Screening-Level Techniques for Estimating Pollutant Removal by Wetlands

PURPOSE: This technical note gives a basic overview of screening-level techniques for estimating the amount of pollutant removal by wetlands. Such estimates are useful for evaluating water quality functions of existing wetlands or for designing constructed wetlands for pollution abatement (see WRP Technical Note WQ-SW-3.1).

BACKGROUND: Since water quality improvement is potentially an important function of wetlands, quantitative techniques are needed to assess this function. WRP Technical Note WQ-EV-2.1 should be used in conjunction with this technical note since it provides background information on the use of a screening-level approach for estimating the amount of water quality improvement provided by wetlands. A technical report by Dortch and Gerald (1995) provides the detailed model formulations and guidelines for computer program implementation.

A screening-level assessment refers to the use of simplified quantitative methods that minimize time and effort for implementation. Simplification is achieved by making assumptions that reduce complexity of the mathematical formulations and input data requirements. These techniques have been programmed into an interactive, user-friendly, PC-based computer program.

APPROACH: The objective is to estimate removal efficiency (*RE*) for a specific pollutant given a limited amount of basic information about the wetland. *RE* (percent) is defined as

$$RE = 100 \times \frac{W_L - QC}{W_L} \quad (1)$$

where

W_L = total loading of pollutant entering the wetland (that is, $\Sigma Q_i C_i$)
Q_i = water flow rate entering the wetland at point i
C_i = pollutant concentration of flow entering at point i
Q = total water flow rate exiting the wetland
C = pollutant concentration of flow exiting the wetland

Thus, RE = 100 percent denotes total removal of a pollutant. Equation 1 is applicable to both point and nonpoint source loadings since $W_L = \Sigma Q_i C_i$. That is, the total load (mass/time) entering can be considered. If the outflow from the wetland occurs at more than one location, then QC would also be summed for all outflow points since RE should be a measure of the total mass flux removed by the wetland.

The primary assumption made with this model to achieve simplicity is that the wetland is at steady state (that is, flow and concentrations are constant in time). With this assumption, the analysis is most valid for determining long-term, average values of *RE*. Mean annual input conditions (for example, flows, depth, etc.) are consistent with this assumption.

Either of two conditions is assumed for spatial gradients in concentration: 1) fully mixed (that is, no gradients) or 2) gradients along the main flow axis (longitudinal gradients, but well mixed laterally and vertically). The mass balance equation for the first spatial assumption is stated as

$$\frac{d(VC)}{dt} = W_L - QC - KVC \tag{2}$$

where

V = volume of the wetland
C = pollutant concentration in the wetland and flowing out of the wetland for the fully mixed assumption
t = time
K = bulk loss or removal rate of the pollutant due to physical, chemical, or biological processes

For the steady-state assumption, Equation 2 reduces to

$$QC = \frac{W_L}{1 + K\tau} \tag{3}$$

where τ is the hydraulic residence time, V/Q. Rearranging Equation 3 and substituting Equation 1 results in

$$RE = \left(\frac{K\tau}{1 + K\tau} \right) \times 100 \tag{4}$$

The relationship for *RE* with the second spatial assumption (that is, existence of longitudinal gradients or plug flow) and steady-state conditions is derived from the one-dimensional mass transport equation (neglecting dispersion), as shown in WRP Technical Note WQ-EV-2.1, and is stated as

$$RE = \left(1 - e^{-K\tau}\right) \times 100 \tag{5}$$

Now, *RE* can now be estimated from either Equation 4 (fully mixed) or Equation 5 (plug flow) given K and τ. Values for K depend upon the pollutant of concern and the wetland characteristics, as discussed below. The choice of Equation 4 or 5 depends on wetland mixing characteristics. A bowl-shaped wetland with little sheltering from the wind would be expected to exhibit relatively uniform concentrations; thus, Equation 4 should be used. Well-mixed conditions also tend to be associated with wetlands having small hydraulic residence times (V/Q) and small length-to-width ratios (for example, $L/W \approx 1.0$). A long, narrow wetland would tend to exhibit longitudinal gradients, requiring the use of Equation 5. The plug flow condition is expected with large L/W ratios ($L/W > 10.0$) and large residence times. In most cases, Equation 5 should be used.

HYDRAULIC VARIABLES: Hydraulic residence time is defined as the theoretical maximum detention time, V/Q, where V and Q are mean annual values for wetland volume and flow, respectively. However, the true detention time of water parcels can be less than V/Q due to dominant flow paths that result in dead zones and short-circuiting. Additionally, the location where the pollutant is introduced in the wetland (a point source load) affects the detention time. The detention time, τ (days), as affected by L/W, can be estimated from (Thackston and others 1987)

$$\tau = 0.84 \frac{V}{Q} \left(1 - e^{-0.59 \frac{L}{W}} \right) \tag{6}$$

where L/W is the ratio of wetland length to width. If a wetland is considered to be well mixed, then Equation 4 should be used, and τ should be approximated as V/Q. For plug flow conditions, Equation 5 is recommended, and τ should be estimated from Equation 6 or set equal to V/Q for large L/W ($L/W > 10$).

Other hydraulic variables needed by the model include flow velocity, hydraulic depth, and the water surface area. The wetland hydraulic depth, H (m), is defined as V/A, where A (m^2) is the water surface area, and V (m^3) is the volume. Thus, with an estimate of two of the three variables (V, A, and H), the third variable can be computed. The mean velocity of the flow, U, is either input by the user or estimated from L/τ or Q/WH.

WATER QUALITY CONSTITUENTS: The model contains algorithms for the following water quality constituents:

- Total suspended solids.
- Total coliform bacteria.
- Biochemical oxygen demand.
- Total nitrogen.
- Total phosphorus.
- Contaminants.

The *RE* for each constituent depends on the removal rate, K, for the constituent via Equation 4 or 5. The removal rates depend on a number of processes, such as microbial metabolism, adsorption, volatilization, denitrification, settling, etc. Additionally, these processes are dependent on ambient conditions, such as water temperature, so obtaining a representative K value can be problematic. The approach here is to focus on the dominant long-term removal mechanisms, making use of literature values or formulations for those mechanisms. Presentation of formulations for estimating K values is beyond the scope of this technical note, but these are presented by Dortch and Gerald (1995). The computer model includes the formulations for estimating K rates for each water quality constituent.

MODEL IMPLEMENTATION: Formulations for estimating pollutant removal have been coded into a user-friendly, interactive computer program operational on PCs. The program is called PREWet, which is an acronym for Pollutant Removal Estimates for Wetlands. The equations and logic are programmed in C. The graphical user interface was developed with Zinc, a commercially available interface library. PREWet displays menus for selection of variables and parameters. Wherever applicable, default values for parameters are also provided. The model is designed to be self-explanatory, but on-line help features are available if necessary. PREWet can soon be downloaded through the Internet via FTP. Point of contact for information on model retrieval is Ms. Toni Schneider, (601) 634-3670, e-mail: *schneil@ex1.wes.army.mil.*

REFERENCES:

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