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Simulation/Validation of Pollutant Transport in Rivers Using COMSOL

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Green Streets Infrastructure LLC

Our atmosphere, land, and water are being continuously besieged by pollutants caused by such events as heavy metals leaching from mine tailing ponds, chemical spills from railroad and truck tanker accidents, and petroleum pipeline failures, to name just a few. These environmental insults are usually point generated but quickly become expanded to 2 and 3-dimensional problems, depending upon the flow regimes of the receiving surface and subsurface water bodies.

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Dye tracer studies have been used to develop an understanding of water feature based pollutant transport. Because they require significant time and preparation to conduct, these studies are not practical for rapid response to an event that has already happened, and much too expensive to do on a wide scale for emergency planning exercises.

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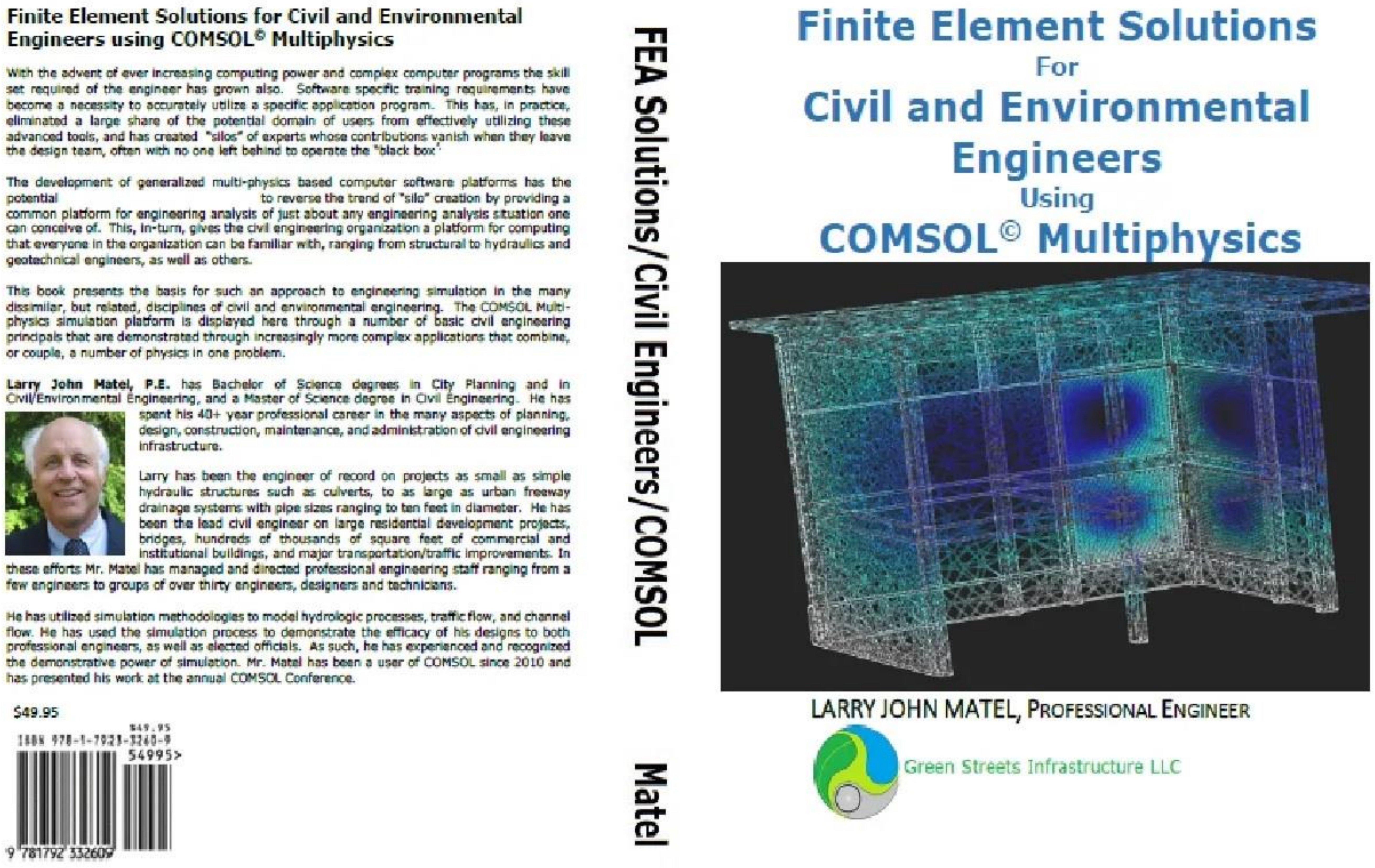
This paper is an excerpt from the book *"Finite Element Solutions for Civil and Environmental Engineers using COMSOL Multiphysics"* - ISBN 978-1-7923-3260-9, 2020. Look for it on Amazon or contact me at ljm@greenstreetsinfrastructure.com.



Interested Communities

- Environmental Engineers
- River Engineers
- Emergency Response Professionals
- Water Resource Managers

Theory

- **The physics of the Navier-Stokes equations and the Mass Transport equation contained in the Fluid Flow Interface, coupled with the Transport of Diluted Species Interface, can be used to estimate the extent and movement of pollutants introduced into flowing water bodies.**

Navier-Stokes and Mass Transport Equations

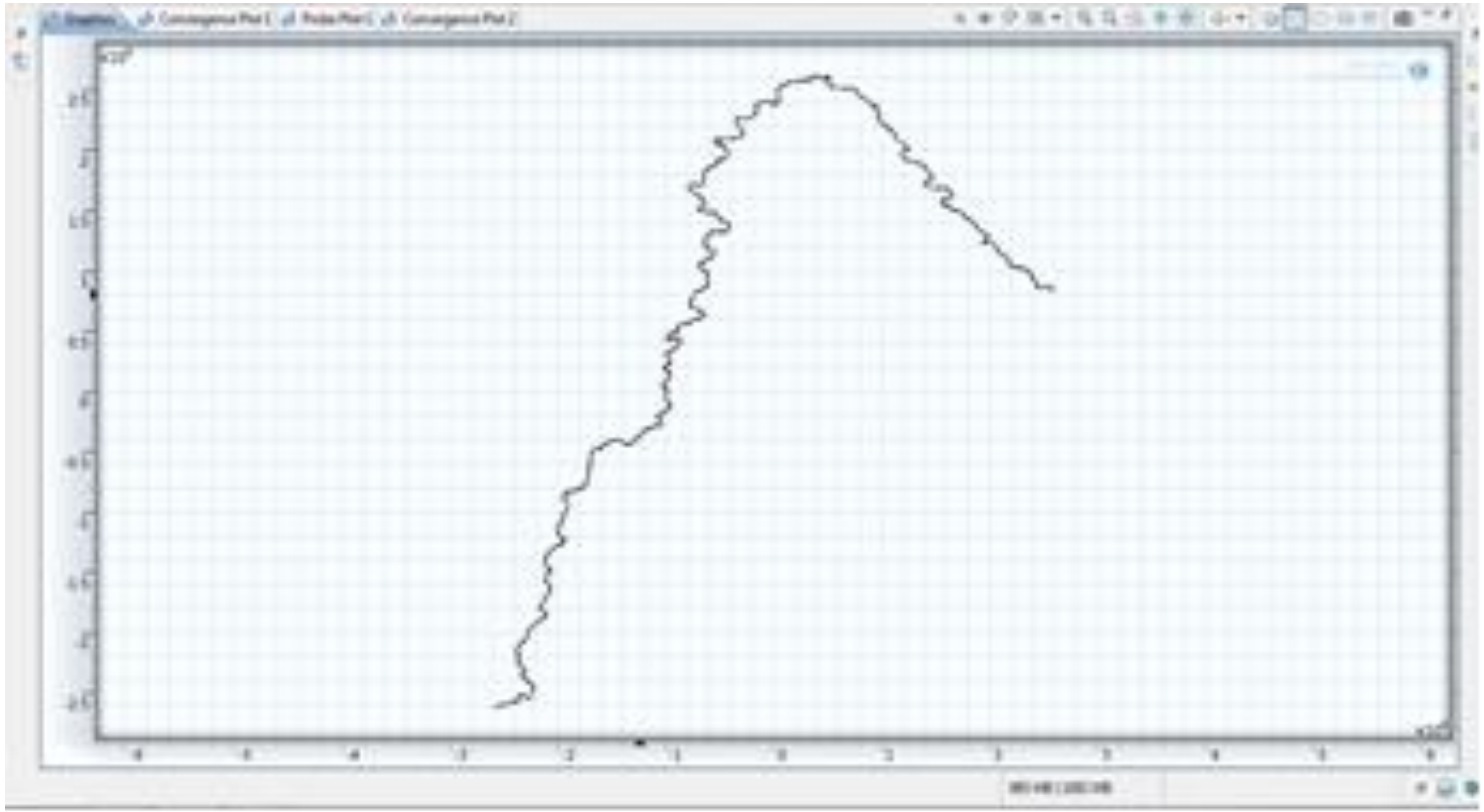
$$\rho\frac{\partial \mathbf{u}}{\partial t} + \rho(\mathbf{u}\cdot\nabla)\mathbf{u} = \nabla\cdot[-p\mathbf{I} + \mu(\nabla\mathbf{u} + (\nabla\mathbf{u})^T)] + \mathbf{F}$$

$$\frac{\partial c_i}{\partial t} + \nabla\cdot(-D\nabla c_i) + \mathbf{u}\cdot\nabla c_i = R_i$$

Data Needs

- Riverbank Aerial Photos - Mapping
- Historical River Flow Records
- Mass of Material

Model Geometry – 25.5 Miles



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The meandering course of the Pilchuck River travels 25.5 miles from its upstream reaches near Menzel Lake Road in Snohomish County to its confluence with the Snohomish River. The river surface drops from an elevation of approximately 450 feet above sea level at Menzel Lake Road to an elevation of approximately 15 feet above sea level at its confluence with the Snohomish River. The flow in the river during this study ranged from approximately 50 cubic feet per second at Menzel Lake Road to on the order of 100 cubic feet per second at its confluence with the Snohomish River near the Town of Snohomish. This .3 percent gradient is consistent and has no significant or abrupt grade changes or waterfalls.

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Initial Values and Boundary Conditions

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Laminar Flow: The inflow velocity for the Laminar Flow interface at the head end of the study reach is initially estimated at .22 meters per second based upon available hydrologic model data of the river provided by the WaDOE. This estimate is more readily available than actual flow measurements determined in the field. The inflow velocity is adjusted to .24 meters per second so that the simulated peak is more closely aligned with the actual measured concentration peak at Robe Menzel Road, .28 days from the introduction of the dye, approximately 4 miles downstream.

The WaDOE reports that 375 milliliters were introduced into the river, or 435 grams. When converted to mass using a density of 1.16g/ml for Rhodamine WT, this equates to approximately .48 moles when using a molecular weight of 567g/mole for the dye. The flux rate estimated from these measurements is .12 moles per square meter per second for the four seconds required to empty the dye bottles across the river section. The diffusion coefficient for Rhodamine dye is approximately 4e-6 centimeters squared per second. The water temperature in this area is on the order of 60 degrees F.

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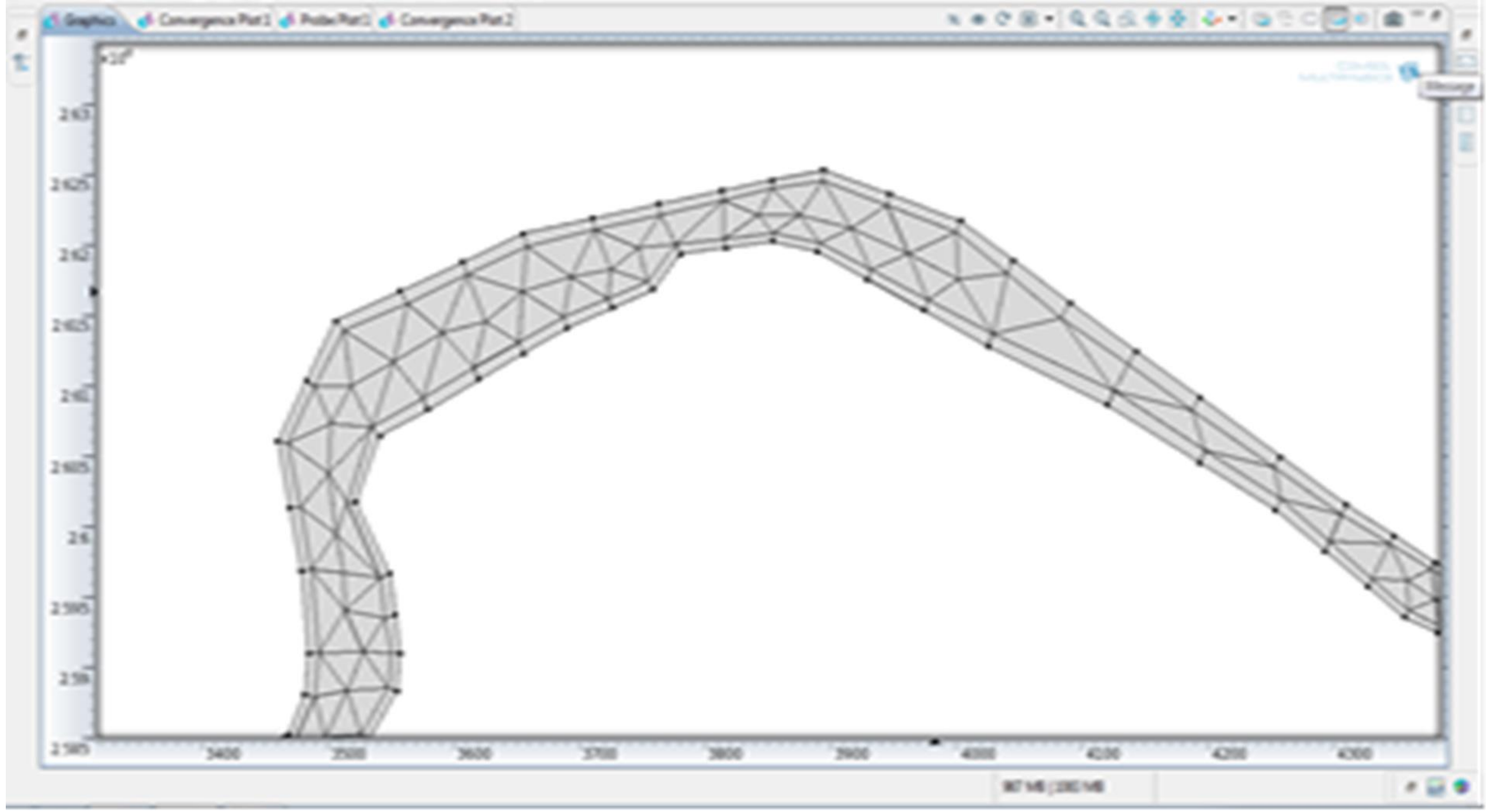
Model Mesh

A Physics based mesh is used, with a pre-defined mesh size of Coarse. Boundary layers are automatically created on each river bank by COMSOL's automatic meshing procedure. The boundary layers are modified to include just one layer on all bank segments. A width factor of 5 is used.



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Study

The COMSOL predefined solver settings in the time-dependent mode are reflective of the settings used in the *Process Control Using a PID Controller* model available in the COMSOL application library.

The time range starts at time zero and ranges to the time to traverse the river length as estimated by the average velocity of the inlet conditions. For this example time steps of 900 seconds are initially used for expediency, but any step size can be entered depending upon the need for time precision. Time stepping of 1 second is used for the first 5 seconds during the period when the dye is introduced into the river. The study runs to convergence in approximately two to three hours.

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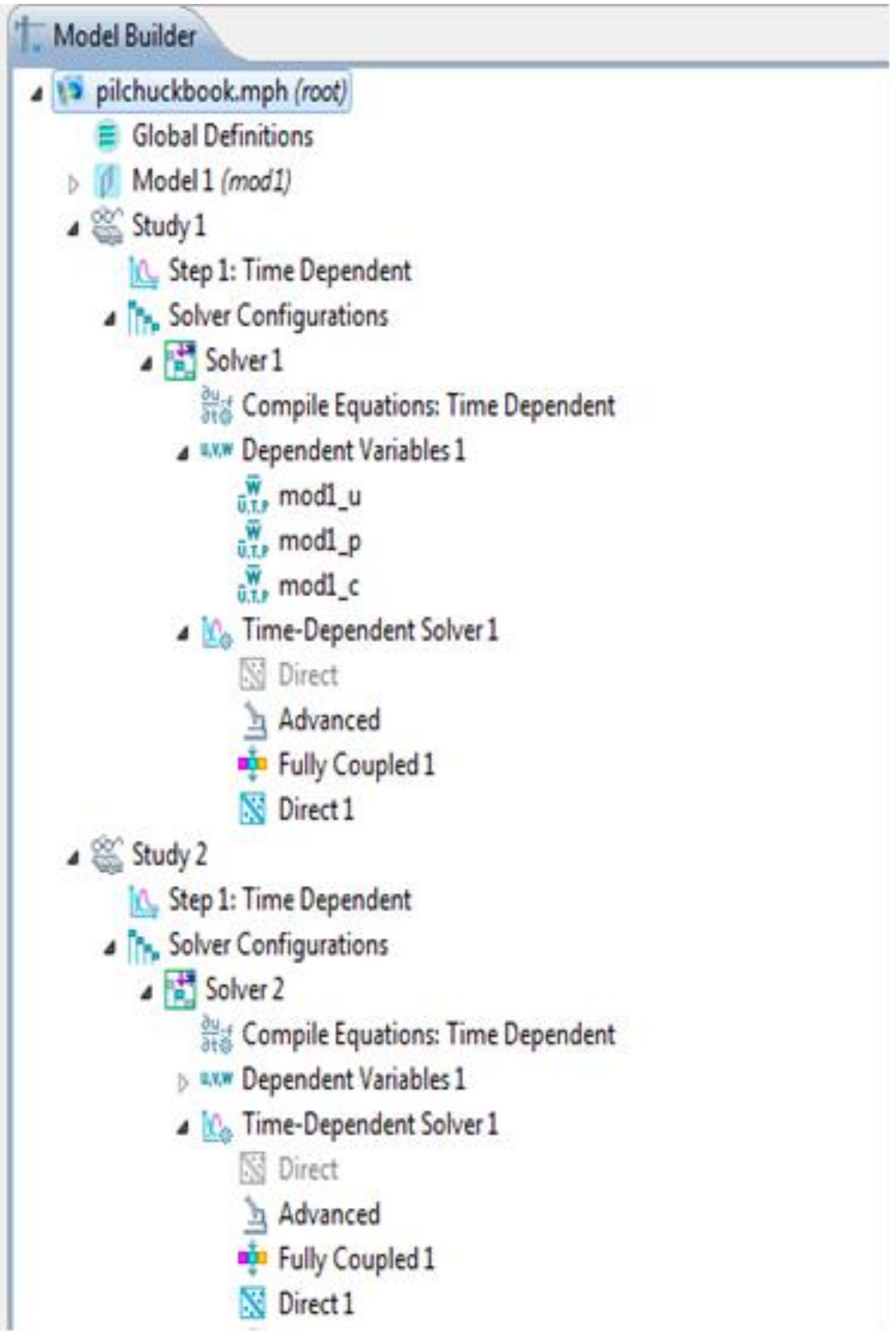
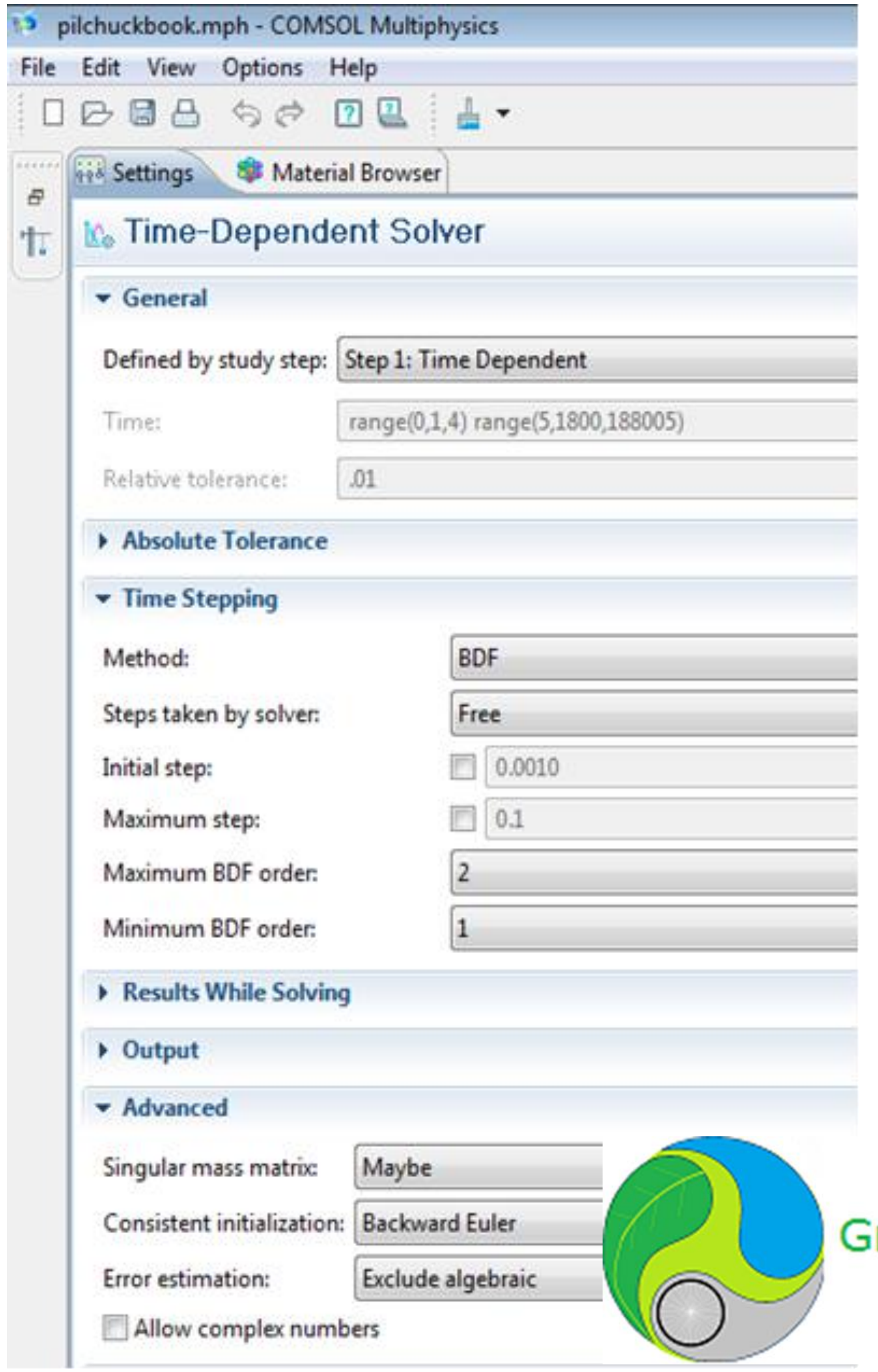
Study





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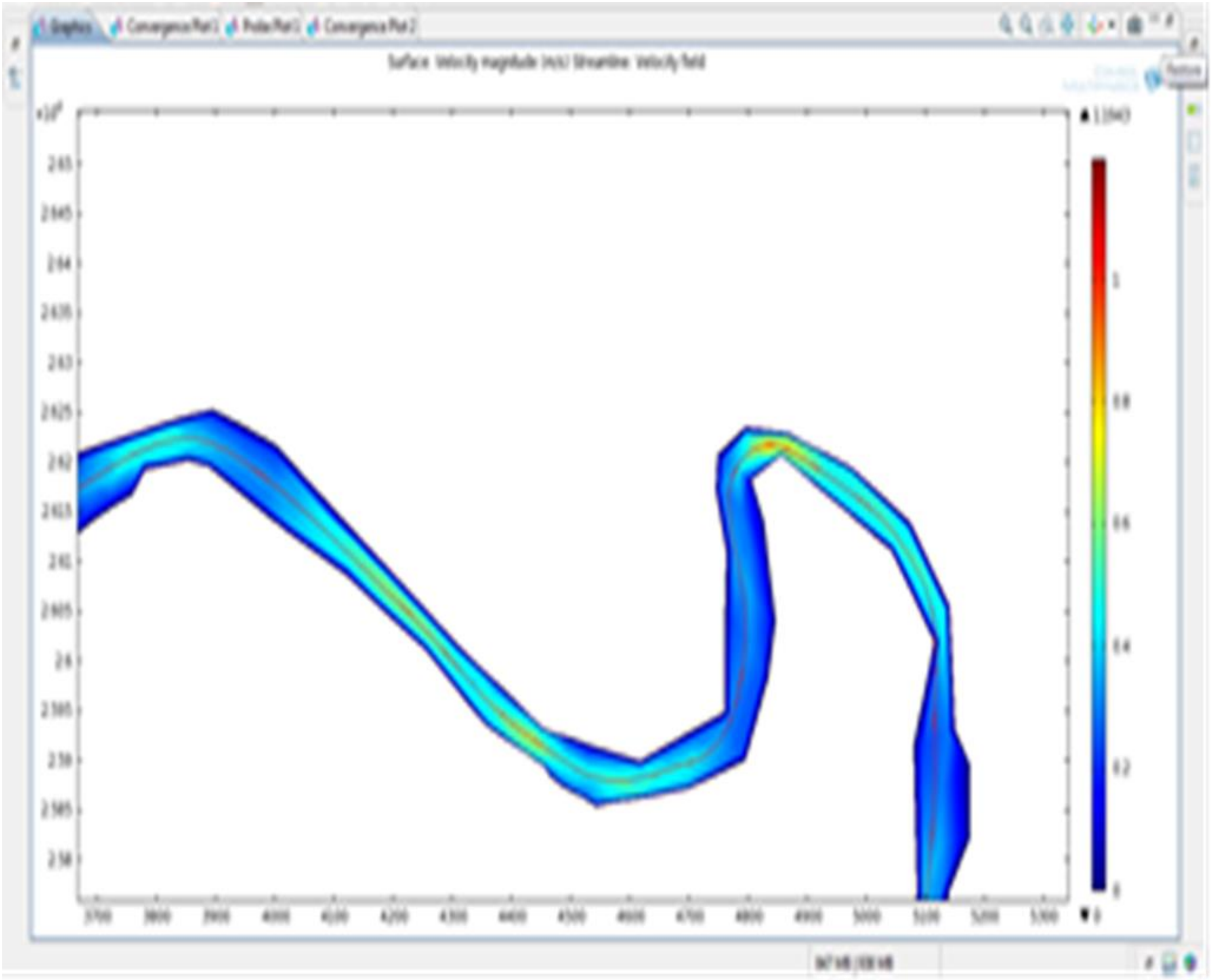
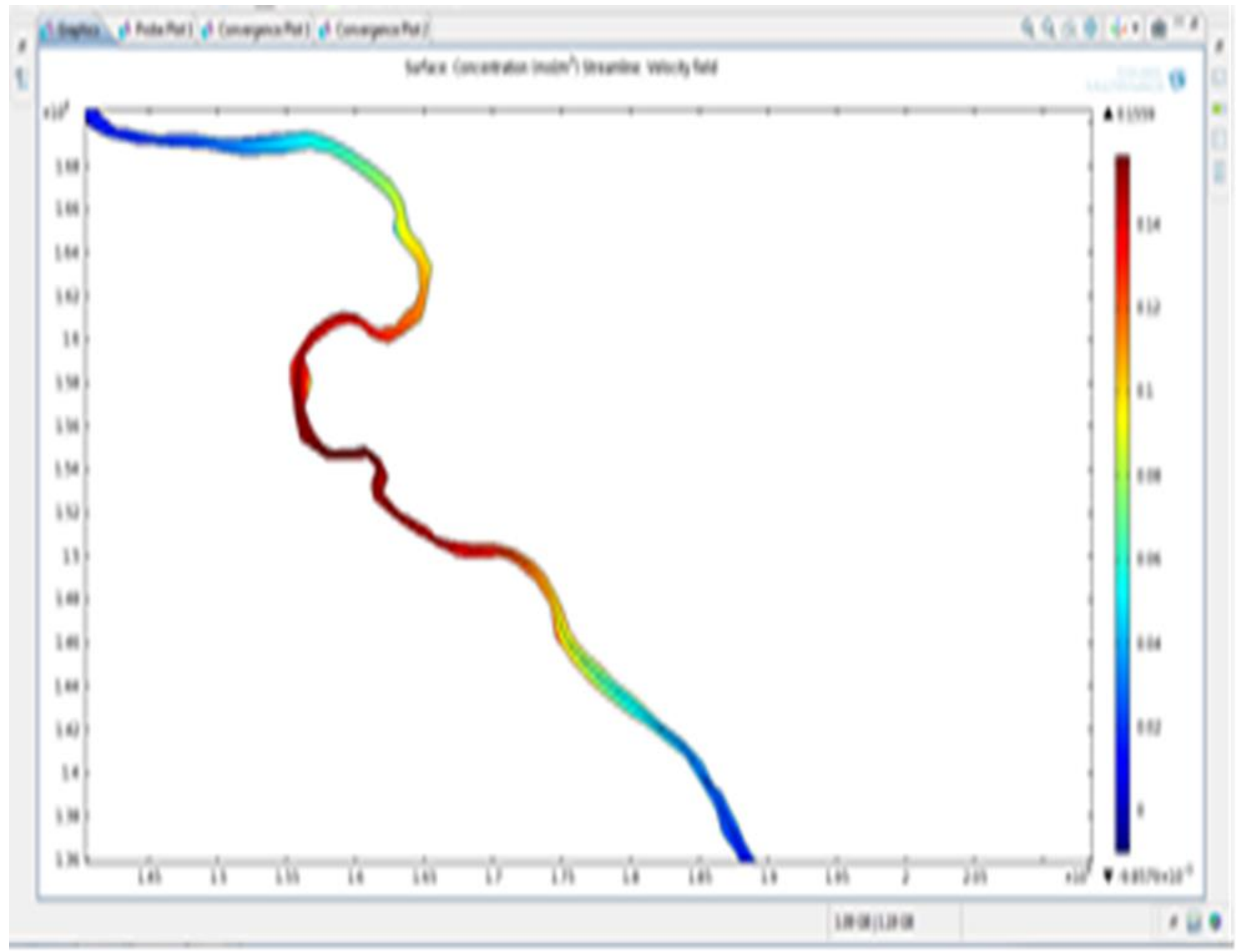
Simulation Results

Velocity Field



Concentration Field



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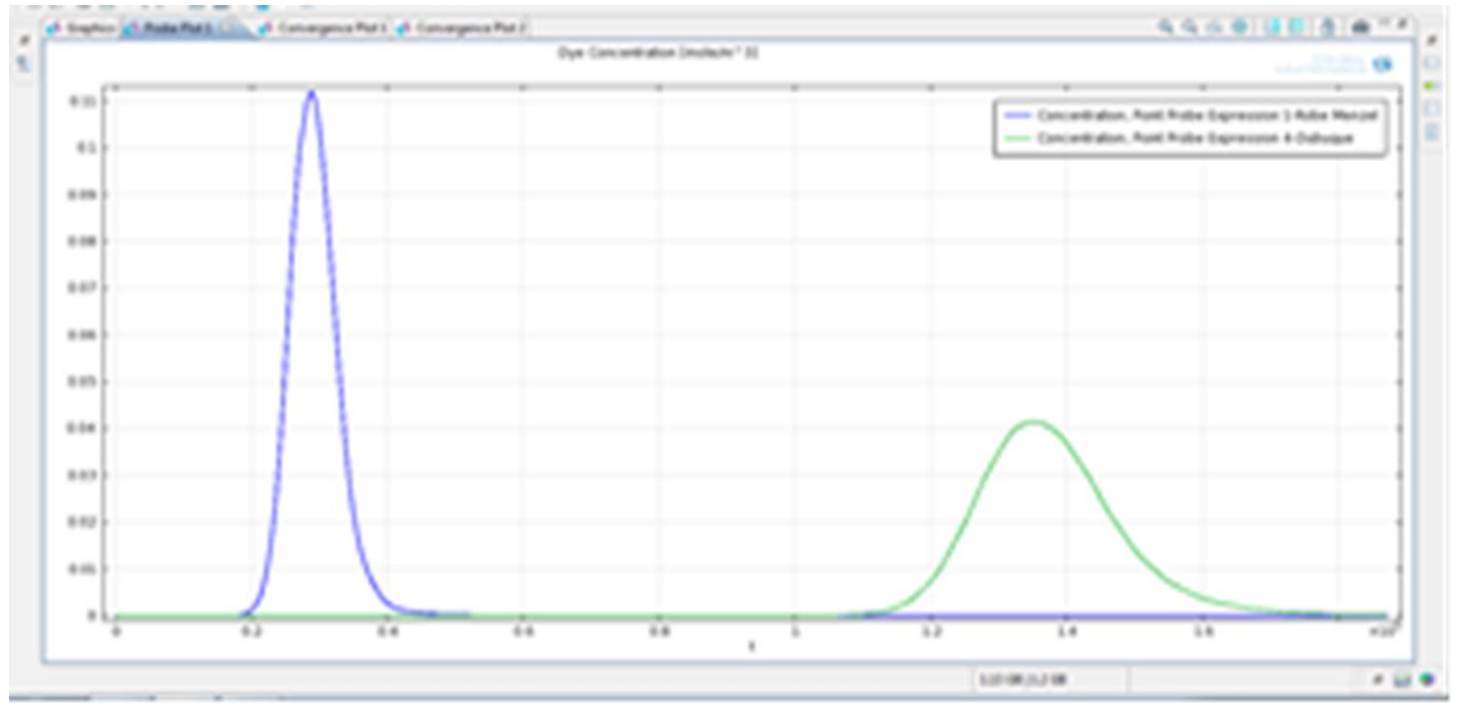
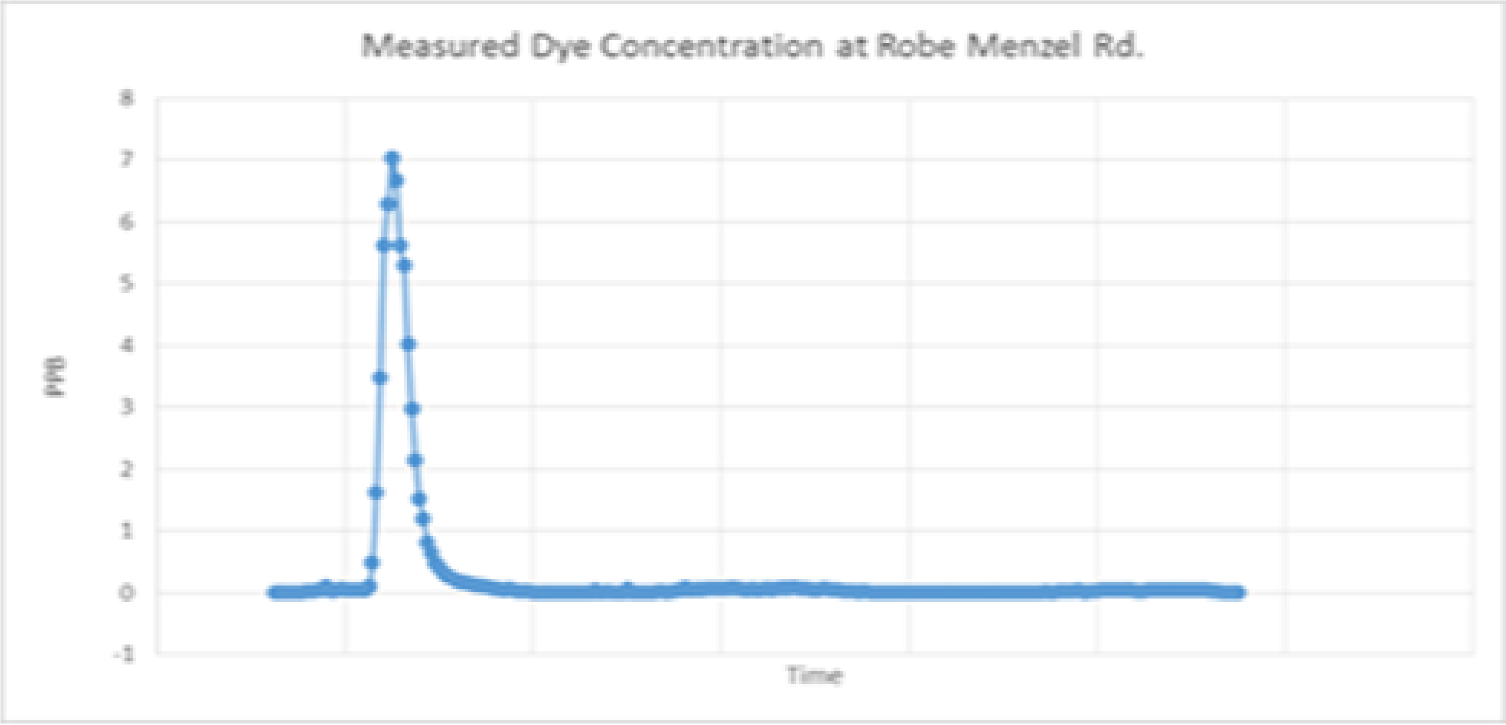
Validation Results

Simulation Probe Plot



Measured



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Conclusions

- COMSOL is able to simulate dye tracer studies in rivers and streams and, by extension, can be used as a quick response tool for estimating travel time and concentration degradation of pollutants and other chemicals in rivers and streams. This can be done with nothing more than stream bank geometry, readily available estimates of stream flow, and estimates of the mass of chemical introduced into the watercourse.

References

- K. Kachiashvili, G. Gordeziani, R. Lazarov, and D. Melikdzhanian, Modeling and Simulation of Pollutant Transport in Rivers. Applied Mathematical Modelling, Volume 31, Issue 7, Pages 1371-1396, ISSN-0307-904X,2007. https://doi.org/10.1016/j.apm.2006.02.015.

- F .A. Kilpatrick and J .F. Wilson, Jr., Techniques of Water-Resources Investigations of the United States Geological Survey, Chapter A9 - Measurement of Time of Travel in Streams by Dye Tracing, This manual is revision of Measurement of Time of Travel and Dispersion in Streams by Dye Tracing, E.F. Hubbard, Kilpatrick, L.A. Martens, and J .F Wilson, Jr., Book 3, Chapter A9, 1982.

- T. Swanson, A. King, N. Gurdian, and J. Zhen, French Creek and Pilchuck River Temperature, Dissolved Oxygen, and pH Total Maximum Daily Load Water Quality Study Design Quality Project Plan, Publication Number 12-030114, August 2012.

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