS/m	35.7
$CaCo_3$ equivalent, %	0.9
pH wet	7.6
pH reconstituted air-dried	6.6
Oil and grease, mg/g	17.5
Total sulfur, %	1.3

plants to survive. Previous investigations*,** involving similarly acidic saline sediments have shown that growth of the index plants on such sediments is possible only if the sediments are rinsed with freshwater to remove salt and are limed to increase pH.

Total metal content (Table 2) of the BRH sediment was relatively high;

Table 2

Total Acid Digestible and DTPA Extractable Concentrations ($\mu g/g$) of Selected Metals in Black Rock Harbor Sediment

Heavy Metal	Total Acid Digestible Original Sediment	DTPA Extractable: Original Sediment, Flooded	DTPA Extractable: Original Sediment, Upland	DTPA Extractable: Washed Sediment, Upland
Zn	1370	344	962	925
Cd	23.3	0.02	28.7	26.6
Cu	2860	0.15	387	262
Ni	203	2.46	66.9	77.0
Cr	1403	0.10	0.83	1.29
Pb	399	0.06	16.3	10.1

the copper content was extremely high (Folsom, Lee, and Bates 1981). The data show that air-drying resulted in increased DTPA-extractable metals. Washing the sediment before air-drying had little or no effect on DTPA metal extractability. Based on results of the DTPA extractions, one could predict that plant uptake of metals in the field would be greater from the air-dried upland disposed sediment than from the flooded wetland disposed sediment. The chemical data from the laboratory portion of the plant bioassay would indicate that *S. alterniflora* and *S. virginicus* should grow under anticipated wetland conditions, but under upland conditions the plants would not grow especially well and would accumulate excessive levels of heavy metals.

* B. L. Folsom, Jr. 1982a. "Heavy Metal Content of *Spartina alterniflora* from the Texas City Prototype Marsh on the Texas City Dike," Memorandum for Record, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

** B. L. Folsom, Jr. 1982b. "Heavy Metal Content of *Spartina alterniflora* from Pawtuxet Cove, Rhode Island," Memorandum for Record, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

As expected from the chemical analyses of BRH sediment (Tables 1 and 2), *S. alterniflora* and *S. virginicus* did not grow well in the laboratory in the original unwashed air-dried (upland) sediment: only one plant of one replicate survived. The elevated heavy metal content of the surviving plants (*S. alterniflora* - Table 3, *S. virginicus* - Table 4, Folsom and Lee 1985) could be explained by the reduced plant growth. Plants grown in washed sediment under an upland condition grew better than those grown in the unwashed sediment under upland condition. However, heavy metal content of plants grown in the oxidized washed sediment was much greater than that of plants grown in sediment under flooded condition. This same effect was observed by Folsom and Lee (1981a, b) when freshwater plants were grown in freshwater sediments under both flooded and upland disposal environments. Apparently, once estuarine sediment is washed free of excess salt and plant growth occurs, the air-drying process results in increased plant availability of metals. Removing excess salt from sediment by washing relates to natural salt leaching from rainfall, and therefore washing can be used in an estuarine plant bioassay to estimate contaminant mobility into plants growing on estuarine dredged material in upland disposal sites.

Table 3

Plant Content (mg/g) of Selected Metals in Leaf Tissue of *S. alterniflora* Grown in Sediment from Black Rock Harbor

Heavy Metal	Greenhouse: Original Sediment, Flooded	Greenhouse: Original Sediment, Upland*	Greenhouse: Washed Sediment, Upland	Field: Wetland, (Flooded)	Field: Upland, Upland
Zn	14.1 (1.26)**	219	35.5 (26.5)	19.2 (7.05)	No survival
Cd	0.04 (0.01)	0.91	0.10 (0.08)	0.41 (0)	
Cu	15.2 (1.39)	18.7	85.7 (98.2)	6.55 (5.55)	
Ni	1.62 (0.39)	‡	4.50 (3.33)	21.9 (0.67)	
Cr	18.8 (1.16)	0.93	97.2 (103)	7.97 (5.49)	
Pb	0.28 (0.42)	1.53	2.79 (3.66)	0.83 (0.89)	

* Only one replicate supported plant growth.
** Number in parentheses is ±1 standard deviation.
‡ Not analyzed.

Table 4

Plant Content (mg/g) of Selected Metals in Leaf Tissue of *S. virginicus* Grown in Sediment from Black Rock Harbor

Heavy Metal	Greenhouse: Original Sediment Flooded	Greenhouse: Original Sediment Upland	Greenhouse: Washed Sediment Upland	Field: Wetland (Flooded)	Field: Upland Upland
Zn	27.0 (5.9)*	65.0 (38.1)	90.8 (54.0)	No survival	66.0 (18.1)
Cd	0.86 (0.86)	0.68 (0.46)	1.34 (0.59)		2.22 (1.11)
Cu	<0.025 (0)	<0.025 (0)	<0.025 (0)		19.8 (4.00)
Ni	7.90 (1.97)	58.8 (46.1)	19.9 (20.0)		5.38 (0.93)
Cr	31.4 (12.3)	610 (720)	187 (189)		7.64 (1.52)
Pb	<0.013 (0)	<0.013 (0)	<0.013 (0)		1.56 (0.47)

* Number in parentheses is ±1 standard deviation.

The wetland site was planted with *S. alterniflora* and *S. virginicus* after laboratory evaluations were completed and construction of the confined disposal sites was accomplished. Plant growth was poor during the first year of the project. *S. alterniflora* survived from the first year to the second year, but good growth and subsequent propagation did not occur until the second year. *S. virginicus* did not survive in the wetland site. Low survival and poor growth of both *S. alterniflora* and *S. virginicus* could have been due to a combination of a late planting in the fall followed by an early frost and the extremely low oxidation-reduction potential of the dredged material since the water level was not sufficiently low to allow complete drainage at low tide. Plant tissue of surviving *S. alterniflora* was sampled and analyzed for selected metals. Heavy metal content in plant tissue of field-grown *S. alterniflora* was in general agreement with that predicted from the greenhouse data (Table 3).

Plant death in the upland site was very strongly predicted from the chemical data and results of the greenhouse portion of the plant bioassay. An in situ plant bioassay was attempted at the FVP upland site, but no plants survived. Since prediction of plant death was so strong, *S. alterniflora* was not planted in the upland site. However, *S. virginicus* should have survived, based on the greenhouse prediction, if the acidic condition were corrected by addition of lime. *S. virginicus* was subsequently planted in limed rototilled dredged material. These plants survived and developed normally. Heavy metal uptake by *S. virginicus* showed mixed results (Table 4). Zinc and cadmium contents in the field-grown plants were relatively close to values observed in the laboratory. Laboratory test results indicated plant contents of zinc and cadmium would be elevated; field results showed they were elevated. Copper and lead contents in laboratory-grown plants were much lower than field-grown plants. Chromium and nickel contents in laboratory plants were much higher than in field-grown plants.

The overall conclusion from this study was that the estuarine plant bioassay procedure predicted growth and contaminant mobility under wetland conditions and the initial growth under upland conditions. The longer term effects of aging and salt leaching from the upland portion and an appropriate index plant to predict contaminant uptake were not successfully verified and require further research.

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Environmental Effects of Dredging Technical Notes

THE WETLAND EVALUATION TECHNIQUE (WET): A TECHNIQUE FOR ASSESSING WETLAND FUNCTIONS AND VALUES

PURPOSE: This technical note provides a brief overview of a technique for assessing functions and values of wetlands. The Wetland Evaluation Technique (WET) version 2.0 (Adamus et al. 1987) represents a revision of a technique developed for the Federal Highway Administration (FHWA) (Adamus 1983). WET is intended to address regulatory and environmental planning needs for multifunction assessment of wetland areas. It consists of documentation to implement the technique and software to aid in data analysis.

BACKGROUND: In 1981 the US Army Engineer Waterways Experiment Station was assigned responsibility for developing a technique to assess wetland functions and values for regulatory and planning needs. Numerous techniques were reviewed (Lonard et al. 1984) and a survey of Corps' needs was conducted (Forsythe, Clairain, and Smith 1985). A technique developed by the FHWA was selected as the method most capable of examining many different wetland functions and values and meeting the Corps' time and manpower constraints for assessment. This technique has been revised and published as an operational draft for testing and subsequent further revision.

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Introduction

Wetlands have long been recognized as important habitat for many fish and wildlife species, and within the last two decades an increasing awareness of other functions provided by wetlands has occurred. Executive Order 11990, "Protection of Wetlands," identifies numerous functions and values associated with wetlands including water-quality improvement, sediment retention, groundwater recharge and discharge, flood storage, production of fauna and flora, recreation, scientific advancement, and cultural benefits in addition to the traditional fish and wildlife habitat functions. That order requires that the planning effort for any federally funded projects in wetlands consider wetland functions and values and minimize adverse impacts in wetlands. Wetland functions and values must also be assessed under legislative mandates such as the National Environmental Policy Act (NEPA) and the Clean Water Act (CWA). NEPA requires environmental planning for federal construction projects. Section 404b.(1) of the CWA requires consideration of functions and values as part of the Corps of Engineers' regulatory responsibility for dredged and fill activities in wetlands. Additionally, numerous state laws and local ordinances require governing bodies to evaluate wetland functions and values when these habitats are threatened. Although several evaluation techniques such as the Habitat Evaluation Procedures (US Fish and Wildlife Service 1980) and the Habitat Evaluation System (US Army Engineer Division, Lower Mississippi Valley 1980) assess wildlife habitat, few techniques assess all wetland functions (Lonard et al. 1984, Lonard and Clairain 1986, and US Environmental Protection Agency 1984).

Assessment of wetland functions and values typically relies on professional judgment. An alternative requires detailed, site-specific studies, which are often expensive and time-consuming and usually not practical in a regulatory decision-making context where time and funds are often constrained. Results derived from professional judgment can be extremely variable and depend largely on the expert's past experience and expertise. In addition, obtaining the services of several professionals is often necessary, which limits this approach in the regulatory context.

What is WET?

The Wetland Evaluation Technique (WET) is a procedure for the assessment of a number of wetland functions and values, providing a balance between professional judgment and detailed, site-specific studies. WET is a rapid, systematic wetland assessment technique based upon information derived from the published literature--the best professional judgment available, expressed in documented format. The objective of WET is to provide an evaluation technique that: (1) assesses most recognized wetland functions and values, (2) is applicable to a wide variety of wetland types, (3) is reproducible and rapid (can usually be implemented within one day or less), and (4) has a sound technical basis in the scientific literature. WET examines the following 11 wetland functions and values:

- Groundwater recharge
- Groundwater discharge
- Floodflow alteration
- Sediment stabilization
- Sediment/toxicant retention
- Nutrient removal/transformation
- Production export
- Wildlife diversity/abundance
- Aquatic diversity/abundance
- Recreation
- Uniqueness/heritage

WET also assesses the suitability of wetland habitat for 14 waterfowl species groups, 4 freshwater fish species groups, 120 species of wetland-dependent birds, 58 species of saltwater fish and invertebrates, and 47 species of freshwater fish.

How Does WET Work?

WET assesses wetland functions and values by characterizing a wetland in terms of its physical, chemical, and biological processes and attributes. These attributes (examples are hydroperiod, pH, and vegetative type) are referred to as predictors. Information about the predictors is established by addressing a series of questions. Responses to these questions are analyzed in interpretation keys.

WET is structured into several levels of analysis to provide a systematic approach for assessing wetland functions and values under different time and data constraints. This feature is important in regulatory activities of the Corps of Engineers because permit decisions must often be provided within a short time period and site-specific data are usually nonexistent or not readily available. However, WET also allows the user to incorporate new information into the original assessment to refine results if additional data or time becomes available.

Analysis of data in the interpretation keys results in the assignment of qualitative probability ratings of high, moderate, or low to functions and values in terms of social significance, effectiveness, and opportunity. Social significance assesses the value of a wetland to society due to special designation, potential economic value, or strategic location. Effectiveness assessment examines the capability of a wetland to perform a function due to its physical, chemical, or biological characteristics. Opportunity assesses the chance a wetland has to perform a function to its level of capability.

The following example illustrates the concepts of opportunity, effectiveness, and social significance as they apply to floodflow alteration. Opportunity for a wetland to alter floodflows will depend on many factors (predictors) associated with the wetland's surrounding environs that influence delivery of floodwaters to the wetland. Some examples include size of the watershed, permeability of watershed soils, and watershed land cover characteristics. In order for the wetland to have an opportunity to alter floodflows, a significant input of surface water must occur. The effectiveness of a wetland in performing this function will largely depend upon characteristics associated with the wetland itself, such as floodwater storage capacity, presence or absence of constricted inlets and outlets, wetland hydroperiod, and water-velocity reduction capability. To be effective, the wetland must be able to retain or retard surface flows. Assessment of social significance of the wetland for floodflow alteration would be influenced primarily by factors downstream of the wetland, such as the presence of a town. This function may have social significance if damage is reduced or prevented downstream. Brief descriptions of these analyses are presented below.

Social significance

Social significance is evaluated at two levels. Level 1 consists of 31 questions designed to determine whether the wetland has specific characteristics that indicate it may be performing functions and values beneficial to society. A Level 1 assessment can be completed in 1-2 hours using information resources typically found in one's office, such as US Geological Survey (USGS) quadrangle maps, regional atlases, and lists of national historical locations. Level 2 is an optional step to refine the probability rating for the uniqueness/heritage function.

Effectiveness and opportunity

The effectiveness and opportunity of a wetland to provide functions and values is analyzed by addressing a series of questions designed to characterize the wetland and surrounding area. This evaluation has three assessment levels with each successive level building a more detailed characterization of the wetland and surrounding area and consequently providing increased confidence in probability ratings resulting from the assessment.

The first level of analysis for effectiveness and opportunity can be conducted in the office using information found on USGS quadrangle maps, Soil

Conservation Service soil survey maps, National Wetlands Inventory maps, and other data sources that indicate wetland size, configuration, slope, and juxtaposition relative to surrounding environs. The analysis can generally be performed in an hour or less and does not require a site visit.

The second level of assessment requires visiting the wetland area for observation and data collection. This level of analysis will take approximately 1-3 hours to complete.

The third level of assessment requires detailed (and in some situations, long-term) physical, chemical, and biological monitoring data from the wetland. For example, data obtained from water table wells would be used, if available, at this level of analysis to indicate groundwater relationships to the wetland. The time required to conduct this level of analysis varies depending upon the size and complexity of the wetland being evaluated.

Data analysis

Data can be analyzed either manually or electronically with a computer program. Manual analysis is performed by physically comparing question responses to required responses in the interpretation keys. One to several hours would be required to conduct an analysis manually, depending upon the type of evaluation performed and the level of analysis for each type.

Data analysis using the computer software requires less than 15 minutes regardless of the level of analysis performed. Results are obtained instantly upon completion of data input. Substantially revised from an earlier version (Clairain 1986), the WET computer program version 2.0 is written in C language and compiled. It will run on any IBM or true IBM-compatible microcomputer, operating under MS-DOS version 2.0 or later. WET requires less than 256 kb of storage on a double-sided, double-density diskette and will run from a floppy or hard disk. The program is menu driven and provides the user with options to input data, edit existing files, analyze data, print data files or results of data analyses, or exit the program. Data results are presented in the format displayed in Figure 1.

Evaluation Site: Hypothetical Wetland Site

Wetland Functions and Values	Social Significance	Effectiveness	Opportunity
Groundwater recharge	L	U	*
Groundwater discharge	M	H	*
Floodflow alteration	M	H	M
Sediment stabilization	M	H	*
Sediment toxicant retention	H	L	M
Nutrient removal transform	M	L	M
Production export	*	M	*
Wildlife diversity/abundance	M	*	*
Breeding	*	L	*
Migration	*	H	*
Wintering	*	H	*
Aquatic diversity/abundance	H	H	*
Uniqueness/heritage	H	*	*
Recreation	L	*	*

An asterisk indicates functions and values not evaluated by WET; H = high, M = moderate, L = low, and U = uncertain.

Figure 1. Example of an evaluation summary sheet for a hypothetical wetland

Future Directions

WET version 2.0 has been published as an operational draft but will undergo considerable review and refinement during the next several years before it will be published as the next operational draft. The technique will be tested by the Corps of Engineers and other Federal and state agencies for an 18-month period with revisions consolidated into the next operational draft (version 3.0). During this testing period several other tasks will also be conducted to enhance the technical accuracy of WET and make the software more user friendly. Field research in bottomland hardwood forests in the southeastern United States is underway by WES to enhance WET's ability to assess these complex wetland systems. This study will be conducted over the next three years, although field research in other wetland systems will be conducted according to priorities established in the Wetlands Functions and Values Study Plan (Clairain 1985 and Clairain et al. 1985) as funds are available. Interpretation keys will also be refined based on results of field research studies and published information. Although WET currently provides an analysis for many different fish and wildlife species, additional species-specific interpretation keys will be developed and integrated into future versions of WET. Also several important wetland functions and values, such as hunting and fishing, which are not available in version 2.0, will be developed for future versions of WET. Expert systems will be examined to evaluate the potential applicability of this new technology to implementation of WET. Training courses will also be provided each year to train potential users and assure consistency in results.

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Environmental Effects of Dredging Technical Notes

LONG-TERM BIOLOGICAL STUDIES IN BOTTOMLAND HARDWOOD WETLANDS, CACHE RIVER, ARKANSAS

PURPOSE: This technical note provides an overview of vegetation, fish, and wildlife research studies underway in bottomland hardwood wetlands along the Cache River in Arkansas. The objectives of these studies are to obtain quantitative data to improve the technical accuracy of assessing biological functions and values of bottomland hardwoods, and to improve fish and wildlife habitat models in the Wetland Evaluation Technique (Adamus et al. 1987).

BACKGROUND: A survey of US Army Corps of Engineers district and division personnel was conducted in 1982 (Forsythe, Clairain, and Smith 1983) to determine which wetland types should receive the highest priority for research funding. Bottomland hardwood wetlands in the Lower Mississippi River Valley were assigned the highest priority for research. Consequently, a comprehensive study examining physical, chemical, and biological functions of bottomland hardwood wetlands was initiated in 1985 and will continue through 1989.

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Introduction

A wetland evaluation technique developed for the Federal Highway Administration (Adamus 1983) was revised by the US Army Engineer Waterways Experiment Station (WES) and published as an operational draft (Adamus et al. 1987). The Wetlands Evaluation Technique (WET) provides an assessment of 11 different functions. This operational draft will be revised and refined during the next several years to improve its technical accuracy. One major revision planned during this period is improving the technical accuracy by developing regionalized wetland evaluation models. Research initiated by WES in bottomland hardwood wetlands will provide information necessary to develop these regional models for this wetland type. This technical note describes biological research underway in bottomland hardwood wetlands along the Cache River in Arkansas.

Site Description

The Black Swamp Wildlife Management Area (BSWMA) in east central Arkansas was selected for comprehensive study after a detailed evaluation of sites throughout the southeastern United States. The BSWMA consists of approximately 80 km^2 of floodplain and adjacent uplands along the Cache River in Woodruff County, Arkansas (Figure 1). The Cache River has a watershed of about 2,875 km^2 upstream of the study area, and local stream gage data are available from 1937 to the present. The Cache River Basin floodplain supports one of the largest remaining tracts of bottomland hardwood and alluvial swamp forests in the Lower Mississippi River Alluvial Plain (Cache River Basin Task Force 1978). The BSWMA has been reported as one of the most ecologically significant areas in the Cache River system (US Army Corps of Engineers 1974).

Plant communities in bottomland hardwoods have been divided into six different zones, based on species composition, soils, and hydrology (Clark and Benforado 1981). Plant zonation is evidenced at the study area. Zone 2, dominated by cypress-tupelo (*Taxodium distichum-Nyssa aquatica*), is the most prevalent in the study area. Plant communities in Zone 2 are fairly homogeneous with very little understory diversity. Zones 3 and above tend to exhibit greater diversity. Water hickory (*Carya aquatica*) and overcup oak (*Quercus lyrata*) are prevalent in the overstory of Zone 3, and common buttonbush (*Cephalanthus occidentalis*) and English dogwood (*Cornus foemina*) are common in the understory. Evidence of logging within the last 25 to 30 years (primarily high-graded timber) can be seen in some areas, but overall little disturbance is observed at the site.

Lands bordering the forested areas are primarily in private ownership and agricultural production. Harvesting of row crops, such as cotton and soybeans, results in exposed soils subject to erosion and sediment transport into the wetland via overland flows and several small channels.

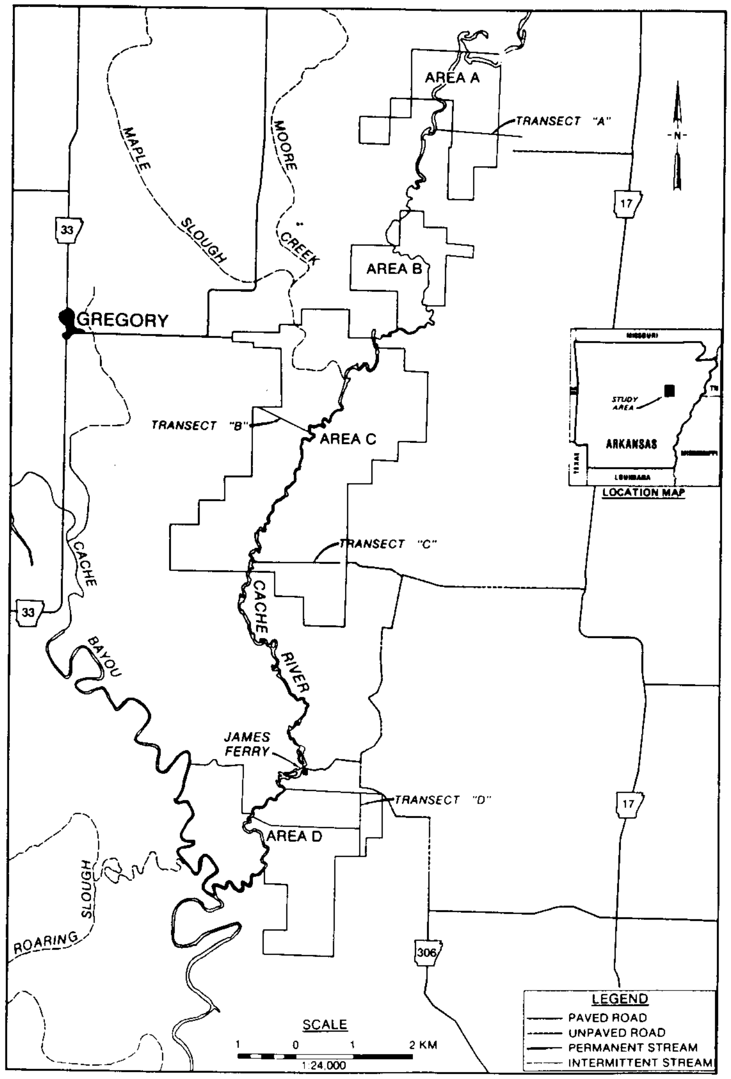

Figure 1. Sample transect locations, Cache River, Arkansas

Biological Studies

Biological studies in the BSWMA were divided into three interrelated components: vegetation, fish, and wildlife. Research efforts during 1987 were directed toward characterizing the site and developing a data base of biological information. This data base includes information on the physical features of the site (e.g., roads and streams), land use, elevations, soils, hydrology, and vegetation types. Research designs will be refined in 1988 and 1989 based on these characterization studies. The study design and preliminary results of the characterization studies are discussed below.

In the spring of 1986, 1:12,000-scale color infrared aerial photography was taken of the site to aid in establishing vegetation transect locations, type mapping vegetation communities (Society of American Foresters 1980), and determining adjacent land use. Based on preliminary type mapping and field reconnaissance, four areas along the Cache River were examined for potential intensive vegetation sampling (Figure 1). Sample transects were subsequently located within three of the areas. Transect directions and locations were established to traverse the hydrologic gradient from the Cache River upslope to the highest vegetated ground and to cross as many vegetative zones as possible. Within each transect at least two vegetation zones are represented with Zones 2, 3, and 4 represented throughout the project area. Most of Zone 6 has been cleared and converted to agricultural production.

During the fall of 1986, temporary benchmarks were established at the highest point along each transect. A total of 171 0.04-ha sampling plots were located along the transects at 60-m intervals. Plot elevations were subsequently determined to assess flood duration at each vegetation plot. Parallel transects were established at transects A and C to provide additional data for wildlife studies.

Vegetation

Vegetation is not a wetland function or value and, therefore, is not specifically assessed by WET. However, wetland vegetation is considered when fish and wildlife habitat, water quality, hydrology, and other functions are assessed by WET. Vegetation sampling was initiated during the summer and fall of 1987 along the four transects. Within each 0.04-ha plot, trees greater than 6.6 cm diameter at breast height (dbh) were identified by species and the diameter breast height measured. Saplings (2.5 to 6.6 cm dbh), shrubs, and woody vines were also identified by species and tallied in two 0.004-ha circular subplots randomly located within the larger 0.04-ha plot. Woody seedlings (<2.5 cm dbh) were identified and tallied in two 0.0004-ha subplots nested within the 0.004-ha subplots. Absolute and relative density of seedlings, saplings, woody vines, and trees are being calculated for each plot and subplot. Absolute and relative basal area of trees are also being calculated for each plot. The Importance Value (IV) 200 (relative density + relative basal area) (Curtis 1959) is being calculated for trees at each plot. These data will be placed into separate matrices for tree basal area, density, and IV 200 as well as matrices for sapling, seedling, and woody vine relative densities.

Matrices will be used as input to the Two-Way Indicator Species Analysis (TWINSPAN), a classification algorithm that objectively classifies plots into community types (Hill 1979). The original forest cover types will be evaluated and revised using the community types identified by TWINSPAN. Forest cover types will be characterized in terms of species composition; dominance and density of trees; density of saplings, woody seedlings, shrubs, and woody vines; and soil characteristics.

Fish habitat

WET evaluates freshwater fishery habitat according to general aquatic diversity/abundance, four freshwater fish species groups, and 47 species of freshwater fish. The overall purpose of the fish habitat study is to test and refine the fish habitat models in WET. Specifically, fisheries studies will: (1) assess the use of bottomland hardwood forests by fish found within nearby watercourses; (2) relate the abundance and distribution of fish to variations in measured physical, chemical, and biological attributes (such as vegetation composition and distribution) of the wetland; (3) construct a testable model to evaluate use of bottomland hardwoods by fish; and (4) incorporate the findings of this field study into bottomland hardwood evaluation models.

The sampling protocol for fish studies in 1988 is based on data needs for WET, results of several site visits, and two preliminary sampling trips for adult fish made in June and July 1987. Both larval fishes and adults will be collected during 1988. Only transects B and C (Figure 1) of the four study areas will be sampled for fish since these areas were found to represent all the physical features characteristic of the BSWMA. Within each area, three habitats will be sampled. The cypress-tupelo zone (Zone 2) will be sampled as a homogeneous unit. Zone 3 consists of two distinctly different types of microhabitats: areas with little understory vegetation and areas with dense understory growth. These microhabitats will be sampled separately so that any variation between them can be distinguished. Actual sampling began in March. Sampling will occur at approximately 3-week intervals, through late June or early July, resulting in six potential sampling trips.

Sixty larval fish samples will be collected within the forested wetland during each sampling trip. Ten samples will also be obtained from the Cache River above and below the study area. Larval fish samples will be collected using a diaphragm pump and light traps. Adult fish will be sampled at 35 locations, including the Cache River, using a boat-mounted electroshocker.

A subsample of adult fish will be examined to assess stage of maturity and to indicate species potentially spawning in the wetland. Samples taken with each type of sampling gear will be randomly allocated within each transect area and vegetation zone.

During fish sample collections, several physical-chemical parameters will also be measured. Current velocity, depth, and amount and general type of vegetation will be recorded at each fish sampling station. In addition, water temperature, dissolved oxygen, turbidity, pH, and conductivity will be collected at two sampling stations within each habitat type.

Fish samples will be analyzed separately for larval and adult species. Data from sampling will be separated according to sampling method, so that the effects of sampling methods on the samples obtained can be analyzed. Multiple regression techniques will be used to assess the relationship of fish density and species composition to physical-chemical variables measured for the sampling areas. Physical and chemical variables used will include both those measured during fish collections and those collected during other studies being conducted on the BSWMA.

Wildlife habitat

WET contains procedures for assessing the probability that a wetland supports a high density or diversity of wetland-dependent bird species. It also assesses 14 waterfowl species groups and 109 individual wetland-dependent birds. Other segments of the vertebrate community, such as mammals or reptiles, are not considered in the evaluation.

The general objectives of the wildlife habitat studies are to expand the scope of the wildlife component of WET to include other vertebrate groups in addition to birds, improve the structure and flow of the method, and develop and incorporate modifications to improve the accuracy of results.

Wildlife habitat has been examined more thoroughly and has a broader literature base upon which to develop evaluation models than most other wetland functions. Therefore, early emphasis of the wildlife studies has been and will continue to be directed toward detailed reviews and revision of WET models. Many wildlife models have also been developed for use in the Habitat Evaluation Procedures (US Fish and Wildlife Service 1980) and will be reviewed to determine applicability to WET.

Baseline wildlife information is being collected from the study area during the spring and summer of 1988. Samples are being collected from plots along transects A and C (Figure 1). Characteristics of the sample plots, such as canopy cover of the overstory, species composition and density of shrubs, herbaceous cover, and abundance of downfall and litter, will be measured on the 0.04-ha plots used in the vegetation studies. These data, along with information on flooding regime, juxtaposition of cover types, and other topographic features, will be used to generate WET ratings for wildlife for each of the sites on the study area.

The study sites will be surveyed in the spring to determine bird species diversity. Time-area counts will be done simultaneously to estimate use of the sites by squirrels. Tracks and other indicators of animal use will be noted during field investigations. Trapping will be conducted to estimate the use of the sites by small mammals, reptiles, and amphibians. These data, along with available literature, will guide the model modification process.

To supplement the waterfowl models currently in WET, several other species or species groups will be selected and models developed. These models will allow users the option of making a more detailed assessment.

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Environmental Effects of Dredging Technical Notes

A METHOD FOR CALCULATING CHEMICAL LOADING RATES IN RIVERINE WETLAND SYSTEMS

PURPOSE: This note describes the application of FLUX (Walker 1986) to riverine wetland systems. FLUX is a computer program designed to estimate tributary mass discharges (loadings) into reservoirs. The program uses periodic concentration data and continuous flow records to estimate chemical loadings. This information can be used to consider the influence of wetlands on the water quality of adjacent lotic water bodies.

BACKGROUND: In 1982, a survey of US Army Corps of Engineers District and Division personnel was conducted to determine priorities for wetland research funding (Forsythe, Clairain, and Smith 1983). The bottomland hardwood wetland type in the Lower Mississippi Valley was assigned the highest priority. A comprehensive study examining the physical, chemical, and biological functions of a bottomland hardwood wetland in eastern Arkansas was subsequently initiated in 1986. Loading rates and mass balance calculations of chemical constituents in the wetland and adjacent river are an integral part of the chemical and physical work units.

ADDITIONAL INFORMATION: Contact the author, Ms. Barbara A. Kleiss, (601) 634-3836, or the manager of the Environmental Effects of Dredging Programs, Dr. Robert M. Engler, (601) 634-3624. For technical information on the FLUX program, or to obtain a copy of the program, contact Dr. Robert H. Gaugush, (601) 634-3626.

Introduction

As part of a multidisciplinary approach to determining the value of bottomland hardwood wetlands, the US Army Engineer Waterways Experiment Station is conducting a study of the biogeochemistry of a bottomland hardwood wetland adjacent to the Cache River in eastern Arkansas. To determine how this wetland influences the water quality of the Cache River, loading rates of selected chemical components must be determined. Past investigations of wetlands biogeochemistry have frequently described chemical concentrations rather than chemical loadings because of insufficient water budget data. Nixon and Lee (1985), LaBaugh (1986), and others point out that this lack of water budget data has hindered the construction of mass-balance studies in wetlands and has handicapped attempts to draw definitive conclusions about the water quality impacts of wetlands on adjacent aquatic systems.

The most accurate estimate of chemical loading rates can only be obtained from continuous concentration and discharge measurements, but such measurements are generally unavailable due to time and cost constraints. Consequently, most calculation methods rely on daily hydrological discharge information, such as that available from US Geological Survey gaging stations, and periodic sampling for chemical concentration data. Many methods have been developed to estimate chemical export by interpolating measured concentration data over the entire hydrologic record, e.g., Dann, Lynch, and Corbett (1986) and Johnson (1979).

FLUX, a tributary-loading program originally designed for reservoir application, which calculates loading rates using five alternative methods, was used in this project. This program can be acquired from the US Army Engineer Waterways Experiment Station. The utility of this program for wetland systems has not yet been fully evaluated. However, the program has many attributes that wetland researchers and managers may find beneficial. This technical note discusses the organization of the program, and the use of the program is demonstrated by examining program estimates for chemical loadings at the Cache River wetland research site.

Organization of the FLUX Program

FLUX is an easily used, well-documented, interactive program for the personal computer, developed for the US Army Corps of Engineers by William W. Walker, Environmental Engineer, Concord, MA. The program estimates loadings or mass discharges passing a tributary or outflow monitoring station over a given period. The function of FLUX is to integrate water quality and flow information derived from intermittent grab or event sampling to estimate mean (or total) loadings over the complete flow record. Much of the following section is a synopsis of Walker (1986), which should be referred to for more detailed information.

The FLUX program offers five alternative calculation methods enabling the user to select the one most appropriate for a given aquatic system and chemical sampling scheme. These five methods are: direct mean loading; flow-weighted concentration (ratio estimate) (Cochran 1977); modified ratio estimate (International Joint Commission 1977, and Bodo and Unny 1983, 1984); regression, first-order (Walker 1981); and regression, second-order (Benjamin and Cornell 1970).

FLUX includes an option to divide the input flow and concentration into a series of groups (strata) and calculate loadings separately within each group using the methods described above. In many cases, stratification of the data set reduces variance and reduces potential biases in loading estimates. The strata can be defined based upon flow, time, or any other variable which seems to influence the loading dynamics.

A variety of graphic and statistical diagnostics are provided to assist the user in evaluating data adequacy and in selecting the most appropriate calculation method and stratification scheme for each loading calculation. These include plots of concentrations versus flow or date, plots of sampled load versus flow or date, and the calculation of the regression of these plots, and an analysis of the residuals from the loading estimation calculation.

Individual runs of the program are restricted to one chemical parameter during one specified hydrologic period. However, a single data file can contain 300 data points for each of six chemical parameters and 2,000 hydrologic data points.

Program Demonstration--Cache River Study

To demonstrate an application of FLUX in bottomland hardwood wetlands, data from the Cache River wetlands research site will be considered. This site has an upstream hydrologic gaging station at Patterson, AR, which is administrated by the US Army Engineer District, Memphis, and another gaging station about 12 miles downstream at Cotton Plant, AR, which is operated by the US Geological Survey in Little Rock, AR. Daily average flows for the Cache River are available from these stations. Chemical sampling for over 30 parameters is also being performed at these stations biweekly. Loading rates for total organic carbon (TOC) for the 1988 water year (October 1987 to September 1988) are presented in this demonstration.

Data can be entered directly into the program using a data entry routine which is part of the FLUX program or by importing existing computer data files. Table 1 is a copy of the output which results from this entry. It summarizes the data which has been input for use in the subsequent calculations and gives parameter means. Of special interest is the note. This information is one aspect of the program which indicates the adequacy of the periodic chemical sampling program. In this case, it was found that over 18 percent of the flow volume at the Patterson gage occurred at discharges greater than the highest discharge at which chemical sampling occurred. In order to more fully evaluate chemical budgets during these high-flow periods, a modified sampling program, which included storm event sampling and increased sampling frequency during high water, was instituted.

The plotting capabilities of the FLUX program may be used for a preliminary visual interpretation of data patterns. A plot, as generated by the program, of TOC concentration versus the discharge at the Patterson gage and the regression of these parameters is given in Figure 1. The r-squared value given for the regression of these data is 0.0052. The log transform of the data can also be graphed. The regression of the log transform data resulted in a r-squared value of 0.11. These r-squared values indicate virtually no relationship between TOC concentration and discharge in this case.

A program-generated table with the results of the actual loading calculations is given in the next step (Table 2). In this example, all five methods gave similar estimates. However, at both the Patterson and Cotton Plant gages, method 2 resulted in the lowest coefficient of variation, so the values from this method should be used in subsequent calculations. This results in an annual TOC loading of about 11 million kg at the Patterson and 14 million kg at the Cotton Plant gages. The difference represents nearly a 20 percent increase in TOC between the upstream and downstream sites on the Cache River.

At this point, several steps can be taken to reduce the variance of the loading estimate. The FLUX program allows the examination of the residuals of estimation process. The residuals often indicate effects of seasonal or flow-related variability, which potentially can be minimized by stratifying the data. Additionally, the FLUX program will automatically stratify the flow data into groups of minimum variance.

In the case of TOC in the Cache River, the stratification of the data by

Table 1

Summary of the Data Input into FLUX for Subsequent Calculations

---

```
   FLUX - VERSION 3.0
FLUX INPUT FILE?   pattssc.flx
CACHE RIVER, PATTERSON, ARKANSAS

1 flow             .8900
2 TSS          1000.0000
3 OSS          1000.0000
4 ISS          1000.0000
5 TOC          1000.0000
6 DOC          1000.0000


FLOW SUBSCRIPT <N.> ?  1
CONC SUBSCRIPT <N.> ?  5
MINIMUM DATES FOR CONCS <YYMMDD.> ? 871001
MAXIMUM DATES FOR CONCS <YYMMDD.> ? 870930

NUMBER OF CONC SAMPLES = 26

MINIMUM DATES FOR FLOWS <YYMMDD.> ? 871001
MAXIMUM DATES FOR FLOWS <YYMMDD.> ? 870930

NUMBER OF FLOW SAMPLES = 366


   NOTE: 18.61% OF TOTAL FLOW VOLUME EXCEEDS MAXIMUM SAMPLED FLOW

COMPARISON OF FLOW DISTRIBUTIONS
```

	SAMPLED			TOTAL					
STRAT	N	MEAN	STD DEV	N	MEAN	STD DEV	DIFF	T	PROB(>T)
1	26	900.8	1055.7	366	943.0	1293.4	-42.2	-.194	.842
ALL	26	900.8	1055.7	366	943.0	1293.4	-42.2	-.194	.842

Note: The note above gives an indication of the completeness of the chemical sampling scheme. This is discussed in more detail in the text.

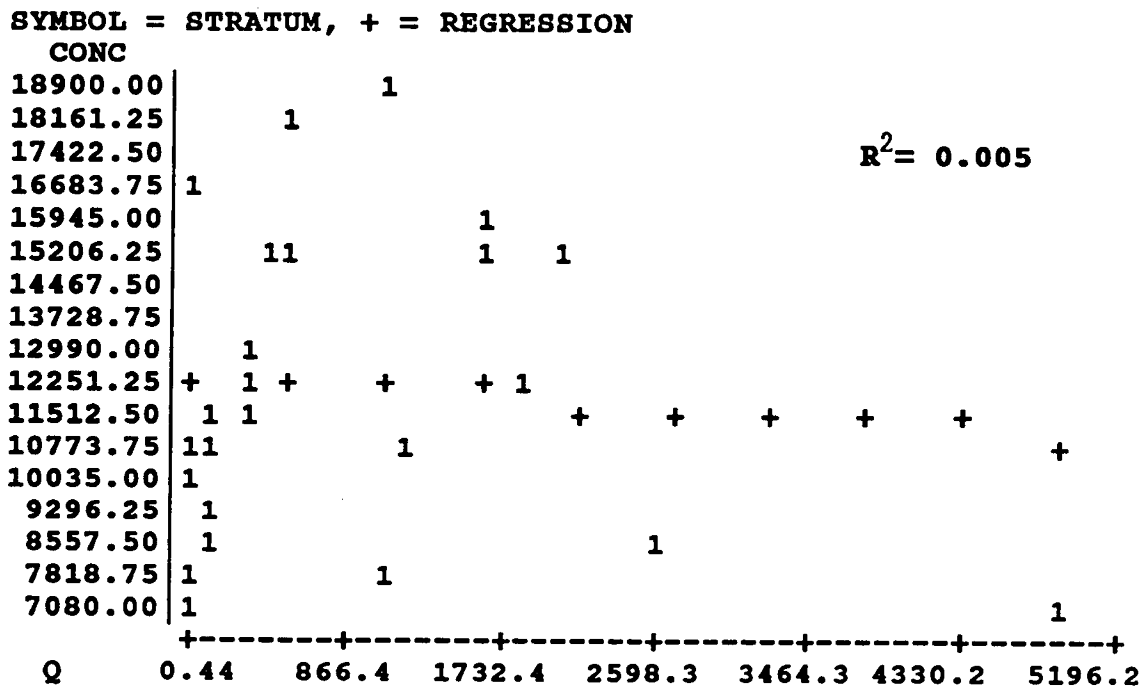

Figure 1. FLUX plot and regression of TOC concentration (in mg/m^3) versus flow (hm^3/year); data are shown by "1's" and the regression line is shown with "+" symbols

date or discharge did not significantly reduce the variance, and an examination of the residuals did not provide much information with which to modify the analysis. However, in order to consider the interactions between the wetland and the river, the flow was stratified into the following three flow regimes to reflect distinct hydrologic conditions within the wetland system: low flow, when the water is contained within the river channel; intermediate flow, when the river has flooded into the "first bottom" or the "Zone 2 wetland" (Clark and Benforado 1980), which is primarily composed of the cypress-tupelo community; and high flow, where much of the forested floodplain is inundated.

An analysis of the upstream/downstream differences in TOC under the wetland flow stratification scheme is presented in Figure 2. Under low-flow conditions, TOC increased between the upstream and downstream stations on the river by more than 70 percent. During this flow regime, there is little flow, the water temperatures are generally warm, and the water is confined to the stream channel where there is more light available than in the forested floodplain. The conditions are suitable for algal growth, which may explain the export of TOC. However, TOC appears to be retained by the wetland during the

Table 2

Flux (Loading) Calculations at Patterson (Upstream) and Cotton Plant (Downstream), AR

CACHE RIVER, PATTERSON, ARKANSAS TOC

LOADING TABLE - STRATIFIED ESTIMATES

METHOD	NC	NQ	FLOW	FLUX	VARIANCE	CONC	CV
1 AV LOAD	26	366	943.02	9999543.0	.128E+13	10603.77	.113
2 Q WTD C	26	366	943.02	11187440.0	.151E+13	11863.44	.110
3 IJC	26	366	943.02	11044270.0	.176E+13	11711.62	.120
4 REGRES-1	26	366	943.02	10925220.0	.228E+13	11585.38	.137
5 REGRES-2	26	366	943.02	10813180.0	.268E+13	11466.57	.152

CACHE RIVER, COTTON PLANT, ARKANSAS TOC

LOADING TABLE - STRATIFIED ESTIMATES

METHOD	NC	NQ	FLOW	FLUX	VARIANCE	CONC	CV
1 AV LOAD	26	366	1212.39	13258820.0	.384E+13	10936.13	.148
2 Q WTD C	26	366	1212.39	14173510.0	.166E+13	11690.58	.091
3 IJC	26	366	1212.39	13976180.0	.183E+13	11527.82	.097
4 REGRES-1	26	366	1212.39	14061990.0	.168E+13	11598.60	.092
5 REGRES-2	26	366	1212.39	14014260.0	.165E+13	11559.63	.092

Note: The results of calculation Method 2 are underscored. This method resulted in the lowest coefficient of variation, and values from this method are used in all remaining calculations.

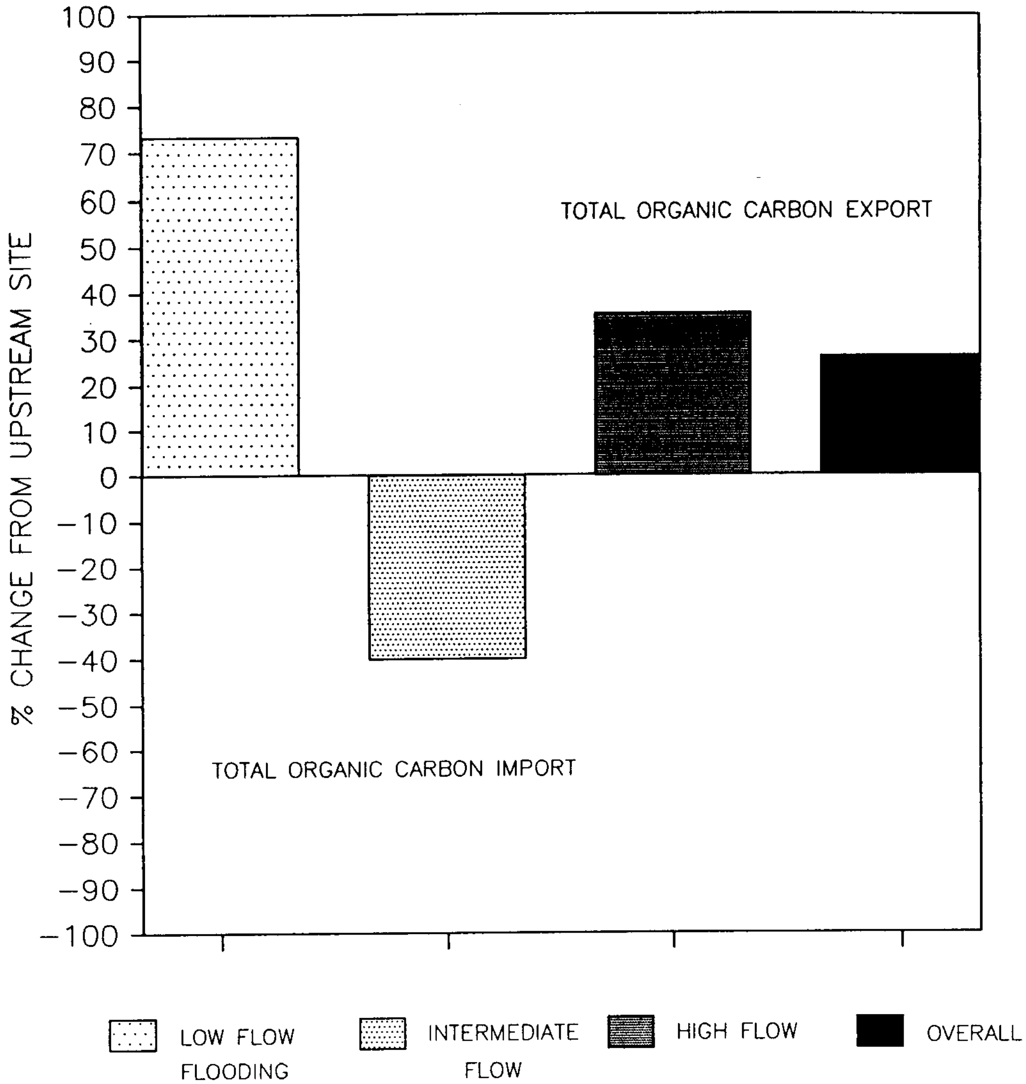

Figure 2. Difference in Cache River TOC loadings between the upstream and downstream stations, expressed as percent change, for three different hydrologic stages during the 1988 water year

swamp flooding stage. At this hydrologic stage, turbid floodwaters enter the cypress-tupelo zone in the wetland and perhaps the water velocity is decreased sufficiently to result in the sedimentation of particulate organic materials. During high-flow periods, the floodwaters enter into the upper zones of the forest, where leaf litter can accumulate. Water velocities may be sufficient during high water to wash this organic material into the river. This loss of organic material from the forested wetland resulted in about a 30 percent increase in TOC load between the upstream and downstream sites during high water. The hydraulic discharge during high flow constituted a majority of the 1987 annual flow volume, so that the TOC load during the high-water period dominated the entire annual mass balance, and resulted in wetland export of TOC on an annual basis.

Conclusions

FLUX is an useful method to begin the analysis of water chemistry and hydrologic discharge data in riverine wetland systems. The program is readily available and not difficult to set up on personal computer systems. It provides inputs on sampling design and provides clues to sources of systematic variance, such as season and flow regime. FLUX allows the rapid formulation of estimates of the mass balances of chemical constituents in streams adjacent to wetlands. The simultaneous calculation of loading using five methods allows the choice of the method which is most appropriate for each set of data. The capability to analyze residuals facilitates the determination of confidence in the program estimation. Program options which readily permit time and flow stratification assist in the comparison of seasons and hydrologic regimes which may influence the fate of chemicals in wetlands.

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Environmental Effects of Dredging Technical Notes

Long-term Evaluation of Plants and Animals Colonizing Contaminated Estuarine Dredged Material Placed in a Wetland Environment

Purpose

This technical note summarizes data collected between 1983 and 1989 that relate to plant and animal communities colonizing the wetland creation site of the US Army Corps of Engineers/Environmental Protection Agency Field Verification Program (FVP). The management of contaminated dredged material and the mobility of contaminants from the dredged material into plants and animals are also described and related to the evaluation of test results by Lee and others (1991). This site will be evaluated through September 1995 under the Long-Term Effects of Dredging (LEDO) Program.

Background

Long-term evaluation of ecosystems developing on dredged material has been accomplished on some of the marsh creation sites established during the Dredged Material Research Program (DMRP). These sites were not classified as contaminated and their evaluations did not consider contaminant mobility. Contaminated dredged material has been evaluated only on a short-term basis, such as laboratory tests before dredging and disposal operations and during the operational phases of some confined disposal facilities (CDFs). Monitoring is normally conducted during the operational phase of a dredging/disposal project and perhaps during the first year after completion of the dredging/disposal activity. Changes in contaminant mobility may occur over the long-term, but no long-term evaluation data are available to document such changes.

Additional Information

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Introduction

Contaminated sediment was dredged from Black Rock Harbor, Connecticut, in October 1983 and placed in aquatic, upland, and wetland environments as part of the US Army Corps of Engineers/Environmental Protection Agency Field Verification Program (FVP), 1981-1986 (Peddicord 1988). Wetland tests (plant, snail, sandworm, and mussel bioassays) were conducted on the sediment before dredging to evaluate potential contaminant mobility. Laboratory test results were subsequently field verified at the field test site at "Tongue Point," Bridgeport, Connecticut. The results of the wetland creation portions of the FVP and the changes occurring since the completion of the FVP for the wetland creation environment are summarized herein. This technical note emphasizes the contaminant mobility of heavy metals. Contaminant mobility and the progressive development of the wetland ecosystem at this site will be evaluated until September 1995.

Site History

The initial field survey of "Tongue Point" included wetland areas. Plants were collected along several transects. The species collected included *Phragmites australis*, *Solidago sempervirens* (seaside goldenrod), *Distichlis spicata* (spikegrass, saltgrass), *Juncus gerardii* (blackgrass), *Limonium carolinianum* (sea lavender), *Spartina patens* (saltmeadow grass), and *Spartina alterniflora* (smooth cordgrass). The field survey also listed animals which inhabited the stagnant and intertidal ponds. These included fish, shrimp, sandworms, snails, mussels, clams, and several species of crabs.*

Construction

Before construction, *Spartina alterniflora* was collected from 650 m^2 of the wetland. The construction involved the excavation of material to achieve the desired elevation. The total surface area was approximately 7,060 m^2. A weir was installed and allowed an interchange of tidal flow with tidal pools within the "Tongue Point." At high tide, the water level within the site reaches a depth of approximately 0.3 m (Simmers and others 1989). Simmers and others (1989) provide further discussion of wetland construction.

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* Lance L. Stewart, Douglas Moffat, Kurt Buchholz, and Michael Coon. 1983. "Field Work Report," unpublished report, Marine Sciences Institute/Sea Grant Advisory program, University of Connecticut, Groton, CT.

Plants

Spartina alterniflora and *Sporobolus virginicus* were used in laboratory and field bioassays. Laboratory tests indicated that the contaminated sediment was not toxic to the saltmarsh plants *Spartina alterniflora* or *Sporobolus virginicus* (dropseed) when placed in a wetland environment. *Spartina alterniflora* also survived well in the field test. However, *S. virginicus* did not survive in the field (Simmers and others 1989).

One half of the created FVP wetland was planted with *Spartina alterniflora* supplied by Environmental Concern, St. Michaels, Maryland. Initial growth of Environmental Concern's transplants on the FVP field site appeared to be slow up to 1986, but then in 1987, 1988, and 1989, the vegetation on the created wetland gradually expanded until the side planted with Environmental Concern's transplants was covered by a dense stand of *S. alterniflora*. The highest biomass production (798 g/m^2) was observed in 1987. The other half of the wetland was planted with native *S. alterniflora* collected prior to construction of the dredged material created wetland. These transplants were slower to grow in 1986 and 1987, but exceeded Environmental Concern's transplants in 1988 and 1989 (Brandon and others, in preparation).

Contamination of Plants

The 1988 and 1989 plant tissue concentrations are generally no greater than those measured in the naturally occurring *Spartina alterniflora* at "Tongue Point" before wetland creation or those measured in nearby naturally occurring saltmarshes (Table 1). Copper and chromium tissue concentrations are possible exceptions. These metal concentrations tended to be higher than the natural marsh or preconstruction concentrations in 1985, 1986, 1988, and 1989.

Animals

Animal bioassay results from static and tidal simulation tests indicated that tidal simulation procedures are superior to static tests for measuring uptake by organisms in the intertidal wetland habitat (Simmers and others 1989). Comparison of FVP field-collected animal data with laboratory tidal bioassay suggests that tidal simulation bioassay procedures overpredict organic bioaccumulation. No clear pattern between laboratory and field tests emerged for metals (Simmers and others 1989). Native sandworms (*Nereis succinea*) colonized the wetland in 1986. Since 1986, fish, crabs, and snails have been observed in the FVP created wetland. Simmers and others (1989) listed the bird and mammal species observed on this site in August 1984.

Table 1

Tissue Contaminant Contents (μg/g) of *Spartina alterniflora* Grown on Contaminated Estuarine Dredged Material from Black Rock Harbor

Heavy Metal	Natural Marsh*	Field Collected Prior**	1985	1986	1988	1989
	N=20	N=7	N=7	N=7	N=8	N=9
	Concentration, μg/g					
Zn	44.3 (24.8)	22.5 (9.5)	13.5 (5.0)	19.2 (7.1)	21.1 (4.3)	20.3 (8.2)
Cd	0.20 (0.19)	0.17 (0.11)	0.02 (0.05)	<0.003 (0.0)	0.25 (0.05)	0.23 (0.03)
Cu	7.16 (2.16)	3.62 (1.18)	5.65 (1.74)	7.48 (5.55)	16.5 (8.9)	14.0 (13.1)
Ni	2.47 (1.76)	5.64 (2.90)	4.23 (6.13)	0.74 (0.68)	1.1 (0.4)	1.7 (0.9)
Cr	3.41 (1.8)	1.11 (1.70)	10.4 (8.2)	6.17 (5.5)	5.7 (3.4)	6.3 (3.9)
Pb	4.85 (6.5)	2.17 (0.80)	3.45 (4.9)	0.95 (0.9)	3.4 (2.0)	3.8 (3.0)
Hg	0.027 (0.02)	0.003 (0.01)	--	--	0.02 (0.003)	0.02 (0.007)

Notes: N equals the number of samples collected and analyzed. Values given in parentheses are the standard deviations.
* From Simmers and others (1981).
** Samples collected before construction; from Simmers and others (1989).

Contamination of Animals

Snails *Ilyanassa* (=*Nassarius*) *obsoleta* were collected in 1988 and 1989 and have been analyzed for contaminant contents (Table 2). The 1988 and 1989 copper, cadmium, and mercury concentrations are less than the respective concentrations of FVP laboratory control snails. It was noted that *I. obsoleta* typically contained elevated levels of copper possibly due to the high copper concentration in the respiratory pigment haemocyanin. Zinc, nickel, chromium and lead concentrations were not measured in the FVP control animals. Organic analyses will be evaluated in a later report.

Table 2

Tissue Contaminant Contents (μg/g) of Snails *Ilyanassa obsoleta* Exposed to Contaminated Estuarine Dredged Material

Parameter	Control Sand*	1988	1989
	N=1**	N=1	N=2
Zn	NS†	878.18	675.2 (31.9)
Cu	2,913	1,335.68	1,881.7 (574)
Cd	8.6	2.9	3.6 (0.5)
Ni	NS	8.79	13.3 (1.6)
Cr	NS	9.02	29.7 (16.0)
Pb	NS	10.21	16.1 (5.3)
Hg	0.26	0.08	0.1 (0.05)

Notes: N equals the number of samples collected and analyzed. Values given in parentheses are the standard deviations.
* From Table 9, Simmers and others 1989.
** One composite sample.
† No sample.

Summary

In the wetland creation field site, there are developing plant and animal communities. The *Spartina* marsh appears to be gradually expanding and it is likely that *Spartina* will eventually cover the entire site. With the establishment of *Spartina*, the mudflat community has been reduced in size and fewer sediment-related species are now present, a trend that is expected to continue as *Spartina* coverage increases. It is also anticipated that through time the animal and plant components of the ecosystem will become more diverse. The extent of the populations and the species compositions of the ecosystems may require management procedures if unanticipated routes of contaminant mobility develop. Continued evaluation will better define the extent and nature of contaminant mobility at the FVP site. This evaluation should include the contaminant mobility of organics into both plants and animals. The development of the wetland ecosystem at this site will be evaluated through September 1995.

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