A Hybrid Empirical-Numerical Technique for Water Intakes Smart Operation

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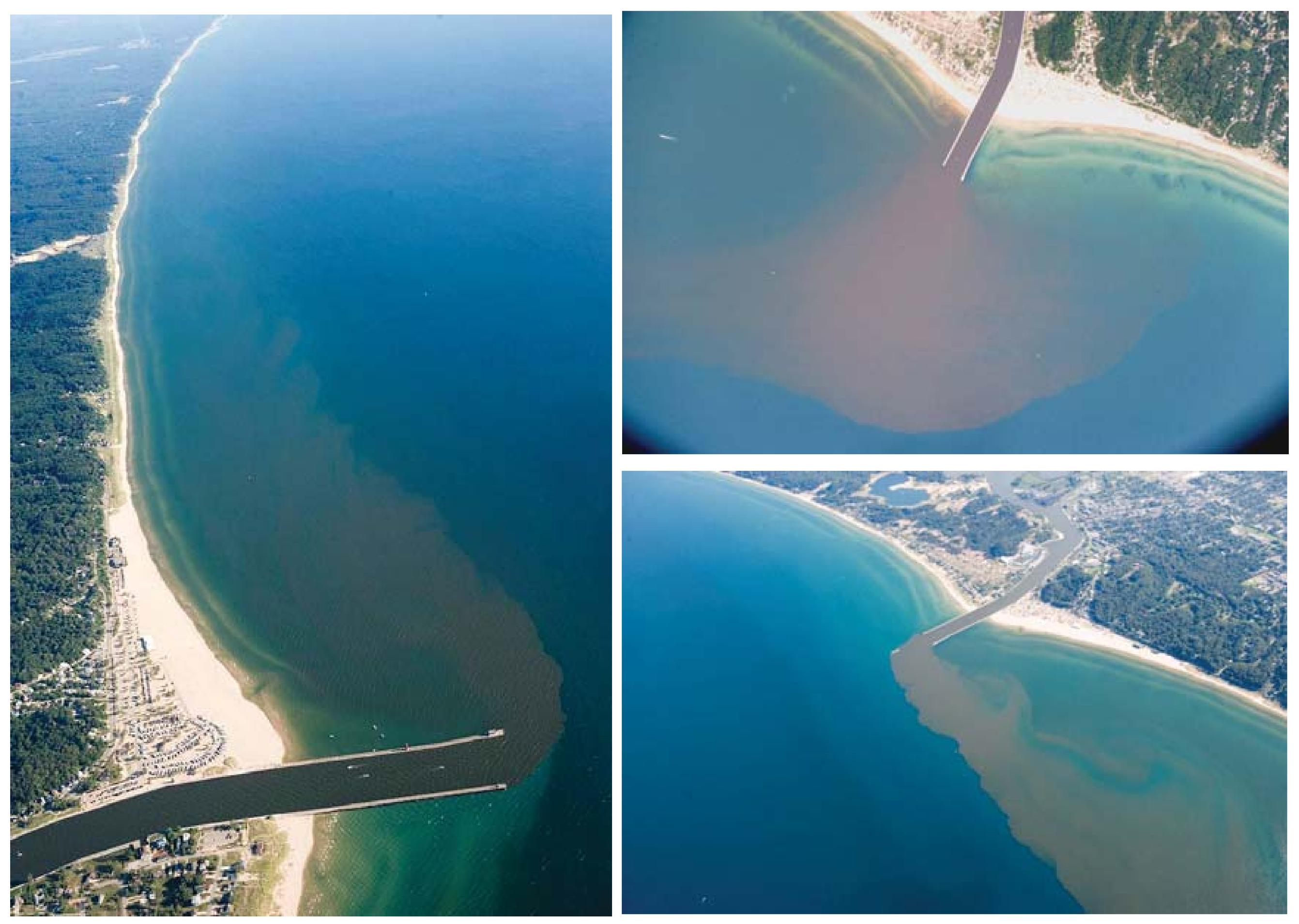
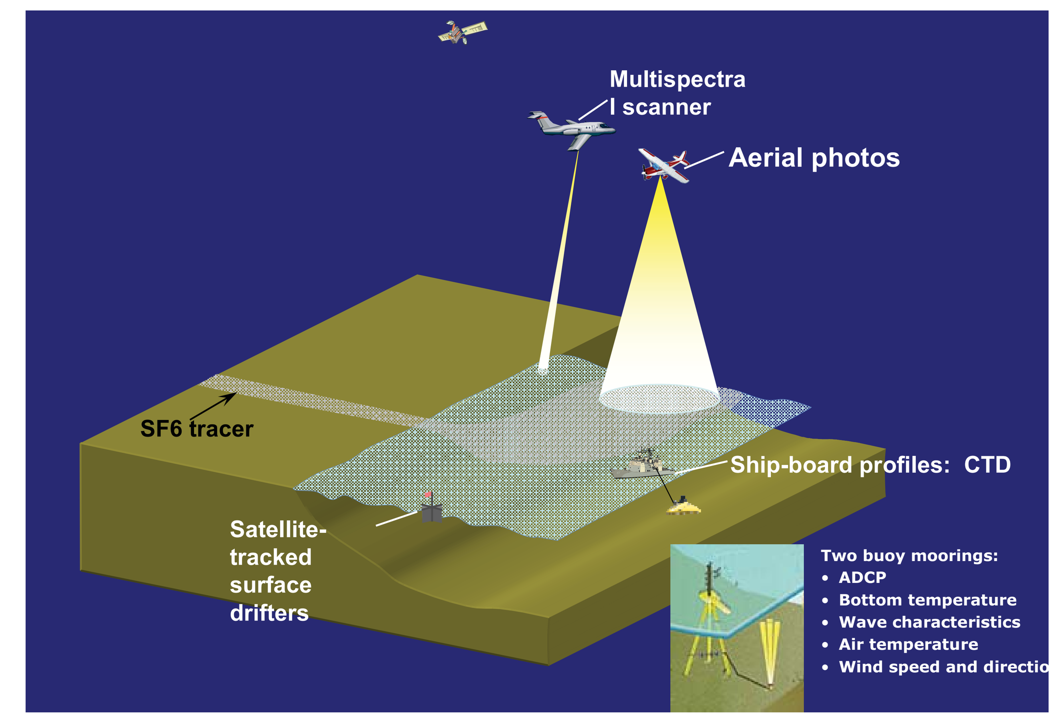
The Great Lakes, largest freshwater source in the world, are the nation's single most important aquatic resource and can impact human health because of high concentrations of humans, major cities and industries in the watershed. In addition, there are over 500 recreational beaches in their basins that their closures can dramatically influence the region economy. During natural and human-made events, pollutants that enter into the Great Lakes can also pose a health risk to swimmers, boaters, and other recreationists. One of these highly impacted sites is located at Grand Haven Michigan. Grand River plume has been studied as a part of beach and human health project in conjunction with Great Lakes Environmental Research Laboratory. Field studies, experimental and numerical modeling are carried out in order to predict the dynamics of the plume.

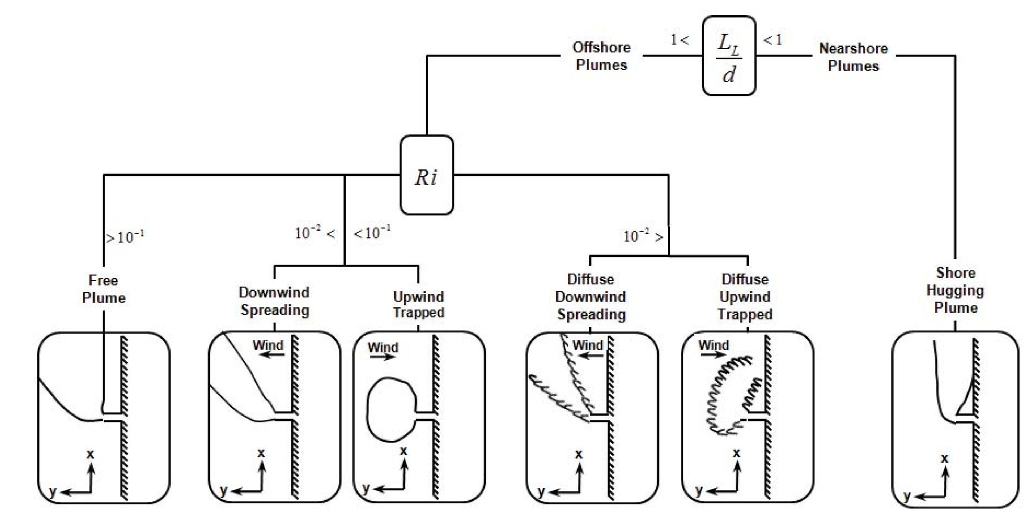


Aerial Photography



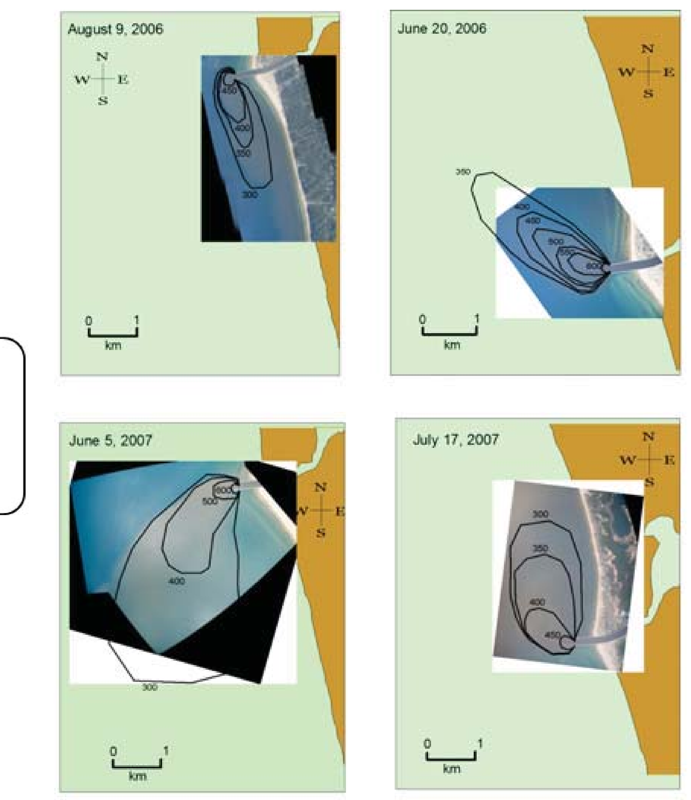
In June and August 2006 extensive field studies were performed around Grand Haven plume. Field activities included real time CTD sampling, deployment of three Acoustic Doppler Current Profilers (ADCP), tracer release experiment and current meter drifters in the vicinity of Grand Haven. This tributary to Lake Michigan is known to contain high levels of coliform bacteria and is adjacent to the Grand Haven National Lakeshore.

Field Experiments

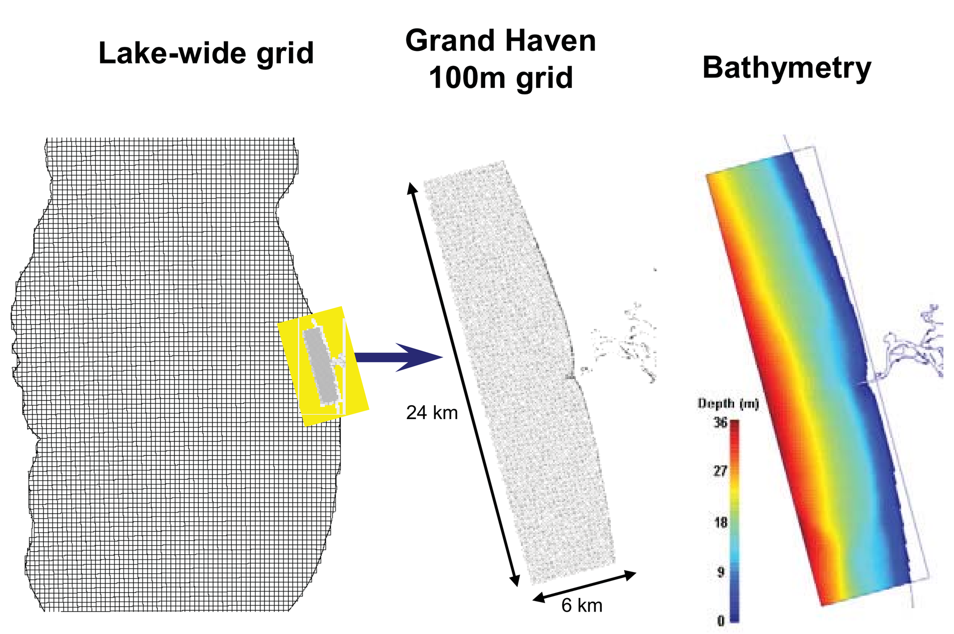


A new classification scheme based on the relative magnitude of the plume-crossflow length scale and a Richardson number based on wind speed was devised, that included longshore current components and onshore-offshore wind effects. Our observed results showed more flow classes than included in previous studies (e.g. CORMIX). A near field empirical model of trajectory and minimum dilution for large aspect ratio surface discharge channels was also developed that is better suited to conditions typical of the Great Lakes than previous models. The issue of near field dynamics have been rarely acknowledged in river plumes with large aspect ratio that are common for rivers discharging to the Great Lakes.

Surface Buoyant Plumes Classification and the Near Field Model

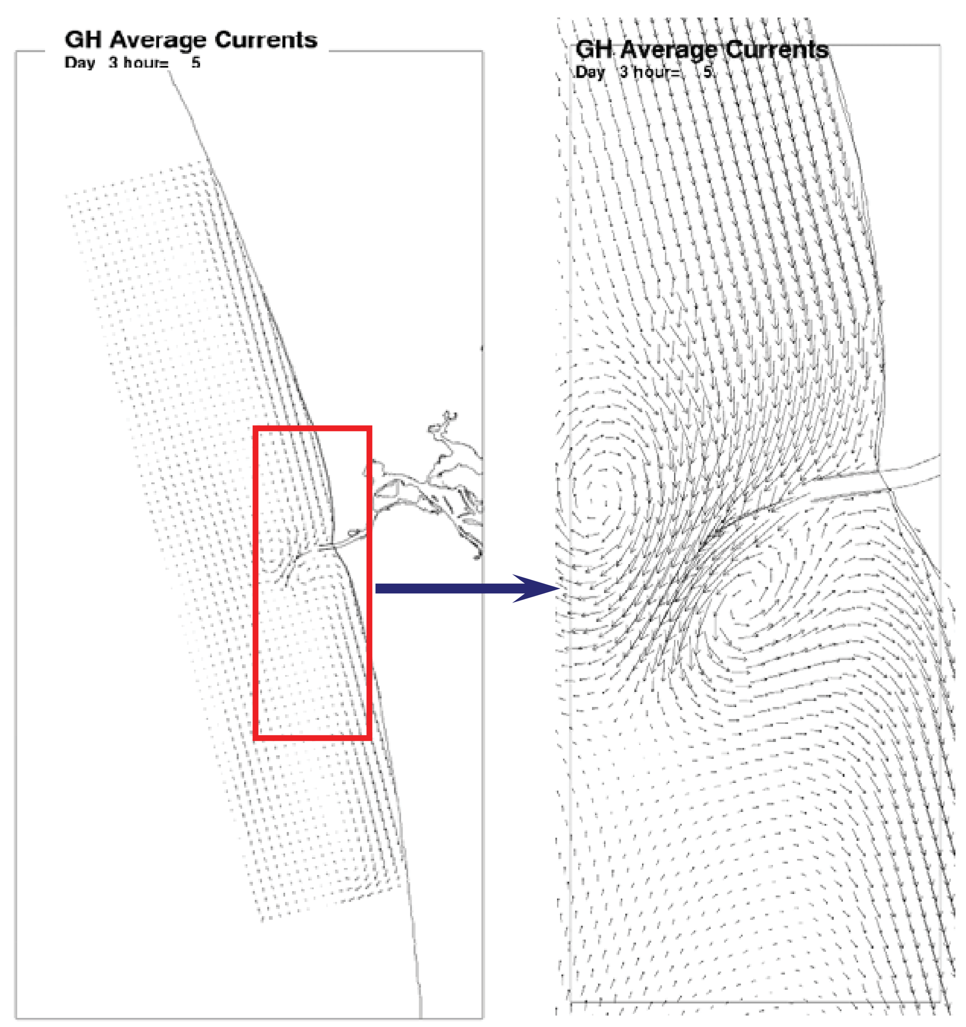


Observed Surface Conductivity Overlain on the Aerial Photos



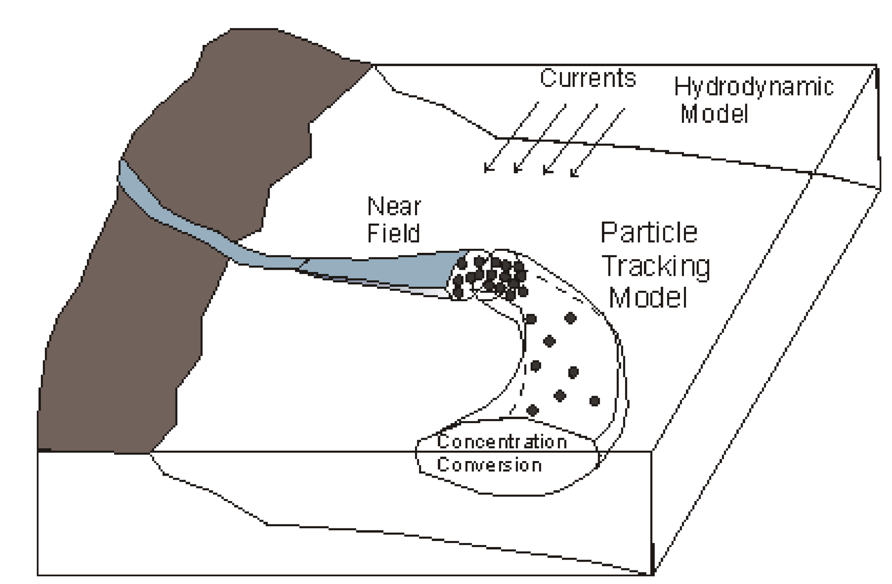
The hydrodynamic modeling approach was developed for linking 2 km resolution lake-scale hydrodynamic simulations with a nested local grid (covering on the order of 25 km of shoreline with a horizontal resolution of 100 m). Results from the whole-lake simulations were used to specify the open water boundary conditions for the nested grid simulations. All modeling modifications and implementations were performed so as to maximize the ease of applying it to other Great Lakes sites in the future. In addition to the simulation with actual Lake Michigan bathymetry, the nested grid method has been implemented for a fine (nested) grid size of 6km × 24km with a 100m horizontal resolution.

Grid Nesting



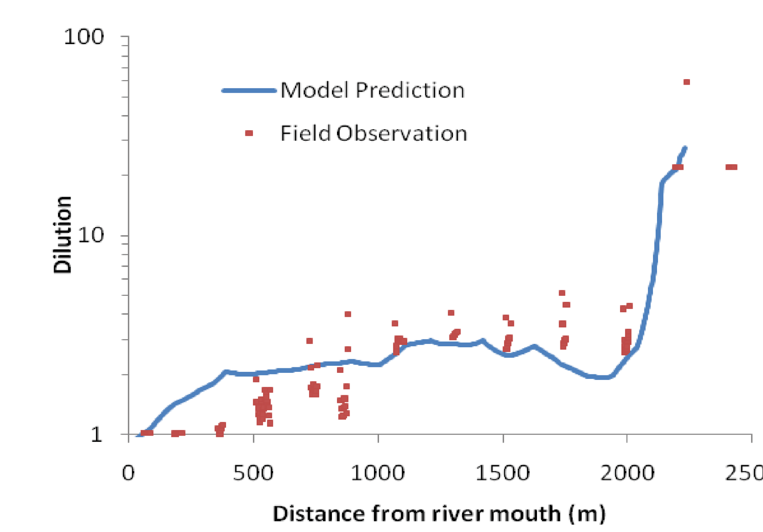
The left graph shows the depth averaged currents in January 3, 2005. The gyres and vortices magnified show a complex hydrodynamic structure near shore. A nested hydrodynamic modeling scheme was employed. The nearshore refined hydrodynamic simulation associated with the 3D transport predictions also represented the surface river discharges better than present 2D models. The measured and modeled currents agreed fairly well. 2D models (often depth-averaged) are a poor approximation to the thin surface spreading layer that actually occurs in the Great Lakes where the processes are clearly 3D.

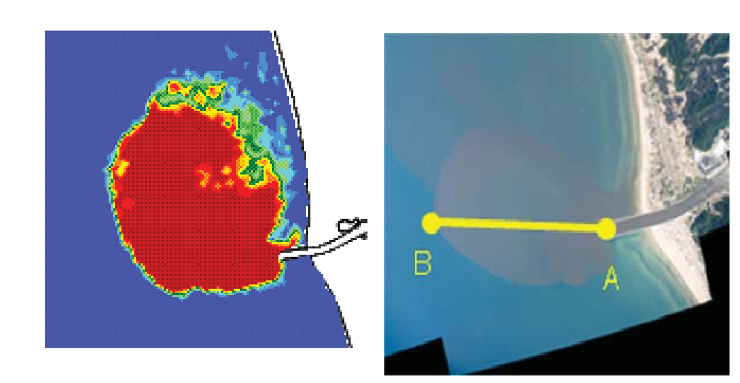
Far Field Hydrodynamic Model



Due to computational limitations, it is not presently feasible to capture the wide range of spatial and temporal hydrodynamic processes in one mathematical model. A coupled empirical near field model with the far field particle tracking model was developed that improved prediction of the behavior of the Grand River discharge nearshore compared to the existing models. The coupling technique application was novel for buoyant surface discharges and revealed the deficiencies of the usual engineering approach of using single models.
The method can also have implications for forecasting and real-time assessment of pathogen indicators in recreational beach waters. This goal was accomplished by refining POMGL large scale hydrodynamic simulations, applying a 3D far field particle tracking model coupled with an empirical near field model that was tested with Grand Haven extensive field studies.

Hybrid Model

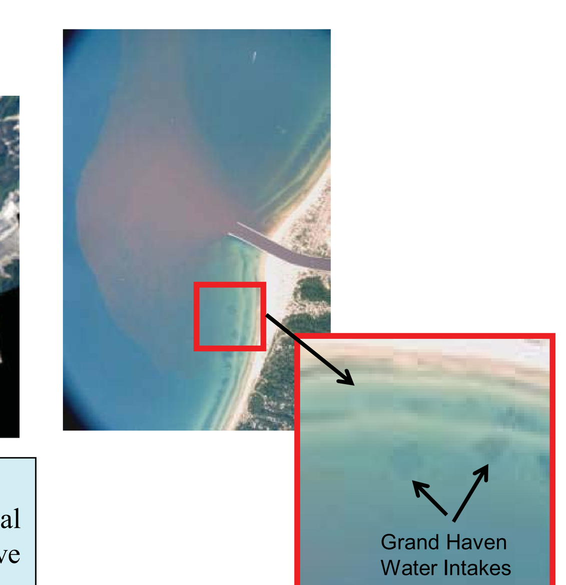




Random walk particle tracking models have considerable advantages over gradient diffusion models in simulating bacterial behavior nearshore. A particle tracking model was used that gave us the capability to track a decaying tracer and better quantify mixing due to turbulent diffusion. This resulted in an improved representation of bacteria diffusion, decay and transport.

Particle Tracking Prediction

The results of this research can also have broad industrial application and implications for environment protection, and assist in minimizing economic operation and construction costs of water and wastewater related infrastructure. The model can be applied to locate the best water intake locations that minimizes the entrainment of bacteria (and sediment), therefore protecting drinking water supplies.



Water Intakes Smart Control and Regulation