4. Public Summary

Very low levels of dissolved oxygen (DO) have occurred in the near bottom waters of western Long Island Sound (LIS) each summer since measurements began in 1988 and this causes stress to the marine life in the region. Similar patterns of low DO occur in many urbanized estuaries and the phenomenon is termed hypoxia. To mitigate the extent and duration of hypoxia in LIS, the EPA and the States of New York and Connecticut have developed a Comprehensive Conservation and Management Plan (CCMP) using a computer model to assess the likely impact of reductions in nitrogen discharged from water treatment plants and non-point sources. An improved model, the System Wide Eutrophication Model (SWEM), has been developed and tested by Hydroqual Inc. to simulate the biogeochemistry and circulation in Long Island Sound and adjacent waters and is being used to reassess the effectiveness of the plan. SWEM is a complex model with many parameters that represent the rates of the processes that influence the DO concentration. In this project we implemented SWEM at the University of Connecticut to independently study the sensitivity of the model predictions of DO concentrations to parameter choices and boundary conditions, and to assess the effect of year-to-year variations in precipitation and wind patterns. Since there have been many important advances in the understanding of LIS and the coastal ocean since the initiation of the development of SWEM, we also assess whether SWEM is consistent with recent new knowledge.

SWEM has two major modules. Circulation and mixing are simulated by solving the equations describing the hydrodynamics of the coastal ocean with boundary conditions that represent river flow, winds and the state of the ocean at the model boundaries. This component is called ECOM. The products of this module (velocities and vertical eddy coefficients) are passed to the water quality module to compute the evolution of nutrients, plankton, dissolved oxygen etc. During the development and calibration of SWEM, an ad-hoc reduction to the vertical eddy coefficients predicted by the ECOM module was introduced to reduce nearbottom dissolved oxygen in the western Sound in the summer. Recent work on mixing in the coastal ocean and comparison of ECOM results to recent observations in the Sound suggest that the original ECOM values were actually realistic and that the values imposed by the ad-hoc reductions were much too small. The need to distort the representation of mixing in order to obtain a reasonable representation of hypoxia points to other under-lying problems in SWEM. By comparing recent observations in LIS and SWEM predictions, we found that both respiration and production were significantly underestimated in SWEM while the levels of mixing predicted by the original circulation module were in a realistic range. We conclude that it is likely that the underestimation of respiration was the cause of the problems that led to the need for the artificial reduction of vertical mixing rates. Though outside the scope of the original project, we investigated the cause of the under-estimation of respiration and found we could correct it and improve the model skill without the distortion of vertical mixing that is currently implemented in the SWEM model.

To quantitatively assess how well the model performed we employed a statistical summary of the misfit between the model solutions for 1988-99 and 1994-95 with observations of the DO concentrations made by ship surveys in these same years. We called how well the model matched the actual observed data the model *skill*. We used several variants of this metric, but for the purposes of comparing different versions of the same model, a higher skill means a better simulation. SWEM has 120 parameter values that must be selected. We examined the effect on the model skill of increasing and decreasing each parameter by 10% from the value chosen by Hydroqual for simulations of 1988-99 and 1994-95. The results demonstrated which parameters were most important and suggested some changes to parameter values that might lead to improved predictions.

We also investigated the consequences of doubling the fluxes of nitrogen from point sources and setting these to zero on the predictions of the model. We found little difference between the solutions in areas prone to hypoxia. With zero discharges, the minimum DO in the late summer was approximately 1mg/L higher than with using the 1995 discharge levels and only 0.1 mg/L lower with double the 1995 discharges. Since SWEM was designed to mimic the existing plankton community structure, which would be expected to be different if nutrient ratios were changed radically, these simulations should not be considered realistic. However, they do provide a bound on the magnitude of DO changes to be expected from management actions which might reduce discharges 30 to 50%. The model predicts that changes are likely to be small. Of course this result must be checked once production and respiration rates are simulated more realistically.

The validation and verification studies of SWEM used two years of observations. However, it is well established that there are significant differences in the pattern of river discharge and wind variations from year to year, so it was important to assess whether these simulation years were representative. We contracted with Hydroqual to provide ECOM solutions for four additional years (1998-99, 1999-2000, 2000-2001, and 2001-2002) and used these, together with the 1994-95 boundary source fluxes, to simulate what the conditions in LIS would have been with different weather conditions. We then compared these solutions and found that they were similar to each other. We conclude that SWEM does not have the ability to distinguish the influence of inter-annual meteorological variability on hypoxia.

We finish our study with recommendation for future research needs. Clearly, the model must be improved to better represent the critical processes that determine the rate of decline in DO in the summer: production, respiration, and vertical mixing. We have outlined how that should be accomplished. This is a substantial change and the implications for the management decisions that have been instituted should be reassessed by repeating at least some of the simulations used in the development of total maximum daily loads (TMDLs). However, that is not enough. For the model to be useful in predicting the impact of changes to sources of nutrients, it is essential to observe how community respiration and production rates depend upon the available nutrient concentrations in LIS. A capability to simulate that response will establish confidence that the model can represent the effect of management actions correctly. This will require sustained field observations in addition to the existing monitoring program.

Recent buoy observations have shown that the magnitude of the variation in DO and chlorophyll that occurs during a single day is comparable to the differences in the monthly mean concentrations between years. It seems likely that nutrients will show similar variability. Since the surveys occur during the day and only twice a month, it is not surprising that comparing this data to the model predictions does not really assess whether the model is adequate. Much of the difference between the predictions and observations is due to the uncertainty in the observation of the several-day mean. Though the precision of the measurements may be high, the sampling scheme does not provide a good estimate of the values that SWEM was being used to predict.

Further, only the availability of high frequency moored DO observations and ship based measurements of respiration and production rates provided the insight that led to identification of the weaknesses in the model. The existing observations of the community respiration and production rates show that these are highly variable in time and location. It is unclear what causes this variability. The high frequency variability in the nutrient levels are unknown at present and this must be established. Finally, the crude resolution of the lateral variations in the circulation model essentially prohibit the possibility that lateral gradients strong enough to drive substantial lateral circulation can be established. The low spatial resolution of the model also diminishes its value to the management of water quality in embayments like Hempstead Harbor, Smithtown Bay, etc.

We believe that some improvements to the modeling process are also needed. It is critical that engagement between observationalists and theoreticians be enhanced. There are good paradigms for how to do this. Use of open-source models and data sharing standards are essential to allow more engagement by experts and constructive criticism.