DEVELOPMENT OF A WINDOWS-BASED PREDICTIVE MODEL FOR ESTIMATING SEDIMENT RESUSPENSION AND CONTAMINANT RELEASE FROM DREDGING OPERATIONS

Chung-Hwan Je[1], and Kyung-Sub Kim[2]

[1] Research Associate, Dept. of Civil and Envir. Engineering, University of Utah, Salt Lake City, UT 84112

[2] Assistant Professor, Dept. of Envir. Engineering, Hankyong National University

---

Abstract: A windows-based software package, named DREDGE, is developed for estimating sediment resuspension and contaminant release during dredging operations. DREDGE allows user to enter the necessary dredge information, site characteristics, operational data, and contaminant characteristics, then calculates an array of concentration using the given values. The program mainly consists of the near-field models, which are obtained empirically, for estimating sediment resuspension and the far-field models, which are obtained analytically, for suspended sediment transport. A linear equilibrium partitioning approach is applied to estimate particulate and dissolved contaminant concentrations. This software package which requires only a minimal amount of data consists of three components; user input, tabular output, and graphical output. Combining the near-field and far-field models into a user-friendly windows-based computer program can greatly save dredge operator's, planners', and regulators' efforts for estimating sediment transport and contaminant distribution.

Key Words: dredging, near-field, far-field, sediment resuspension, contaminant release

1. Introduction

Each year large amount of sediment are removed from rivers, waterways, ports, and harbors. The processes involved in removing, transporting, storing, and disposing dredged material must be carefully managed to insure that dredging projects are completed in a environmentally safe manner. Bottom sediments disturbed by dredging operations pose several environmental concerns. In addition to water quality impacts associated with a visible turbidity plume, there is also concern that the turbidity plume may inhibit fish migration or reproduction patterns, impair fish gills, or cover fish larvae, eggs, or bottom feeding invertebrates (LaSalle, 1990). These concerns are exacerbated when contaminants are associated with the bottom sediments being dredged (Thomann and Mueller, 1987; Chapra, 1997). Public or regulatory pressures associated with dredging operations and associated sediment resuspension sometimes makes it desirable to estimate suspended sediment and particulate and dissolved contaminant concentrations for a specific dredging operation.

Observed sediment resuspension rates and contaminant concentrations during dredging operations show that concentrations are generally less than historically thought. While these raw data provide valuable general information, it is difficult to extrapolate these data to other dredging sites with different conditions or dredging equipment. This paper describes predictive methodologies for estimating resuspended sediment and contaminant concentrations based upon sediment characteristics and dredging conditions. Because of the unique operating traits of different dredge types, it is not possible for a single model to describe all dredge types. Thus, while the general approach applies to any dredging operation, it requires the development of dredge-type specific relationships(McLellan et al., 1989 ; Hayes et al., 1988 ; USACE, 1990)

Since the advent of the personal computer in the mid-1980's, the use of computer models in design and analysis had become commonplace within the engineering community. Currently, the windows-based simulation tools with graphical user interfaces (GUI) are being developed for various applications in civil and environmental engineering(WMS, 1997). GUI provide the user with interactive visual communication with the tasks on hand and the solution process. In this paper, the DREDGE software which is a windows-based predictive tool with GUI feature is developed for estimating sediment resuspension and contaminant release from dredging operations using the near-field and far-field models.

2. Near-field and Far-field Transport Models

DREDGE calculates water column suspended sediment concentrations resulting from a static, continuous source. The geometry and strength of the source depends upon the operating characteristics of the dredge and the bottom sediments. DREDGE assumes that dredge movement and temporal variations in resuspension are small compared to downstream suspended sediment transport.

2.1 Near-field Models

DREDGE utilizes empirical formulations developed from field studies to estimate the rate of sediment resuspension that results from a dredging operation (near-field source strength). DREDGE allows the user to estimate this value using Nakai's TGU method or dredge specific Correlation Models. Additionally, DREDGE allows user specified source strength values to be entered for any dredge type. Nakai's TGU method can be used for most dredge types. Correlation models are available for cutterhead and bucket dredges.

2.1.1 TGU Method

Nakai (1978) proposed the source strength models as part of the Turbidity Generation Unit (TGU) concept. The fundamental equation for this method is given by

$$m_R = \frac{q_s G}{(R_o / R_{74})} \qquad (1)$$

where m_R is mass rate of sediment resuspension (kg/sec), q_s is volume rate of sediment removal (m^3/sec), G is mass rate of sediment resuspended per volume rate of sediment dredged (turbidity generation unit, kg/m^3), R_o is particle fraction that has a critical resuspension velocity smaller than the ambient current velocity (unitless), R_{74} is particle fraction less than 74 mm (unitless). This approach allows the source strength from any dredge type to be estimated by formulating an equation to calculate the volumetric rate of sediment removal based upon the dredge operation. Nakai (1978) suggests that particles less than 0.005 mm in size (clay-size) have a critical resuspension velocity of 0.03 cm/sec and the critical resuspension velocity of silt size particles (0.005 to 0.074 mm) ranges from 0.03 to 7 cm/sec.

Nakai's approach is also limited by the availability of G values or a method for estimating G based upon sediment characteristics and dredge operating parameters. However, Nakai (1978) presented G values for a variety of equipments and conditions.

2.1.2 Correlation Method

The second group of near-field models are empirical models based upon observed resuspension rates, sediment characteristics, and dredge operating parameters at a series of field sites. Observed concentrations were utilized to formulate these models of sediment resuspension. These "correlation models" utilize variables which can be readily obtained as part of the dredging projects and also calculate the mass rate of sediment resuspension, m_R. Because of the field data required to yield a reasonable empirical correlation, correlation models have been developed only for cutterhead and bucket dredges. These models and their development are described in detail by Hayes, et al. (1995) and Collins (1995).

2.1.3 Sediment Loss

DREDGE also calculates the amount of sediment loss that results from sediment resuspension during the dredging operation.

$$S_{loss} = \frac{100\, m_R}{(q_s/\gamma_{sed})} \tag{2}$$

where S_{loss} is sediment loss rate (%), γ_{sed} is sediment dry density (kg/m^3).

2.2 Far-field Transport Models

It is necessary to translate the near-field source strength into downstream(far-field) concentrations. Transport models for plume geometries characteristic of cutterhead and bucket dredges are used to estimate downstream transport of suspended sediments under steady-state conditions. Considerable simplifications are necessary to solve the fundamental transport equation analytically. While these simplifications limit the applicability of the resulting models, the analytical solutions allow for rapid calculation of suspended sediment concentrations with an accuracy compatible with the near-field strength models.

2.2.1 Cutterhead Dredge Model

DREDGE utilizes a model developed by Kuo, Welch, and Lukens (1985) to estimate the transport of suspended sediment from cutterhead dredges. The model assumes a continuous point source of suspended sediment (located at the point of dredging) transported downstream by a strong directional current. The model calculates the suspended sediment concentration at any position in the water column. The cutterhead dredge model is as follows;

$$TSS_{wc}(x,y,z) = \frac{m_R}{4\pi x\sqrt{k_y k_z}} \exp\left[-\frac{y^2}{4k_y\frac{x}{u}} - \frac{\left(z+\omega\frac{x}{u}\right)^2}{4k_z\frac{x}{u}}\right] \tag{3}$$

where TSS_{wc} is suspended sediment concentration at a specific position in the water column (mg/L), k_y is diffusion coefficient normal to the direction of flow (y-direction, m^2/sec), k_z is vertical diffusion coefficient (z-direction, m^2/sec), u is uniform velocity in the x-direction (m/sec), ω is average particle settling velocity (m/sec), x is downstream distance from the dredgehead (m), y is lateral distance from the dredgehead (m), z is vertical distance from the dredgehead (m). Note that the dredgehead position is at $x=0$, $y=0$, and $z=0$ (bottom). The settling velocity of the suspended sediment particles is calculated using Stokes' Law.

2.2.2 Bucket Dredge Model

DREDGE utilizes a model developed by Kuo and Hayes (1991) to estimate the transport of suspended sediment from bucket dredges. A vertical line source of suspended sediment located at the point of dredging is assumed. Thus, the model calculates the depth averaged suspended sediment concentration at any position in the water column. The bucket dredge model is as follows;

$$TSS_{wc}(x, y) = \frac{m_R}{uh\sqrt{4\pi k_y \frac{x}{u}}} \exp\left(-\frac{y^2}{4k_y \frac{x}{u}} - \frac{\omega x}{uh}\right) \tag{4}$$

where h is predredging water depth (m). Note that the vertical line source which represents the dredge position is at $x=0$ and $y=0$.

2.3 Contaminant Release

DREDGE calculates downstream water column contaminant concentrations based upon the equilibrium partitioning concept. A linear partitioning coefficient is used to convert initial contaminant concentrations on in-situ sediment and downstream suspended sediment concentrations to particulate and dissolved contaminant concentrations.

2.3.1 Partition coefficients for metal contaminants

Thomann and Mueller (1987) suggest that the linear equilibrium partition coefficient for most metal contaminants can be estimated using the following equation

$$K_p = \frac{250,000}{C_{sed}} \tag{5}$$

where C_{sed} is contaminant concentration on the sediment (mg/L). While this equation is useful as a starting point, the strong relationship between metal solubility and pH may be an important factor. Thus, DREDGE includes the empirical relationships between K_p and pH as presented by Tessier et. al. (1994). DREDGE allows the user to enter any desired value to estimate K_p.

2.3.2 Partition coefficients for organic contaminants

A linear equilibrium partitioning coefficient for organic contaminants is proportional to the organic content of the sediment (Karichoff et al., 1979). Thomann and Mueller (1987) present the following equation for K_p based upon the organic fraction (f_{oc}) and the octanol-water partition coefficient (K_{ow}).

$$K_p = \frac{2f_{oc}K_{ow}}{1 + 0.714 f_{oc}K_{ow}TSS_{wc}} \tag{6}$$

Alternatively, we can estimate the organic carbon partition coefficients, K_{oc} (L/g), based upon K_{ow}, then calculate K_p from the following equation

$$K_b = f_{oc} K_{oc} \quad (7)$$

Empirical relationships between K_{oc} and K_{ow} have been developed for some organic contaminants or groups of similar organic contaminants. The K_{oc} values can be found in a variety of references (Hemond and Fechner, 1994; Bierman, 1994).

3. DREDGE Software

The methodology used in DREDGE is described to assess water quality impacts associated with dredging contaminated sediments. In this part, we briefly introduce a windows-based application software. DREDGE is developed exclusively using MS Visual Basic to run in the Windows environment (Language Reference, 1997). The many advantages of windows-based programming are utilized. The standard MS-windows functions and features are also included. Some basic features of DREDGE software are as follows;

1. easy and rapid calculation of risk-based dredge plume concentrations resulting from mechanical (bucket etc.) and hydraulic (cutterhead etc.) dredging operations.
2. extremely easy graphical user interface (GUI) for user data input, spreadsheet out, and graphical output.
3. relational database system with point-and-click interface for contaminant modeling.
4. extensive toxic organic chemical and heavy metal database system plus default K_{ow} values for over 200 chemicals.
5. on-line help system to guide users through the application.
6. spreadsheet and graphical output capabilities.
7. the ability to save all output information in MS Excel (*.xls) file format.

The integrated environment in DREDGE consists of menu options and three main

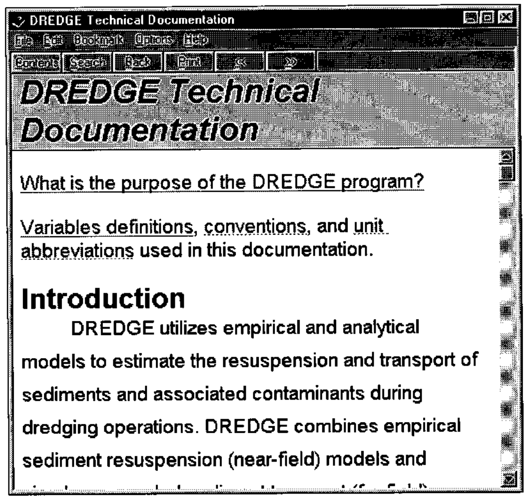

Fig. 1. Online Help Window

windows; **Input Data Entry, Spreadsheet Output**, and **Graphical Output**. Multiple windows for the data entry can be open at the same time. Three main windows can be displayed by selecting **Window** or **View** from the menu options. In addition, user can open or print the existing files and save the edited file by selecting **File** button in the menu options. Menu will always appear as long as the DREDGE is open. Online help system references nearly all aspects of DREDGE (Fig. 1). User can access this system by clicking **Content** command in the **Help** menu. Technical documentation of dredging topics relating to DREDGE is included. The fastest way to find a particular topic in **Help** is to use the Search dialog box. To display the **Search** dialog box, either choose Search from the **Help** menu or click the **Search** button on any **Help** topic screen. Three main windows are briefly described next.

3.1 Input Data Entry

Data can be entered or edited in the **Input Data Entry** window (Fig. 2). To enter data required in the **Input Data Entry** window,

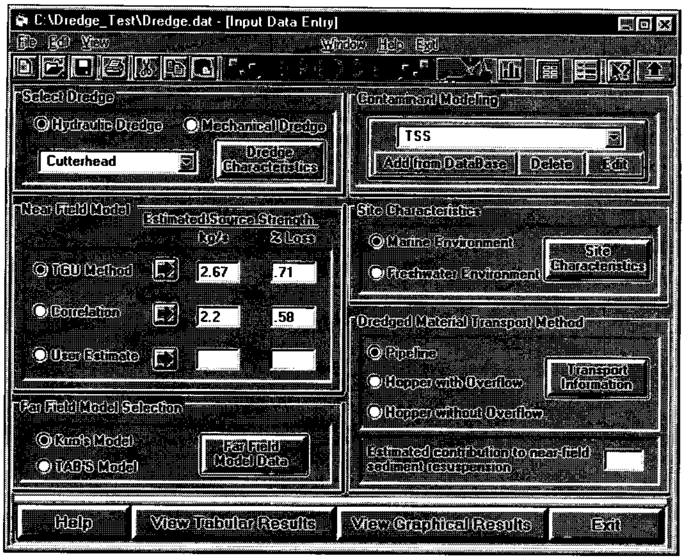

Fig. 2. Input Data Entry Window

click the push buttons for the each category such as dredge characteristics, far-field model data, site characteristics, TGU and correlation methods for the near-field source strength models. After completing the data input, user may click either the button of **View Tabular Results** to see the calculation results based on the options user selected or the button of **View Graphical Results** to view the resulting graph such as TSS concentration contour.

3.2 Spreadsheet Output

Mathematical models developed in DREDGE are used to calculate sediment concentration distribution and the running results interpreted by the program user are produced. In case of

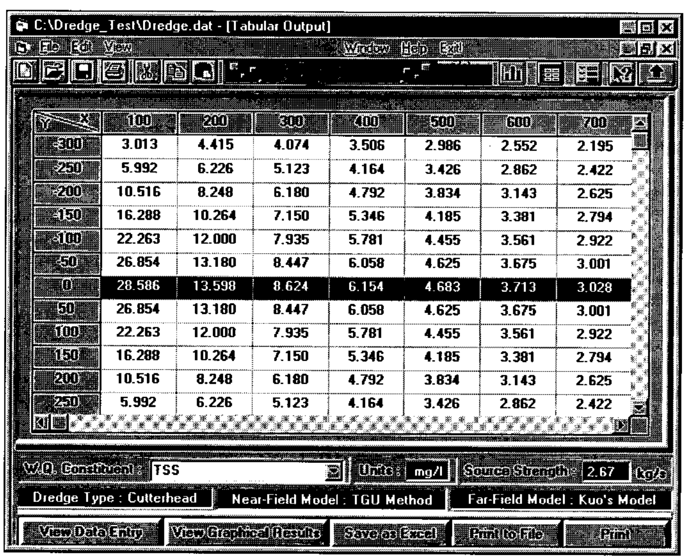

Fig. 3. Spreadsheet Output Window

many engineering computer models, the output is generally provided in text form, as a series of numbers such as the concentration of pollutant at various locations. DREDGE can reproduce the output into spreadsheet control and the calculation results are shown in the **Spreadsheet Output** window (Fig. 3). **Spreadsheet Output** window shows all calculation options and contaminants user selected in the **Input Data Entry** window. To create a MS excel file from the calculation results, first select the button of **Save as Excel** at the bottom of **Spreadsheet Output** window. Furthermore, it allows user to print the resulting output to the printer. To do this, click the **Print** button at the bottom of **Spreadsheet Output** window.

3.3 Graphical Output

DREDGE can translate numerical output into a series of graphic images such as contour or X-Y graph to improve the analysis capability of the running results (Fig. 4 and 5). The shown images which are represented in a

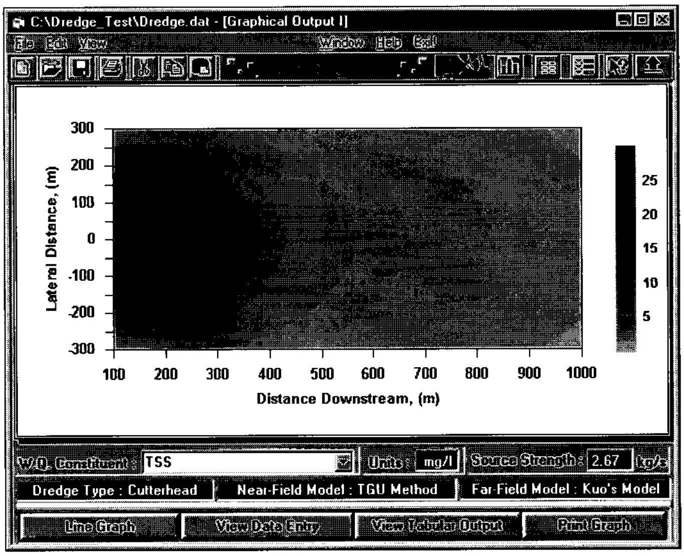

Fig. 4. Graphical Output Window (Contour graph)

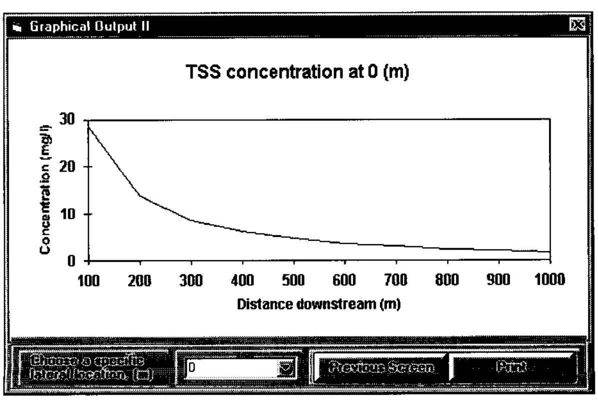

Fig. 5. Graphical Output Window (X-Y graph)

graphical form can be easily interpreted and intuitively analyzed. All of the graphs are automatically sized and positioned to fit on the print page. Follow the steps listed below to create a graph in DREDGE.

1. enter or modify the required input data into the pop-up windows on the **Input Data Entry** window.
2. click the button of **View Graphical Results** at the bottom of the **Input Data Entry** window.
3. the 2-D contour graph window will appear, and then click on the button of **Line Graph** to see the resulting concentration distributions at specified locations.
4. click the combo box for water quality constituents and select one of contaminants user selected from the contaminant modeling database.
5. the selected component graph will be displayed immediately.

3.4 DREDGE Limitations

There are a number of limitations associated with the models used in DREDGE. The sediment resuspension models are only applicable to dredging operations similar to those used in the development of the empirical equations. The models generally produce reasonable estimates for normal operating characteristics, but unusual operating parameters may yield unreasonable results. The far-field transport models applied assume a dominant, uni-directional current that exists sufficiently long for suspended sediment concentrations to reach steady-state. They also assume a steady source from a specific location (identified in the models as $x=0$, $y=0$, $z=0$). DREDGE uses a linear equilibrium partitioning approach. The partitioning of contaminants associated with colloidal particles involves a number of very complex physical and chemical processes.

3.5 Hardware Requirement

DREDGE is written for the Microsoft Windows 95/NT operating system and requires 2 MB of disk space and 8 MB of RAM.

The software is not only easy to use but also helps end-users predict suspended sediment and contaminant concentration distributions through the water column during dredging operations as well. In order to increase the robustness, a lot of pop-up forms with on-line HELP system are included in this software.

4. Conclusions

The process of estimating water column suspended solids and contaminant concentrations is straightforward, but requires a number of calculations. A computer program, currently named DREDGE, has been written to implement these calculations. This software is written in Visual basic 5.0. A windows-based graphical user interface to provide reasonable estimate of resuspended sediment and contaminant concentrations under a variety of conditions for use in planning-level analysis of dredging operations is developed. The standard Windows function and formats are also provided. The program includes on-line help with the ability to cross-reference information and allows user to enter the necessary dredge information, site characteristics, operational data, and contaminant characteristics. Then this calculates an array of concentration values.

DREDGE utilizes simplistic methods in the far-field models. More accurate models exist and have been applied successfully. However, more complex models require substantial field information and usually site-specific calibration based upon field observations. However, environmental dredging operations are usually one time efforts; thus, it may be impossible to gather the necessary calibration data. DREDGE can be applied for projects where a priori estimates of suspended sediment and contaminant concentrations are desired. A windows-based DREDGE software becomes a valuable tool for predicting sediment resuspension and contaminant release, and transport during dredging operations.

This software is developed to assist engineers, planners, and dredging operations managers in planning, designing, and managing dredging activities. The program is freely available to the interested people without any charge. You can download DREDGE model from the following web address; http://www.wes.army.mil/el/elmodels/index.html.

Acknowledgements

This paper was supported by a part of ADDAMS Project associtated with dredging studies. The authors greatfully appreciate the financial support from the U.S. Army Corps of Engineers (USACE).

References

Bierman, V.J., Jr. (1994). "Partitioning of Organic Chemicals in Sediments: Estimation of Interstitial Concentrations Using Organism Body Burdens." *Transport and Transformation of Contaminants Near the Sediment-Water Interface*, Joseph V. DePinto, Wilbert Lick, and John F. Paul, Editors, Lewis Publishers, Boca Raton, Florida.

Chapra, S.C. (1997). *Surface water-quality modeling*. McGraw-Hill, New York, NY.

Collins, M.A. (1995). "Dredging Induced Near Field Resuspended Sediment Concentrations and Source Strengths." *Miscellaneous Paper D-95-2*, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Hayes, D.F., Crockett, T.R., and Ward, T.J. (1995). "Estimating Near Field Sediment Resuspension for Cutterhead Dredges." draft Contract Report, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Hayes, D., McLellan, T., and Truitt, C. (1988). "Demonstrations of Innovative and Conventional Dredging Equipment at Calumet Harbor, Illinois." *Miscellaneous Paper EL-88-1*, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Hemond, H.F. and Fechner, E.J. (1994). *Chemical Fate and Transport in the Environment*, Academic Press.

Karichoff, S.W., Brown, D.S., and Scott, T. A. (1979). "Sorption of Hydrophobic Pollutants in Sediment Suspensions." *Water Res.*, Vol. 13, No. 3, pp. 241-248.

Kuo, A.Y., Welch, C.S., and Lukens, R.J. (1985). "Dredge Induced Turbidity Plume Model." *Journal of Waterways, Port, Coastal, and Ocean Engineering*, ASCE, Vol. 111, No. 3, pp. 476-494.

Kuo, A.Y. and Hayes, D.F. (1991). "A Model for Turbidity Plume Induced by Bucket Dredge." *Journal of Waterways, Port, Coastal, and Ocean Engineering*, ASCE, Vol. 117, No. 6, pp. 610-623.

Language Reference (1997), *Microsoft Visual Basic: Version 5.0.* Microsoft Corporation.

LaSalle, M.W. (1990). "Physical and Chemical Alterations Associated with Dredging: An Overview." *Effects of Dredging on Anadromous Pacific Coast Fishes*, Charles A. Simenstad, Editor, Washington Sea Grant Program, Seattle, WA.

McLellan, T., Havis, R., Hayes, D., and Raymond, G. (1989). "Field Studies of Sediment Resuspension Characteristics of Selected Dredges." *Technical Report HL-89-9*, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Nakai, O. (1978). "Turbidity Generated by Dredging Projects." *Proceedings of the 3rd U.S./Japan Experts Meeting*, US Army Engineer Water Resources Support Center, Ft. Belvoir, VA.

Tessier, A., Carignan, R., and Belzile, N. (1994). "Reaction of Trace Elements Near the Sediment-Water Interface in Lakes." *Transport and Transformation of Contaminants Near the Sediment-Water Interface*, Eds. by Joseph V. DePinto, Wilbert Lick, and John F. Paul, Lewis Publishers, Boca Paton, Florida.

Thomann, R.V., and Mueller, J.A. (1987). *Principles of surface water quality modeling and control.* Harper and Row, New York, NY.

U.S. Army Corps of Engineers, New England Division (1990). "New Bedford Harbor Superfund Pilot Study: Evaluation of Dredging and Dredged Material Disposal." US Army Engineer Division, New England, Boston, MA.

Watershed Modeling System Reference Manual (1997), Engineering Computer Graphics Laboratory, Brigham Young University.

Chung-Hwan Je, Research Associate, Dept. of Civil and Envir. Engineering, University of Utah, Salt Lake City, UT 84112
(e-mail: chung.je@m.cc.utah.edu)

Kyung-Sub Kim, Assistant Professor, Dept. of Envir. Engineering, Hankyong National University
(e-mail: kskim@hnu.hankyong.ac.kr)

(Received September 7, 1999; accepted March 23, 2000.)