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SECTION 9.0

CWFATE MODEL

OVERVIEW

A pollutant transport model was developed for the Constructed Wetland Demonstration Project. The general purpose of the model, entitled the Constructed Wetland Fate and Aquatic Transport Evaluation (CWFATE) model, was to integrate and interpret the field data to better understand the performance of the constructed wetland. The model's principal objective was to develop a fate and transport model for metals and other pollutants to assist in the operation and performance evaluation of the construction wetland facility. Specific objectives were to:

1. Develop a fate and transport model of constructed wetlands using formulations from existing water quality models of lakes and streams;
2. Demonstrate the reliability of model predictions with calibration and sensitivity analysis;
3. Conduct fate and transport modeling to relate observed removal of pollutants to design and operational parameters including seasonal factors;
4. Simulate the long-term bioaccumulation of pollutants focusing on 10 heavy metals in sediment, vegetation, organic material, aquatic organisms, and resident wildlife;
5. Investigate the potential for more efficient design and operation of the constructed wetland facility; and
6. Evaluate the ability of the effluent to satisfy anticipated water quality requirements for the constructed wetland discharge.

The CWFATE model was originally developed in 1993 by Jones & Stokes Associates (JSA, 1993). The model was evaluated annually and a review of its performance included each annual report. Model performance for calendar years 1995, 1996, and 1997 can be seen in the respective annual reports (Nolte, 1996; Nolte, 1997; Nolte, 1998).

The purpose of this section of the Summary Report is to briefly describe the concept and formulation of the CWFATE model. It should be noted that the model is being modified to include several important processes not simulated in the original version. An updated version of the model will be issued as a stand-alone document. Therefore, the reader is recommended to seek out the upcoming CWFATE Report or the past annual reports for specific details on the model and its performance.

MODEL CONCEPT AND FORMULATION

The general organizing concept for the CWFATE model is an accounting of the water balance and mass budgets for inflowing nutrients (carbon and nitrogen) and metals within the water, sediment, and biomass components of the constructed wetland.

The seasonal factors that influence hydrology (rainfall and evapotranspiration), biology (production, respiration, growth, and decay), and biochemistry (temperature effects on biochemical processes) are accounted for by using a daily time step for an annual simulation of the constructed wetlands. Long-term accumulation of organic material and metals can be simulated by modeling a sequence of annual cycles. The effects of longitudinal gradients in the constructed wetland are simulated by dividing the constructed wetland into a series of 25 connected segments. All modeled variables can have different values in each segment for each simulated day.

Four major groups of variables and associated physical, chemical, and biological processes were included in the constructed wetland model:

1. Water Budget - Hydrologic processes including inflow, rainfall, seepage, evaporation, transpiration, and possible recycle terms.
2. Carbon Budget - Aquatic plant growth and decay processes, including roots, shoots, the mat of dead vegetation, suspended and deposited detritus resulting from the decay of mat, and peat accumulation in the soil.
3. Nitrogen Budget - Nutrient cycling processes, including both aerobic and anaerobic processes.
4. Metals Budget - Metals uptake, adsorpotion, immobiliation, atmospheric deposition, and general partitioning processes.

Water Budget

The basic framework for the CWFATE model is the water budget. Wetland cells have been modeled as a series of 25 connected segments (each 50 ft by 50 ft). Each segment is assigned a water depth for each model simulation. Therefore, the segment volume as well as the volume of the entire wetland cell can be easily calculated.

The model water balance calculations are made using daily input values for inflow, outflow, recycle, seepage, rainfall, and reference evapotranspiration. The inflow to the first segment is the measured inflow from the wastewater treatment plant, but can also contain a recycle term from the last segment. The outflow from the wetland reflects the influences of net rainfall, evapotranspiration, and seepage.

Carbon Budget

The constructed wetland is a unique aquatic wastewater treatment facility because of the growth of attached and free-floating aquatic plants and the subsequent accumulation of vegetative materials within the wetland cell. Estimating the seasonal magnitude of these plant biomass terms is an important part of the CWFATE model. Each of the biomass components are simulated with units of areal biomass density within the wetland cell. The specific components include:

- Plant roots
- Plant shoots
- Mat of dead plant material
- Particulate detritus material
- Soil organic peat material
- Attached and floating algae and other aquatic vegetation

Net primary production in the wetlands is modeled as a function of solar radiation, water temperature, soil nitrogen content, and an assumed maximum plant shoot canopy density. As the plant shoot biomass approaches the maximum assumed canopy density, more of the primary production is diverted to the roots. In the model, the growth of shoots is stopped on a specified date to simulate the senescence of the plants in the fall.

Algae biomass generally constitutes a small portion of total biomass production in the constructed wetlands. Algae primary production is modeled like the aquatic plant growth, but with shading from the shoot canopy and self-shading as the algae approaches a peak biomass level. No nitrogen limitation is assumed.

Decay and decomposition processes are assumed to result from the activities of invertebrate and microbial organisms. The dead shoots are transferred to mat material at a specified rate. A mat decay rate is specified, whereby an assumed loss of the mat biomass is converted to detritus and the remainder to the atmospheric carbon. Detritus can also decay to soil organic material (peat) and to atmospheric carbon. The detritus is assumed to be partially suspended in the water column, allowing some of the detritus to be transported to the next segment or to leave the wetland cell in the effluent. The peat is assumed to accumulate within the anaerobic zone and to be relatively resistant to bacterial decomposition, and thus has a slow decomposition rate. Root biomass is transformed to peat at an assumed decay rate.

The peat component within the wetland soil is assumed to be the principal long-term recipient of accumulating organic materials. The net accumulation rate for peat in the wetland soil is difficult to measure directly. Therefore, the CWFATE model has been used to show the sensitivity of peat accumulation within the wetland soil.

Nitrogen Budget

Nitrogen and phosphorus are the most abundant nutrients in the SRWTP effluent. They have been found to stimulate growth of wetland plants in some situations. However, only nitrogen is included in the CWFATE model primarily as an indicator of the relative magnitude of anaerobic processing within the constructed wetland peat component. The mass balance for nitrogen is modeled to provide an indirect estimate of denitrification, which is the dominant nitrogen removal process expected to occur in the peat layer.

Ammonia, which is the dominant form of nitrogen in the SRWTP effluent, is assumed to be oxidized to nitrate in the wetland and to be incorporated in the algae, roots, and shoots, which subsequently become detritus and peat material. Denitrification of nitrate in the water column is assumed to occur in the peat near the water-peat interface and to reduce the nitrogen content of the water column. The modeled reduction in outflow nitrogen compared with the inflow nitrogen will indicate the magnitude of anaerobic processing within the peat layer of the constructed wetland. Denitrification in the peat layer is affected by the available supply of organic carbon; therefore, the carbon budget and the nitrogen budget are linked.

Metals Budget

The specific biochemical processes that bind and transform metals within each of the biomass components, soil layers, and water column of the constructed wetland are extremely complex and thus difficult to model accurately. Therefore, the CWFATE model assumes that the inflow of a specified metal will become distributed within the biomass components of the constructed wetlands according to simple partitioning and passive uptake mechanisms.

UPDATED MODEL

As previously stated, the CWFATE model is being modified to include several important processes that were not simulated in the original model such as plant harvesting and oxygen-limited nitrification of ammonia to nitrate. The revised model will be calibrated using field measurement collected from 1995 to 1998.

The goal of the revised model will be to match the available measurements from each year with a single set of coefficients. The most important model coefficients will be identified from sensitivity analyses and coefficient will be adjusted to provide the most reasonable match with all available measurements.

The results from the revised model calibration will be summarized for a Final CWFATE Report. This report will include a description of the major pathways for metals in the constructed wetlands and the magnitude of these pathways. The revised model formulations (i.e., assumptions and calculations) will be described briefly. The calibration results will be discussed for several of the metals. The value of the field measurements for confirming the simulated pathways and ultimate fate of the metals within the wetlands will be emphasized. The potential for long-term buildup of metals within the wetland soil will be discussed.

REFERENCES

Jones & Stokes Associates, *CWFATE: Constructed Wetland Fate and Aquatic Transport Evaluation Model,* prepared for the Sacramento Regional County Sanitation District, July 1993.

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