Environmental Effects of Dredging
Technical Notes

Documentation of the EFQUAL Module for ADDAMS: Comparison of Predicted Effluent Water Quality with Standards

Purpose

This technical note describes a technique for comparison of the predicted quality of effluent discharged from confined dredged material disposal areas with applicable water quality standards. This note also serves as documentation of a computer program called EFQUAL written for that purpose as part of the Automated Dredging and Disposal Alternatives Management System (ADDAMS).

Background

The quality of water discharged from confined dredged material disposal areas during filling operations (effluent) is a major environmental concern associated with such disposal. Techniques for predicting effluent quality are presented in Technical Notes EEDP-04-1 through EEDP-04-4 (Palermo 1985). These notes describe the use of modified elutriate tests and column settling tests to predict the quality of the effluent discharged. Guidance for calculating the size of mixing zones is found in Technical Note EEDP-04-5 (MacIntyre 1987). Before calculations of the size of the mixing zone are made, the required dilution of each contaminant of concern to meet its respective water quality standard must be determined. This technical note presents a technique for comparing contaminant concentrations in the elutriate with water quality standards and documents a computer program which calculates the required dilutions considering all pertinent factors.

Guidelines have been published to reflect the 1977 Amendments of Section 404 of the Clean Water Act (US Environmental Protection Agency (EPA) 1980). Proposed testing requirements define dredged material according to four categories. Category 3 includes potentially contaminated material proposed for confined disposal that has "potential for contamination of the receiving water column only." The proposed

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testing requirements call for evaluation of short-term water column impacts of disposal area effluents. Under Section 401 of the Clean Water Act, a water quality certification is required from the state in which the discharge occurs. The certification may include water quality standards for contaminants of concern and should specify the geometric limits of a mixing zone for initial dilution in the vicinity of the discharge where receiving water quality standards may be exceeded.

Additional Information

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EFQUAL Application of ADDAMS

Requirements

The quality of water discharged from confined dredged material disposal areas during filling operations (effluent) is a major environmental concern associated with such disposal. Modified elutriate tests and column settling tests are used to predict the quality of the effluent discharged. The predicted concentrations can be used with appropriate water quality standards to determine the mixing zone required to dilute the effluent to an acceptable level. Before calculations of the size of the mixing zone are made, the required dilution of each contaminant of concern to meet its respective water quality standard must be determined.

Comparison of the predicted effluent concentration with the water quality standard and, if necessary, calculation of the dilution required to meet the water quality standard must be determined for each contaminant of concern. For some projects, the number of contaminants of concern can easily exceed a hundred. The predicted effluent concentration, the water quality standard, and the background concentration of the contaminant in the receiving water all influence the dilution required. Further complicating the process is the fact that any of these three concentrations may exceed the others and that some of the concentrations may be below the detection limit of the chemical analysis used to predict the effluent concentration. The computational effort and data management effort required for such an evaluation can be substantial. Therefore, a computer program has been developed to efficiently perform the required calculations and present the data in a manner which can be easily interpreted.

EFQUAL Capabilities

The computer program for effluent quality described in this note has been developed as a module of the Automated Dredging and Disposal Alternatives Management System (ADDAMS) and can be run on a personal computer (PC). The module is entitled EFQUAL.

ADDAMS is an interactive computer-based design and analysis system for dredged material management. The general goal of the ADDAMS is to provide state-of-the-art computer-based tools that will increase the accuracy, reliability, and cost-effectiveness of dredged material management activities in a timely manner. The ADDAMS is described in more detail in Technical Note EEDP-06-12 (Schroeder and Palermo 1990).

EFQUAL has the following capabilities:

● Compute predicted dissolved and total contaminant concentrations in the effluent from a confined disposal site using modified elutriate test data.

● Compare predicted effluent concentrations with specified water quality standards.

● Compute required dilutions of effluent to meet specified water quality standards, considering background concentrations in the receiving water.

Using the EFQUAL Module

The EFQUAL module of ADDAMS uses a menu-driven environment with a full-screen data-entry method. The initial menu contains options for entering/editing input data, selecting existing data files or performing file management operations, selecting/entering/editing water quality criteria, performing calculations, printing output, and exiting the EFQUAL module. In general, single keystrokes are required to select menu options displayed on the screen. Cursor keys are used to select between highlighted input fields much like a spreadsheet program. Results from computations are generally displayed in tabular format on the screen, saved in ASCII files, or sent to a printer. Detailed assistance is available on-line by pressing the F2 key for help.

Input/Output

The main data requirements for the EFQUAL module include modified elutriate test conditions and results, background receiving water concentrations, and water quality standards for contaminants of concern. Other data describing the samples and parameters used in the modified elutriate tests can also be entered for documentation purposes. The final output of the module consists of tabular summaries of modified elutriate data, predicted effluent quality concentrations, and water quality standards; absolute and statistical comparisons of predicted effluent water quality with standards; and computed dilutions required to meet the standards. Table 1 lists the necessary input parameters with their corresponding units. Instructions for data entry and additional descriptive information for some parameters are provided directly on the EFQUAL input screens or are available from the on-line user guide.

Table 1 EFQUAL Input Parameters	
Parameter	**Units**

For each evaluation:
   Descriptive title
   Number of modified elutriate replicates	

For each modified elutriate replicate:
   Slurry concentration (optional)
   Retention time (optional)
   Total suspended solids (TSS) concentration
	
	 g/L
	 hr
	 mg/L

For each contaminant of concern:
   Detection limit
   Test sediment concentration (optional)
   Test water concentration (optional)
   Background water concentration
   Water quality standard
	
	 µg/L
	 mg/kg
	 µg/L
	 µg/L
	 µg/L

For each contaminant of concern and each modified elutriate replicate:
   Modified elutriate dissolved concentration
   Modified elutriate total concentration (required only if total
    concentrations used for comparison to standards)
	
	 µg/L
	 µg/L

For each evaluation:
   Estimated effluent TSS concentration (required if total concentrations
    used for comparisons to standards)
   Percentage increment above background and dilution calculations
    (used when standards are below or very close to background)
	
	 mg/L
	
	 percent

Considerations in Comparing Predictions with Criteria

Contaminants of Concern and Water Quality Standards

Before entering water quality standards or elutriate test data, the user must build a list of all contaminants of concern. The list must contain the names of all contaminants measured in the modified elutriate tests or listed in any water quality criteria set of interest, such as the EPA acute toxicity water quality criteria, the Federal drinking water standards, or state water quality standards. The EFQUAL module comes with a list of contaminants for the Federal acute toxicity water quality criteria. To update the list, the user should select the water quality criteria set option of the EFQUAL module and then choose the criteria set of interest or build a new criteria set (up to a maximum of 12 sets). The program will display the current list of contaminants and provide instructions for adding or deleting contaminants from the list.

When building or editing the list of contaminants, the user should also enter the value of the water quality standard for all contaminants having that data available. Entry of the standard is made on the same screen in a column adjacent to the entry of the contaminant name. Many of the contaminants initially listed on the screen may not have standards for the selected criteria set but may have values in other criteria sets. A criterion value equal to or less than zero will be treated as a missing value. Contaminants having missing values in the selected set should not be deleted from the list since the contaminant may be used for other criteria sets.

EFQUAL allows comparisons to be made using any of the several sets of criteria or standards which are stored in a file of criteria sets. The EPA acute water quality criteria for protection of freshwater or saltwater aquatic life are initially available as choices. It should be noted that chronic criteria are technically inappropriate because water column effects are considered short-term. As noted earlier, EFQUAL allows the user to build additional sets of water quality standards (for example, state standards specified under Section 401 water quality certifications), which can then be permanently stored in the table of standards for use in future evaluations. The water quality standards may be left blank if a standard does not exist for a particular contaminant. If no water quality standard for a given contaminant is specified in the set of standards selected for comparison, EFQUAL displays N/A blanks for the standard and comparison results.

Modified Elutriate Test Description

Modified elutriate test results and related information are the majority of data that must be entered. When new data are entered, a text description of the samples used for the tests can be entered for documentation purposes.

The modified elutriate procedure calls for the test to be performed with a minimum of three replicates. Up to nine replicates can be entered in EFQUAL. Separate sets of replicates of the modified elutriate test may be analyzed for classes of contaminants, for example, metals or organics. Therefore, the definition of a replicate for purposes of EFQUAL is any separate sample analyzed for chemical concentrations and for which a separate total suspended solids (TSS) determination is made. The slurry concentration used in the test, the retention time prior to sample extraction, and the TSS concentrations for each replicate are then specified.

Test Data

EFQUAL displays a table of the contaminants of concern for purposes of entering the modified elutriate and other data for specific contaminants. The test data can be entered for any contaminant listed on the displayed table of contaminants by a menu selection. EFQUAL marks those contaminants with an asterisk on the displayed table for which data has been entered. All data previously entered for a contaminant can be deleted by pressing the delete key after highlighting the contaminant.

Once a specific contaminant has been selected for data entry, EFQUAL presents an input screen for that contaminant. Data from the modified elutriate test procedure (see Technical Note EEDP-04-2) includes dissolved concentrations of contaminants,

total concentrations of contaminants, and the TSS concentration. This allows a contaminant fraction of the TSS to be calculated so that a prediction of the total concentration of contaminants in the effluent can be determined for any effluent TSS loading (see Technical Note EEDP-04-3). The EFQUAL module automatically performs the needed data reduction and displays the results.

The test sediment concentrations and test water concentration for the contaminant may be entered for documentation purposes, but these parameters are not used in any calculations. The detection limit, the background water concentrations, and the dissolved and total modified elutriate concentrations for the contaminant are required for the computations. EFQUAL displays the TSS concentration for all replicates to aid in replicate identification for each contaminant of concern. Care should be exercised in assigning the contaminant concentrations to the correct replicate when entering the data, since this will directly affect computations of total contaminant concentrations.

Once the dissolved and total concentrations for a replicate are entered, the EFQUAL program calculates and displays a value for the contaminant fraction of the TSS. If the contaminant concentration for a replicate as determined by the test is below detection, a zero may be used for ease of data entry; however, the value of the detection limit with a less than (<) sign is displayed by the program. If the entered value of the dissolved concentration for any replicate exceeds that for the total concentration (a possibility considering variability and low concentrations), a value of zero is displayed for that contaminant fraction. After any replicate data is entered or edited, the program calculates and displays values of the mean and standard deviation for the dissolved and contaminant fractions data. No statistics are displayed for the modified elutriate total concentrations, because their mean has little value since the suspended solids concentration may vary among the replicates.

Detection Limits

The detection limit entered for each contaminant of concern plays a potentially important role in later computation of dilutions. The value entered should be the detection limit for chemical analysis of the modified elutriate samples. If elutriate concentrations of all replicates analyzed are below detection, the mean is assumed to be zero, and zero is used in subsequent computations. If one or more of the replicates is above the detection limit, the detection limit is assumed for any replicates with values below detection in computing the mean. This approach is conservative in that the predicted effluent concentrations will be higher than if zero were assumed for replicates below detection.

Background Concentrations

The value of background concentration for each contaminant is used for later computation of dilutions. This value must be determined by a separate chemical analysis of the receiving water. In some cases, the receiving water and the test water used in the modified elutriate test (water from the dredging area) are the same. If the background water or test water concentrations are below detection, a value equal to the detection limit is used in the computations of required dilution. This

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assumption is conservative in that the required dilution will be greater than if zero were assumed for the background concentration.

Predicted Effluent Concentrations

The EFQUAL module computes both predicted dissolved and total effluent discharge concentrations. The predicted dissolved concentrations are equal to the mean of the modified elutriate dissolved concentrations. If the total effluent concentrations will be used in the evaluation, a value of the anticipated effluent discharge TSS concentration must be given to compute the total concentrations. Column settling test results (see Technical Note EEDP 04-2) should be used to determine the effluent TSS concentration. The total contaminant concentrations are computed using the dissolved modified elutriate test concentrations, the computed contaminant fractions in the TSS, and the specified effluent TSS concentration (see Technical Note EEDP-04-3). Either the dissolved or total effluent discharge concentrations can be used for comparison with specified water quality standards and in computing required dilutions to meet standards.

Evaluation of Results

Comparison of Effluent Discharge with Standards

The output from the EFQUAL module of most interest is the comparison of predicted effluent discharge concentrations with specified water quality standards. The user has an option to choose either the dissolved or total effluent discharge concentrations and one of several sets of standards for the comparison. Any water quality standards imposed as part of a Section 401 water quality certification should be based on potential for environmental impact. The standards are usually set in terms of dissolved concentrations, but could be set in terms of total concentrations. Care should be exercised in selecting the appropriate predicted effluent discharge concentration (dissolved or total) for comparison to the standards. For example, if the standards are equivalent to or are based on the EPA acute water quality criteria, comparison of dissolved effluent discharge concentrations is technically appropriate. This is because the EPA criteria were developed using effects data for exposure of organisms to dissolved concentrations of contaminants.

Whenever the predicted effluent concentration and a standard can possibly be compared and data for multiple replicates are available, the mean of the replicate data and the standard are statistically compared considering the variance of the replicate data. The statistical test performed is a two-tailed Student's t-test (Miller and Freund 1985). The test consists of efforts to reject the null hypothesis, that is, that the two values are equal. The test does not produce a proof, but produces various confidence levels that the result is correct. The confidence level in percent that the predicted concentrations exceeds the standard (P > S _ %) or that the standard exceeds the predicted concentration (S > P _ %) is computed for each parameter. If the confidence level is less than 50 percent, then the test results indicate that the two values are essentially equal (that is, the null hypothesis cannot be rejected). Expressed another way, the confidence level of asserting that the two values are not equal is less that 50 percent (P ≠ S < 50 percent).

Calculation of Dilution Factor

If the predicted effluent discharge concentration exceeds the standard and the standard exceeds the background concentration, a value for dilution to meet the standard is calculated. However, if both the effluent and background concentrations exceed the standard, neither the standard nor the background concentration can be met by dilution. For this case, the user specifies a percentage above the background concentration for which a dilution will be calculated (110 percent of the background or 10 percent above background is recommended for this value). Similarly, if the background concentration is less than but very close to the standard, very large dilution would be required for effluents to meet the standard. Consequently, dilution to the percentage above the background is also computed for this condition. If the background concentration is below detection, the detection limit is used for the background concentration. Use of the detection limit for background under this condition is conservative and will result in the largest dilution that could be required for the given standard and effluent concentration.

The EFQUAL module computes dilution factors for each contaminant of concern using the following equation whenever the effluent concentration is greater than the standard to be met:

$$D = \frac{P - S}{S - B} \tag{1}$$

where
- D = dilution factor required to dilute the contaminant of concern to the appropriate water quality standard, S, volume, of background water/volume of effluent
- P = concentration of the contaminant of concern in the effluent discharge, µg/L
- S = receiving water quality standard for the contaminant of concern, µg/L (or a concentration equal to the specified percentage above background concentration)
- B = background concentration of the contaminant of concern in the receiving water, µg/L

Three concentration variables are used in the above equation. When the detection limit and a specified percentage above background are considered, there are five concentrations that can possibly be used in the comparison. Sixty different conditions are possible, considering every possible combination of the relative magnitude of the five concentrations. However, many of the conditions result in the same conclusion with respect to the interpretation of the comparison and dilution factor required, leaving only eight meaningful cases. These eight cases are illustrated in Figure 1. Additional discussion of each of the eight cases is given

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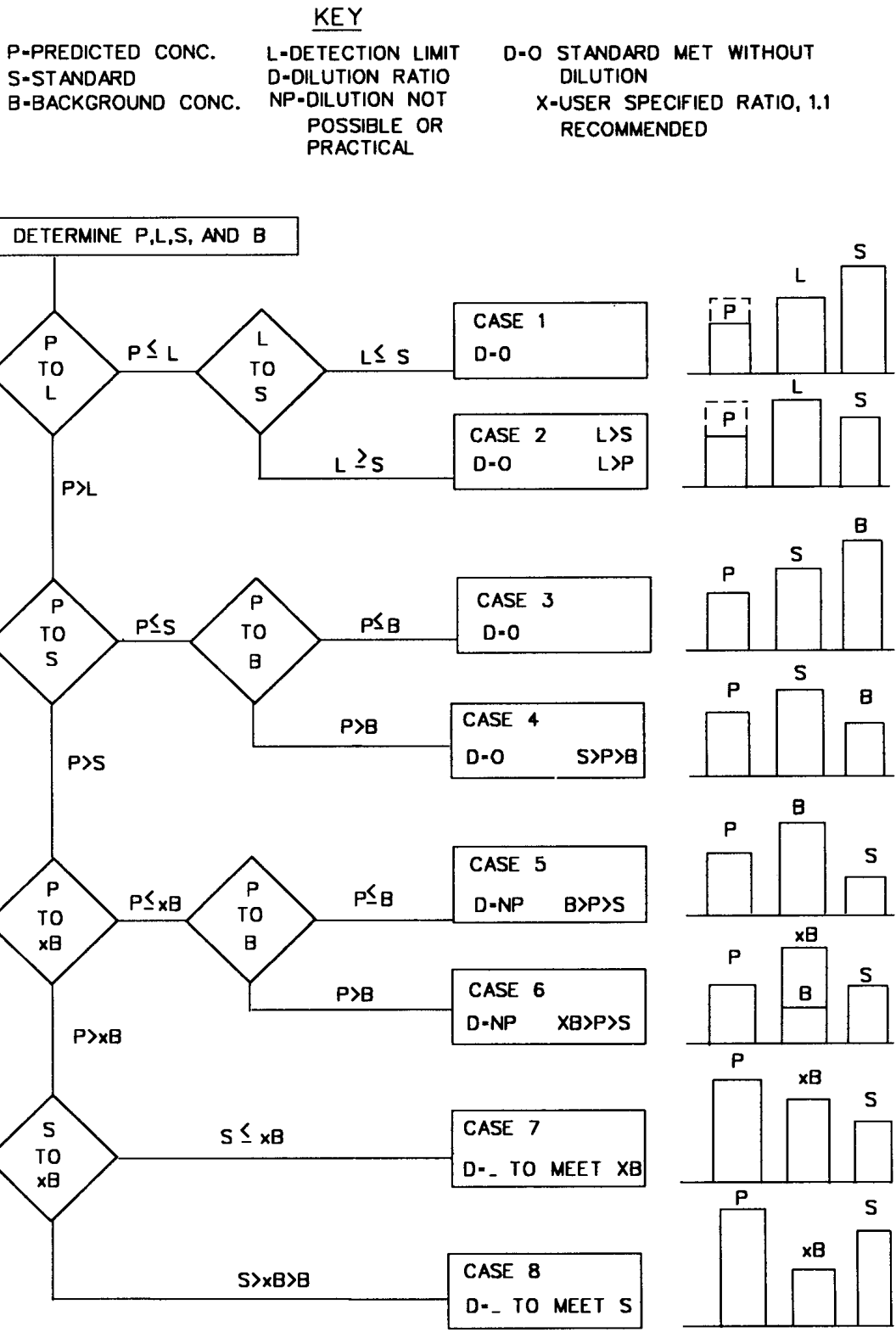
Figure 1.   Possible conditions for comparison of effluent concentrations with standards

below. In addition to the symbols D, P, S, and B defined above, the following symbols are used in the descriptions of the cases:

xB = concentration equal to a multiple, x, of the background, equivalent to S in Equation 1 when S < = xB
L = detection limit for tests, used in B in Equation 1 if L > B

Case 1: S > L > P. For this case, the predicted concentration is less than the detection limit and the detection limit is less that the standard. The standard is met with no dilution, and the EFQUAL program displays the comment "D = 0" for the dilution required.

Case 2: L > (S,P). The predicted concentration and standard are both less than the detection limit. The test results do not clearly indicate that the standard is met since the exact concentration of the effluent is unknown, so the EFQUAL program displays the comment "D = 0, L > (S,P)" for the dilution required.

Case 3: (S,B) > P > L. All concentrations are greater than the detection limit, and the predicted concentration is less than the standard and the background. Under these conditions the effluent discharge is cleaner than the background receiving water for the contaminant of concern. The standard is met with no dilution, and the EFQUAL program displays the comment "D = 0" for the dilution required.

Case 4: S > P > (B,L). The predicted concentration and standard are greater than the detection limit; the predicted concentration is less than the standard; but the predicted concentration is greater than the background. The standard is met with no dilution, and the EFQUAL program displays the comment "D = 0 S > P > B" for the dilution required. This indicates that an acceptable deterioration of the background receiving water occurred.

Case 5: B > P > (S,L). The predicted concentration and background are greater than the detection limit and the standard, but the predicted concentration is less than background. Under these conditions, the standard is less than the background, and the receiving water is already in violation of the standard. Since the predicted concentration is less than the background, the receiving water will be improved for the contaminant of concern. No dilution is possible, and the EFQUAL program displays the comment "D = NP B > P > S" for dilution required.

Case 6: xB > P > (B,S,L). The predicted concentration exceeds the detection limit, the standard, and the background, but the predicted concentration is less than the specified percentage above background. Under these conditions, the predicted concentration is only slightly above the background; therefore dilution is not practical. In addition, the receiving water is already or nearly in violation of the standard. Since the predicted concentration exceeds the background, some degradation of the receiving water will occur. No dilution is practical, and the EFQUAL program displays the comment "D = NP xB > P > S" for dilution required. If B is less than L, L is used in place of B to compute xB.

Case 7: P > xB > (S,L). The predicted concentration exceeds the detection limit, the standard, and the specified percentage above background, and the specified percentage above background exceeds the standard. Under these conditions, the receiving water is already or nearly in violation of the standard. Since the predicted concentration also exceeds the background, degradation of the receiving water will occur. Dilution to meet the specified percentage above background is calculated, since the background exceeds or is very close to the standard. The EFQUAL program displays the comment "D = __ to meet xB," entering the calculated value for dilution. If B <= L, L is used in place of B to compute xB, xB is used as S in Equation 1, and L is used as B in Equation 1.

Case 8: P > S > (xB,L). The predicted concentration exceeds the detection limit, the standard and the specified percentage above background, and the standard exceeds both the background and the specified percentage above background. The dilution to meet the specified standard is calculated, and EFQUAL enters the comment "D = __ to meet S," entering the calculated value for dilution. If B is less than L, L is used in place of B in Equation 1.

Summary

These procedures provide a consistent, rational, and conservative approach to compare predicted effluent water quality with water quality standards. In addition, the approach computes dilution requirements which are needed to evaluate mixing zones.

References

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