

Report as of FY2009 for 2006NV101B: "Modeling Biotic Uptake of Mercury in the Lahontan Reservoir System"

Publications

- Dissertations:
 - ◆ Carroll, Rosemary, 2010, Modeling Mercury Transport and Bioaccumulation in the Carson River - Lahontan Reservoir System, Nevada, PhD Dissertation, University of Nevada, Reno, Graduate School of Hydrologic Sciences, Reno, Nevada, 170 pp

- Articles in Refereed Scientific Journals:
 - ◆ Warwick, J.J. and Carroll, R.W.H. (2008). Evaluating the impacts of uncertainty in geomorphic channel changes on predicting mercury transport and fate in the Carson River system, Nevada. *International Journal of Soil, Sediment and Water*.
- Conference Proceedings:
 - ◆ Warwick, J.J., and Carroll, R.W.H. 2007. Evaluating the impacts of uncertainty in geomorphic channel changes on predicting mercury transport and fate in the Carson River system, Nevada. 23rd Annual International Conference on Soil, Sediment and Water. Oct 15-18, 2007. University of Massachusetts, Amherst. Published in conference proceedings, *Contaminated Soils, Sediment and Water*, vol 13.

Report Follows

Modeling Biotic Uptake of Mercury in the Lahontan Reservoir System

Final Report

Problem and research objectives

The timing of maximum growth of phytoplankton relative to that of mercury loading could matter greatly if the loading signal varies strongly over time. Therefore, accurate prediction of mercury bioaccumulation may depend upon understanding mercury loading mechanisms and associated uncertainty to the system as well as the interaction between this loading and phytoplankton growth at sub-annual time scales (i.e. days to weeks). Also, using a well defined and strongly varying mercury signal may help to elucidate important bioaccumulation features (e.g., bioavailable forms of mercury and the rate of mercury transfer through different trophic levels).

The geologic and geochemical controls on THg and methylmercury (MeHg) transport through the Carson River have been successfully modeled with a linked and modified version of RIVMOD (Hosseinipour and Martin, 1990) and WASP5/MERC4 (Ambrose et al., 1991) by Carroll et al. (2004), Carroll and Warwick (2001), Carroll et al. (2000) and Heim and Warwick, (1997). Proposed research will better quantify physical parameters impacting mercury transport into/through Lahontan Reservoir as well as quantify uncertainty associated with geomorphologic and biogeochemical controls influencing mercury loading into the Carson River and subsequently into Lahontan Reservoir. Results will be evaluated in their relationship to a varying mercury signal within the lower trophic levels occupying Lahontan Reservoir.

Methodology

Proposed research has been divided into two distinct phases based on site location. First, a detailed uncertainty analysis looks at geomorphic controls, bank moisture history, as well as methylation-demethylation on mercury loading into the Carson River and subsequently into Lahontan Reservoir. Second, Lahontan Reservoir will be investigated in greater detail. Detailed cross sections and stage modeling will ensure a correctly moving delta region which dictates sediment and mercury deposition at the mouth of the Carson River. With proper hydrodynamic modeling of the reservoir established, it is proposed to observe and model a temporally varying mercury signal in the lower food web, specifically within the phytoplankton communities.

Collected data will parameterize/drive a bioaccumulation model with the original proposal indicating the use of the Bioaccumulation and Aquatic System Simulator (BASS) by the US EPA (Barber, 2004). This approach has been modified to no longer use BASS. Instead a bioenergetic and mercury mass balance model (BMMBM) has been developed in Stella software to model Hg body burden in the plantivorous Sacramento Blackfish (*Orthodon microlepidotus* – Ayres) with calibration and verification using site specific and species specific data. The model is a user friendly tool for researchers and managers alike. It is coupled with the Carson River transport model output to assess if a

dynamic loading signal is important in Hg body burdens or if mean loading is adequate. Importance of dynamic loading is investigated in the context of uncertainty in both the transport model and the BMMBM model.

Principal findings and significance

Research findings are broken into the four papers listed in publications

Paper 1: Evaluating the impacts of uncertainty in geomorphic channel changes on predicting mercury transport and fate in the Carson River system, Nevada.

- Uncertainty related to modeled geomorphic processes of bank erosion and overbank deposition describe observed variation in Hg water column concentrations prior to and during the 1997 flood.
- The model places relatively greater uncertainty in modeled behavior on earlier over-bank discharge events than for later events. This is most evident in river reaches that have shallow channel slopes which experience the greatest increases in channel widths during the earliest modeled overbank flow events.
- A change in the system appears to occur at Fort Churchill during the 1997 flood that is not adequately modeled since uncertainty in modeled parameters alone cannot explain Hg variation following the 1997 flood.
- MeHg loading appears dominated by diffusion processes as opposed to geomorphic channel changes.
- Diffusion from river banks is included (indirectly) in the uncertainty analysis via the amount of MeHg in the banks and it is an important mechanism for MeHg loading. However, its influence diminishes with time due to increased channel widths.
- Uncertainty in geomorphic channel change and MeHg bank concentrations are not enough to capture observed variation in MeHg water column concentrations at Fort Churchill.

Paper 2: Temporal variation of mercury associated with different phytoplankton size fractions in Lahontan Reservoir, Nevada.

- Water column and phytoplankton data collected in Lahontan Reservoir was done to assess the importance of dynamic mercury loading into the reservoir as well as the importance of algal growth on the accumulation of THg and MeHg in two different phytoplankton size fractions (total and those less than 35 μm).
- The sampling location proved to be turbid with THg associated with suspended particulate matter (SPM) explained mostly by unfiltered THg and suspended sediment water column concentrations originating from the Carson River and not by any association with Chl a . The tendency for THg concentrations to decrease with increased Chl a helps to defend this claim. Results for THg in smaller sized SPM are less certain with a weak positive relationship to the fraction of Chl a in the water column.
- In contrast to THg, MeHg appears to have a stronger affinity to living biomass, with substantial MeHg concentrations and K_d values in smaller particles during the late summer. Fluvial loads of DMeHg do not appear important to MeHg

- uptake, but biomass and long residence times in the reservoir (i.e. slow velocities) are significant.
- Very different results for MeHg accumulation occur if the small particle fraction is not isolated from total SPM. Under these circumstances, MeHg accumulation was very low, reflecting the dilution effect of *Aphanizomenon flos-aquae* on the calculation. Inability of *A. flos.* to accumulate MeHg reduces the possible transfer of MeHg from the pelagic system to the benthic system in the form of detrital *A. flos.* Instead, small, more palatable phytoplankton appear the likely mechanism of MeHg transfer to zooplankton.

AGU conference/Paper 3: Mercury transport model of the Carson River and Lahontan Reservoir System, Nevada: An investigation of total and dissolved species and associated uncertainty. NOTE: continued Monte Carlo analysis is ongoing and may/will modify the results below for the final paper submittal.

- Massive amounts of modeled THg entering the river during overbank flows necessitated a new approach to dealing with mercury associated with washload and the relative amount of DHg in relationship to these contaminated particles. Stokes settling velocities are now augmented with the assumption that mercury laden particles are slightly heavier than uncontaminated washload and settle at a faster rate. The fraction of DHg is computed as the ratio of Hg contaminated fine particles loads to the total Hg load modeled in a given river segment. This ratio is updated every timestep.
- Flow regimes are now divided into four categories to reflect different mercury loading mechanisms. Extremely low flows are dominated by diffusion. Low flows incorporate an advective flux term from the river bottom sediments. Medium to high flows are dependent on bank erosion inputs while overbank events experience massive bank erosion coupled with overbank deposition.
- All post-flood (re)calibration was done on THg and DHg species. No calibration was performed on TMeHg or DMeHg. DMeHg well modeled with trends in concentration matching observed (Spearman Rank $r_s = 0.72$, $p < 0.01$).
- The model is computationally extensive taking several days to complete one realization and thus requiring months on a multi-node processor to complete each simulation. However, generalized uncertainty likelihood estimate (GLUE) posterior means of input parameters stabilize with fewer than 300 realizations for both pre-flood and post-flood simulations. Standard deviations are nearly the same between simulations.
- GLUE analysis suggests that a relatively small but significant increase in THg in the river banks occurred as a result of the flood. A shift in mass erosion rate has also occurred which mitigates any large change in THg bank concentrations.
- The 95% confidence interval captures less than 30% of the observed data (pre and post-flood) such that ongoing efforts are expanding the range in prior input parameter uncertainty, adjusting the prior distributions as well as adding parameters to the analysis. Parameters added include: B_f , D_{bed} , and D_{bank} , E with ranges established to capture 90% of the data. 1000 realizations are currently running. Monte Carlo takes several months to complete. Results from this final Monte Carlo will be those presented in paper 3.

- Total species have larger uncertainty in the river than in the reservoir. Uncertainty increases with flow. Dissolved species tend to have greater uncertainty at very low flows and slow reservoir velocities. The exception being overbank events when there is the potential to transport large amounts of dissolved species into and through the reservoir.
- Relative uncertainty computed using first order- second moment analysis is based on observed data. Uncertainty associated with inorganic species in the river is dominated by transport parameters (λ_1, ψ_2 and L_{riv}) while river uncertainty in MeHg species is controlled by biogeochemical input parameters (M/D).
- Uncertainty in the reservoir pertaining to both DHg and DMeHg is related to river bank erosion processes ($\lambda_1, \psi_2, M/D_{bank}$) and not to diffusion from benthic sediments ($M/D_{up}, M/D_{low}, L_{res}$). Ongoing work will verify if this is the case.

Paper 4: The importance of dynamic mercury loads on mercury body burdens in a planktivorous fish: a modeling perspective.

- Work is ongoing and will continue beyond NIWRR funding period but full acknowledgement of funding will occur.
- The bioenergetic approach is adopted from the Wisconsin Bioenergetic model (Hansen et al., 1997) but coded within the Stella framework. Modifications for multi-species diet are inspired by Megrey et al. (2007) and Monte Carlo calibration by Petersen and Paukert (2005).
- To date a bioenergetic model has been calibrated and verified for juvenile Sacramento Blackfish (*Orthodon microlepidotus* – Ayres) using published growth, diet and metabolic data for the species. Ongoing work continues to calibrate to mature fish using gut contents, eating strategies, pumping rates, and non-linear regressions relating length and age to weight. Shifting diet occurs at age 1 from sight feeding to filter feeding. The bioenergetic model is almost complete.
- The mercury mass balance model is based off of work by Trudel and Rasmussen (2001; 2006). It is also coded in Stella, but is not yet calibrated. Calibration will occur with completion of the bioenergetic model.
- Dynamic and average loads for the post-flood period will drive accumulation rates. Accumulation rates for phytoplankton will use results from the sampling work done in Lahontan (paper 2) and published zooplankton accumulation rates. Results of the final paper will compare Hg body burdens of the fish for the different loading scenarios. First order – second moment analysis will compare relative uncertainty of loading (from paper 3), as well as several bioenergetic and Hg assimilation parameters. Principal discussion will focus on the importance of dynamic loads in the context of relative uncertainty and how important it is in describing Hg body burdens in planktivorous fish.
- The final bioenergetic and mercury mass balance model will be available for continued research and to those managers interested. I will provide it on my DRI webpage and acknowledge NIWRR support of the project.

Information Transfer Activities

Four papers, two conference presentations and one associated student award are provided in the opening section of this report. One paper was published in 2008, one is in a final review by all co-authors before being submitted and two are still in preparation, but will be submitted by the spring of 2010 as part of this project.

Student Support

This grant has funded the doctoral research for Rosemary Carroll who attends the University of Nevada, Reno graduate program of Hydrologic Sciences. Anticipated graduation is May 2010. Work from this project will serve as the entirety of her dissertation. The four chapters will be the four papers listed above. In addition, two conference presentations were conducted as part of this project by R. Carroll, with a student award for best platform presentation granted at the Annual International Conference on Soils, Sediment and Water. Completion of the last two chapters/papers for this project will continue beyond the funding period and will contain full acknowledgement of NIWRR funding.

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