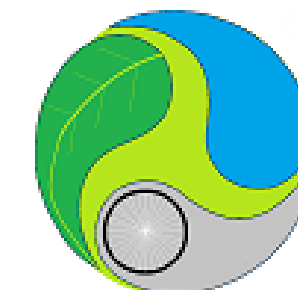


Simulation/Validation of Pollutant Transport in Rivers Using COMSOL

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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.



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.

Finite Element Solutions for Civil and Environmental Engineers using COMSOL® Multiphysics

With the advent of ever increasing computing power and complex computer programs the skill set required of the engineer has grown also. Software specific training requirements have become a necessity to accurately utilize a specific application program. This has, in practice, eliminated a large share of the potential domain of users from effectively utilizing these advanced tools, and has created “silos” of experts whose contributions vanish when they leave the design team, often with no one left behind to operate the “black box”.

The development of generalized multi-physics based computer software platforms has the potential to reverse the trend of “silo” creation by providing a common platform for engineering analysis of just about any engineering analysis situation one can conceive of. This, in-turn, gives the civil engineering organization a platform for computing that everyone in the organization can be familiar with, ranging from structural to hydraulics and geotechnical engineers, as well as others.

This book presents the basis for such an approach to engineering simulation in the many dissimilar, but related, disciplines of civil and environmental engineering. The COMSOL Multi-physics simulation platform is displayed here through a number of basic civil engineering principals that are demonstrated through increasingly more complex applications that combine, or couple, a number of physics in one problem.

Larry John Matel, P.E. has Bachelor of Science degrees in City Planning and in Civil/Environmental Engineering, and a Master of Science degree in Civil Engineering. He has spent his 40+ year professional career in the many aspects of planning, design, construction, maintenance, and administration of civil engineering infrastructure.



Larry has been the engineer of record on projects as small as simple hydraulic structures such as culverts, to as large as urban freeway drainage systems with pipe sizes ranging to ten feet in diameter. He has been the lead civil engineer on large residential development projects, bridges, hundreds of thousands of square feet of commercial and institutional buildings, and major transportation/traffic improvements. In these efforts Mr. Matel has managed and directed professional engineering staff ranging from a few engineers to groups of over thirty engineers, designers and technicians.

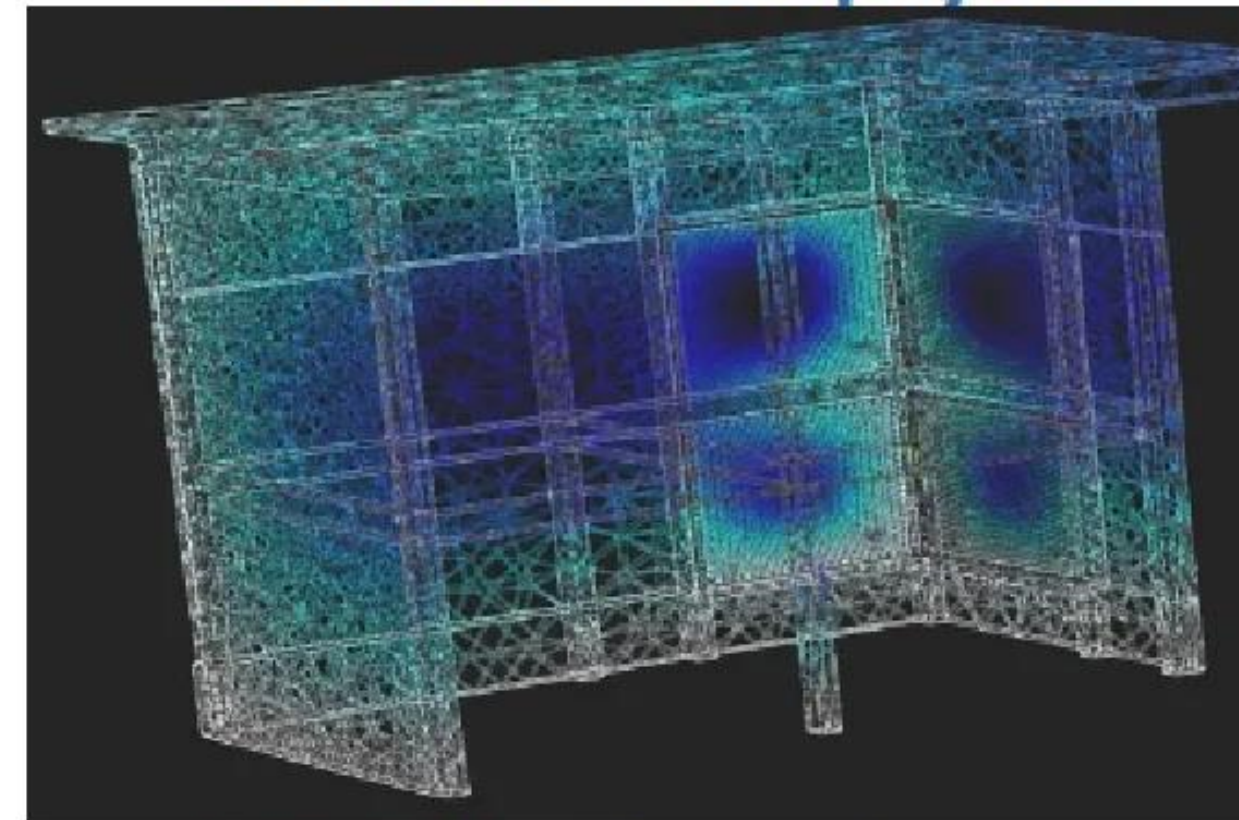
He has utilized simulation methodologies to model hydrologic processes, traffic flow, and channel flow. He has used the simulation process to demonstrate the efficacy of his designs to both professional engineers, as well as elected officials. As such, he has experienced and recognized the demonstrative power of simulation. Mr. Matel has been a user of COMSOL since 2010 and has presented his work at the annual COMSOL Conference.



FEA Solutions/Civil Engineers/COMSOL

Matel

Finite Element Solutions For Civil and Environmental Engineers Using COMSOL® Multiphysics



LARRY JOHN MATEL, PROFESSIONAL ENGINEER



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

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

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

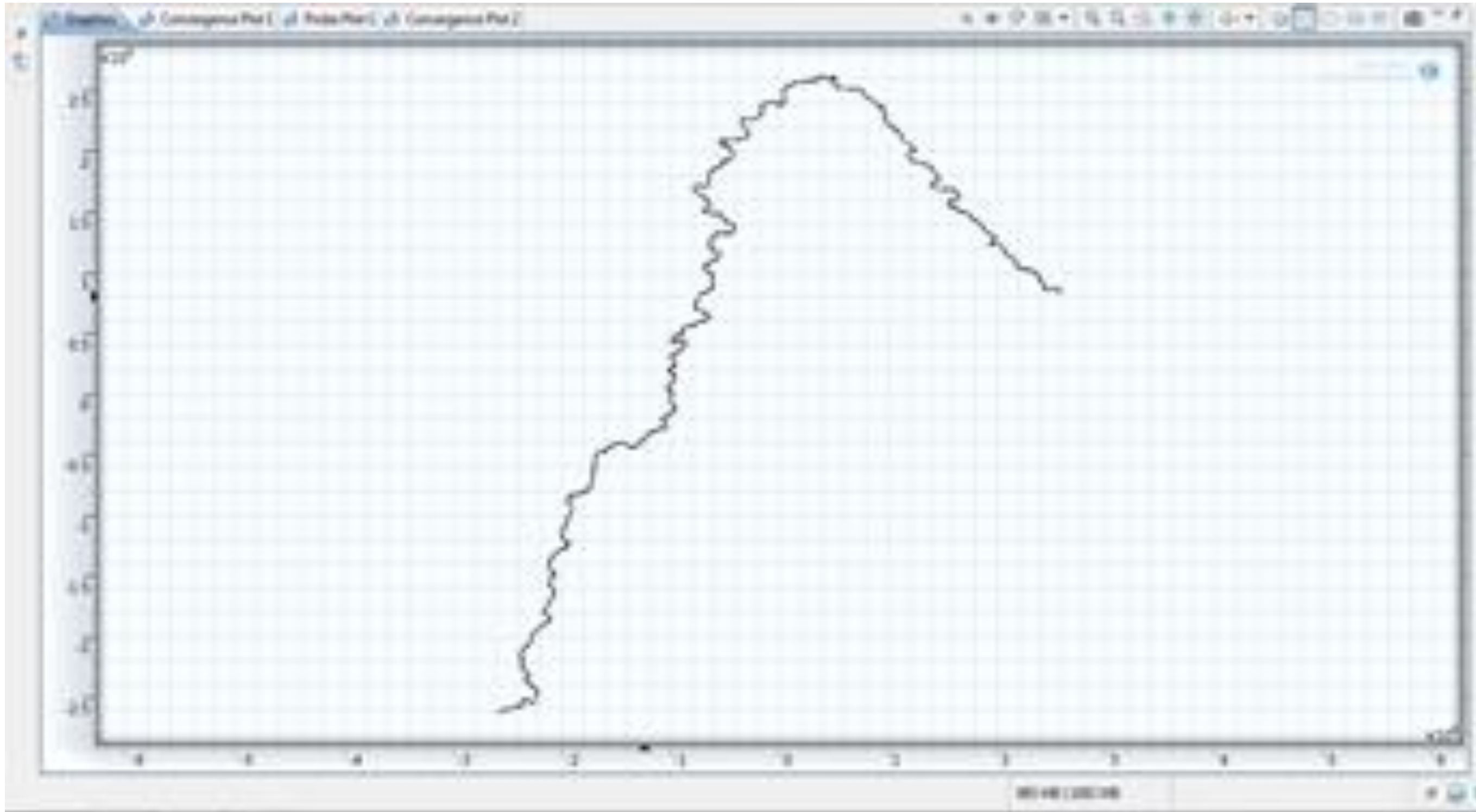


Data Needs

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



Model Geometry – 25.5 Miles



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.



Initial Values and Boundary Conditions



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.

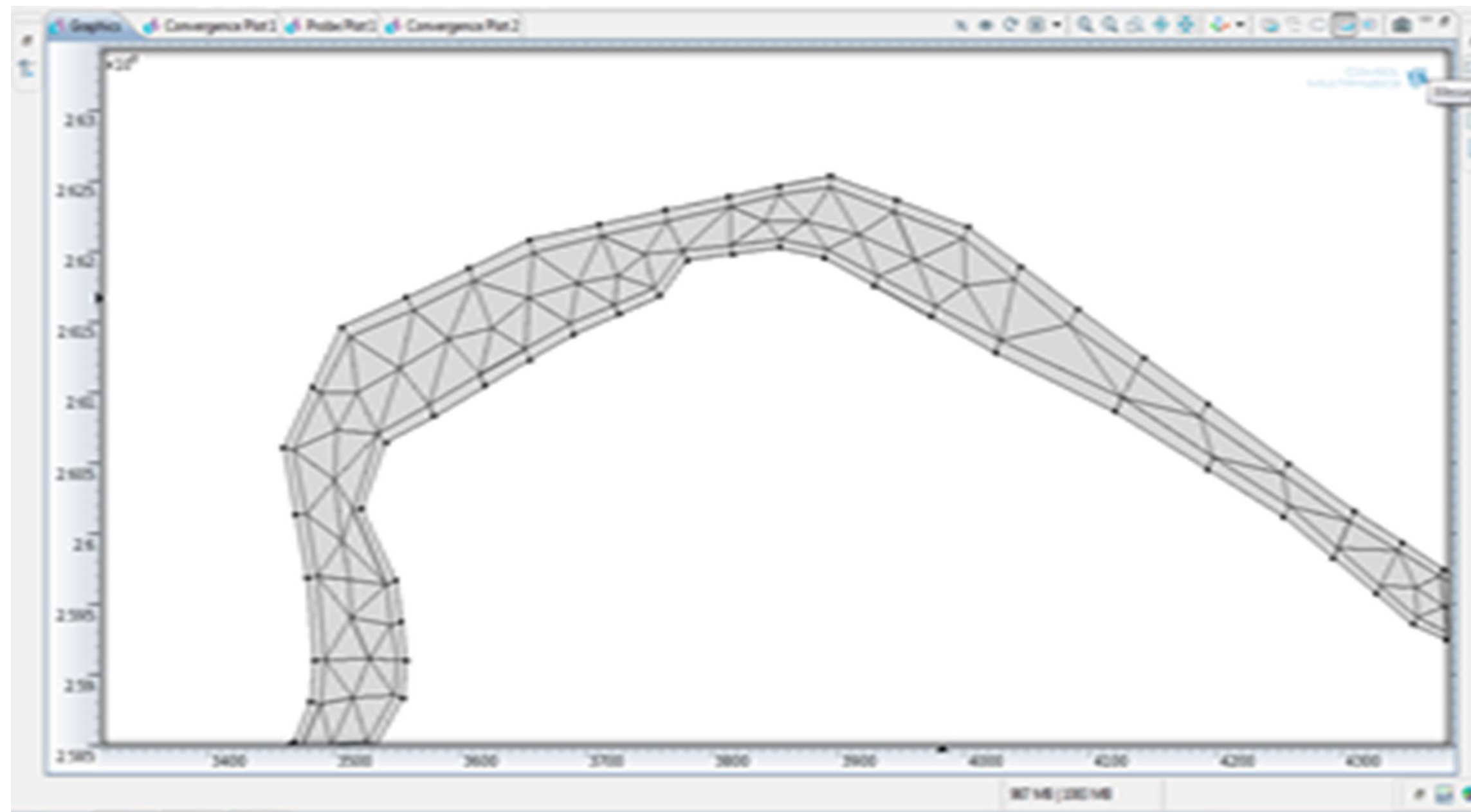


The WaDOE reports that 375 milliliters were introduced into the river, or 435 grams. When converted to mass using a density of 1.16g/ml for Rhodamine WT, this equates to approximately .48 moles when using a molecular weight of 567g/mole for the dye. The flux rate estimated from these measurements is .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.



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.



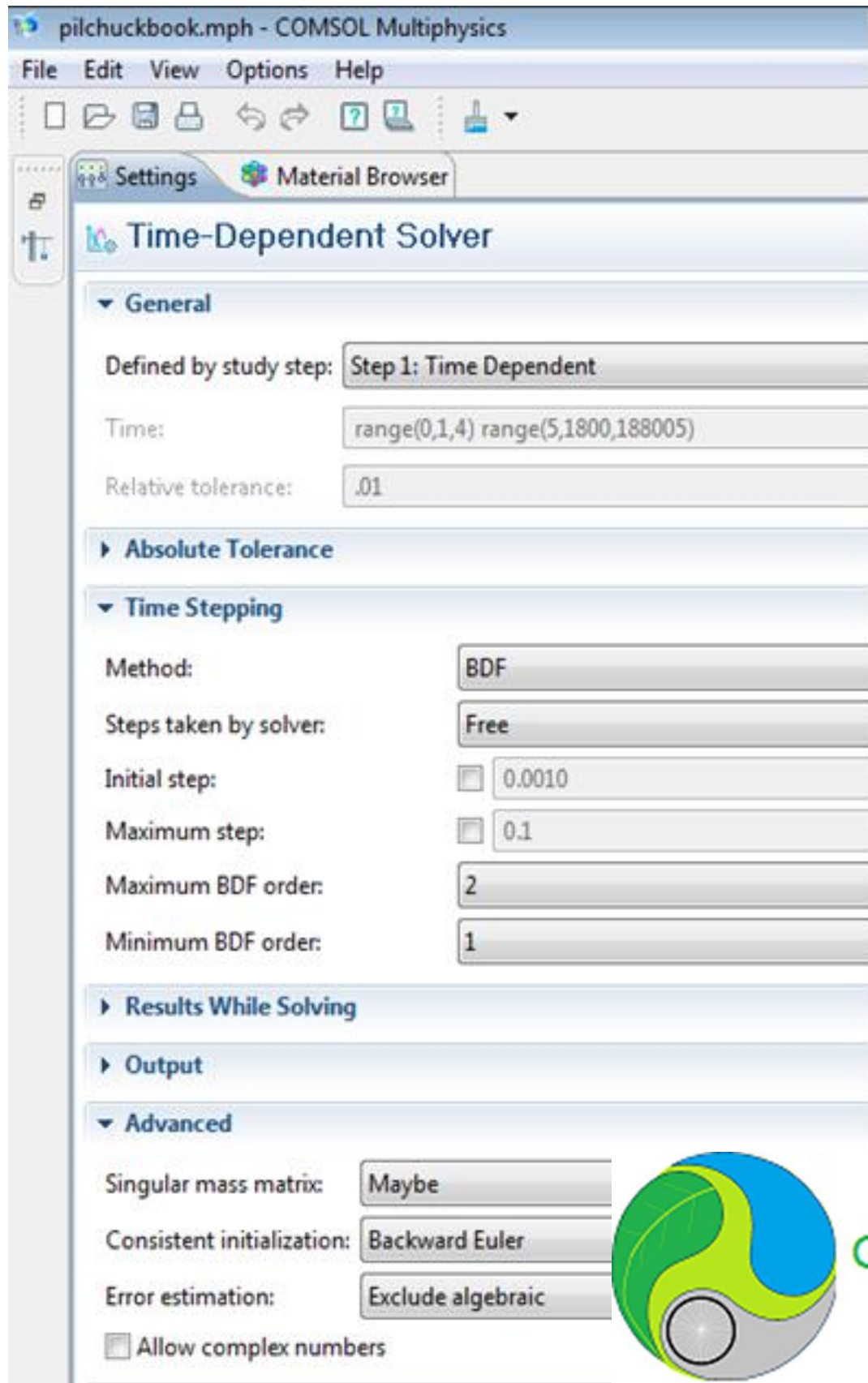
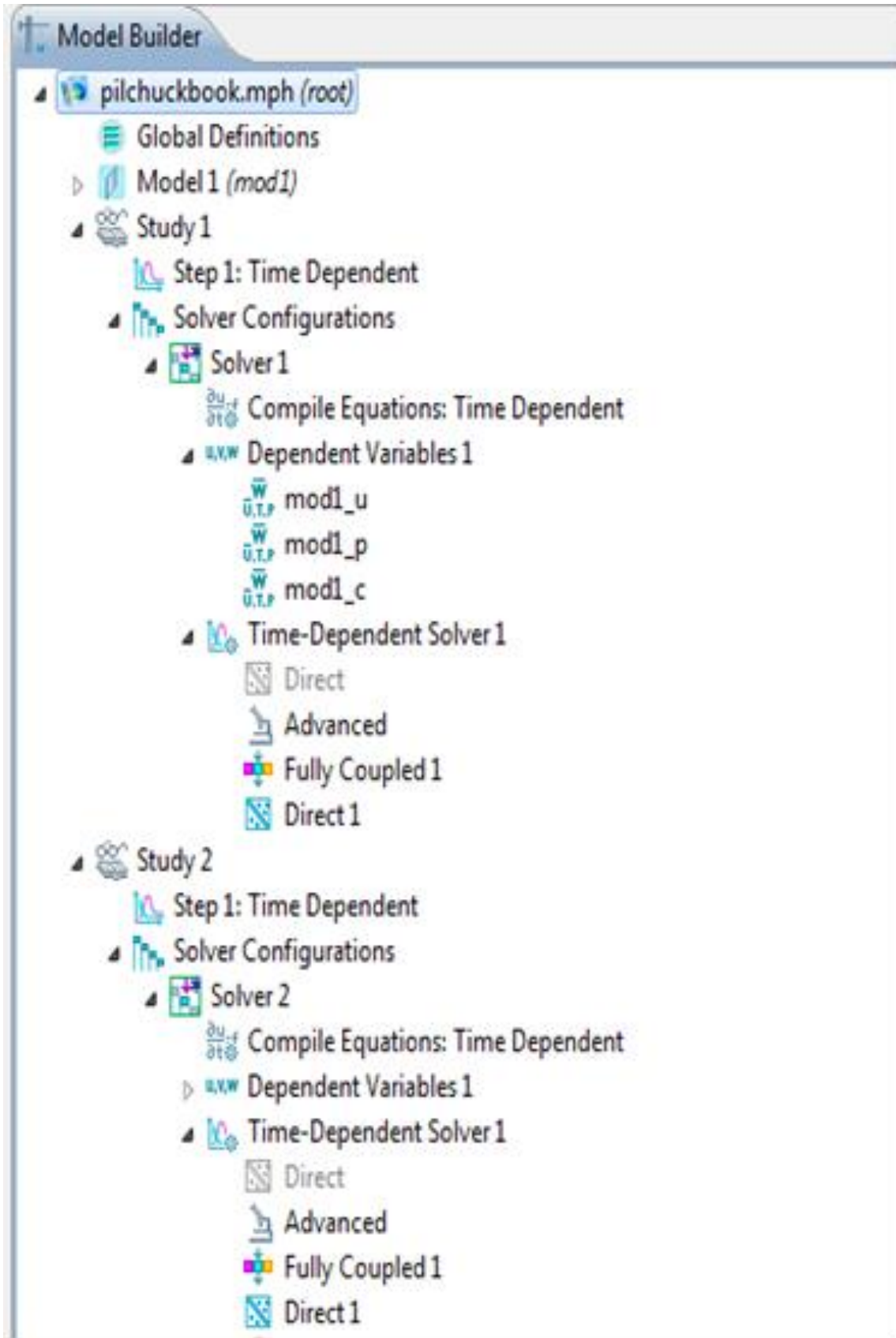
Study

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.

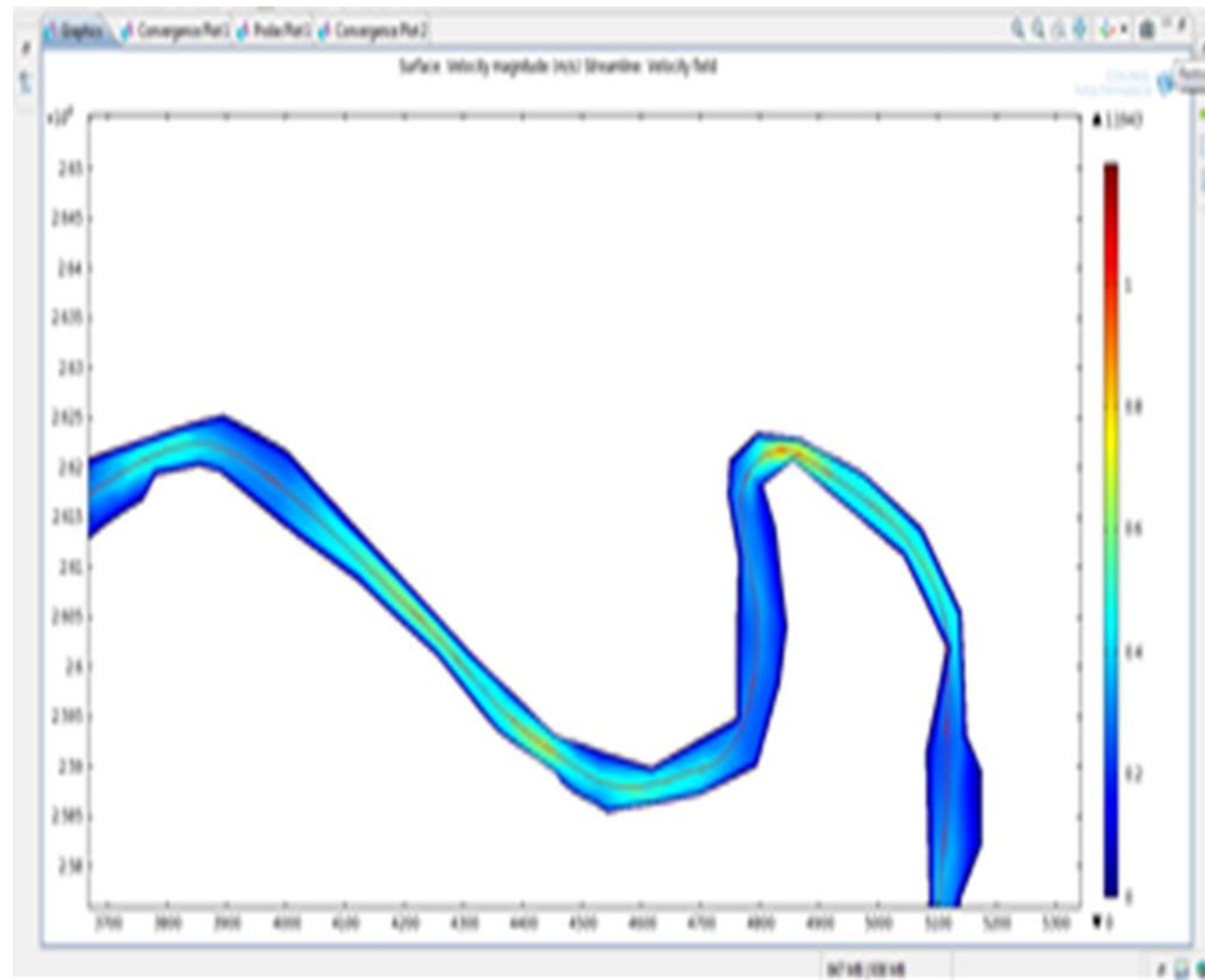


Study

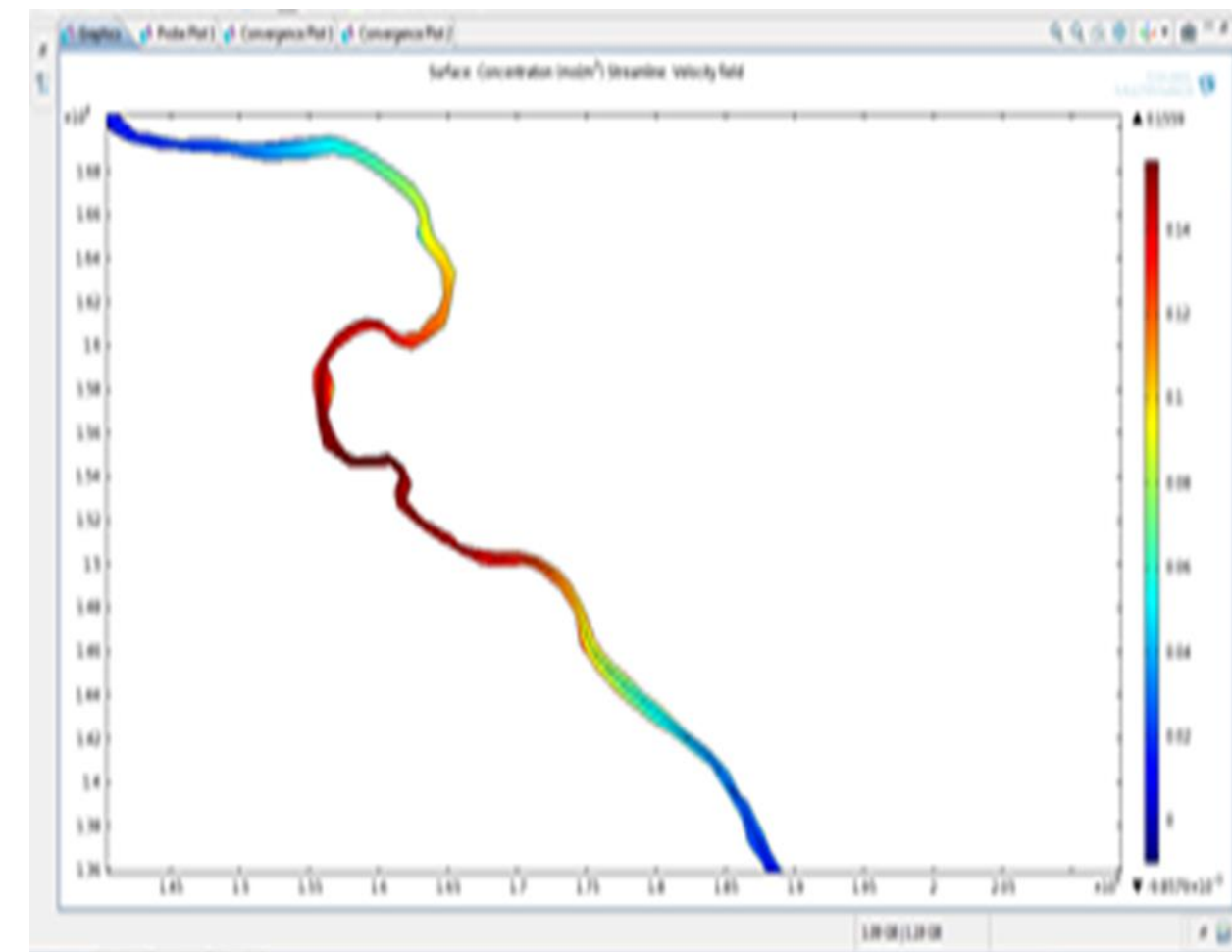


Simulation Results

Velocity Field

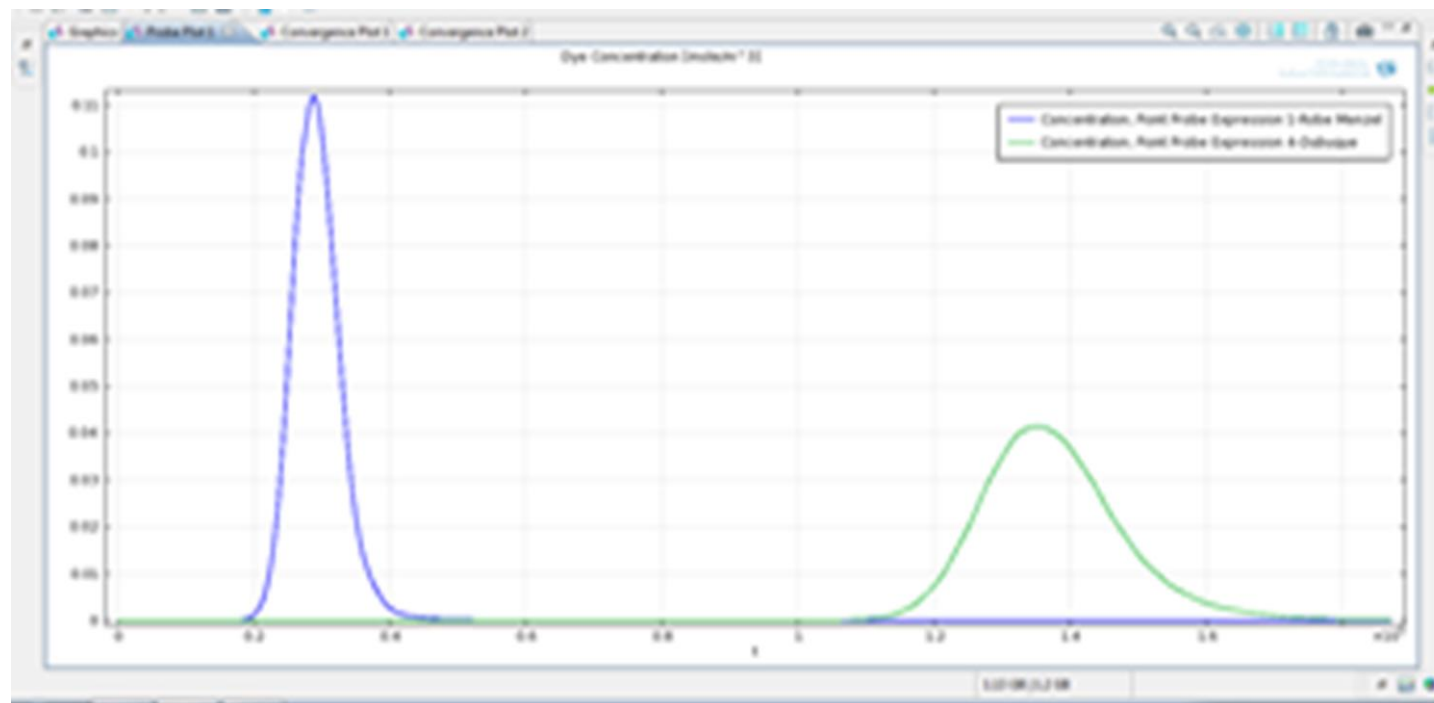


Concentration Field

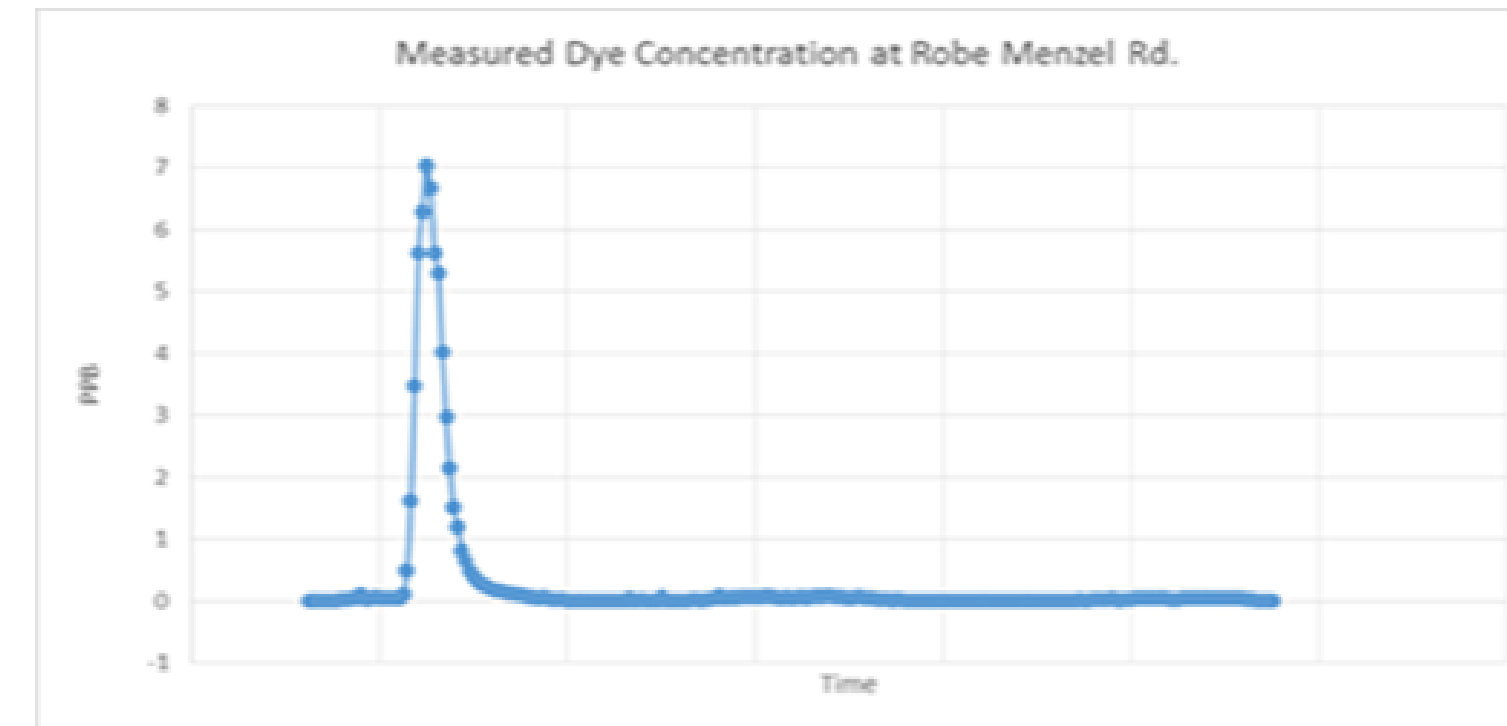


Validation Results

Simulation Probe Plot



Measured



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.



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