

Appendix

Pathogen Transport in Surface and Subsurface Systems at Different Space and Time Scales - A Roadmap: Fundamental Understanding to Advanced Modeling

The task force has produced a very comprehensive report on the need and possible approaches to be undertaken to address the daunting task of bacteria TMDL for sustaining and improving the quality of water resources in the state of Texas in the coming years and decades. While we agree with most of the issues and approaches proposed, we tried to summarize the vision of the Biological and Agricultural Engineering faculty emphasizing a focused need of basic science and engineering questions relating bacteria TMDL below:

Faculty Expertise:

Binayak Mohanty – Flow and Transport Physics and Conceptual Modeling, Biogeochemistry in un/saturated medium, Spatial Variability, Scaling Techniques, Forward/Inverse Numerical Modeling, Air/Space-Based Remote Sensing, and 4-Dimensional Data Assimilation

Vijay Singh – Watershed Hydrology, Surface Hydrologic Modeling, Entropy Theory / Monitoring Design, and Data Analyses

Patti Smith – Surface Hydrologic Modeling, Land Cover Land Use Change Effects on Hydrology, Stochastic Modeling and Uncertainty Analyses

Raghupathy Karthikeyan – Contaminant Fate and Transport and Applications of GIS

Clyde Munster – Watershed Hydrology, Best Management Practices, Field Experiments, GIS, and Applied Modeling

Yong Huang – Physicochemical Processes in Water Engineering, Dynamics of Colloidal Processes in Aquatic Systems, Geochemistry, Contaminant Transport, and Field Studies

Saqib Mukhtar – Animal Waste Management, Water Quality, Education and Outreach

Bruce Lesikar – Waste Water Treatment, Education and Outreach

&
Others

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Statement of need/Description: This program will address the critical issue facing the State of Texas regarding the presence of pathogens in our water resources. The Total Maximum Daily Load (TMDL) process has identified pathogens as a major contributor to the degradation of the State's water resources. While we agree that there does need to be a methodology in place that maximizes benefit while reducing time of implementation and cost as described in "Recommended Decision-Making Process for Texas TMDL and I-Plan Development", we also believe that fundamental research remains to be done in all areas concerning the fate and transport of bacteria in Texas waterways. Effective methods are needed to remove, track, describe and model pathogens.

Relevance/Background: Bacterial TMDLs are being developed for the Leon River, White Oak Bayou and Buffalo Bayou. These TMDLs are attempting to allocate the pathogen load in the water resources to the sources in the watershed. The end goal is to improve the quality of the water resource by reducing the concentration of pathogens to a level below acceptable water quality standards. Effective implementation of this program will require a thorough understanding of where the pathogens are originating, how effective are the best management practices at preventing pathogens from reaching the streams, what processes are occurring during transport to the water resource, what happens to the pathogens while in the water resource and how can this process be modeled. In addition, we need to quantify the limitations of current technologies and models used to measure, monitor and predict indicator bacteria species, in the form of uncertainty estimates on measured and predicted values. All of these questions will need to be answered through a comprehensive approach to evaluating pathogen cycling in the environment.

Goals: These recommendations will develop methods to describe and predict the processes associated with pathogen load, transport, die-off, and regrowth in our water resources.

1. Source, Fate and Transport – Data Collection, Process Understanding, and Modeling

- a. Determine background levels of bacteria in representative watersheds in the various regions throughout the State of Texas. Samples would be collected at the source, catchment, stream, and lakes/reservoirs. Study catchments will include both rural and urban settings. This would permit an assessment of existing bacteria levels as a function of climate, land use, topography, soil type, wildlife population, etc. Bacteria growth/die-off/re-growth patterns will be very different in the humid gulf coast region to the more arid regions of west and north Texas.
- b. Determine the effect of sediment resuspension on the rate of bacteria growth/die-off/re-growth patterns.
- c. Develop multi-scale data collection protocols in the surface and subsurface systems. In the surface system samples will be collected at the source, catchment, stream, and lakes/reservoirs. Study catchments will include both rural and urban settings. In the subsurface system data will be collected for a better understanding of spatio-temporal evolution of bacteria at the pore, core,

pedon and plume scales. Relative significance of surface versus subsurface transport processes will be evaluated. In addition, most important surface and subsurface environmental factors controlling bacteria fate and transport will be determined.

- d. Determine the true bacterial loads from “permitted” WWTP.
 - e. Establish protocols and QC plans for the collection of water samples for evaluation of bacteria concentrations including quantifying the uncertainty in these measured data.
 - f. Develop biogeochemistry-based fate and transport modeling and scaling rules for pathogen loads in surface and subsurface systems across space-time scales.
2. Develop tools and models for tracking pathogen
 - a. Utilize advanced genetic / molecular biology (including nano- and atomic scale) techniques to monitor/characterize the pathogen characteristics which tie pathogens in our surface and subsurface water resources to their source.
 - b. Develop streamline based history matching techniques and other inverse modeling tools to model bacterial fate and transport in surface and subsurface systems.
 3. Describe the processes associated with pathogen transport during the use of various best management practices (BMPs) utilized to manage waste.
 - a. Evaluate the effectiveness of current BMPs used for sediment/nutrient control to reduce bacterial loads. It seems that some of the current BMPs used for stormwater control won't be effective for retaining bacteria.
 - b. Develop new BMPs that address all constituents of concern in stormwater runoff.
 4. Evaluate methods to improve the current models used to predict pathogen transport from the various sources to our water resources.
 - a. Evaluate the parameter uncertainty in models to use as a guide for pinpointing where time and effort is best spent to improve predictions of water quality. A recent uncertainty analysis of HSPF showed that peak in-stream fecal coliform concentrations are most sensitive to the parameter used to represent the maximum storage of fecal coliform bacteria on pervious land segments and to the amount of surface runoff needed to remove 90% of the water quality constituent from a pervious land segment. A subsequent First Order Analysis showed that 99.86% of the variance in simulated peak in-stream fecal coliform concentration was contributed by the maximum storage parameter. These results were directly related to the difficulty in finding reliable values for these types of parameters given the current state of research. This leads to the question, can the model as it is be improved or would it be better to develop a new bacteria subroutine that relies less on assumption and more on the basic transport and dynamic nature of bacteria in water and on the land surface? The other question that needs to be asked is if we do develop more physically based models that include an even wider range of parameters does this decrease or increase the uncertainty in the model results. Certainly a more

physically based, process model may reduce model uncertainty, but may increase parameter uncertainty as more and more parameters are added to the mix.

- b. Establish modeling protocols for urban vs. rural watersheds. The approach to modeling these is likely to be very different.
5. Develop basic approaches to modeling pathogen transport from the source to State water resources.
 - a. Perform experiments from lab to field scale to understand how bacteria move both across the surface and through the soil profile.
 6. Develop the informational resources to convey this knowledge to the engineering consultants, decision makers and general public.
 - a. Key to this process is risk assessment and communication. What are the risks associated with the various pathways of human contamination by fecal coliform? How do you communicate the science to stakeholders? The perception today is that we are just guessing (what we like to call estimating). How do we change that perception?

Capitalizing on the expertise of BAEN water faculty, the following six overarching research objectives are proposed to accomplish a comprehensive understanding of bacteria/pathogens fate and transport and to develop predictive models.

Broad Research Objectives

1. *To identify, characterize, and quantify pathogen sources.*

Key Sources:

- Livestock
- Wildlife
- Pets
- Human

2. *To study key governing processes of fate and transport of microbial pathogens in terrestrial water and soil (porous media).*

Key Processes:

- Advection and Dispersion
- Deposition/Adsorption and Release
- Inactivation and Die-off
- Coupled Bio-Geo-Chemical processes
- Dominant Transport Mechanism under Laminar and Turbulent Flow Conditions
- Preferential Transport over Land and in Subsurface
- Other (Space and Time) Scale-Appropriate Transport Processes!

3. *To investigate key anthropogenic and environmental factors and their characteristic properties (and inter-relationships) controlling the fate and transport processes of microbial pathogens in surface water and porous media for rural/urban catchments/watersheds.*

Key Factors:

- 3-D Hydrologic Setup, Initial/Boundary Conditions, and Forcings
- Precipitation
- Temperature
- Stream flow
- Runoff
- Infiltration
- Irrigation and Drainage
- Pathogen Type
- Soil and Mineralogy
- Topography
- Vegetation
- Animal Populations
- Sediment

- Nutrients
- Agricultural/Cropping Practice
- Waste water treatment facilities
- Soil and Water Management Practice
- Surface/Ground Water Interface and Interaction

4. *To develop (deterministic/stochastic) conceptual and numerical models to describe the transient pathogen transport in runoff, stream, and unsaturated/saturated porous media with embedded hydrological, and biogeochemical heterogeneity at multiple spatial scales.*

Spatial Scales:

- Molecular/Process scale
- Pore Scale
- Continuum/Column Scale
- Representative Elementary Area/Volume Scale
- Plot/Pedon Scale
- Field/BMP Scale
- Catchment Scale
- Watershed/Aquifer Scale

5. *To test the conceptual and computer model with controlled experiments at lab and field scales and develop inverse modeling algorithms for model parameter(s) estimation and study the process/parameter uncertainty*

- Micromodel Experiments
- Controlled Lab Column/Lysimeter Experiments
- Field/Catchment-Scale Experiments
- In-Stream Pathogen-Sediment-Nutrient Interaction Experiments
- Novel BMP/Pathogen Experiments
- Watershed Monitoring and Data Analyses
- Inverse Modeling and Data Assimilation
- Parameter Uncertainty Analyses

6. *To identify and quantify scaling features (spacing, extent, support) for developing long-term monitoring protocol for pathogens across space and time in terrestrial environment*

- Time Series Analyses
- Entropy Analyses
- Geostatistical Analyses
- GIS Tools
- Insitu vs. Possible Remote Sensing Techniques
- Discrete vs. Lumped Measurement Techniques