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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.

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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

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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.

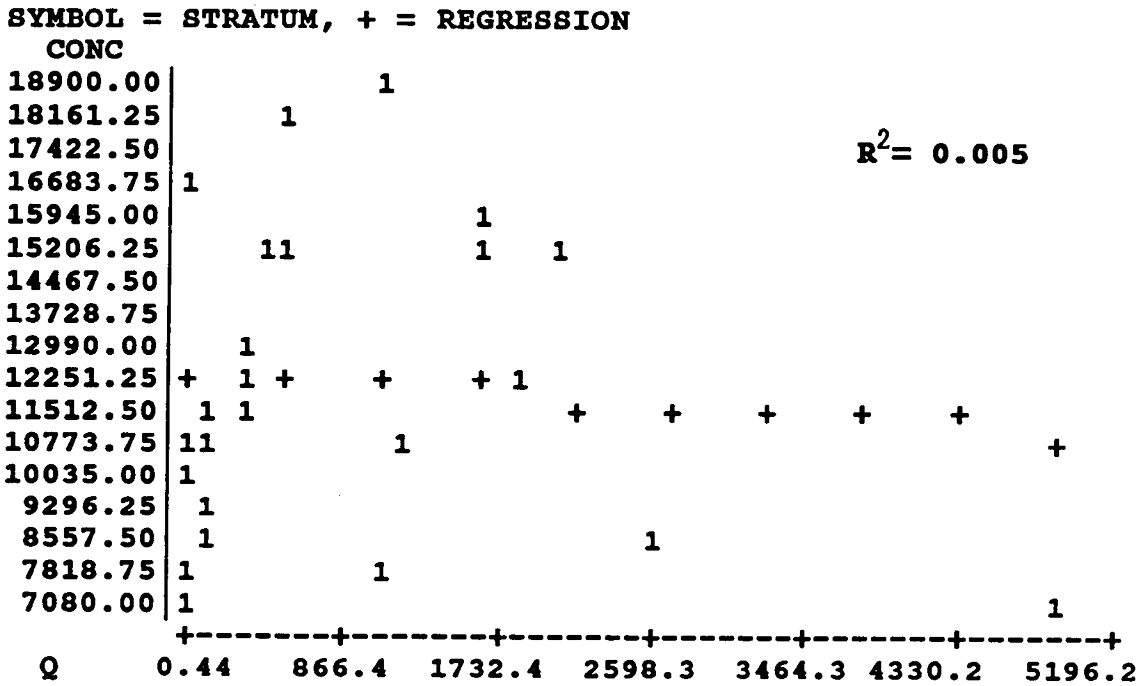

Figure 1. FLUX plot and regression of TOC concentration (in mg/m^3) versus flow (hm^3/year); data are shown by "1's" and the regression line is shown with "+" symbols

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.

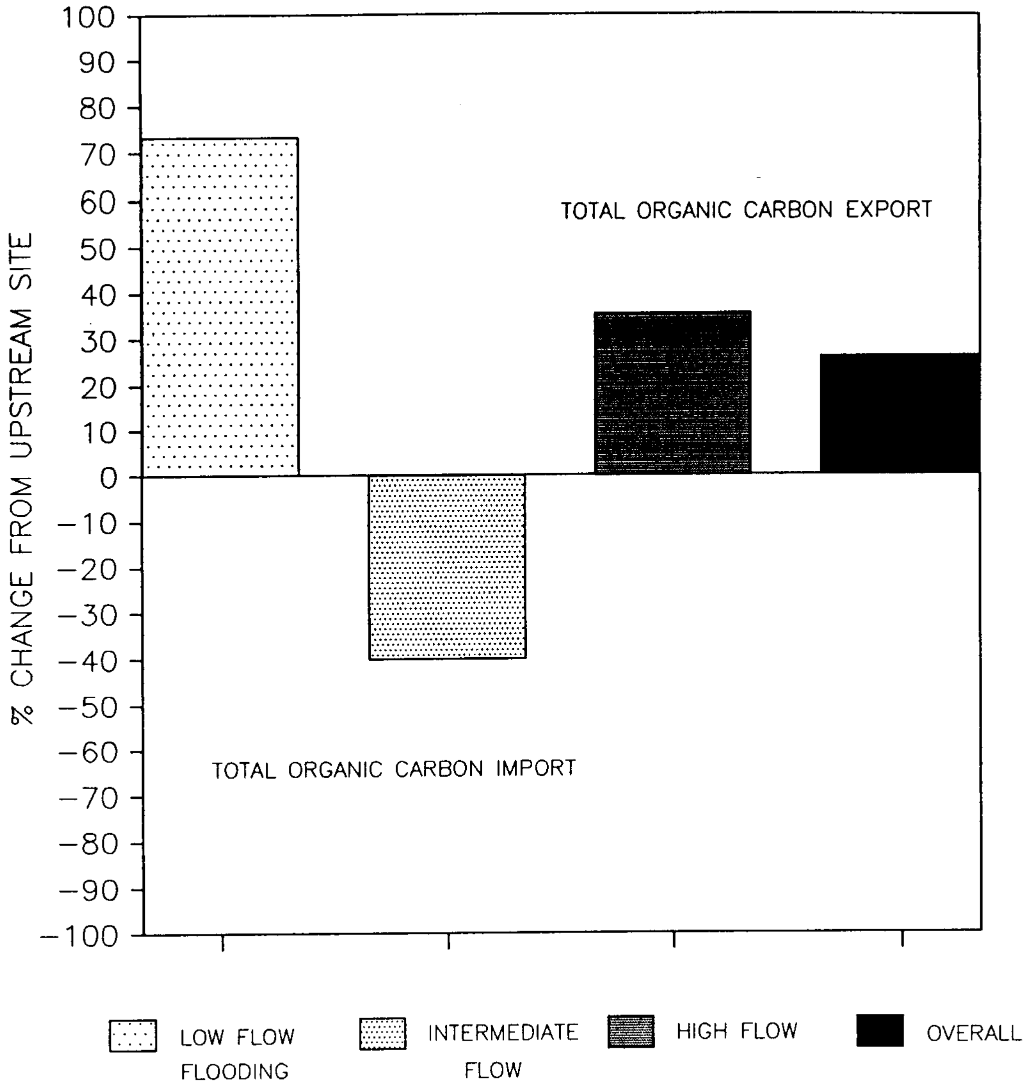

Figure 2. Difference in Cache River TOC loadings between the upstream and downstream stations, expressed as percent change, for three different hydrologic stages during the 1988 water year

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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