University of Minnesota
St. Anthony Falls Hydraulic Laboratory

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ESTIMATION OF COMMUNITY OXYGEN PRODUCTION AND DEMAND IN THE MISSISSIPPI RIVER AT ST. PAUL, MINNESOTA, BY USE OF A DISSOLVED OXYGEN ROUTING MODEL

by

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SUMMARY

Dissolved oxygen production and consumption in two reaches of the Upper Mississippi River at St. Paul were determined from diel[1] dissolved oxygen measurements by a routing method. One reach was above the Metro Wastewater Treatment Plant (WWTP) outlet, the other below it. Dissolved oxygen, water temperature, and river flow were measured by the USGS on July 13-14 and August 10-11, 1982. Weather data (wind and solar radiation) were collected simultaneously by the authors. The numerical dissolved oxygen routing model (DORM) developed for the Environmental Protection Agency (EPA) with data from the Monticello Ecological Research Station (MERS) was adapted to the much larger Mississippi River system.

The results obtained by the DORM analysis using four sets of field data are given in Table V-1. Total daily oxygen consumption ranged from 6.5 to 14.7 g m^{-2} day^{-1} and total daily oxygen production from 2.7 to 6.1 g m^{-2} day^{-1}. Uptake rates are temperature-corrected to 20°C. Included in the oxygen consumption are biochemical and sedimentary oxygen demand (BOD and SOD) and respiration by all plants and animals. Oxygen production is by photosynthesis and therefore dependent on availability of light in the water. Both periods of investigation had partially cloudy days with only 54 percent and 78 percent of clear day radiation on July 13 and August 10, respectively.

A comparison of the results with those obtained by a light and dark bottle method is given in Appendix I. The oxygen consumption rates found by the DORM method are with one exception similar to those found by light and dark bottle incubation in 1976/77 (Megard et al., 1978). This would indicate that phytoplankton and other suspended materials are the major consumers of oxygen in the Mississippi River and that rooted and attached aquatic plants consume small amounts of oxygen in the river.

The photosynthetic oxygen production rates given by the DORM are less than those which were calculated from Megard et al.'s (1978) semi-empirical relationships. Possible reasons are: (a) July 13 and August 10, 1983, were partly cloudy days, while the equations are derived from data on sunny days; (b) light attenuation coefficients measured in 1983 were larger (2.8 to 4.1 m^{-1}) than those calculated from the equations (2.3 to 2.6 m^{-1}) possibly because flow rates and suspended sediment concentrations were also larger; and (c) methods by which chlorophyll-a was measured in 1976/77 and 1983 were different and specific volumetric rates of photosynthesis may therefore also be different (higher if Chℓa was estimated lower).

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[1]Involving a 24 hour period.

Oxygen production in the reaches investigated is much dependent on availability of sunlight and on particulate matter in the water including phytoplankton (chlorophyll-a), detritus, silt and other substances. The concentration of the latter is a function of river flow rate.

The size of the Mississippi River system may be thought to overtax the spatially one-dimensional form of the governing equation especially if stratification of productivity is dominant. This did not seem to be the case during the field study conducted. In general, the DORM appears to be a good basis for estimates of total riverine community oxygen consumption (R) and oxygen production (P).

Because the measured diel D.O. amplitudes were only on the order of 1 mg/ℓ, the results for oxygen consumption (R) were found to be sensitive to small errors in D.O. measurements; those for oxygen production (P) were not. Very accurate D.O. measurements over a period of 30 hours or more are needed to calculate reliable values of oxygen uptake.

The model results were insensitive to a 30 percent change in longitudinal dispersion, and to changes in wind speed by a factor of three. It was concluded that reaeration (oxygen surface exchange) did not have much influence on the study because of large river depths, short residence times, and D.O. values not far from saturation. In this analysis, flow and wind effects on reaeration were accounted for by using coefficients developed from data measured on small streams (Gulliver and Stefan, 1981).

I. BACKGROUND

The Metropolitan Waste Control Commission and its predecessors have long been interested in the dissolved oxygen (D.O.) levels in the Mississippi River below the outlet of the Metro Waste Water Treatment Plant (WWTP), sometimes called the Pig's Eye Sewage Treatment Plant. In the past, D.O. profiles along the river course (oxygen-sag curves), have been measured on numerous occasions and D.O. monitors in several locations along the river have measured and recorded D.O. levels as a function of time. Computer simulation models of D.O. and other water quality parameters have been developed in order to predict the consequences of various waste load allocation alternatives.

Because river D.O. levels are dependent on biochemical decomposition of organic detritus, reaeration, photosynthesis and respiration of aquatic plants and on processes at the sediment/water interface, the kinetics of these processes have also been studied to some extent. Biochemical oxygen demand (BOD) of the WWTP effluent and of the river water have been measured extensively, sedimentary oxygen demand (SOD) has been measured in a few places, photosynthesis and respiration of river phytoplankton have been measured. Studies have also been made of other life forms including zooplankton and fish. Studies of mixing processes which influence D.O. distributions in space and time have been limited to some observations of D.O. stratification in the river, and of spatial variations of D.O. in Pool No. 2.

VII. CONCLUSIONS

A dissolved oxygen routing model (DORM) has been set up for two reaches of the Mississippi River near St. Paul, one above the Metro WWTP outlet, the other below it. The objective was to calculate community oxygen consumption and community photosynthesis by routing of diel dissolved oxygen measurements. The results obtained by the DORM analysis using four sets of field data are given in Table V-1.

The results for oxygen consumption are sensitive to small changes in D.O. measurements because differences between upstream and downstream D.O. measurements are also small. Very accurate D.O. measurements are needed.

The model's sensitivity to a 30 percent change in longitudinal dispersion coefficient was not significant.

In a previous study (Ref. 1) it was found that the two parameters to which DORM is most sensitive were the hydraulic residence time and the surface exchange coefficient. The best available hydraulic data has been used in the model. The surface exchange (reaeration) as applicable to the Mississippi River needs further study. In this study flow and wind effects were accounted for by using coefficients developed for small streams (Gulliver et al., 1980). Results were found to be insensitive to wind, suggesting that reaeration was not a very important factor because of the large depth of the river.

The size of the Mississippi River system may overtax the spatially one-dimensional form of the governing equation in some cases where stratification of productivity is dominant. This was not the case during the two measurement periods. In general, the DORM appears to be a good basis for estimates of total riverine oxygen consumption (R) and oxygen production (P).