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Water Environment Research Foundation

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Update on Modeling Approaches to Developing Site-Specific Nutrient Goals, Criteria, and Management

NACWA 2013 Winter Conference

Water Quality Committee

February 4, 2013

Presentation Outline

- Rationale
- Overview
  - Project team and objectives
- Activities
  - Inventory ecological response indicators
  - Develop model-based approaches
  - Develop Nutrient Modeling Toolbox
  - Evaluate considerations for regulatory application
  - Conduct case studies to inform guidance for modeling process
  - Recommend model enhancements and data/research needs
  - Draft and final report

Rationale for this Project

Rationale for Project

- Nutrient pollution is a serious concern
- The relationship between nutrients and environmental response is complicated
- Guidance exists for two of the three recommended approaches for developing nutrient criteria
- Guidance is needed on methods for conducting more rigorous site-specific assessments

Nutrient Pollution is a Serious Concern

- Excess loadings of nitrogen and phosphorus is a primary cause of water quality impairment
  - More than 10,000 water bodies impaired nationally
- EPA has been calling for states to develop numeric nutrient criteria for more than a decade

Relationships between Nutrients and Endpoints Are Complicated

- Response of aquatic plants to nutrient loads are highly dependent on site-specific factors
  - e.g., clarity, shading, habitat, hydrology
- Multiple potential endpoints
  - e.g., hypoxia, harmful algal blooms, aesthetics
- Many endpoints of concern require consideration of multiple levels of relationships
  - Nutrients -> aquatic plants
  - Aquatic plants -> fish productivity

Methods for Developing Numeric Nutrient Criteria

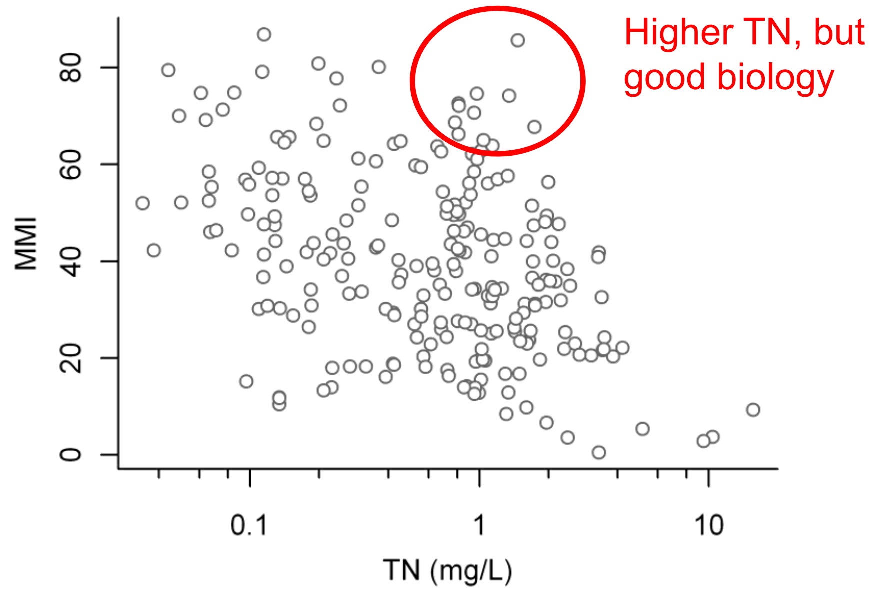
- EPA has defined three categories of approaches
  - Reference condition approach
    - Base numeric nutrient criteria at levels consistent with those observed in relatively pristine (i.e. “reference”) water bodies
  - Stressor-response analysis
    - Empirically derive statistical relationships between in-situ nutrient concentrations and the response variable
  - Process-based (mechanistic) modeling
    - Describe systems using equations representing specific ecological processes, calibrated to site-specific data

The Most Readily Applied Approaches Can Be Inaccurate

- Reference condition approach can be (relatively) easily applied to broad areas, but is potentially very imprecise
  - Doesn't consider the dose-response relationship between nutrients and environmental response
    - Unable to define the threshold where impairment begins
  - Doesn't consider potentially important site-specific factors

The Most Readily Applied Approaches Can Be Inaccurate

- Stressor-response analysis considers thresholds, but still not accurate for all sites
  - Doesn’t consider important site-specific factors



  - Correlation does not mean causation

Simple Approaches Can Result in Expensive Controls

- Existing TMDLs using reference condition-based numeric nutrient criteria have led to some extremely low wasteload allocations to WWTPs for nutrients
  - TP = 0.007 mg/l
  - TN = 0.289 mg/l
- No assessment of site-specific biological response to nutrient levels

Guidance Is Needed on Rigorous Methods for Nutrient Criteria

- EPA provides guidance for developing nutrient criteria using the reference condition and stressor-response approaches
- Similar guidance is not currently available for the process-based modeling approach
  - Lack of guidance will serve as an impediment for more rigorous approaches being taken
- This project is designed to provide such guidance

Project Overview
Project Team and Objectives

Project Team

WERF Project Manager & Advisory Committee		Stakeholder Advisory Panel	
• Lola Olabode, WERF • Steven J. Peene, ATM • Jim Pletl, HRSD • Thomas Stiles, KDHE • David Taylor, MWRA • Elke Ursin, Florida Department of Health	• Jennifer Wasik, MWRDGC • Steve Whitlock, EPA • Harry Zhang, CH2M HILL • Elgin Perry • Paul Stacey, NH Fish and Game Department	• Arthur Butt, VA DEQ • John Buzzone, Washoe County, NV • Tom Fikslin, Ph.D. DE River Basin Commission • David Senn, SF Estuary Institute	• Mike Suplee, MT DEQ • Susan T. Fitch, AZ DEQ • Mindy Scott, Sanitation District No. 1 of NKY • Terri Svetich, Reno, NV • Martha Sutula, S CA Coastal Water Research Project

Co-Principal Investigators	Project Manager
• Joe DePinto, Ph.D., LimnoTech • Steve Chapra, Ph.D., F. ASCE, Tufts University • Clifton Bell, P.E., PG Brown and Caldwell	• Penelope Moskus, LimnoTech

Project Team

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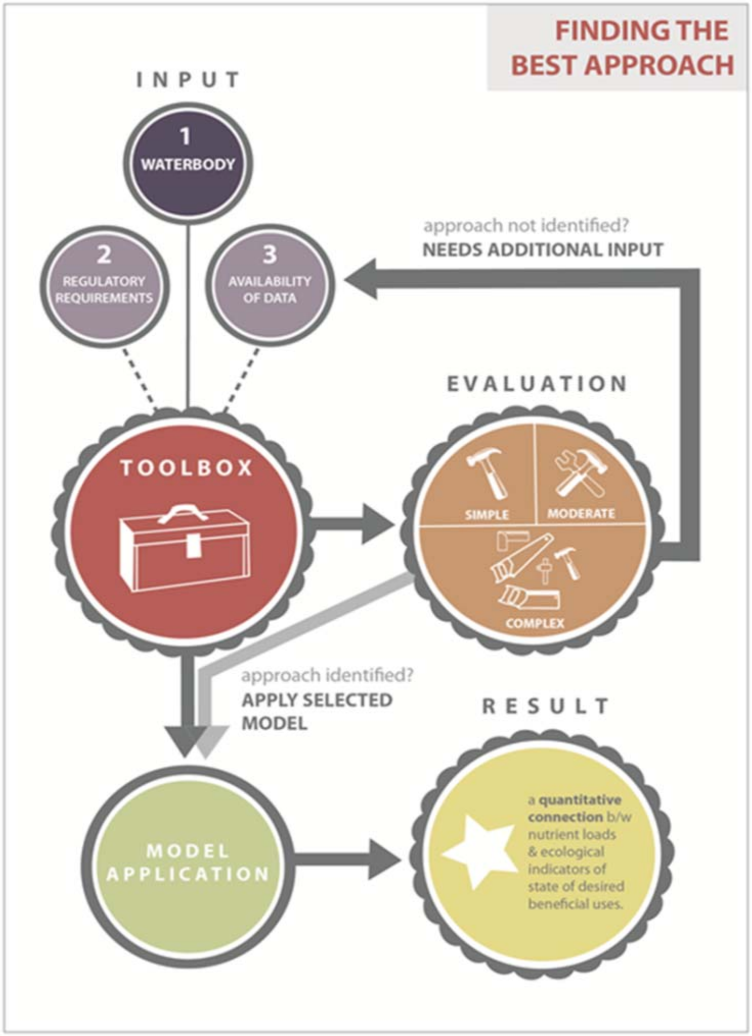
- Hua Tao, Ph.D., LimnoTech
- Tad Slawecki, LimnoTech
- Scott Hinz, LimnoTech
- Kyle Flynn, Tufts University
- Patricia McGovern, PME
- Lorien Fono, Ph.D., P.E., PME
- Nicole Clements, Clements Consulting

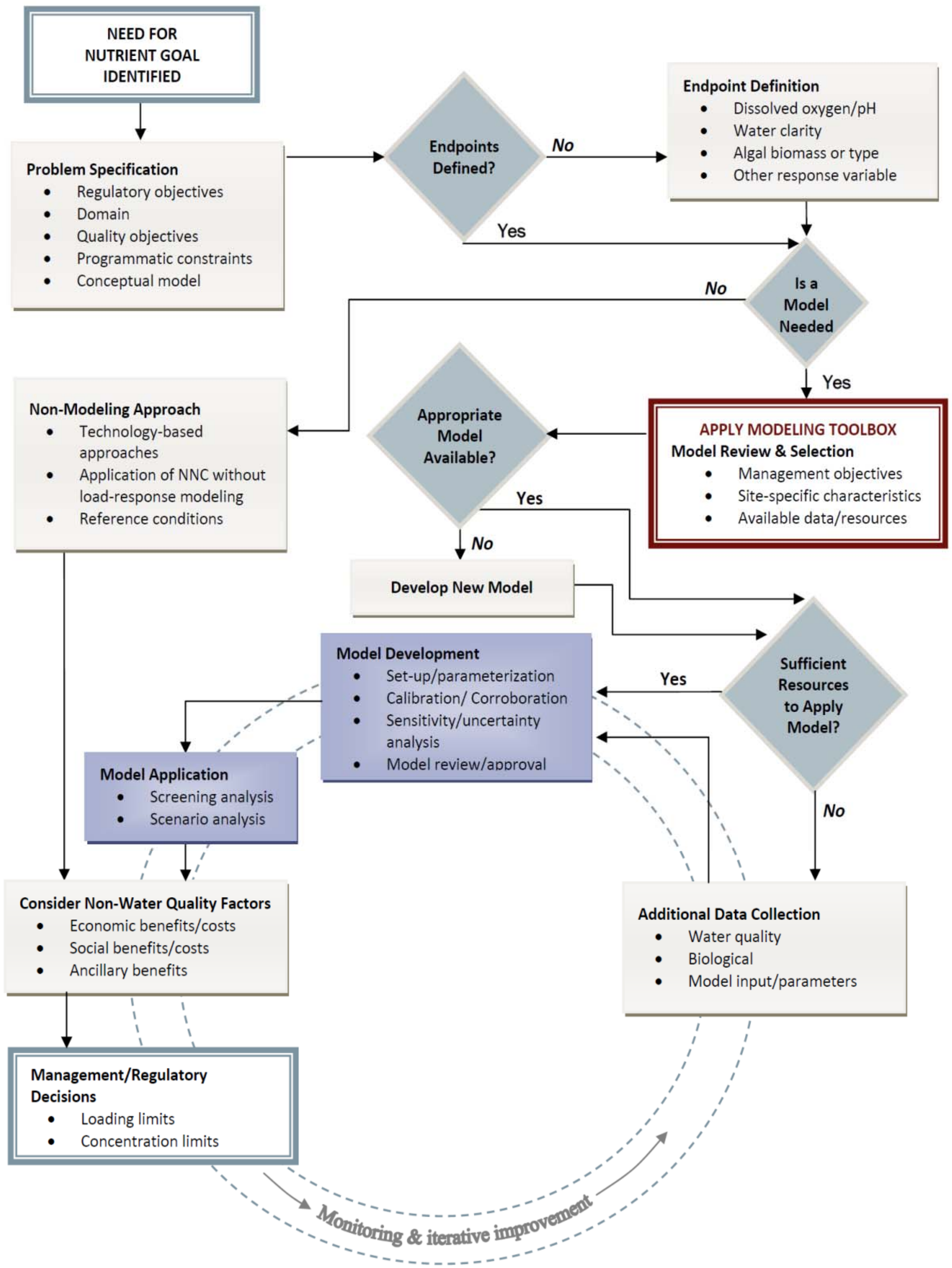
LimnoTech Water | Environment | Scientists | Engineers · Brown AND Caldwell · Tufts UNIVERSITY · ftn Associates Ltd. · CLEMENTS Consulting, LLC · Patricia McGovern Engineers

Project Objectives

- Build a Nutrient Modeling Toolbox (NMT) containing models that can quantitatively link nutrient loads to water quality and ecological response indicators on a site-specific basis
- Provide nutrient modeling guidance (including selection, development, and application of models in the NMT) in the form of a project report



Overall Process for Setting Site-specific Nutrient Goals



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Project Activities

Task Overview

Phase I: February to August 2012

1. Inventory of nutrient-related ecological response indicators
2. Develop model-based approaches for site-specific numeric nutrient goals
3. Develop Nutrient Modeling Toolbox and process for site-specific model selection (Model Selection Decision Tool)

Phase II: July to December 2012

4. Evaluate considerations for regulatory application
5. Conduct case studies to inform guidance for modeling process

Phase III: January to March 2013

6. Compile and prioritize recommendations for model enhancements and data/research needs
7. Draft and final report

Task 1 – Inventory of Water Quality/Biological Response Indicators

- Inventoried States on response indicators being used to connect nutrient levels to beneficial uses
  - Cross-referenced recent ACWA work
- Developed list of response indicators that may be used as desired response variables for the Nutrient Modeling Toolbox

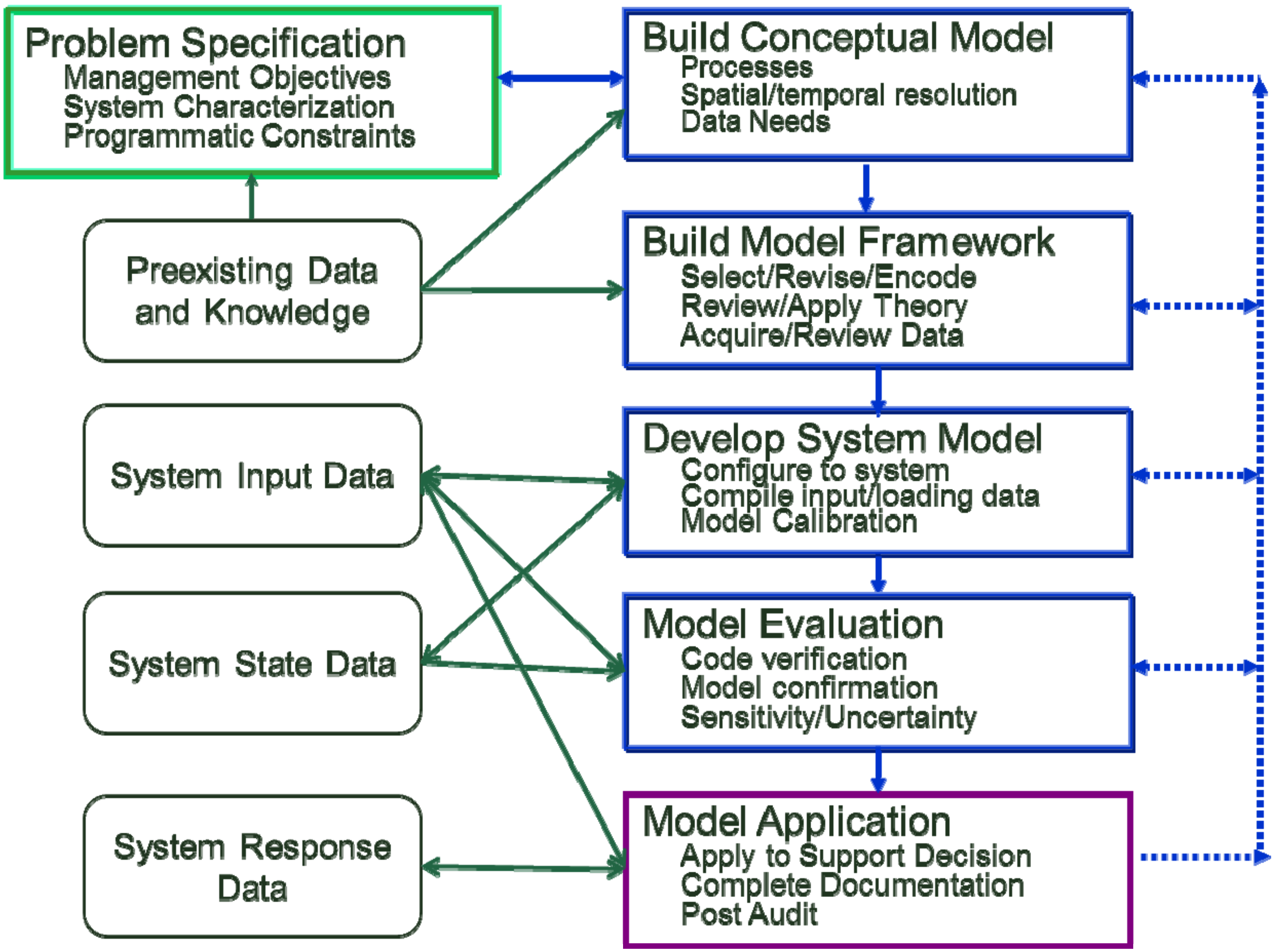
Summary of Indicators Currently Used

Indicator	Rivers and Streams	Lakes and Reservoirs	Estuaries
Dissolved Oxygen	●	●	●
Chlorophyll a	◒	◒	◒
Clarity	◔	◒	◔
Alkalinity	○	○	○
pH	◒	◒	◒
Taste & Odor	○	○	○
Composite Indices: Water Quality	○	○	○
Macrophyte Density	○	◔	◔
Periphyton Abundance, Community Structure, or Filament Length	◔	○	○
Fish Community Structure	◔	○	○
Benthic Macroinvertebrate Community Structure	◒	○	◔
Harmful Algal Blooms and Toxins	◔	◔	◔
Algal Species	○	○	◔
Fish Kills	◔	◔	◔
Fungi or Filamentous Bacteria	○	○	○

● = used by essentially all states
◒ = used by most states
◔ = common, but used by less than half of all states
○ = rare

Task 2 – Nutrient Modeling Guidance

Modeling Steps Showing Interaction With Data Throughout The Process



Task 3 – Categories of Nutrient Modeling Toolbox Application

- Development of site-specific numeric nutrient criteria, without consideration of site-specific loads
- Development of site-specific numeric nutrient criteria in conjunction with nutrient loading controls
- Definition of load limits necessary to meet designated water quality or ecological thresholds

- All three categories use response variables as endpoints of concern, not just nutrient concentrations

Task 3 – Nutrient Modeling Toolbox

- Development of list of models
  - Internet review
  - Literature search
  - Team experience
- Approximately 50 models identified
  - 24 process-based load-response
  - 4 empirical-based load-response
  - 23 stressor-response sub-models
    - Used to create <u>hybrid</u> models
  - Excludes watershed and proprietary models
    - Summary information on separate lists
- Information on each model – fact sheet

Fact Sheet Example

QUAL2K Fact Sheet

Name and Acronym:	QUAL2K / Q2K - A Modeling Framework for Simulating River and Stream Water Quality
Brief Description of Model and Other Notes:	QUAL2K (or Q2K) is a river and stream water quality model that is intended to represent a modernized version of the QUAL2E (or Q2E) model (Brown and Barnwell 1987). It employs steady, non-uniform hydraulics and simulates diel variations of oxygen, nutrients, pH, phytoplankton and bottom plant biomass.
Developed by:	Steven C. Chapra, Gregory J. Pelletier and Hua Tao, Tufts University
Current Version:	2.11b8 (January 2009)
Distributed by:	U.S. EPA Watershed & Water Quality Technical Support Center (WWQTSC) http://www.epa.gov/athens/wwqtsc/html/qual2k.html
Contact Info:	Tim Wool, Watershed and Water Quality Modeling Technical Support Center (404)562-9260 wool.tim@epa.gov
Model Availability:	☒ Public Domain w/ Source ☐ Public Domain w/o Source
Waterbody Type	☒ Wadeable stream ☒ River ☐ Lake ☐ Estuary
Physical Dimensions	1-D (longitudinal)
Temporal Variability	Steady-state (diel variability)
State Variables (response variables shown in bold)	State Variables: **Dissolved oxygen, phytoplankton biomass, bottom algae biomass**, temperature, conductivity, inorganic suspended solids, , CBOD (slow, fast reacting), organic nitrogen, ammonia nitrogen, organic phosphorus, inorganic phosphorus, phytoplankton nitrogen, phytoplankton phosphorus, detritus, pathogen, alkalinity, total inorganic carbon, bottom algae nitrogen, bottom algae phosphorus. Other Response Variables: **pH,** sediment flux (SOD, ammonia, inorganic phosphorus, methane).

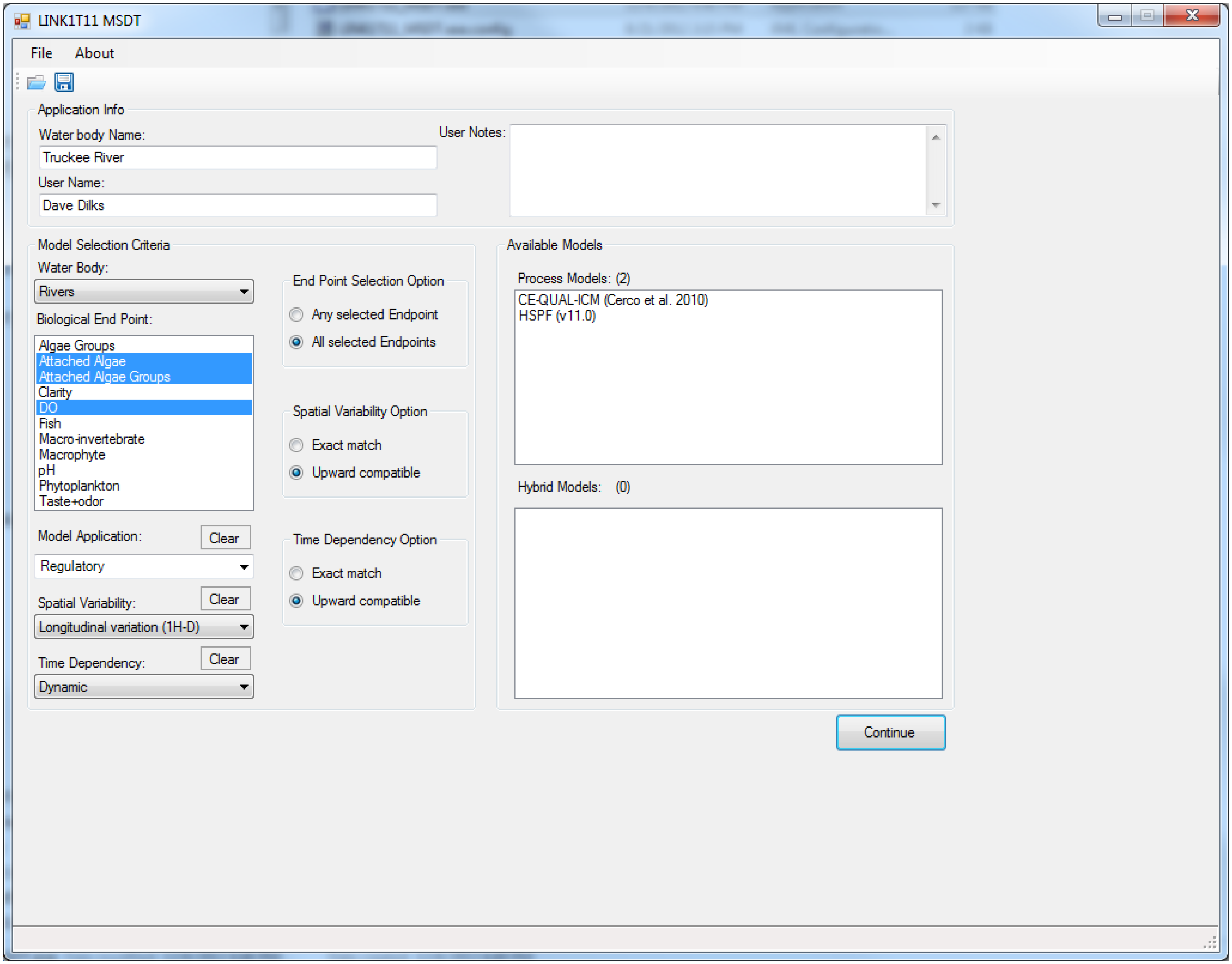
Input Data Needs:	• Stream geometry characterizing steady-state hydraulic conditions.
	• Steady-state inputs at receiving water boundaries and other locations (e.g., point and non-point sources)
	  ○ Flow
	  ○ Concentration of all state variables
	• Heat sources/sinks (including sediment bed)
	• Meteorological conditions
	  ○ solar radiation
	  ○ wind
	• Kinetic coefficients for the following processes
	  ○ Plant photosynthesis and respiration
	  ○ Nitrification, denitrification
	  ○ Fast and slow CBOD decay rates
	  ○ Algal stoichiometry
	  ○ Detritial dissolution and settling
	  ○ Hydrolysis
	  ○ Reaeration coefficient (or formulation type)
	  ○ Prescribed sediment fluxes (if not simulated)
	• Observed data on state variables for model calibration

Estimated Model Resource Need (Data, Level of Effort)	• Minimum of two synoptic sampling events during conditions reasonably approximating steady state. • Weeks to months of time for input preparation and calibration.

Model Selection Decision Tool

- Begins with model classification matrix
  - Water body type
  - Response endpoint(s)
- Additional questions to refine model selection
  - Model application
  - Dimensionality
  - Temporality
  - Other secondary factors
    - Need to simulate sediment flux

Model Selection Decision Tool Prototype



Task 4 – Considerations for Regulatory Application

- Ultimate goal of these models is regulatory decision-making
- States surveyed for model review protocols
  - Half of states currently have no formal review process
  - Fourteen states have some type of protocol
    - Guidance document, Review panel, Modeling QAPP requirements
  - Six states have a list of approved models
  - Some states aren't using models

Regulatory Interaction Recommended at Multiple Steps

- At Project Initiation
  - Local regulatory environment regarding nutrient controls
  - Existing protocols for regulatory review of models
- Prior to model development
  - Problem specification
  - Modeling QAPP
- Prior to model application
  - Reconciling differences between model results and regulatory frameworks

Task 5 – Case Studies

- Specific examples of the entire modeling process
  - Problem specification, model selection and associated data needs, development, application, and documentation of model
- Selection Criteria
  - At least one case study for each waterbody type
  - At least one case study for each of the three model application categories

Task 5 – Case Studies

- Screening analysis of Virginia streams
  - AQUATOX
- Managing nitrogen impacts on Massachusetts estuaries
  - Hybrid: RMA2/RMA4/Empirical model
- Phosphorus TMDL in the Wenatchee River, WA
  - QUAL2Kw
- Numeric nutrient criteria in the Yellowstone River, MT
  - QUAL2K-AT2K application
- Phosphorus TMDL in upper Mississippi River system, MN
  - ECOMSED-RCA
- Numeric nutrient criteria for Klamath River Watershed, CA
  - Hybrid: QUAL2K/empirical model, BATHTUB/empirical model

Task 6 – Findings and Recommendations

- Few models available for high-level ecological endpoints
  - Hybrid approach (process model -> empirical model) shows greatest near-term potential
- Existing monitoring data insufficient to support complex models or modeling conducted for regulatory purposes
  - Commitment to long-term and frequent data collection is necessary

Task 6 – Findings and Recommendations

- Understanding of many aquatic processes will benefit from research
  - Processes that trigger harmful algal blooms
  - Factors controlling the growth of submerged aquatic vegetation
  - Processes that convert nutrients from unavailable to available forms
  - Relationship between underwater light attenuation and different types and sizes of particles
  - Processes affecting bedded sediment-water interactions
- Research on model uncertainty should be increased

Task 6 – Findings and Recommendations

- Pre- and post-processing software is not currently considered a major limitation to model development
  - As model complexity increases, demands for pre- and post-processing software will increase
- Opportunity to improve the accuracy and utility of models by conducting a model “post-audit” process

Current Status

- Preparing final project report
  - Finalized in March, 2013

Questions/Comments?

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