Research Scoping Report 01 (Project ID 2320) by Merlynn D. Bender on 9/29/10

BOR, R&D, S&T scoping proposal title: Zebra and Quagga Mussel Scoping to Incorporate Mussels in Flow and Water Quality Models.

Abstract:

Support from Tennessee Valley Authority (TVA), the U.S. Army Corp of Engineers (COE), and Reclamation regional offices were solicited. Funding is tight and no firm monetary commitments were received for incorporating mussels into the CE-QUAL-W2 (W2) model. Upgrading the W2 model to include mussels is on hold until fiscal year 2012 (FY12).

Introduction:

Mussel invasion causes many problems that are not easily fixed. Understanding zebra and quagga mussel colonization is one of the keys to predicting if mussels will impact a water resource. However, it is difficult to model the act of colonization due to the input requirements and complexity of chemical and biological interactions.

Veligers, the mussel larva, have been found during one sampling trip and not during subsequent sampling trips at some reservoirs, even though sampling efforts were greatly ramped up. Establishment of adult mussel populations does not always occur when veligers are found due to insufficient calcium or other environmental parameters. Instead of trying to predict colonization of mussels, existing water quality modeling efforts might concentrate on changes to existing models to accommodate investigation of future mussel colonization and subsequent impact to water quality.

An example of a predictive modeling scenario would be to model two identical reservoirs; a reservoir without mussel colonization and the same reservoir with zebra or quagga mussel colonization at a future date. These are two different water quality situations that require different model calibrations and different water resource management strategies.

The focus of this research proposal is on manipulation of the algorithms or coefficients in the CE-QUAL-W2 model (Cole and Wells, 2006) and its control and input files to mimic the effects of mussels on current and future reservoir water quality. Mussels strip the algae out of the water column and increase water clarity. A model would need three components including flags to turn on and off the effects of mussels, mechanisms to limit the amount of mussel colonization due to limiting parameters such as a lack of calcium, and subroutines to strip algae from the water column and settle mussel feces and biomass on the sediments. Additionally, sedimentation and buildup of mussel feces on the sedimentation interface may also need to be modeled in terms of organic decay and subsequent loss of dissolved oxygen from the water column.

So how should mussels to be represented in the W2 model? This would need to be coordinated with the CE-QUAL-W2 model developers and keepers of the research version of the code. Currently W2 does not have calcium as an input. Mussels would likely alter the calcium concentration over time and calcium could become a limiting factor. A mussel flag might be manually input at the beginning of the simulation in the input control file, WCCON.NPT. W2 algorithms and algal code currently used to model limitations to algal growth and survival of different algal assemblages (diatoms, greens, and blue-greens) might be modified to include zebra and quagga mussel assemblages that are dependent on different concentrations of calcium or different temperature regimes for optimum growth. Algal stripping from the water column might be factored into a modification of the algal mortality coefficient. Decay of settled deceased mussels might be factored into the sediment oxygen demand (SOD) coefficients. Alternately, the existing W2 zooplankton subroutine might be used directly to mimic mussel grazing.

The difficulty of modeling predator-prey dynamics makes this a challenging option. Superimposing widely fluctuating predator-prey dynamics affecting population growth and decline into a fully hydrodynamic model with complicated water quality makes it difficult to calibrate with certainty. Historical attempts to add predator-prey dynamics to the W2 model have not been widely successful due to the prey curve exploding and then crashing by predation; the predator curve subsequently crashes as the prey base falls. With fewer predators, the prey curve recovers. The monthly timing of the predator-prey explosions and crashes is difficult to measure and the amount of data required is expensive. Algae are preyed upon by several zooplankton species making modeling the food chain difficult.

Another challenge is the modeling of metalimnetic dissolved oxygen (DO) concentration maxima caused by algal growth at depth due to a clearer water column. Mussels will strip algae from the upper water column allowing algae to grow deeper, including blue-green algae which have heterocysts to assist vertical mobility in the water column on a diel basis. Heterocysts can occur in all filamentous species except those in Oscillatoriaceae (Wetzel, 1975 pg 345). Blue-green algae, especially Oscillatoria are often major contributors to metalimnetic maxima (Wetzel, 1975, pg. 164). This might be one of the keys to modeling algal growth at depth in the W2 model. Initial attempts to stimulate algae at depth in the W2 model have been successful during early summer; however, modeling late summer and autumn metalimnetic DO maxima are problematic. Nutrients are depleted in the model, and algae cease to grow at depth in the model until autumn lake turnover and mixing disperses nutrients throughout the water column.

Model changes would need to be proposed, approved, designed, modeled, and calibrated before a test mussel water quality model could be released for public use.

Machaelis-Menton type modeling techniques used to model enzymes may not work adequately for mussels. Reaction rate kinetics for exponential growth may be more appropriate if limiting functions can simultaneously be applied to mussel growth and subsistence.

Due to over four thousand existing CE-QUAL-W2 reservoir and riverine models in the world, there should also be a concerted effort to adapt existing model calibrations using existing model input structure. Without changing the W2 model, coefficients could be stretched to mimic stripping of algae from the water column by filter feeders. Increasing the algal mortality coefficient would reduce algal biomass. Diatoms typically bloom in the spring when particulate biogenic silica is plentiful. Similarly a generic constituent group for mussel formation, when calcium is plentiful, might be implemented in the W2 model. That generic constituent in W2 has four calibration knobs or parameters including 1) an Arhennius temperature rate multiplier, 2) a zero-order decay rate (per day), 3) a first-order decay rate (per day), and 4) a settling rate (m/day). The combination of a generic mussel constituent and an attached epiphyton constituent might be used to mimic mussel filter feeding in the water column. Adding a zooplankton component is problematic for existing models as well as models yet to be calibrated.

The more than four thousand W2 reservoir or riverine models have often been calibrated to wet, average, and dry years (or some multiple scenarios) to cover a range of expected hydrologic conditions. None of those calibrated (or not calibrated) W2 models have mussel formulations embedded within the model code, control files, and input files. If mussels have to be added to those models to predict what happens to water quality after a mussel invasion, it requires changing thousands of W2 model control files and tens of thousands of W2 model input files "if a newer version of the W2 model is used." However, much file and data manipulation time will be saved if a clever and crude way to use the old W2 model construct (old or legacy versions of W2) can be developed to incorporate mussels into the existing W2 control files, for instance, by using a combination of generic constituents. This might be attempted by using Arhennius temperature rate multipliers (by adjusting zero-order decay, first-order decay, and a burial settling rate), by using epiphyton attached growth, or by manipulating diatom, green, blue-green algal assemblages (by adjusting respiration, excretion, mortality, limiting factors (such as nitrogen, phosphorus, or light) and settling sink/source representation of the algal and detrital matter while avoiding the complicated zooplankton (predator-prey) route (advective transport, settling, excretion, and mortality). Zooplankton was not in the old W2 model construct which was used during the building of more than four thousand W2 models; adding zooplankton to the old models is challenging.

This is the kind of problem that gives water quality modelers nightmares. There isn't enough time and energy to upgrade the old existing model calibrations. It will likely take years to develop and test a new debugged W2 model code version with embedded mussel parameters. In the interim, rebuilding many input files, will result in much pre- and post-processing of existing model input and control files and require re-calibration of many reservoir models.

Mussel Invasion Risk:

Which models need to be changed? Reservoir models in some areas of the country likely do not need to be rebuilt and recalibrated for mussels initially. Regionally, the Pacific Northwest has a “very low” risk of mussel invasion, as defined and reported by Whittier, Ringold, Herlihy, and Pierson (2008), based on calcium concentration data.

Mussels will likely colonize last in the wetter areas of the Pacific Northwest where there are diluted calcium-poor conditions. However, eventually colonies will form in some Pacific Northwest areas.

The current caretaker of the CE-QUAL-W2 model code is at Portland State University in Oregon which is located in a part of the United States where calcium concentrations are low. Research and testing might need to be done in a part of the United States where calcium concentrations are higher and mussels have a better chance of colonizing. Determining if mussels can colonize is difficult to model due to the many variables. Where mussels already have colonized throughout a region, models will likely need to be changed to compare water quality before and after mussel invasion. The Tennessee Valley Authority (TVA) and the U.S. Army Corp of Engineers may be able to provide both monetary and in-kind-services support for testing mussel formulations developed for the W2 model. Likewise reservoirs and lakes in several areas of the country may need to be modeled and tested for mussel incorporation.

Coding specifications:

The coding for the CE-QUAL-W2 (W2) model would likely need to be done by or managed by Portland State University under contract with the U.S. Army Corp of Engineers. Even though additional tasks will likely surface as the project progresses, an outline of some of the specifications for the W2 model coding could include the following items:

Item 1: Incorporation of mussel flags into the W2 model control file named W2CON.NPT.

Item 2: Incorporation of calcium data into the branch and tributary W2 model input files.

Item 3: Coding changes to the W2 model for replicating the affects of mussels on algal removal, water clarity, decaying organics, and dissolved oxygen.

Item 4: Testing of the CE-QUAL-W2 model on existing model calibration data sets to assure that nothing was broken during model coding changes.

Item 5: Recalibration Method A of the CE-QUAL-W2 model on an existing model calibration data set should be done by using the mussel model code changes and a different input structure.

Item 6: Recalibration Method B of the same data set of the model recalibrated in item 5 should be done using the existing model construct (version 3.5 has been tested and debugged for years and might be used rather than the recent research W2 model version 3.6 or newer version) while only changing existing model coefficients to mimic mussel incorporation into existing models.

Item 7: Comparison between item 5 and item 6.

Item 8: Documentation and summary of the challenges and advantages of both methodologies.

Item 9: Advertisement of new code changes on a website link for the rest of world.

Item 10: Status reports every three months on model development activities.

Item 20: Upgrading the CE-QUAL-W2 user's manual and technical reference manuals to reflect the mussel changes to the model. This would include online reference material at both PSU's website and the U.S Army COE website.

Item 30: Incorporation of mussel training into the five-day W2 model training course offered at PSU.

Item 40: Providing support to users upgrading to the mussel version of the W2 model.

Item 50: Maintaining a log of W2 models used around the world that have and do not have mussel formulations.

Item 60: Producing a protocol for closeness-of-fit-statistics on modeled versus field reservoir profile data and a methodology to determine if a mussel version of the W2 model is calibrated adequately.

Item 70: Testing the modeling changes on a reservoir using a data set collected before mussel infestation and after infestation. A W2 model of Arrowhead Lake in California been calibrated. This may be an opportunity to test a calibration with mussels before and after infestation. Arrowhead Lake does not have adult mussels yet. However, veligers were apparently found during only one sampling trip which might be a false positive reading. A Lake Powell W2 model also exists (Williams, April 2007) and may be another candidate for this research due to improved geometry (Ferrari, 1986). Veligers from Lake Powell which is upstream of Lake Mead appear in the headwaters of Lake Mead however there is no confirmation of mussels in Lake Powell yet. Lake Mead bathymetry is now available (Ferrari, February 2008). There may be other reservoir candidates for before and after mussel infestation testing of the W2 model coding changes.

Item 80: Producing a practical application report for how to address mussel modeling in reservoirs including development of a sampling analysis plan for eventual W2 mussel model calibration.

Item 90: Recommendations for relational databases that will be set up for mussel data collection that might also be used for W2 modeling.

Item 100: Conclusions from the model modification study including lessons learned.

Applications:

The Lake Arrowhead W2 model has been calibrated to water quality data collected during 2008 and 2009. This application provides the opportunity to proactively investigate mussel incorporation for a small, deep, and strongly stratified W2 reservoir model. The volume of Lake Arrowhead is 46,855 acre-feet to spillway water surface elevation 5106.7 feet AMSL with a maximum depth of about 150 feet. This relatively-high California lake, located nearly a mile above sea level on the top of a mountain with a relatively small isolated watershed, is a good location for a controlled test case. The Lake Arrowhead Community Services District (LACSD) has funded the collection of bathymetry, water quality data collection, and cursory W2 test modeling of Lake Arrowhead to date and may be interested in modeling mussels since one sample turned up positive for mussels during 2009. However, mussels have not colonized this relatively small monomictic impoundment. LACSD has stringently controlled boat access to prevent mussel colonization of this excellent private two-story fishery. Unfortunately private reservoirs are not being funded for sampling for mussels by government agencies. Samples for mussels are collected voluntarily by the government agencies. For Lake Arrowhead, tow rope samples collected by LACSD are sent to the government for analysis of mussels only. Therefore calcium data is sparse. On August 13, 2008, one Lake Arrowhead reservoir water grab sample was analyzed for calcium and magnesium and it indicated that future mussel colonization is potentially possible for this private reservoir.

The existing Lake Powell W2 model control file could be modified to incorporate a scenario in which mussels dominate a large and deep reservoir. The gross volume of Lake Powell is 27 million acre-feet to water surface elevation 3700 feet AMSL. Extensive historical data collection on this important water resource provides a long term and extensive historical record and represents a large reservoir test case. Both a two-dimensional Lake Powell BETTER model and a W2 model exist and use the same geometry. Reclamation's Upper Colorado Regional Office has generously funded water quality modeling investigations of Lake Powell and the staff has the technical expertise to guide future modeling activities. There is some indication that mussels may be discharged from Lake Powell into the headwaters of Lake Mead. However, there are no official reports of mussels and the latest intake inspections did not reveal a problem. Mussels have colonized Lake Mead and boats transported from Lake Mead to Lake Powell may have inadvertently carried mussels to Lake Powell which is just upstream.

Quagga mussels have been found in Lake Powell according to Whittler, et al. (2008). However, local officials have not acknowledged confirmation just yet.

Preliminary Conclusions:

As hypothesized, data is being collected for determining if mussels are present in reservoirs; however little water chemistry data is being collected for water quality modeling. The sixty reservoirs being investigated for mussels are scheduled to collect one August 2010 water chemistry sample. Private reservoirs are not collecting water chemistry samples. A data inadequacy exists for potential future water quality models that will need to model mussels. There are several approaches that can be used to incorporate mussels into water quality models. The bottom line is that reservoir ecosystem food chain dynamics are difficult to model due to the amount of data required; mussel dynamics further complicate any ecosystem. At best, modelers can crudely model large changes to the ecosystem due to mussel invasion.

Recommendations:

1) Additional water quality data should be collected in both the reservoir and inflows to the reservoir while sampling for mussels.
2) Calcium in both the epilimnion (top layer) and hypolimnion (bottom layer) should be collected as composite samples on reservoirs sampled for mussels. Such data may become calibration data for future water quality models with mussel formulations.
3) Calcium in major riverine inflows to a reservoir should be collected. Inflow calcium concentrations might become inputs to future water quality models with mussel formulations.
4) Investigate both a simplified approach (Method B) for initially adding mussels to water quality models using existing model formulations and data input requirements and an advanced approach (Method A) requiring additional data collection and model modifications including changes to the input structure of input files.
5) A simplified protocol for mussel incorporation into the W2 model might be attempted using the existing subroutines.

References:

Cole, T.M. and S.A. Wells, 2006. *CE-QUAL-W2: A Two-Dimensional Laterally Averaged, Hydrodynamic and Water Quality Model, Version 3.5, User Manual.* Draft Instruction Report EL-06-1. Prepared for the U.S. Army Corp of Engineers. Washington, D.C.

Ferrari, Ronald L. (1988), "1986 Lake Powell Survey." REC-ERC-88-6, Bureau of Reclamation, Technical Service Center, Denver, Colorado.

Ferrari, Ronald L., "Lake Arrowhead 2008 Reservoir Survey," Sedimentation and River Hydraulics Group, Water and Environmental Resources Division, Technical Service Center, Technical Report No. SRH-2009-9, U.S. Department of the Interior, Bureau of Reclamation, Denver, Colorado, March 2009, http://www.usbr.gov/pmts/sediment/projects/ReservoirSurveys/index.html

Ferrari, Ronald L. (February 2008), "2001 Lake Mead Sedimentation Survey," U.S. Department of Interior, Bureau of Reclamation, Technical Service Center, Denver, Colorado. http://www.usbr.gov/pmts/sediment/projects/ReservoirSurveys/index.html

Whittier, Thomas R.; Ringold, Paul L.; Herlihy, Alan T.; and Pierson, Suzanne M.; "A calcium-based invasion risk assessment for zebra and quagga mussels (Dreissena spp)," published in Frontiers in Ecology and the Environment by the Ecological Society of America, Front Ecol Environ 2008; 6, doi:10.1890/070073.

Williams, Nicholis T., "Modeling Dissolved Oxygen in Lake Powell Using CE-QUAL-W2," Masters Thesis submitted to Brigham Young University, Department of Civil and Environmental Engineering, April 2007

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