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MEMORANDUM

DATE: June 25, 2008

FROM: Scott Bell, P.E., BCEE

PROJECT: Maumee Bay State Park Project – Phase 2

TO: Bill Petruzzi, Hull & Associates, Inc.
Keith Carr, Hull & Associates, Inc.

CC:

SUBJECT: Berger Ditch Watershed Hydrologic Modeling and Maumee Bay Hydrodynamic Modeling.

Project Background

This memo describes work conducted by LimnoTech in support of ongoing wetland restoration and bacteria fate and transport studies at Maumee Bay State Park in Oregon, Ohio. The work documented in this memo is an extension of previous work conducted by LimnoTech on behalf of Hull & Associates (Hull) to support conceptual design of treatment wetlands in the Wolf Creek/Berger Ditch system to reduce bacteria loading to Maumee Bay. That work, referred to herein as Phase 1, involved development of a hydrologic/hydraulic model of the Wolf Creek/Berger Ditch system using the USEPA SWMM model to evaluate conceptual designs developed by Hull. LimnoTech documented the development of the Berger Ditch SWMM model and the modeling results for the conceptual wetland designs in a technical memo dated December 12, 2007.

Upon completion of Phase 1, LimnoTech was contracted to conduct further model development to support analysis of bacteria transport from Berger Ditch to Maumee Bay. This second phase of work involved two main elements:

- Calibration, to the extent feasible, of the previously developed SWMM model of the Wolf Creek/Berger Ditch system using available rainfall and flow data.
- Development of a hydrodynamic model of Maumee Bay and application of the model to evaluate bacteria transport and dispersal in Maumee Bay.

Each of these elements is described in detail below.

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SWMM Model Calibration

The hydrologic model of the Wolf Creek/Berger Ditch system was developed by LimnoTech using the U.S. EPA Storm Water Management Model (SWMM) version 5.0. LimnoTech's December 12, 2007 memo describes the development of that model, including the inputs used to characterize subwatersheds, open channels, and rainfall. Due to the lack of site-specific data, literature values were used for many of the model input parameters.

In Phase 2, LimnoTech used available local rainfall and flow data to calibrate the SWMM model, to the extent feasible. The following sections describe the data used for calibration, the parameters varied to adjust the model calibration, and the calibration results.

Data Used for Calibration

LimnoTech used the following available rainfall and flow data from the Berger Ditch watershed for calibration of the SWMM model:

- Flow data from the USGS Berger Ditch gage (USGS Gage No. 04194085) from May 1, 2006, through April 1, 2008, were obtained from Ohio USGS staff. These data were available at 15-minute intervals.
- Rainfall data collected by the City of Oregon at the Oregon Wastewater Treatment Plant from January 1 through September 30, 2007, were provided to LimnoTech by Hull. These data were available at both daily and 10-minute intervals.

The overlapping period of rainfall and flow data available for calibration was January 1 through September 30, 2007. Because the effects of winter conditions such as ground freezing, snowfall/snowmelt, and freezing rain were not simulated in the model, only the relatively warm-weather period of April 1 through September 30 was suitable for use in model calibration. LimnoTech reviewed the flow data from this period to identify a time series that included a relatively isolated high flow event, as indicated by a relatively high hydrograph, preceded by a period of base flow conditions. The month of August 2007 presented these conditions, so this period was used for model calibration.

Calibration Process and Results

Model calibration involves adjustment of model parameters, within valid and reasonable ranges, to fit model results to observed data. In the case of the Wolf Creek/Berger Ditch SWMM model, calibration involved comparison of simulated flows at the USGS gage to actual measured flows. The SWMM model is complex, with multiple parameters, and calibration is an iterative process of comparing model results to data and making parametric adjustments based on the observed fit of model to data.

Table 1 presented the model parameters that were modified to achieve calibration; both the original values of the parameters and the final calibrated values are shown.

Table 1: Original and Calibrated Model Parameters for the Berger Ditch/Wolf Creek SWMM Model.

	Subwatersheds											
	1		2		3		4		5		6	
Adjusted Values	Original	Calib.	Original	Calib.	Original	Calib.	Original	Calib.	Original	Calib.	Original	Calib.
Width[1] (ft)	5400	5400	5600	200	8200	400	8100	800	5400	500	13300	3000
% Slope	1.48	1.00	1.11	1.40	0.58	1.40	0.78	1.40	1.34	1.70	0.97	1.60
% Impervious	3.9	25	2.4	25	2.2	25	2.2	25	7.5	30	13	33
N-Impervious	0.01	0.13	0.01	0.06	0.01	0.06	0.01	0.10	0.01	0.08	0.01	0.08
N-Pervious	0.2	0.2	0.2	0.07	0.2	0.07	0.2	0.15	0.2	0.1	0.2	0.1
Dstore-Impervious (In)	0.05	0.05	0.05	0.25	0.05	0.25	0.05	0.25	0.05	0.25	0.05	0.25
Dstore-Pervious (In)	0.15	0.15	0.05	0.08	0.05	0.08	0.15	0.08	0.15	0.09	0.15	0.09
% Zero-Impervious	25	0	25	0	25	0	25	0	25	0	25	0

[1]Width of overland flow is a hydrologic variable in SWMM and does not necessarily reflect subwatershed width.

After making the parametric changes noted above, a reasonable fit of model to data was achieved, as depicted in Figure 1.

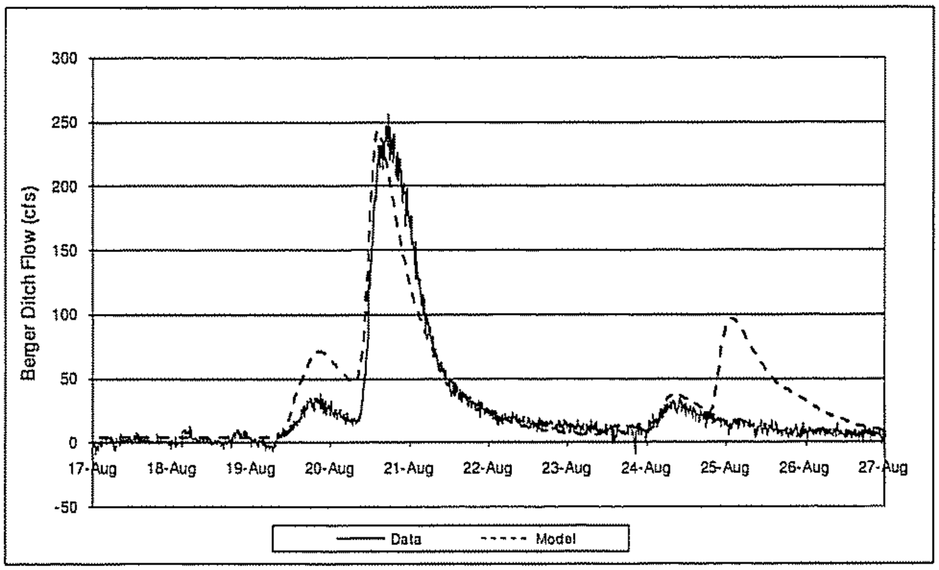

Figure 1: Comparison of calibrated SWMM model to Measured Flows in Berger Ditch

The comparison of model to data depicted in Figure 1 shows that the model reproduces major hydrologic events reasonably well. The overall shape and height of the model hydrograph for August 20-21 shows a good fit to the data. However, the model overpredicts flow for some lesser events, such as the late August 19 event and it produces a late peak following the August 24 minor event. Further manipulation of model parameters did not improve the calibration. There are several potential factors limiting the model calibration including:

The rainfall data used in the model was collected at a single location and applied over the entire Wolf Creek/Berger Ditch watershed, which covers more than 15 square miles. Small variations in the spatial distribution of rainfall can have significant impacts on downstream hydrographs.

There may be physical attributes that effect storage and drainage at a scale finer than the subwatershed level used in the model. Detailed field inspection may be necessary to identify these attributes, if they exist.

The model appears to be sufficiently calibrated to estimate peak flows and runoff volumes from pronounced hydrologic events. If improved calibration is desired, a distributed network of rain gages is recommended to capture spatial variation of rainfall over the watershed. If calibration anomalies still appear, specific field investigations may be necessary, based on the nature of the observed calibration issues.

Hydrodynamic Model Development

LimnoTech developed a hydrodynamic model of Maumee Bay, including the lower reach of Berger Ditch, to simulate the transport of bacteria to and within Maumee Bay. The Maumee Bay hydrodynamic model allows simulation of water levels, velocities, and bottom shear stresses in Berger Ditch and Maumee Bay as a result of external forcing functions including flow from the Wolf Creek/Berger Ditch watershed and wind on Lake Erie. The model was used to simulate sediment transport and particle tracking, to represent bacteria transport. Data for calibration of the hydrodynamic model were not available at the time of model development, therefore the modeling analysis discussed in this memo should be considered a screening-level assessment.

Model Description

LimnoTech used the USEPA Environmental Fluid Dynamics Code (EFDC) to develop the Maumee Bay hydrodynamic model. The EFDC model was selected because it allows two-dimensional hydrodynamic simulation and has sediment transport modeling and particle tracking capabilities.

The EFDC model requires the generation and configuration of a model grid and the specification of model forcings such as Berger Ditch flow and Maumee Bay water level. The development of the model grid and model input parameters is described below. The model domain and grid are shown in Figure 2.

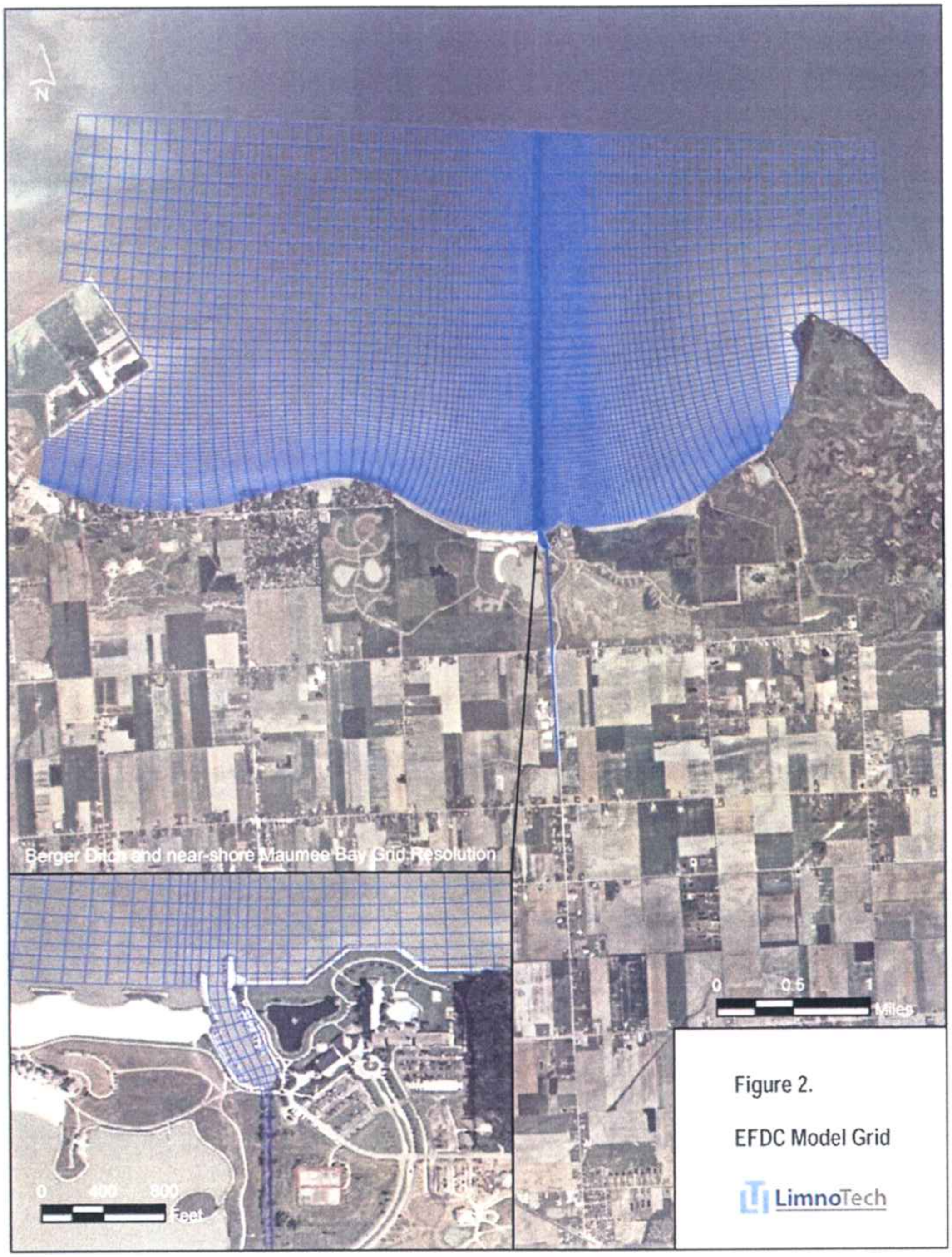

Figure 2: Maumee Bay Hydrodynamic Model Domain and Grid Layout.

Berger Ditch is represented with a single cell spanning the cross-section, making it effectively a one-dimensional representation, which is appropriate for this type of application. Widths of these grid cells were adjusted to approximately equal the actual cross-sectional area of the ditch, based on survey data provided by Hull.

As shown in Figure 2, a two-dimensional grid was used for Maumee Bay. The two-dimensional model grid was configured to represent bathymetry, roughness, and the grain-size distribution of bed sediments in Berger Ditch and Maumee Bay. A National Oceanic and Atmospheric Administration (NOAA) contour map at one-meter intervals, provided by Hull, was used to specify Maumee Bay bathymetry in the model. Bathymetry in Berger Ditch was estimated by using a combination of cross-section measurements made by Hull and a typical longitudinal bed slope of 0.05%. These data sources are considered sufficient to inform a conceptual understanding of sediment transport through the system.

EFDC uses a 'roughness height' rather than the more typical Manning's roughness value. This roughness height is proportional to bed grain size such as the 90th percentile grain size. A roughness height of 2 millimeters was specified for the entire length of Berger Ditch, while a 20 millimeter roughness height was specified for all grid cells within Maumee Bay. These estimates of roughness height were chosen based on the 90th percentile grain size of samples taken from Berger Ditch and Maumee Bay.

The boundary forcing functions that were used in the model included Berger Ditch inflow, Maumee Bay water level, wind speed, and wind direction. High-quality datasets were obtained from the USGS and NOAA in order to specify these boundary conditions. Table 2 summarizes data that were used for model boundary conditions.

Table 2: Data Sources for Maumee Bay Hydrodynamic Model Boundary Conditions.

Parameter	Time Interval	Period of Record	Data Source
Instantaneous Discharge	10 minutes	5/1/2006 – 4/1/2008	USGS
Maumee Bay Water Level	60 minutes	9/1/1996 – 2/1/2008	NOAA
Wind Speed / Direction	60 minutes	4/1/2006 – 4/1/2008	NOAA
Inflow Suspended Sediment Concentration	10 minutes	n/a	Correlation between Discharge and SSC using USGS data

Model Application and Results

The Maumee Bay hydrodynamic model was applied to address three general areas of inquiry related to bacteria loading to, and transport in, Maumee Bay. In each case, the suspension of bed sediments and transport of suspended sediment was used as a surrogate for bacteria suspension and transport. This approach assumes a relationship between bacteria and sediments, which is supported by previous studies (Brady, 2007). Direct suspension and transport of colloidal bacteria was not simulated. The three areas of inquiry are:

- Sediment export from Berger Ditch – The Maumee Bay model was run to calculate velocities and shear stresses in Berger Ditch under a range of flow conditions to estimate sediment export from Berger Ditch.
- Short-term sediment transport into Maumee Bay – The Maumee Bay model was used to simulate sediment transport from Berger Ditch into Maumee Bay during wet-weather events. This type of simulation mechanistically simulates sediment transport using physical parameters specified by the modeler. Because sediment transport modeling is computationally intensive, these simulations were only performed for relatively short duration (e.g. a few days long) events.
- Long-term sediment transport simulations – The Maumee Bay model was run using a particle tracking simulator, to evaluate sediment transport, dispersal and deposition in Maumee Bay over longer time scales. This application is useful in understanding long-term dispersion patterns in the Bay. The particle tracking application was used for this because it is much less computationally intensive than the sediment transport simulation.

It should be noted that, as mentioned previously, data for calibration of the hydrodynamic model were not available at the time of model development, therefore the modeling analysis discussed in this memo should be considered a screening-level assessment.

Sediment Export from Berger Ditch

A five-month simulation of hydrodynamics in Berger Ditch and Maumee Bay was run in order to quantify velocities and shear stresses under a variety of flow and wind conditions and to estimate sediment export from Berger Ditch to Maumee Bay. The period selected for this five-month simulation was from May 1, 2006 to October 1, 2006. This period was selected for the availability of concurrent Berger Ditch flow, wind, and Maumee Bay water level data. This simulation was used to calculate hydraulic conditions in Berger Ditch, a means of assessing conditions that might lead to sediment scour. The model was also run using design event flows generated by the calibrated SWMM model for the following storm events: 0.5-year 24-hour, 1-year 24-hour, 2-year 24-hour, 10-year 24-hour, 25-year 24-hour, and 100-year 24-hour.

The sediment bed was characterized using bed samples that were collected in Berger Ditch and in Maumee Bay by Hull and Associates. Three non-cohesive sediment sizes and one cohesive sediment class were used to represent the particle size distribution of the bed. The following table summarizes the initial particle size distribution for Maumee Bay and Berger Ditch.

Table 3: Initial Sediment Bed Particle Size Distribution.

Location	% of Bed as Cohesive Sediment	% of Bed as Non-Cohesive Class 1 [2mm]	% of Bed as Non- Cohesive Class 2 [10mm]	% of Bed as Non-Cohesive Class 3 [16mm]
Berger Ditch	75	25	0	0
Maumee Bay	25	25	25	25

Mass loading of sediment to Maumee Bay from Berger Ditch was simulated using a load/discharge relationship developed through correlation of suspended sediment concentrations with flows from the USGS gage. The model-predicted sediment loads from Berger Ditch to Maumee Bay are depicted in Figures 3.a through 3.f.

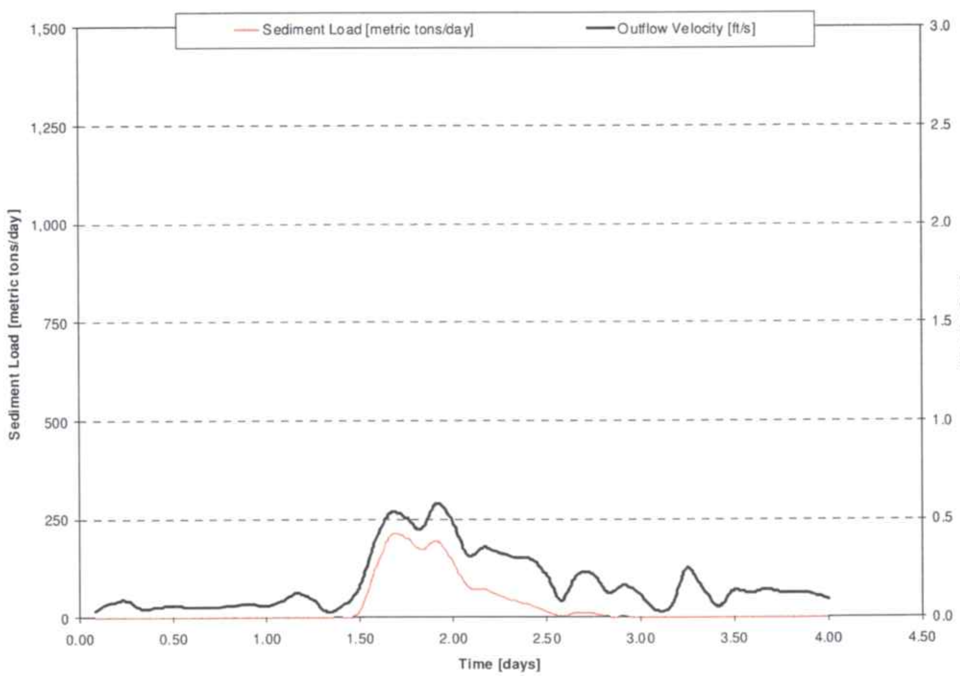

Figure 3.a: Model-predicted Berger Ditch velocity and sediment load to Maumee Bay for the 0.5-year, 24-hour event.

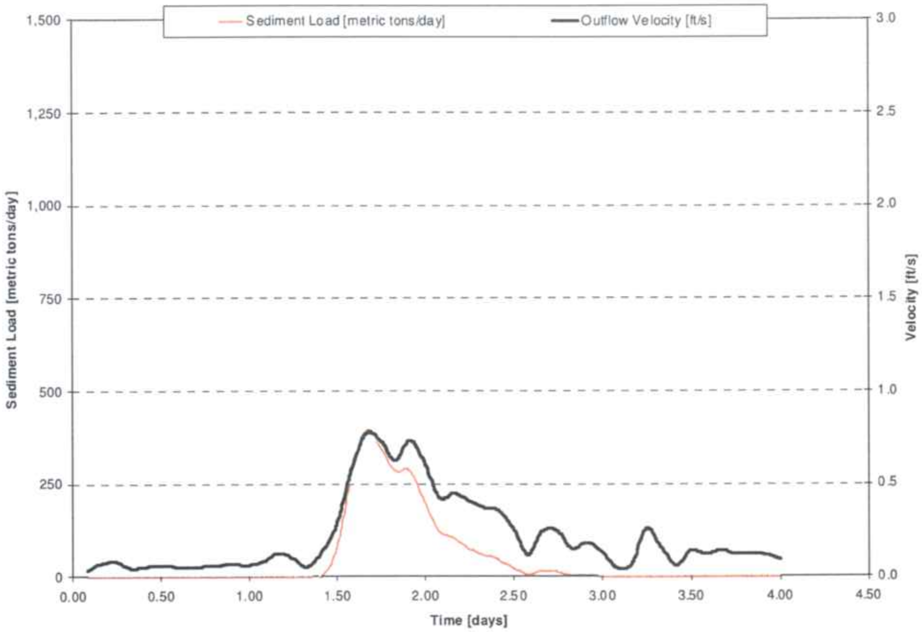

Figure 3.b: Model-predicted Berger Ditch velocity and sediment load to Maumee Bay for the 1-year, 24-hour event.

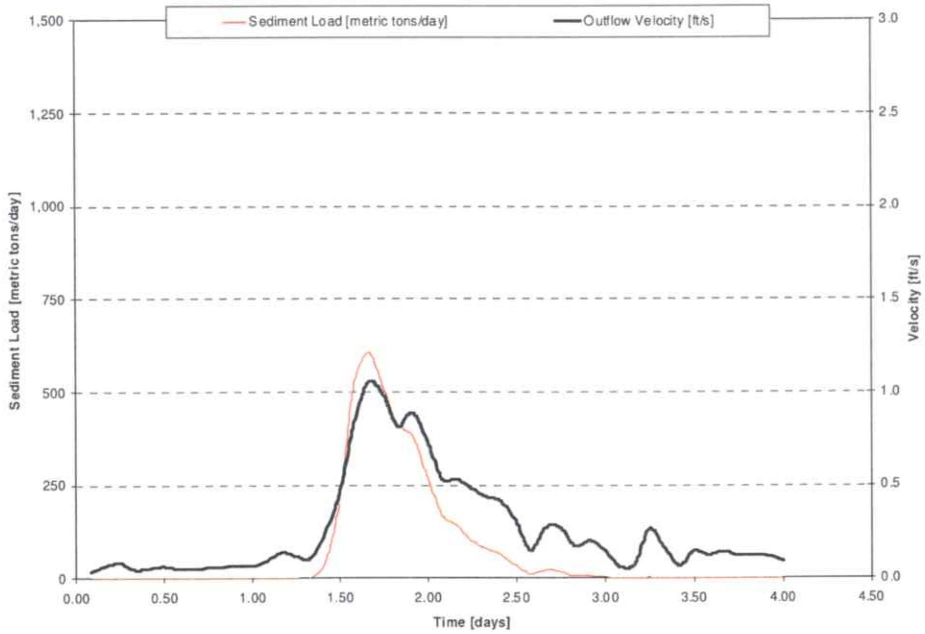

Figure 3.c: Model-predicted Berger Ditch velocity and sediment load to Maumee Bay for the 2-year, 24-hour event.

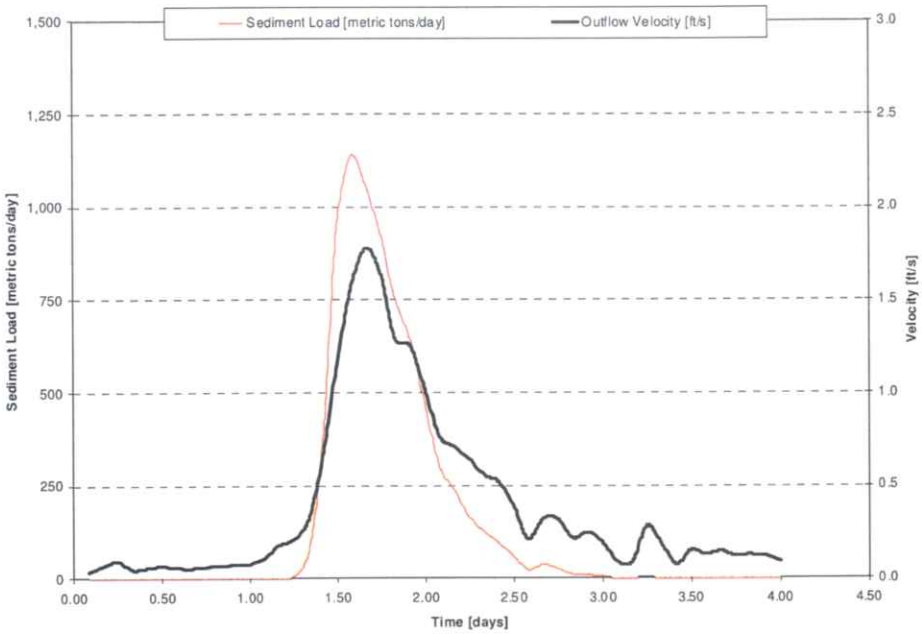

Figure 3.d: Model-predicted Berger Ditch velocity and sediment load to Maumee Bay for the 10-year, 24-hour event.

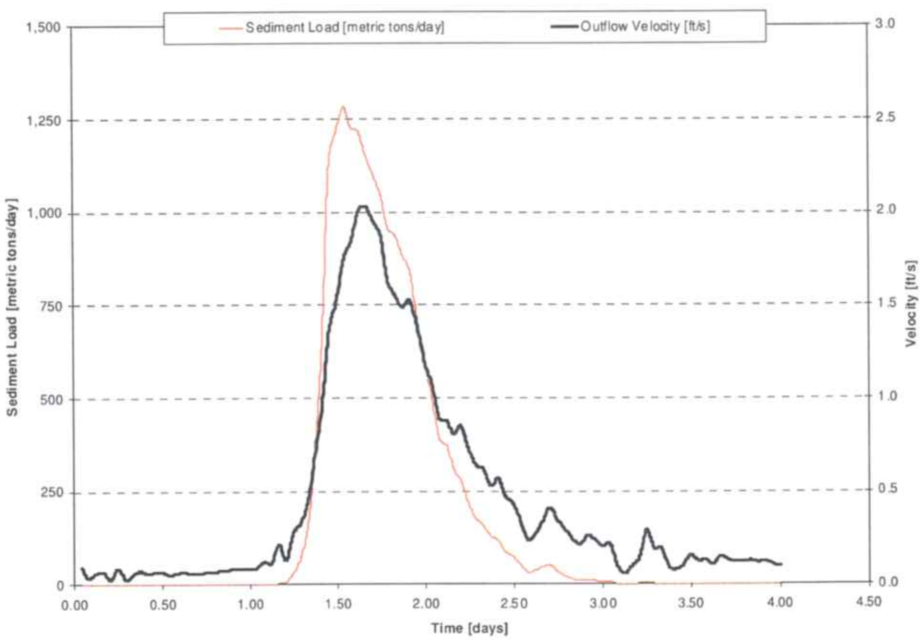

Figure 3.e: Model-predicted Berger Ditch velocity and sediment load to Maumee Bay for the 25-year, 24-hour event.

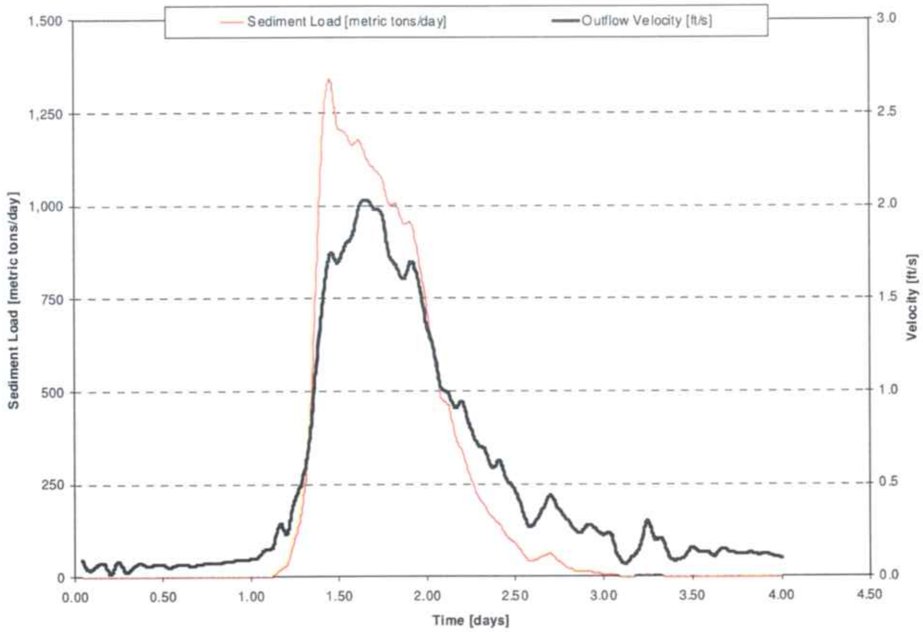

Figure 3.f: Model-predicted Berger Ditch velocity and sediment load to Maumee Bay for the 100-year, 24-hour event.

It should be noted that, although these graphs show that sediment loading to Maumee Bay occurs in response to elevated velocities in Berger Ditch, this should not be interpreted as meaning that the entire sediment load delivered to the Bay is eroded from Berger Ditch. The loads depicted in these plots represent the cumulative load delivered to the Bay from the Wolf Creek/Berger Ditch watershed during given hypothetical storm events.

Short-Term Sediment Transport

Short-term transport of suspended material (sediment and/or bacteria) into Maumee Bay from Berger Ditch is a function of hydrodynamic conditions; as long as velocity and shear stresses remain sfficiently high, the suspended material will remain in suspension. As the energy provided by velocity is dissipated, long-term transport processes in the Bay will begin to dominate, which may result in settling of suspended material or further transport. To investigate the short-term distribution of sediment load in Maumee Bay, Maumee Bay model output was examined to evaluate the dissipation of velocity and shear stress.

Figure 4 shows model results under peak flow conditions (Berger Ditch flow nearly 250 cfs) for the simulation period of May 1, 2006 to October 1, 2006. The figures show that, even under peak conditions, velocity and shear stress are dissipated within 1000 feet of shore. It should be noted that this does not necessarily mean that suspended material will settle out of suspension, but that a transition from Berger Ditch-driven transport to Maumee Bay-driven transport occurs in this region.

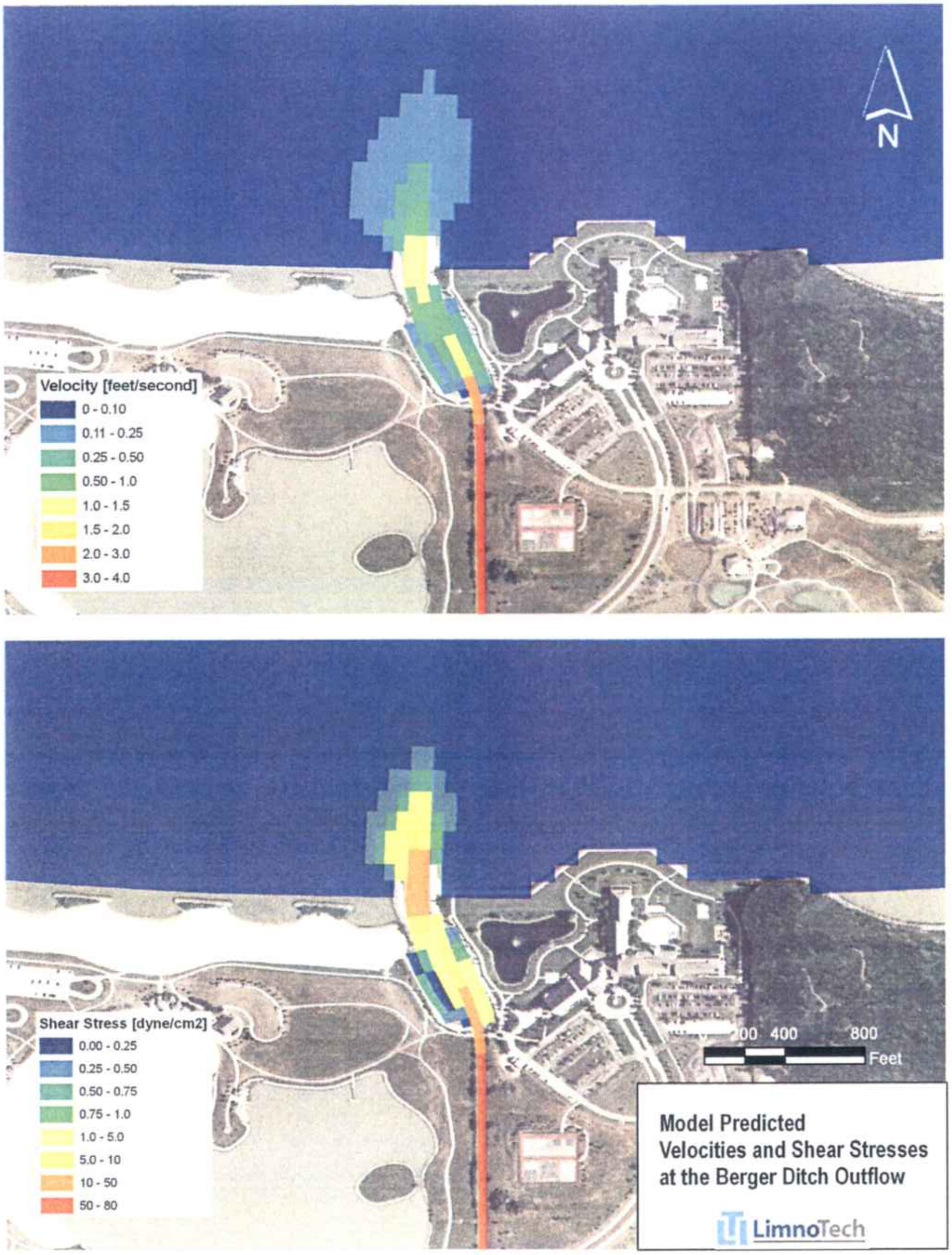

Figure 4: Dissipation of Berger Ditch outflow velocity and shear stress in Maumee Bay (Berger Ditch flow ~ 250 cfs)

Long-Term Sediment Transport

The Maumee Bay model was also used to examine long-term sediment movement in the Bay, to better understand how bacteria associated with suspended sediment might be distributed over time. This was accomplished by using a particle tracking simulator with the hydrodynamic model. The particle tracker simulates the pathway of suspended particles that are driven by advection and are assigned a constant settling velocity. The particle tracker was used for long-term transport simualtions because the actual sediment transport model is computationally intensive and requires much longer run times than the particle tracker.

The particle tracking simulations show that, although momentum from the Berger Ditch outflow persists for hundreds of feet into the Bay, Maumee Bay hydrodynamic processes quickly become dominant after flow enters the Bay. So, within a few hours of entering the Bay, the transport of suspended sediment is entirely dependent on wind-driven currents and other Bay hydrodynamic processes.

The particle tracking simulation was run for a five-month period with a continuous release of particles to observe the potential long-term distribution of suspended materials. Additionally, assuming that constituents that are released from Berger Ditch are mostly associated with fine particles, most of the sediment mass will be deposited in the bay within one mile of the Berger Ditch outflow (in the direction of the shore) and within 1,000 feet of the shore.

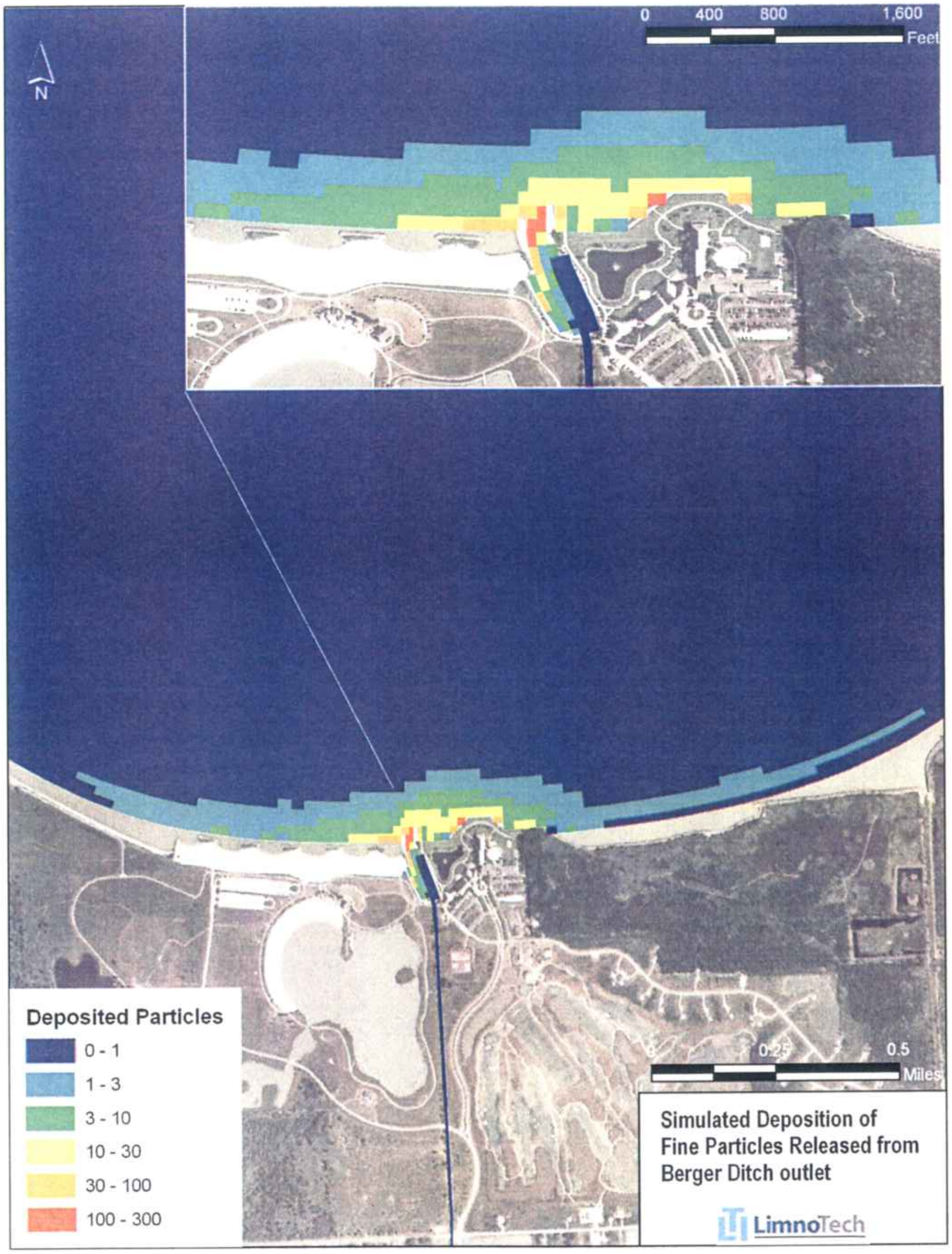

Figure 5: Particle tracking simulation results showing long-term distribution of settled particles (representative of suspended sediment).

Recommendations

The Wolf Creek/Berger Ditch watershed and Maumee Bay hydrodynamic models developed under this scope of work are potentially powerful tools for better understanding the transport of bacteria and suspended sediments from Berger Ditch to Maumee Bay. The models have the potential to be used for a variety of appliations including the design of bacteria load mitigation strategies and coastal wetland restoration. However, some work is required to improve the accuracy of the models. To this end, the folowing recommendations are made:

- Additional rainfall data should be collected in the Wolf Creek/Berger Ditch watershed. The calibration of the SWMM watershed model can be improved by concurrent collection of rainfall data at two or three other locations in the watershed. Short-term deployment of rain gages (two to three months) should suffice. Rainfall data should be recorded at an hourly (or finer) time interval.
- Additional hydrodynamic data should be collected in Maumee Bay near Maumee Bay State Park. The Maumee Bay hydrodynamic model developed under this scope of work is not calibrated and additional data would be useful in calibration.
- More refined bathymetric data should be collected in Maumee Bay near the outflow of Berger Ditch. Currently, the model bathymetry is based on 1-meter contours. Bathymetric data with more detail may improve estimations of near-shore velocities, shear stresses, and depositional patterns.
- An understanding of the processes that result in elevated bacteria concentrations in Berger Ditch should be developed. USGS bacteria data show that bacteria concentrations are sometimes elevated even under low-flow conditions when suspended sediment concentrations are relatively low. Before we continue to model suspended sediment as a surrogate for bacteria, we should understand the extent to which elevated bacteria concentrations are related to resuspension of sediments.

More detailed recommendations, including suggested locations for data collection can be provided upon request.

References

Brady, A. M. G. *Escherichia coli and Suspended Sediment in Berger Ditch at Maumee Bay State Park, Oregon, Ohio, 2006.* United States Geological Survey (USGS) Open-File Report 2007-1244. 2007.

Tetra Tech, Inc. User's Manual for Environmental Fluid Dynamics Code Hydro Version (EFDC-Hydro). 2002.