Division of Hydrologic Sciences
Annual Technical Report
FY 2009

Introduction

Research Program Introduction

None.

Modeling Biotic Uptake of Mercury in the Lahontan Resevoir System

Basic Information

Title:	Modeling Biotic Uptake of Mercury in the Lahontan Resevoir System
Project Number:	2006NV101B
Start Date:	3/1/2006
End Date:	12/31/2009
Funding Source:	104B
Congressional District:	Nevada 02
Research Category:	Water Quality
Focus Category:	Models, Toxic Substances, Ecology
Descriptors:	
Principal Investigators:	Rosemary Woods-Hart Carroll, Rosemary Woods-Hart Carroll

Publications

1. 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. Oral Presentation.
2. 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

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 methylmerncy (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 plantivourous 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 19978 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 rs = 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: Bf, 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 (λ_1,ψ_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 planktivours 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 planktivours 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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Carroll, R.W.H. and J.J. Warwick (2001). Uncertainty analysis of the Carson River mercury transport model. Ecological Modelling, 137, 211-224.

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Megrey, B.A., Rose, K.A., Klumb, R.A., Hay, D.E., Werner, F.E., Eslinger, D.L., Smith, S.L. 2007. A bioenergetics-based population dynamics model of Pacific herring (Clupea harengul pallasi) coupled to a lower trophic level nutrient-phytoplankton-zooplankton model: Description, calibration and sensitivity analsysis. Ecological Modelling. 202: 144-164.

Petersen, J.H., and Paukert, C.P. 2005. Development of a bioenergetics model for Humpback Chub and evaluation of water temperature changes in the Grand Canyon, Colorado River. Transactions of the American Fisheries Society. 134: 960-974.

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Soil Heterogeneity and Moisture Distribution Due to Rainfall Events in Vegetated Desert Areas: Potential Impact on Soil Recharge and Ecosystems

Basic Information

Title:	Soil Heterogeneity and Moisture Distribution Due to Rainfall Events in Vegetated Desert Areas: Potential Impact on Soil Recharge and Ecosystems
Project Number:	2008NV134B
Start Date:	3/1/2008
End Date:	5/31/2009
Funding Source:	104B
Congressional District:	Nevada 01
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Geomorphological Processes, Drought
Descriptors:	
Principal Investigators:	Michael Young, Li Chen

Publication

1. Chen, L. (2010) The parameter optimization of Green-Ampt infiltration model. World Environmental and Water Resources Congress, Providence, Rhode Island.

Final Report

Problem and research objectives

Strong interactions exist between desert soils and plants. These interactions will control the overall movement and distribution of water, which are critical for water resources and desert ecosystems. The high level of spatial and temporal heterogeneities of near-surface soil and plant environments creates significant difficulty for quantifying, understanding, and simulating how climate, soil properties and ecological resources interact with one another. Heterogeneities are observed in physical, geomorphological, and biological properties across the landscape and soil surface, thus affecting hydrological processes. The overriding objectives of this research are to observe and simulate the contribution of surface feature heterogeneity to the landscape response from precipitation events, particularly as they relate to recharge and surface runoff in desert environments.

Methodology

Field Measurements

The methodology implemented for this study applies field experimental and numerical approaches to examine the impact of the soil surface heterogeneity introduced by micro-topography, plant canopies, and soil hydraulic properties on infiltration and runoff processes. In the experimental portion of the study, we set up three experimental plots (20 m by 30 m) on 3 geomorphic surfaces with ages that range from 500 to 100,000 years old (McDonald et al., 2003; Young et al., 2004) at the Mojave National Preserve, CA, and then conducted high-resolution elevation within each plot using a Laser Total Station. Surface elevations were first measured on 5 m x 5 m control grid to represent overall topographic trends. Significant topographic structures such as channels, ridges and mounds were measured in more detail. A vegetation survey was also conducted in each plot. Population density for each plant type (evergreen, drought deciduous, etc.) was counted and characteristic scales (major and minor axes of the crown and height) of selected individual plants were measured, generating a spatial distribution of the plants. Topographic mounds under plants were also measured to investigate the micro-topographic features.

Hydraulic properties (i.e., water retention and hydraulic conductivity functions) were measured using a tension infiltrometer (TI) in each experimental plot for soils located in both interspace and undercanopy microsites. The soil hydraulic properties obtained from the TI data are similar to the method described by Young et al. (2004). Soil samples were collected from each TI location and analyzed for soil texture (i.e., gravel, sand, silt, and clay contents) and bulk density. Spatial distribution and correlation of the texture and hydraulic properties were analyzed. Experimental results were imported to a numerical model (described below) to simulate surface runoff under a variety of different precipitation events.

Leveraging an internally-funded DRI project, rainfall simulation experiments were conducted at the plot located on the oldest (Qf3) surface. This study aims to investigate the impact of the clast (upper rock) layer found on many desert pavement surfaces on runoff and infiltration rates. We used a portable rainfall simulator on adjacent plots on surfaces with and without clasts. In the case where clasts were removed, the underlying Av material was kept intact

to the extent possible; thus, the difference between the two plots is the presence of the clast layer. Seven pairs of experiments (14 plots total) were conducted. In each experiment, characteristic times for runoff generation were recorded (i.e., time to ponding, initial runoff, runoff observed in all quadrant, full runoff connection and runoff to a collection trough) at specific time intervals. Changes in soil water content were also monitored continuously during the experiment using a Water Content Reflectometer (WCR, model 616, Campbell Scientific Inc., Logan UT). The cumulative infiltration curves obtained from the WCR measurements were used in a parameter estimation scheme to obtain the Green-Ampt infiltration parameters.

Numerical Modeling

The numerical model used for this research is known as CeRIRM (Cell-Based Rainfall Infiltration Runoff Model), a physically-based distributed model for rainfall-runoff modeling (Chen and Young, 2008). The model simulates surface runoff and infiltration using a high-resolution distributed modeling approach. CeRIRM was originally developed by co-PI Chen for his Ph.D. dissertation and was further modified through funding from the U.S. Army Corp of Engineers. The model applies a two-dimensional surface runoff routing approach to account explicitly for topographic impact on overland flow movement, and it incorporates the Green-Ampt model to simulate infiltration. This comprehensive modeling technique addresses the interaction between infiltration and surface runoff routing that is greatly complicated by heterogeneity of soil hydraulic properties and topography. The model was modified to accommodate the plot scale rainfall-runoff simulation for this project. Parameter fields of topography and corresponding soil hydraulic properties were generated on a regularilized grid for the research plots using interpolation methods based on the observed properties. Using this model and approach, we have simulated cases with and without micro-topography, with and without vegetation, and for different rainfall conditions.

A primary issue in rainfall-runoff modeling is how to efficiently represent the spatial variability of parameters in hydrologic models. Thus, the numerical modeling work for the past year was focused on the fundamental impact of spatial variability of soil hydraulic properties on runoff and infiltration, given specific storm distributions. The model was applied to the Walnut Gulch Experimental Watershed, near Tombstone, AZ, to investigate how different spatial patterns of watershed characteristics (e.g., vegetation coverage) and soil hydraulic properties (e.g., hydraulic conductivity and saturated water content) could impact runoff and infiltration in a semi-arid environment (Yin, 2008; Yin et al., 2010). In these studies, the model was used to examine how parameter generation – uniform versus random versus co-kriged – could affect the accuracy of runoff predictions at a small (approximately 44,000 m^2) watershed known as Lucky Hills 104 (LH104). Parameter fields for this modeling study were generated using a pedotransfer function, using soil textural data obtained from samples collected at 33 locations across the watershed. Samples were collected at both interspace and undercanopy microsites (66 samples total) using a stratified sampling technique. Saturated hydraulic conductivity (K_s), saturated water content (θ_s), and wetting front capillary pressure for the Green-Ampt model (S) were then derived from the estimated hydraulic properties. Three different methods were used to generate the parameter field: geometric mean for K_s and arithmetic mean for θ_s and S; Latin Hypercube Sampling (LHS); and, cokriging using all three parameters. For each method, parameter fields were generated using only interspace samples, only undercanopy samples, and the entire population (nine combinations of averaging and sample origin). The numerical model was then

run for eight recorded rainfall events during the last 50 years that produced measurable runoff at LH104, using each parameter field respectively (72 simulations total). Runoff generation results were compared to find the best approach for representing soil heterogeneity.

Another issue studied in hydrologic modeling in this research is estimating soil hydraulic parameter. Although Green-Ampt (G-A) model parameters are widely used in modeling practices, the most common parameter estimation method is based on soil texture and pedo-transfer functions. Those functions are not solidly based on field observation, but mainly from conversion of other soil hydraulic parameters. A numerical optimization approach has been developed to inversely determine the parameters from the measured soil moisture release curves. The new method can be useful for directly estimating G-A parameters for practical applications. However, further studies are needed to solve the possible multi-solution issue in this method.

Principal findings and significance

Results from the field studies and numerical modeling studies have shown:

- Soil surfaces have features at various scales of topographic elements, mainly including channels, topographic mounds, under canopy soil mounds. These features can dominate runoff routing dynamics and significantly affect the lateral water distribution and nutrient movement toward or away from ecological niches.
- Even small amount of micro-topographic differences can impact surface runoff significantly. Because of the potential for concentrating flow, microtopography not only can affect the routing time of the water, but may also break lateral continuity and reduce flow connectivity. Such flow patterns will alter the distribution of water resource on the surface, and may profoundly impact nutrient and contaminant transport processes and habitat stability in ecosystems.
- Present hydrologic modeling approaches cannot effectively treat micro-topography at subgrid scales, even with detailed topographic data. Based on our current modeling results, a new and simpler approach has been developed to better represent micro-topography and to more accurately simulate surface runoff. This new treatment will be more important for simulating solute transport in surface runoff because the partial connectivity of flow will lead to much higher dispersion rates compared to fully connected sheet flows.
- Soil hydraulic properties vary significantly across the surface, as seen by a qualitative review of the TI experimental results. Quantitative analyses of the results are ongoing. Results will show more details of the heterogeneity and spatial correlation.
- In rainfall simulation experiments, results of both runoff and soil moisture did not show significant difference between plots with and without clasts, which implies that the rock surface does not impact runoff generation by itself.
- Numerical simulation results showed that impacts of spatial variability depend on flood characteristics such as runoff coefficients. In general, the diffusion wave model captured runoff characteristics for most storm events. Simulation results also showed that the best performance occurred for parameter fields generated using cokriging. Also the results showed that effects of vegetation on interception loss and roughness coefficient cannot be

neglected. Results also indicated that small-scale spatial variability dominates the runoff generation mechanism when storm events are small.

Information Transfer Activities"

Papers:

Yin, J., M. H. Young, L. Chen and Z. Yu (2008) Modeling surface runoff on a semi-arid watershed using a physically based model. World Environmental and Water Resources Congress. Honolulu, Hawaii.

Yin, J. (2008) Spatio-temporal variation in soil moisture and hydraulic properties and their impacts on rainfall-runoff and infiltration processes. Ph.D. Dissertation. University of Nevada Las Vegas, Department of Geosciences.

Chen, L. (2009) The role of clast layer in desert pavement in rainfall-runoff process. World Environmental and Water Resources Congress, Kansas City, Kansas.

Chen, L. (2010) The parameter optimization of Green-Ampt infiltration model. World Environmental and Water Resources Congress, Providence, Rhode Island.

Chen, L., L. Xiang, M. H. Young, J. Yu (2010) Parameter optimization of Green-Ampt infiltration model. Vadose Zone Journal, Submitted.

Yin, J., M. H. Young, L. Chen and Z. Yu (2010) Modeling the effect of spatial variability of soil hydraulic properties on the rainfall-runoff process in a rangeland watershed using a diffusion wave model. (In preparation for submission to Journal of Hydrology).

Student Support:

This grant funded the research endeavors (time, instruments and travel) during Jun Yin's Ph.D. degree study. The grant has also supported the training of Long Xiang, a Ph.D. student visiting Desert Research Institute.

Reference

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Flood Warning System for the Clark County Wetlands Park

Basic Information

Title:	Flood Warning System for the Clark County Wetlands Park
Project Number:	2008NV135B
Start Date:	3/1/2008
End Date:	8/31/2009
Funding Source:	104B
Congressional District:	Nevada 01
Research Category:	Climate and Hydrologic Processes
Focus Category:	Floods, Hydrology, Models
Descriptors:	
Principal Investigators:	Thomas Piechota

Publications

1. Acharya, A., T. Piechota, K. Acharya, 2010. Characterization of First Flush Phenomenon in Urban Stormwater Runoff: A Case Study of Flamingo Tropicana Watershed in Las Vegas Valley. to be published in Proceedings of the World Environmental and Water Resources Congree. Environmental and Water Resources Institute. May 16-20, Providence, Rhode Island.
2. Reilly, J. and T. Piechota, 2005. Actual Storm Events Outperform Synthetic Design Storms: A Test of SCS Curve Number Reliability. Proceedings of the World & Environmental Resources Congress, May 15-19, 2005, Anchorage, Alaska, American Society of Civil Engineers, Washington D.C.

Synopsis

Title: Analysis of past storm events and their contribution to flooding for the Clark County Wetlands Park

Investigators: Thomas C. Piechota and Jim Pollard

Problem and research objectives:

This research project will analyze the historical rainfall pattern and its impact on the generation of runoff from the major watersheds that are contributing to flood in the Clark County Wetlands Park located in the Las Vegas Valley. The Clark County has already experienced more than 11 floods since 1993. The most damaging storms mainly occur in between July and September (CCRFCD, 2008). The average rainfall in the Las Vegas Valley is 4.49 inches with half of the total rainfall generated mainly by summer thunderstorms. Although the rainfalls with magnitude greater than a tenth of an inch occur less than 10 days a year on average in Las Vegas ([1]Caraco, 2000), the flash floods have become a major concern that is causing devastating damage. The 9 major watersheds that are contributing to Las Vegas Wash are shown in **Figure1.** The Clark County Wetlands Park is located adjacent to the Las Vegas Wash and is an invaluable environmental resource. The facility is open to the public with various walking trails; however, there is potential for the facility to be inundated with flood waters during significant rainfall events. The proposed research project will online sources of data from the Regional Flood Control District (RFCD) website to
(1) Evaluate the seasonal variation in the rainfall pattern based on past storm events;
(2) Identify the threshold values of water depth for significant occurrence of flooding;
(3) Analyze the regional variation in the rainfall and water depth for historical events and for major watersheds.

Data and Methodology:

Among the 9 watersheds contributing to Las Vegas Wash, the major watersheds considered for study are Duck Creek (DC), Pittman Wash (PW) and C1 Channel. The runoff from these watersheds is assumed to significantly affect the Clark County's Wetlands Park. Therefore, the analysis of past storm events have been carried out for these watersheds. Each watershed possesses different number of stations throughout the area; most of which are installed by CCRFCD and some by USGS. Altogether 28 weather stations (DC-9, PM-11, C1-8) are actively working in these 3 watersheds with only one streamflow measuring station installed by USGS. The position of the weather stations along with their station ID in 3 different watersheds is clearly shown in **Figure 2.** The rain gauge network possesses both rainfall and water depth measurement at almost all stations. The triangular stations as represented in Figure 2 are considered for water depth analysis. The specific objectives will be met by a data driven analysis using the source of historical data available online. The major tasks include;
Task 1: Identification of major watersheds and download of required data for all stations.
Task 2: Build a program to extract only the significant storm events from the available historical real time data.
Task 3: Carry out the trend analysis for rainfall and water level data.
Task 4: Expand the similar analysis to other watersheds and summarize the concluding remarks.
The study tries to observe the major changes occurred in precipitation over time, flow over time and flow with respect to precipitation for the watersheds. This research project will focus only on the watersheds mentioned above. However, if it seems suitable, the analysis could be extended to

other watersheds as a future work. The measured instrumental data is taken into account to observe the trend change in precipitation and runoff that would serve as a basis to conclude the results.

The stations established earlier possess data for longer periods starting from 1990; while the stations installed later include data only after 2000 in most of the cases. The total rainfall considered in the study is greater than 0.04 inches for each storm event. The number of rainfall events and the historical records of rainfall data available for each station are presented in Error! Reference source not found.. In total, there are 990 rainfall events for C1 channel, 937 events for DC and 1267 events for PM Wash that exceeds the total rainfall of 0.04 inches.Due to lack of stations measuring stream flow, the increase in water level is used to fulfill the objective. The water level station considered is stationed on the downstream side of all the rain gauge stations on each watershed and near to the confluence of the Las Vegas Wash. The water level stations chosen at far d/s do not posses sufficient data for DC and PW watersheds. Thus one more water level station was selected in between with larger no. of data to compare the behavioral change. The stations taken into consideration and the data present for each station are incorporated in **Table 2.**

Principal findings:

This part of research could be considered a preliminary part of graduate study to understand the nature of rainfall and flow patterns in the watersheds. Some of the principal findings from the analysis are presented in this report.

Rainfall Analysis

The rainfall analysis is performed by categorizing the total events in terms of 2 seasons as Dec-May and June-Nov representing the events mainly in winter and summer. As shown in **Figure 3**, almost 90% of the total events are concentrated in the range of 1.0 inches of rainfall followed by approx. 1% events more than 2.0 inches. The number of events is higher for the C1 channel for rainfall below 0.2 inches for both seasons, Dec-May and June-Nov. DC possesses comparatively higher percentage of occurrence of rainfall events above 0.2 inches. The rainfall events are slightly higher for Dec-May within 1.5 inches of rainfall and almost equal above that range.

Based on cumulative occurrence frequency, more than 90 percent of the rainfall events are occurring within the depth range of 1 inch. The rainfall depth considering 90% cumulative probability of occurrence is considered the design storm for management of stormwater quality BMPs.In all 3 watersheds, for both the seasons, the normalized distribution of total rainfall events as in **Figure 4** shows about 0.7 inches of rainfall that possesses 90% of total cumulative events. In terms of intensity, it ranges from 0.4 -0.5 in/hr with higher value for PM wash and lower for DC watershed.

Based on rainfall duration, almost 10 -15 % of events are occurring above 12 hours in wet season and 4-8% in dry season. C1 and DC posses almost equal number of events in the range of 2 to 8 hours for both periods whereas it is comparatively higher for DC for more than 8 hours of duration. Most of the events concentrated on larger duration can be considered the major storm events in case of higher intensity of rainfall. Thus C1 and DC can be assumed to have significant effect (DC with higher dominating effect than C1) on the major rainfall events in comparison to PM wash. The median rainfall duration is higher in case of DC within a range of 2 inches of rainfall whereas the interquartile range in **Figure 5** shows the increasing trend with larger variation in the data. The events above 1 inches of rainfall show almost similar median duration for DC and C1 channel. The

higher intensity of rainfall occurring for longer duration implies the higher generation of runoff. This implies that the runoff produced is higher in case of DC and C1 channel than PM wash. The higher duration observed in the range of 1.5-2 inches of rainfall for PM wash might be due to occurrence of some of the concentrated major storm events in the watershed. The lower duration in case of PM wash for more than 2 inches of rainfall is due to the presence of few observations. The median duration in winter period is almost same for C1 and DC; both contributing equally for higher runoff generation. Very few events above 1.5 inches of rainfall are observed in PM wash. The contribution of smaller events is higher in both seasons with comparatively higher variation in the range of duration in summer than in winter.

Water Level Analysis

The observed precipitation data in the range of 0.2 to more than 2 inches are categorized into 5 classes (0.2-0.5, 0.5-1.0, 1.0-1.5, 1.5-2.0, >2.0 inches). As shown in **Figure 6**, the water depth increasing in a linear pattern up to a range of 1-1.5 inches shows a drastic increase for more than 1.5 inches of rainfall. It represents the higher storm events that occurred in the past in DC watershed. Very few events occur above 2 inches of rainfall and higher runoff can be expected for rainfall in excess of 1.5 inches in DC watershed. The water depth in PM is low in comparison to water depth in DC channel for the same range of ppt. This implies that the runoff is comparatively lower in case of PM wash than DC channel if the median increase in water depth is considered. For C1 channel, the median values for water depth is lower in comparison to DC and almost similar to PM Wash up to a range of 1.5 inches of rainfall. For higher precipitation, the water depths are similar to DC, comparatively more than PM Wash. This depicts the storm runoff in C1 Channel as similar to PM Wash (smaller than DC) incase of lower range (up to 1.5 inches) whereas some storm events show higher runoff (as incase of DC Wash) for more than 1.5 inches of rainfall.

The rainfall corresponding to 90 percent occurrence of rainfall events is 0.7 inches for all watersheds. The median water depth indicated by the box plots corresponds to a value of approximately 1.6, 0.8 and 0.8 ft. respectively for DC, PM and C1 channel respectively. The depth can be considered as the runoff depth that needs to be taken care of during the design of drainage channels. The rainfall events occurring above the indicated depths correspond to higher storm events that may cause devastating damages.The runoff depth and the duration of storm events are highly variable in between the storm events. Thus the median depth can be considered significant from design point of view.

Knowledge of the threshold value of runoff for low flows is also important during dry seasons with very low rainfall. The threshold values for low flows can be observed at a point with sudden change in water depth or higher water depth than previous rainfall events. This point indicates the starting point for the generation of runoff in the watershed. From the step change analysis, the threshold values of low rainfalls for DC, PM and C1 channel are 0.16, 0.04 and 0.08 inches of rainfall respectively as shown in **Figure 7.** The corresponding water depth with respect to low rainfall after which the runoff starts is 0.2, 0.25 and 0.15 ft. respectively for C1, DC and PM respectively. From the contour plot in **Figure 8**, the maximum water depth observed in case of PM wash is very low in comparison to DC and C1 channel. There is no fixed pattern of significant increase in water depth in case of DC. In case of C1 and PM, the maximum water depth is observed for maximum rainfall and duration. The higher depth observed in DC also signifies the occurrence of some major storm events. The higher depth with low rainfall and duration in all watersheds signifies the variation in rainfall pattern within the watershed.

Conclusions

- Large variation in the plot signifies the general nature of rainfall in Las Vegas; heavy rainfall occurring within shorter intervals in summer that lasts for longer duration during winter periods.
- Higher percentages of storm events were observed in lower water depth region that can hardly produce any significant water depth.
- DC comparatively possesses higher percentage of occurrences of events (> 0.2inches) that lasts for more than 12 hours in duration compared to C1 and PM.
- Runoff produced is higher in case of DC and C1 than PM wash; DC with the dominating effect.
- The total rainfall corresponding to 90% of the total cumulative events is found about 0.7 inches that is important in terms of stormwater quality BMPs.The median water depth with respect to rainfall are 1.6, 0.8 and 0.8 ft. for DC, PM and C1 channel respectively.
- During low flows, the generation of runoff for C1, DC and PM occurs at depths of 0.2, 0.25 and 0.15 ft. respectively for 0.08, 0.16 and 0.04 inches of rainfall.

[1]Caraco,D.(2000). Stormwater Strategies for Arid and Semi-Arid Watersheds. *The Practice of Watershed Protection.*Feature article from *Watershed Protection Techniques.*3(3)*:* 695-706.

<u>Information Transfer Activities</u>

a) Meeting with Stakeholders

- March 28, 2008: Clark County Parks and Recreation (Elise Sellars) and Jim Pollard.
- Regular group meetings at UNLV.

b) Conference Presentations:

- A report/ conference paper will be presented at the end of the project work.

c) Publications

- Still under revision. Not presented anywhere yet.

Student Support: No students supported in Year 2. Anil Acharya (grad. student) was working on the project and was funded on a state-supported assistantship in Fall 2008 and Spring 2009.

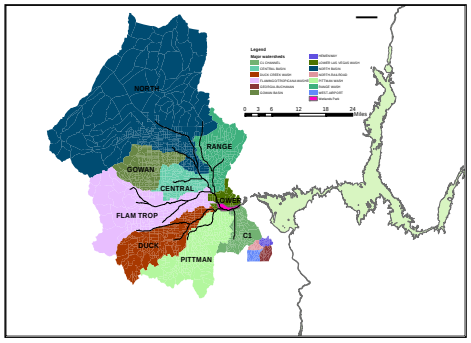

Figure1 Nine major watersheds contributing to Las Vegas Wash

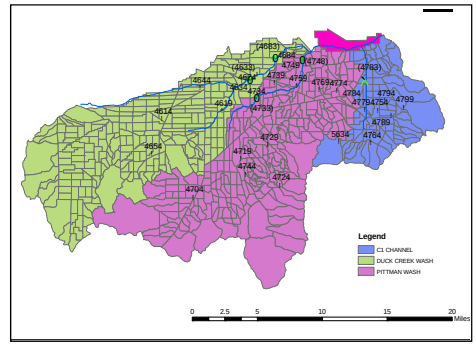

Figure 2 Location of weather stations

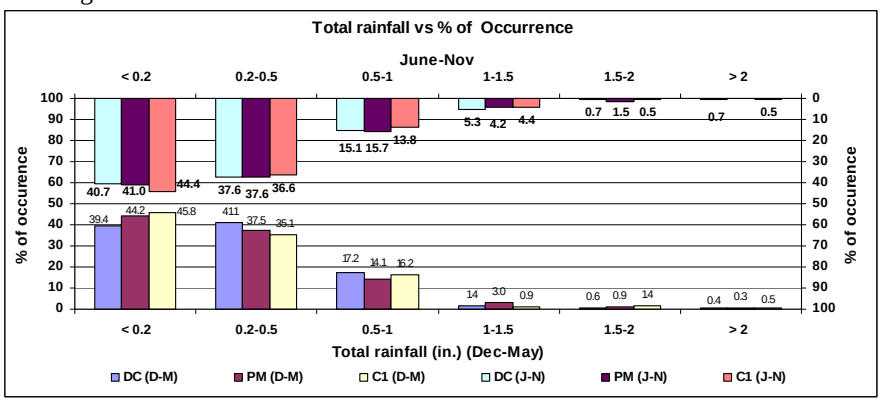

Figure 3 Total rainfall vs % of Occurrence

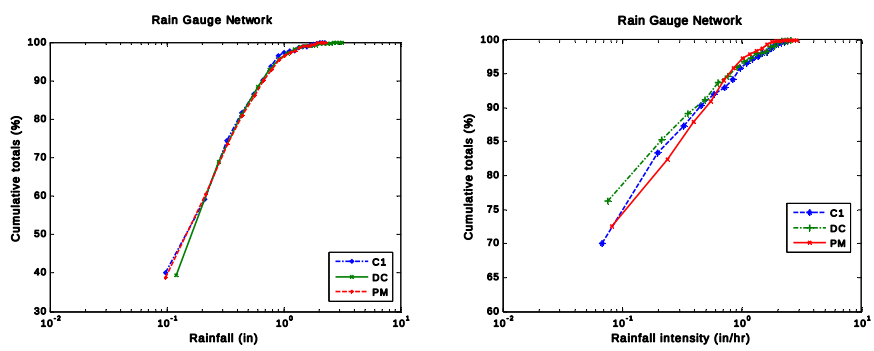

Figure 4 Normalized distribution of cumulative rainfall versus rainfall and rainfall intensity

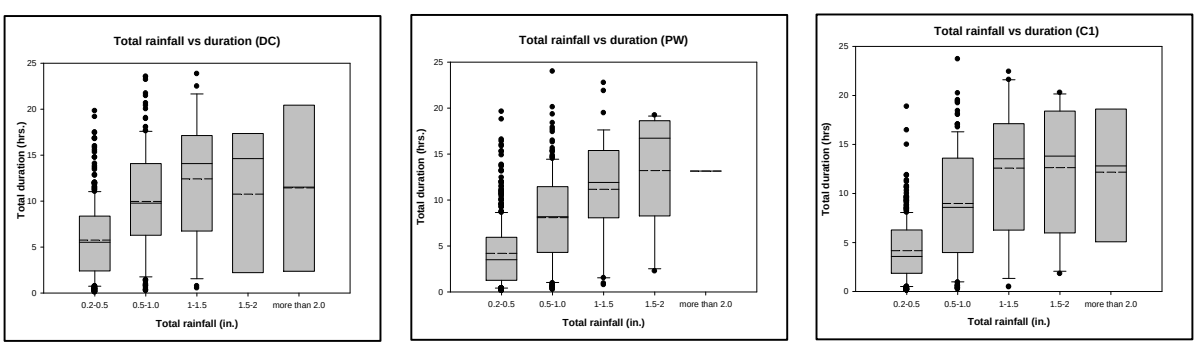

Figure 5 Total rainfall vs total duration; for a) DC channel (b) PM Wash (c) C1 Channel

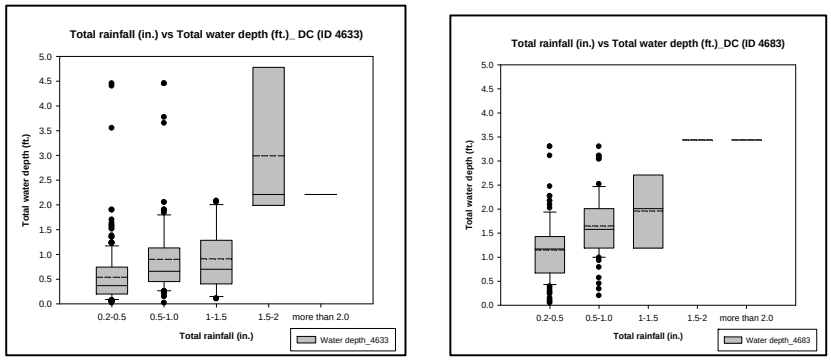

Figure 6 Total rainfall vs total water depth (DC); for water level stations a) 4633 & b) 4683

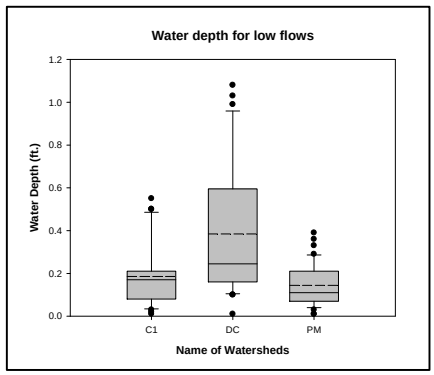

Figure 7 Water depth for low rainfall events that are significant at different depths i) C1 at 0.08" of rainfall ii) DC at 0.16" of rainfall iii)PM at 0.04" of rainfall.

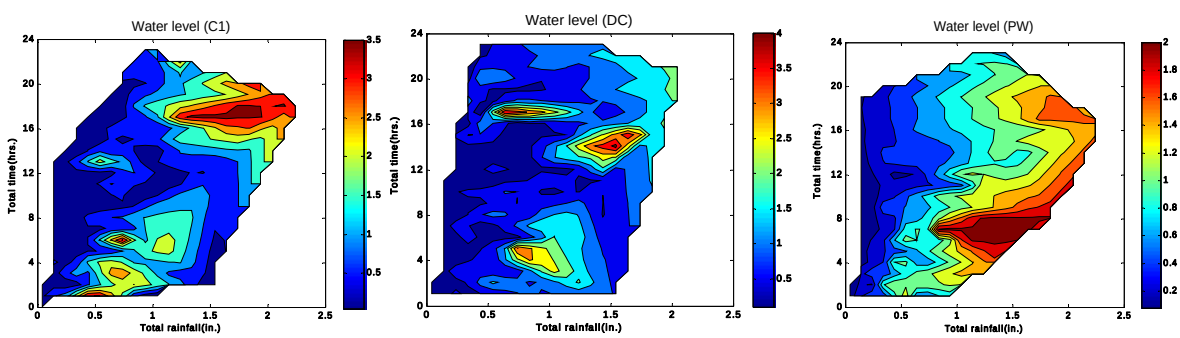

Figure 8 Contour plots of water level w.r.t. total rainfall and duration

Table 1 Rainfall data and total rainfall events considered for analysis

C1 channel								
St. Id	**4754**	**4764**	**4779**	**4784**	**4789**	**4794**	**4799**	**5634**
From	03/97	08/94	09/02	09/89	06/93	01/93	06/00	04/00
To	05/08	05/08	05/08	05/08	05/08	05/08	05/08	05/08
Events (> 0.2”)	66	73	42	108	89	82	35	48
Total Events	141	173	65	185	157	133	58	78

DC channel									
St. Id	**4614**	**4619**	**4624**	**4634**	**4644**	**4654**	**4674**	**4684**	**4694**
From	06/89	09/01	06/91	08/89	03/97	07/97	01/02	07/01	11/05
To	05/08	05/08	05/08	05/08	05/08	05/08	05/08	05/08	05/08
Events (> 0.2”)	103	35	113	98	54	67	45	39	5
Total Events	169	46	178	170	99	116	70	71	12

PM Wash											
St. Id	**4704**	**4719**	**4724**	**4729**	**4734**	**4739**	**4744**	**4749**	**4759**	**4769**	**4774**
From	08/89	01/03	06/01	08/02	10/88	08/95	02/93	03/00	09/99	05/02	04/92
To	05/08	05/08	05/08	05/08	05/08	05/08	05/08	05/08	05/08	05/08	05/08
Events> 0.2”	121	33	44	36	140	68	74	38	50	37	85
Total Events	205	55	70	66	199	127	139	83	85	66	172

Table 2 Water Level Data present for selected stations

Nameof Watersheds	**C1 Channel**	**Duck Creek**		**Pittman Wash**	
Stn Id	**4783**	**4633**	**4683**	**4748**	**4733**
From	02/1993	07/1991	07/2001	01/2004	05/1991
To	05/2008	05/2008	05/2008	05/2008	05/2008

Quagga Mussel Invasion in Lake Mead: Ecological Impact and Containment

Basic Information

Title:	Quagga Mussel Invasion in Lake Mead: Ecological Impact and Containment
Project Number:	2008NV137B
Start Date:	3/1/2008
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	Nevada 01
Research Category:	Biological Sciences
Focus Category:	Acid Deposition, Ecology, Water Quality
Descriptors:	
Principal Investigators:	Kumud Acharya, Charalambos Papelis, Mark Stone

Publications

There are no publications.

Annual Report

Quagga Mussel Invasion in Lake Mead: Ecological Impact and Containment

Problem and Research Objectives

Lake Mead is the largest reservoir in the US and one of the most important water resources in the West. In January of 2007, Quagga mussels (*Dreissena bugensis*) were discovered in Lake Mead, for the first time west of the 100th meridian. This invasive species and the related Zebra mussel (*Dreissena polymorpha*) have disrupted ecosystems in a number of waterways elsewhere in the US and have cost billions of dollars in control efforts. Given the seriousness of the recent Quagga mussel invasion for the ecology and economy of the broader region, and for the overall management of the important water resources of the region, the primary goal of the proposed research is to study the ecology and biology of Quagga mussels and their impact on aquatic biodiversity and water quality in Lake Mead. Specifically, under the proposed research plan we will study the ecological impact of the invasion; the physiological ecology of the mussels; 4) the population structures; and the potential of Quagga mussels to bioaccumulate metalloids under local conditions. This study will use and contribute to the collection of data on Quagga mussels already under way by local, state, and federal agencies. The proposed study will also contribute to the development of local expertise, necessary to address this serious ecological and economic problem. Results will be published in peer reviewed journals and communicated to the public, in an effort to educate the public and to limit the negative impacts of the invasion. Finally, the experience and data collected from the proposed study will be used to support competitive proposals to national funding agencies to further contribute to our understanding of the problem and viable management strategies.

Methodology

The study has focused on the ecological impact and physiological ecology of the species. These studies include development of models for quantifying algae clearance, ammonia production, and measurement of growth rates of the species in controlled laboratory settings using spectrophotometry based regressions. Prefacing laboratory based studies, development of field sampling protocols for collecting mussels via SCUBA and shore collection were undertaken, as well as water collection for laboratory aquaria. Permitting applications for scientific collection were obtained through the Nevada Department of Wildlife. Establishment and maintenance of in-lab aquaria capable of maintaining cultures of the species involved extensive background research along with trial experiments to arrive at appropriate water temperature, flow rate, light cycle, water chemistry, and maintenance schedule parameters. Clearance rate, ammonia production and growth rate studies required development of lengthy experimental designs to ensure proper quantification and minimum variability between samples. Experiments required incubators to ensure proper light allowance or exclusion, and trials were

completed during off-peak hours to minimize interference from other experiments and to ensure machine availability at exact required testing times.

Principle Findings and Significance

The data so far indicates Lake Mead quagga mussels are aggressive feeders of algae. The clearance rate experiments completed in this study indicated the quagga mussels in Lake Mead filter at higher rates per mass when still in an early growth stage, and that they filter smaller algae particles faster than larger ones. The highest filtration rates were observed in the waters with high sediment and low nutrient concentration, an important indication mussel impact. Waters in lakes and rivers that experience high turbidity, or times or high turbidity, may potentially see a larger impact in water clarity and clearance by the mussels.

Our growth study results suggest that quagga mussel growth in Lake Mead may be food limited at this time, and it would be reasonable to predict significant increases in their growth at times during the year when algae concentration is greater, inclusive of summertime increases in lake productivity. Based on our preliminary data, quagga mussels' increasing population could have dramatic implications in the clarity and overall foodweb of the Lake Mead.

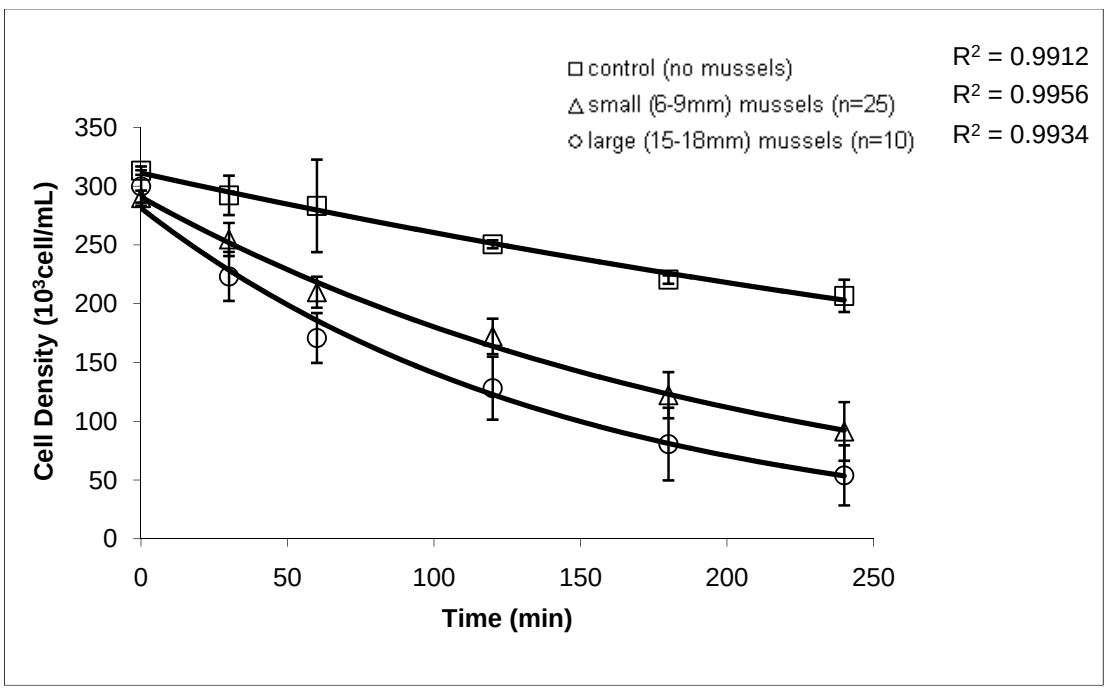

Figure 1.1 Graph of small algae Density over Time in 1L Vessels with Large and Small Quagga Mussels

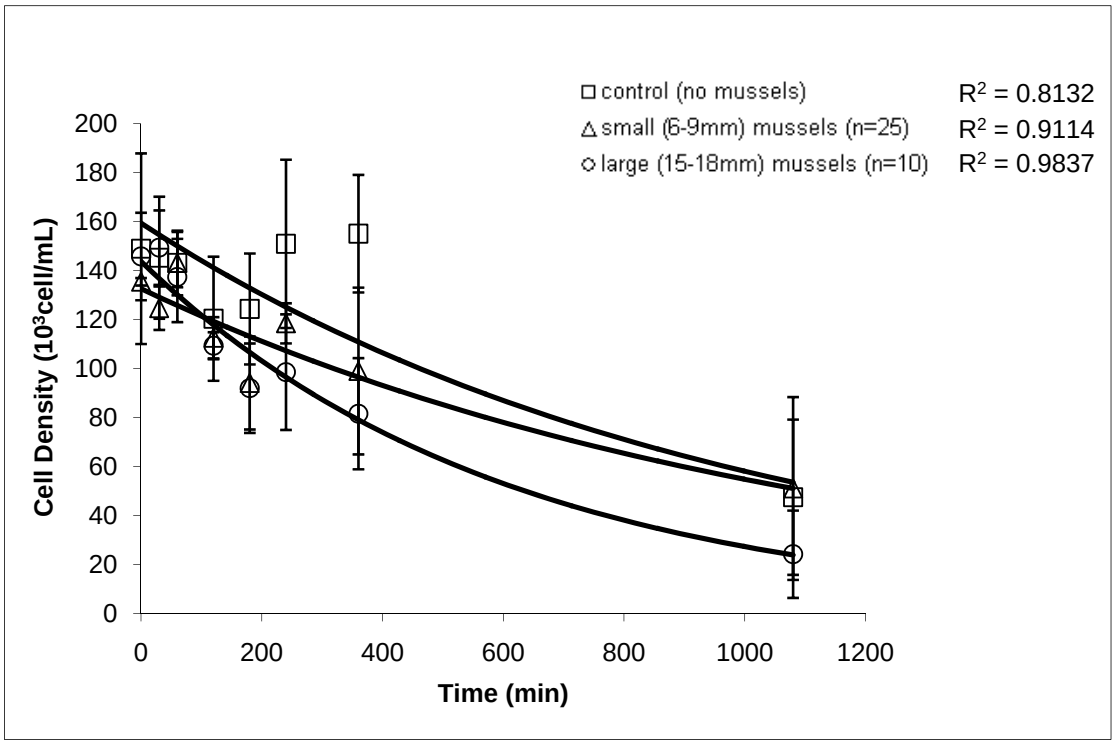

Figure 1.2 Graph of large algae Density over Time in 1L Vessels with Large and Small Quagga Mussels

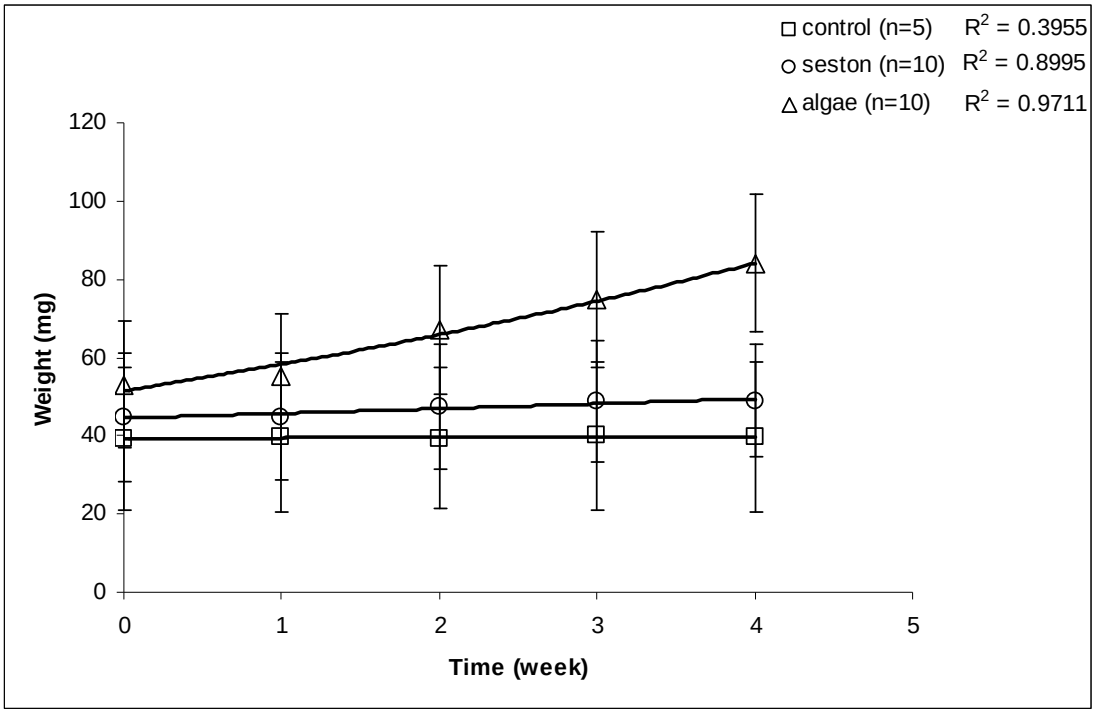

Figure 2.1 Growth in Milligrams of Quagga Mussels in Media over Time

Information Transfer Activities

Results obtained so far were presented at the Lake Mead Science Symposium, in Las Vegas, NV, in January 2009 before stake holders and research communities. Similar efforts will continue as more data become available. The PIs and the graduate student (Carolyn Link) who are working on this project attend the quarterly meeting of Quagga mussels held at Southern Nevada Water Authority (SNWA) for information exchange.

Student Support

The project currently supports two graduate students, Carolyn Link and Lynn Schwaebe for their research associate ships (RA). Both are graduate students in the Water Resource Management Program at the University of Nevada, Las Vegas. Carolyn has been working in this project from the beginning and is planning to graduate this semester (Spring, 2010). Lynn joined from Fall, 2009 and expects to work until the end of this project.

Publications

Link, C., K. Acharya, L. Papelis, 2009. "Will Quagga Mussels Potentially Impact the Native Species' Food Web in Lake Mead by Affecting Plankton and Nutrient Availability?" Lake Mead Science Symposium, Las Vegas, Nevada, January 13-14.

Estimation of Spatio-Temporal Statistics of Precipitation and Snow-Water Equivalent in the Truckee River Watershed

Basic Information

Title:	Estimation of Spatio-Temporal Statistics of Precipitation and Snow-Water Equivalent in the Truckee River Watershed
Project Number:	2008NV138B
Start Date:	3/1/2008
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	Nevada 02
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Surface Water, Water Supply
Descriptors:	
Principal Investigators:	Rina Schumer, Anna Knust

Publication

1. Boyle, D.P.; Schumer, R.; Ashby, J.; Klieforth, H.; Knust, A.; Barth, C.; 2009. An analysis of long term precipitation and snow water equivalent records in the Lake Tahoe and Truckee River watersheds. Western Snow Conference, Canmore, Alberta, Canada.

Annual Status Report:
Estimation of spatio-temporal statistics of precipitation and snow-water equivalent in the Truckee River watershed

Problem and Research Objectives

Introduction

Precipitation-runoff models are used in the Truckee River watershed and other regions of Nevada to support river and reservoir operations. Physically based runoff models are used to estimate water yield based on the accumulation and depletion of snowpack and various water distribution processes (e.g. infiltration, runoff), subject to an energy balance and a water balance. Results are used to forecast the timing and volume of seasonal water supply as well as the effects of climate variability and land use change. The spatial and temporal distribution of precipitation and snow-water equivalent (SWE) are used in the calibration of precipitation-runoff models, yet our knowledge of these variables is highly uncertain because 1) field measurements of SWE and precipitation are sparse and 2) both SWE and precipitation are sensitive to physiographic factors such as elevation and aspect.

In this study, we will compile and analyze a previously undocumented dataset that includes up to 30 years of precipitation and SWE measurements recorded at 29 sites in the Truckee River watershed (Figure 1). The inclusion of this dataset with measurements from established monitoring stations in the watershed, will more than double the spatial sampling resolution, and the combined datasets can be used to 1) estimate temporal and spatial statistics of precipitation and SWE in the Truckee River watershed, 2) improve calibration of precipitation-runoff models in the watershed sub-basins, and 3) test independent models (e.g. SNODAS, PRISM) designed to estimate the distribution of precipitation and SWE.

Statement of regional water problem (Relevance and Importance):

The Truckee River is one of the most highly regulated water bodies in the world, with most of the river water fully allocated to stakeholders including the Department of Interior, State of California, State of Nevada, Sierra Pacific Power Company, Pyramid Paiute Tribe, and Truckee-Carson Irrigation District, among others. The distribution of Truckee River water is regulated by an interstate compact and managed by a federal watermaster.

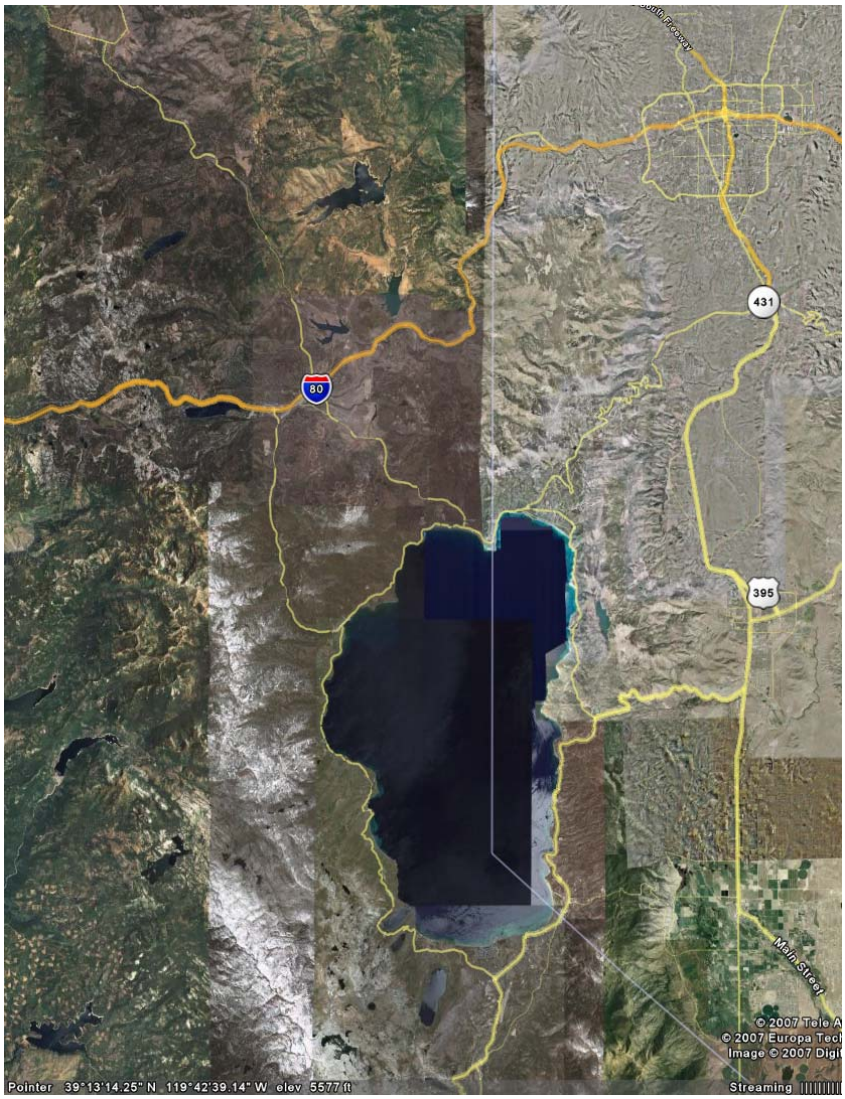

Figure 1. Approximate locations of SWE and precipitation measurement sites described in Table 1.

Water resource managers are increasingly required to incorporate information related to climate in their decisions. Like many watersheds in the Sierra Nevada, it is likely that the first sign of global warming in the Truckee River watershed will be an earlier start to the spring runoff (Dettinger, *et al.,* 2004), requiring a modification of reservoir operation on the river. The resultant reduction in streamflow in the late summer directly affects Truckee River water quality issues, as dissolved constituent concentrations increase dramatically under low flow conditions. The draft Truckee River Operating Agreement Joint Environmental Impact Statement/Environmental Impact Report identified water quality of the Truckee River as a key concern for flow management. As a result, management practices in the basin may require modification based on predicted flows.

The goals of this project are to

1. Collect and organize a previously undocumented data set containing up to 30 years of precipitation and SWE measurements taken after storms events at 29 sites in the Tahoe Basin and Truckee River watershed,

2. Analyze the spatio-temporal statistics of precipitation and SWE from the newly compiled dataset combined with observations recorded by other sources (e.g. Snotel sites),

3. Assess the accuracy of models currently used to estimate the spatial distribution of precipitation and SWE in the Truckee River Watershed, and

4. Publish a database containing the new dataset.

Hal Klieforth, a former Desert Research Institute meteorologist, began measuring monthly precipitation and snow water equivalent at 29 sites between Spooner Summit and Henness Pass Junction (Figure 1) in the early 1970's.

Findings to Date and Future Work

Prior to this project, data only existed as hard copies located in Mr. Klieforth's personal office in Bishop, CA. The organization and digitization of this dataset have required significant time and manpower. Compilation and QA/QC of SWE data are complete. Initial statistical analyses demonstrate that while long term changes in SWE vary by month, spring SWE decreased at all sites between 1968 and 2007. This trend is most pronounced for sites located on the east side of the crest, along the Mt. Rose Highway. In particular, there is a larger decrease in absolute SWE at higher elevations (e.g. Figure 2) but a larger percent decrease in SWE at lower elevations.

We are currently completing QA/QC on recently digitized precipitation data. When this step is complete, we will determine whether changes in SWE in the Truckee River watershed result from changes in total precipitation or changes in percent of precipitation as snow. Results will be compared with similar studies performed in California on the west side of the Sierra Nevada. Finally, we will use the data to measure the accuracy of SWE predicted by rainfall runoff models and PRISM snow product.

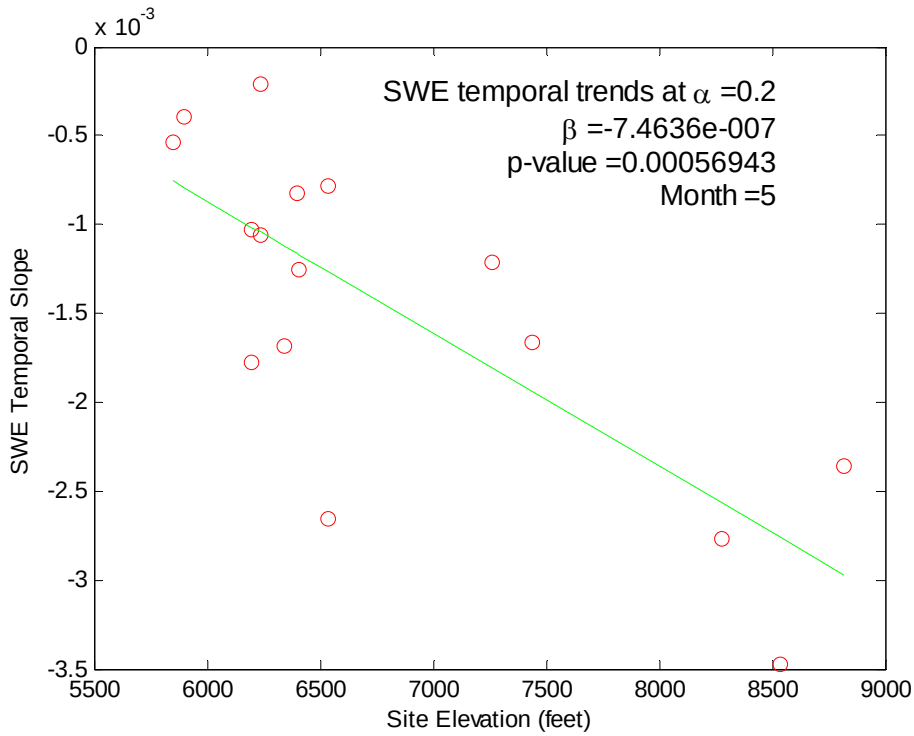

Figure 2. All Klieforth sampling sites show decreasing May SWE between 1968 to 2007. The absolute decrease is more pronounced at higher elevation (shown here) although the percent change is greater at lower elevation (not shown).

Information Transfer Activities

Boyle, D.P.; Schumer, R.; Ashby, J.; Klieforth, H.; Knust, A.; Barth, C.; 2009. An analysis of long-term precipitation and snow-water equivalent records in the Lake Tahoe and Truckee River watersheds. Western Snow Conference, Canmore, Alberta, Canada.

Student Support

This grant continues to fund University of Nevada (UNR) Graduate Program of Hydrologic Sciences PhD student Hal Voepel. In addition, UNR undergraduate student Keri Noack was funded to assist with data preparation.

Uncertainty and Sensitivity of Ground-Water Discharge Estimates for the Shrublands in the Great Basin Area

Basic Information

Title:	Uncertainty and Sensitivity of Ground-Water Discharge Estimates for the Shrublands in the Great Basin Area
Project Number:	2008NV139B
Start Date:	3/1/2008
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	Nevada 01
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Water Supply, Groundwater
Descriptors:	
Principal Investigators:	Jianting Julian Zhu

Publications

There are no publications.

Uncertainty and Sensitivity of Groud-Water Discharge Estimates for the Shrublands in the Great Basin Area

Synopsis

Progress Report (3/1/2009 – 2/28/2010)

Problem and Research Objectives

The current limited water supply to Las Vegas area mainly from Colorado River is not likely enough to support its potential future growth. With future needs of water resources in mind, local water authorities are looking northeast to the Great Basin. One plan – among many others – proposes to pump water from the Great Basin aquifers. Before such action can be taken, it is necessary to investigate the way in which the aquifers are influenced and the potential for long-term pumping to affect water availability to phreatophytic vegetation. Federal legislation (Section 131 of the Lincoln County Conservation, Recreation, and Development Act of 2004) was enacted to conduct a water resources study of the alluvial and carbonate aquifers in Nevada and Utah. The study was known as the Basin and Range Carbonate Aquifer System Study, or BARCAS study. The study area includes 30 sub-basins in 12 valleys. Of particular focus in the BARCAS study was the amount of ground water lost through evapotranspiration (ET). While groundwater ET as an overall water budget component has been estimated in other studies, including BARCAS, the sensitivity and uncertainty of groundwater ET estimates have not been systematically analyzed.

Given the large size of the study area and the dearth of previous studies of the valleys, groundwater discharge through ET was estimated using a rather sparse dataset. As a result, the ET rate and area uncertainty have significant influence on the groundwater discharge estimates. It is therefore beneficial to quantify the uncertainty associated with these estimates in order to help maximize future data collection efforts. This project seeks to develop an integral approach to quantify the uncertainty and sensitivity of groundwater discharge estimates.

Methodology

We first present the general steps for quantifying fractional contributions of uncertainties in individual variables to the estimation uncertainty of groundwater discharge by ET, when large numbers of independent variables are involved:

1. Establish model(s) to estimate groundwater discharge that relate independent variables to the calculations of groundwater discharge.

2. Estimate uncertainty ranges and probability density functions for the independent variables based on field characterization, professional judgment, etc.

3. Randomly select realizations from the prescribed probability distributions of the independent variables, and calculate groundwater discharge values based on the selected model(s) in Step 1 for all realizations.

4. Select influential independent variables, based on the physical characteristics and model structure of the considered problems. The main goal of this step is to reduce the number of independent variables included in the subsequent sensitivity analysis.

5. Conduct sensitivity analysis to quantify the uncertainty contributions from individual independent variables.

To quantify how parameter-level uncertainty affects groundwater discharge estimates, we conduct Monte Carlo simulations that represent independent variables as statistical distributions rather than as single values. Each independent variable is assumed to be characterized by a probability density function, with the mean ET rate estimated either through remote sensing analyses, values taken from the literature, or from existing data. To examine the sensitivity of the total groundwater discharge estimate to the three independent variable categories in general (i.e., ET rate, acreage, and precipitation rate), we also systematically vary the standard deviations for the independent variables. The Monte Carlo simulations based on the estimated standard deviations are considered as the Base Case. By comparing the results relative to the Base Case, we can assess how uncertainty from each independent variable category contributes to the uncertainty of the total groundwater discharge estimate. For this purpose, we investigate two main themes: (1) varying the standard deviations of one individual independent variable category, while holding constant the standard deviations of the other two categories at the Base Case levels; and (2) varying the standard deviations of one individual independent variable category while using the mean of the other two independent variable categories (i.e., standard deviations equal zero). By investigating theme (2), we can explore how uncertainties in individual variable categories propagate to the uncertainty in the total groundwater discharge. After the Monte Carlo simulations, we develop regression models that relate total groundwater discharge to individual independent variables, and we use these models to assess overall sensitivity of the total groundwater discharge estimate to the individual independent variables. The squared values of standardized regression coefficients simply represent the fractional contributions from the individual independent variables to the total variance of the groundwater discharge.

Principal Findings and Significance

The principal findings are:

1. Although the independent variables in this study typically have small CVs, the CV of groundwater discharge estimates in some sub-basins can be quite large.

2. The uncertainty of ET rates is the most significant contributor to the uncertainty of groundwater discharge estimates. We find that a total of 630 variables affect the estimates of total groundwater discharge, but that only seven variables account for almost all of the variability in the discharge estimates. We demonstrate that groundwater discharge estimates using the simplified regression relationship and the full relationship correlate very closely ($r = 0.982$).

3. Quantitatively, the variability in ET rates for the moderately dense desert shrubland contributes to 75% of the variance in the total groundwater discharge estimates. The results indicate that field data collection to reduce overall uncertainty should focus primarily on this ET unit, and less on other units.

Information Transfer Activities

Journal Papers:

Zhu, J., and M. H. Young, Sensitivity and uncertainty of ground-water discharge estimates for semi-arid shrublands, *Journal of the American Water Resources Association (JAWRA)*, 45(3),641-653, doi:10.1111/j.1752-1688.2009.00312.x, 2009.

Pan, F., J. Zhu, M. Ye, Y. A. Pachepsky, and Y.-S. Wu, Sensitivity analysis of unsaturated flow and contaminant transport with correlated parameters, in preparation for submission to *Journal of Hydrology*, 2010.

Abstract and Presentation:

Zhu J., and Young, M. H., Uncertainty and sensitivity of evapotranspiration estimates for semi-arid shrublands, Nevada Water Resources Association Annual Conference, Mesquite, Nevada, March 5 – 6, 2008.

Student Support

This grant was partly used to fund student training. Feng Pan (PhD student at University of Nevada Las Vegas (UNLV), Department of Geoscience) was funded partially from this grant during the project period.

Award No. G09AP00003 Depleted Uranium Transport by Water

Basic Information

Title:	Award No. G09AP00003 Depleted Uranium Transport by Water
Project Number:	2008NV158S
Start Date:	10/23/2008
End Date:	12/31/2009
Funding Source:	Supplemental
Congressional District:	Nevada 03
Research Category:	Climate and Hydrologic Processes
Focus Category:	Toxic Substances, Hydrology, Radioactive Substances
Descriptors:	
Principal Investigators:	David Shafer, Julianne Miller

Publications

1. Shafer, David S., Miller, J.J., Meyer, W.J., Jenkins, Sara, Chief, Karletta, Young, M.H., and Lambis Papelis. 2010. Modeling overland transport of depleted Uranium in arid environments. Proceedings of the 13th International Conference on Environmental Remediation and Radioactive Waste Management (ICEM10). Tsukuba, Japan.
2. Meyer, W. J., Ahmad, Sajjad, Young, Michael H., Shafer, David S., Miller, Julianne J., and Karletta Chief. 2009. A multi-platform approach to examine spatial and temporal variability of antecedent moisture content on model-generated runoff from a watershed. Annual Meeting of the American Geophysical Union. San Francisco.
3. Shafer, David S., Miller, J.J., Chief, Karletta, Meyer, W.J., Jenkins, Sara, Tappen, J.J., Young, M.H., Caldwell, T.G., Papelis, Charalambos, and W. Forsee. 2010. Potential surface water transport of depleted Uranium (DU) and DU oxides on the Nevada Test and Training Range. U.S. Geological Survey Water Resources Research Institute Program Report No. G09AP0003.
4. Meyer, William J, Young, Michael H., Sajjad, Ahmad, Miller, Julianne J., and David S. Shafer. 2009. Spatial and temporal variability of antecedent moisture content on model-generated runoff from a watershed. American Society of Agronomy Annual Meeting, Pittsburgh.

Depleted Uranium Transport by Water in the Mojave Desert

Final Report

Problem and Research Objectives:

Depleted uranium (DU)-armored munitions have seen increasing use in conflicts in arid and semi-arid regions of the world, and have been used as part of training exercises and ballistic tests at U.S. Department of Defense (DOD) installations in the Mojave Desert of the southwest United States. Because of its potential health and environmental effects, DOD is taking steps to limit the area impacted by DU and DU oxides by reducing its transport in the environment. This research focused on the potential transport of DU by water (channel and overland flow) during "flow events" in the Mojave Desert. The focus was mechanical transport of DU and DU oxides. Hydrous DU oxides form quickly on the surface of DU munitions after a precipitation event, slough-off, and form essentially a separate phase in the environment.

Methods:

At the primary study area, the runoff properties of different geomorphic surfaces/soils on which DU occurred were determined to populate a runoff and transport model to predict how far DU and DU oxides may migrate over time by surface water flow. Aerial photos and other imagery were used to make a preliminary map of geomorphic surfaces/soils in the study area. Groundtruthing was done in areas of uncertainty. Bulk density measurements and particle size analysis of soil samples are conducted to determine if any of the geomorphic units could be statistically combined in terms of their physical characteristics. Rainfall simulation tests to develop runoff curve numbers and tension infiltrometer tests to develop unsaturated conductivity values were performed on the different geomorphic units. Samples of soil containing DU oxide particles were analyzed using x-ray diffraction. All of the oxides were a hydrated U oxide phase, the mineral schoepite ($UO_3 \cdot 2H_2O$).

For this research, a FLO-2D model was constructed to study unconfined flow conditions over the complex alluvial fan topography that typified areas where DU had been used by DOD. The Zeller-Fullerton equation was used for sediment transport because of its ability to handle particles of high density (DU, 19.2 grams/cm^3 and DU oxide, 4.8 grams/cm^3). In addition, Zeller-Fullerton has been used when a substantial portion of the sediment transport is expected to be by bedload, an assumption warranted because of the density of DU and DU oxides. The model was also used to assess transport potential of matrix soil, and DU and DU oxide particles during 100- and 10-year, 6-hour storms. For the analyses of the DU and DU oxide particle transport, a modification was made to the procedure used for the matrix soils analyses to account for the substantially increased specific gravities of the DU and DU oxides. It was assumed that both had specific gravities of 2.65 (that of the matrix soil), but the D_{50} values of both DU and DU oxide particles were modified to represent the specific weight of each contaminant. Based on field observations and engineering judgment, D_{50} values for DU and DU oxide particles were selected as 10 mm and 0.25 mm, respectively. Ratios were then developed between the specific gravities of DU and the matrix soil, and again for the specific gravities of DU oxide and the matrix soil. Both the DU and DU oxide particles were assumed to be spherical, and a volume of

each was calculated using the respective selected D_{50} value. These volumes were then multiplied by the respective specific gravity ratio to represent the scaled-up volume of the median particle size for both DU particles and DU oxides. The matrix soil particle size distribution was used for both contaminants, although the distributions were shifted to account for the selected and scaled-up D_{50} values, keeping the same gradation coefficient for all particle size distributions.

Principal Findings and Significance:

As anticipated, during both 10- and 100-year storms, transport potential of DU particles was limited because of its density. During a 100-year storm, the nodes where the model predicted erosion of transport would occur was largely restricted to channels on older alluvial and colluvial surfaces with low infiltration values. However, because of the smaller particle size and lower specific weight of the DU oxides, it had greater transport potential, with the maximum distance of transport on lower gradient surfaces with high infiltration values of 152 m for the study area for a 100-year storm. In addition, transport was not limited to channels, but did occur in areas where sheet flow would occur as well.

The modifications made to matrix sediment size distribution to handle the high density of DU and DU oxides is potentially a new method for using FLO-2D for modeling transport of high density material. In addition, in the results of the study, it was recommended to DOD that it make efforts to distinguish between DU and DU oxides. Reliance solely on the detection of Th-232 (a gamma emitting daughter product of DU) to determine their surface soil spatial distribution does not distinguish between DU and DU oxides. In addition, because of the hydrous nature of the DU in these environments, particles of it continue to break down in size from their swelling and shrinking after precipitation events. As a consequence of its transport potential and mechanical breakdown, long-term, DU oxides pose a greater toxicological risk to human and ecological receptors than DU itself.

Student Support

William Meyer, a graduate student at the University of Nevada, Las Vegas, is using a significant portion of the research conducted for this project toward his Master's thesis. His degree will be in Civil and Environmental Engineering. In addition, Karletta Chief, a post-doctoral fellow and an from an underrepresented group in science and engineering (Native American), was one of the principal investigators, contributed to one of the abstracts and conference proceedings (in addition to the final report to the Air Force), and with be an author and co-author on peer-reviewed publications that are planned.

Information Transfer

Two abstracts were prepared for professional meetings in the fall of 2009 and a presentation will be made and a conference proceeding published for a meeting later this year. Preparation of manuscripts for peer reviewed journals has been slower than desired because of the length of time it took to get the final report approved. Our chief point of contact with the Air Force was deployed to Afghanistan at about the time we were completing the research. He was unable to review the report for a couple of months after his deployment. However, we were able to address his comments in the final report and now can publish results of it. Other information

transfer is that some of the modeling techniques used for this project is proposed for a Department of Energy project involving water transport of Plutonium; and experience from this project was incorporated into a proposal that was awarded to DRI by Jacobs Engineering to support their work at the China Lake Naval Air Weapons Station. DU was used at that site in the past.

Black Carbon in Sierra Nevada Snow: Impacts on Snowmelt and Water Supply

Basic Information

Title:	Black Carbon in Sierra Nevada Snow: Impacts on Snowmelt and Water Supply
Project Number:	2009NV150B
Start Date:	3/1/2009
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	02
Research Category:	Climate and Hydrologic Processes
Focus Category:	Surface Water, Climatological Processes, Non Point Pollution
Descriptors:	
Principal Investigators:	Joe McConnell

Publications

There are no publications.

Black Carbon in Sierra Nevada Snow: Impacts on Snowmelt and Water Supply

Reporting period: March 1, 2009 – February 28, 2010

Problem and research objectives:

Black carbon (BC) aerosols emitted during combustion and deposited on snow decrease reflectance, leading to enhanced snow pack warming, sublimation and melt. Because more than 85% of California and Nevada's water supply originates as mountain snow in higher elevations, quantitative understanding of processes that influence snowmelt and spring runoff is critical to California and Nevada's economic growth and ecological sustainability. Water storage, flood control, and conveyance systems for domestic, industrial, such as power generation, and agricultural uses are designed to capture spring snowmelt from the enormous winter snow pack reservoir.

Objectives of this research are to 1) characterize concentrations of BC in fresh Sierra Nevada snow, 2) measure changes in concentration and movement of BC in snow during melt, 3) simulate surface radiative forcing from BC on snow throughout winter snow accumulation and spring melt periods in collaboration with M. Flanner, and 4) provide the results to hydrologic modeling approaches to improve our understanding of the water balance in snow-dominated watersheds throughout the Eastern Sierra Nevada.

Methodology:

To obtain a more regional understanding of BC in Sierra Nevada snow, sample collections will occur at established research sites to minimize cost and exploit the availability of existing infrastructure and personnel. Field research will be conducted at two Sierra Nevada locations: the Cooperative Snow Study Site on Mammoth Mountain near Mammoth Lakes, CA and the Sagehen Creek Field Station near Truckee, CA both administered by the University of California. To assess the sources of BC, deposition mechanisms, and movement within snow, samples of fresh and aging snow and snowmelt water will be collected along the following criteria.

Approximately twelve snow pits located at the Cooperative Snow Study Site on Mammoth Mountain will be excavated and sampled this coming year during the snow accumulation and snowmelt periods. In addition, samples of melt water draining the snow pack will be collected from existing parallel lysimeters throughout the snowmelt season to monitor release of BC from the snow pack, and snow pack inventories from the snow pits will be compared with BC released in melt water to evaluate mass balance.

All samples were returned to DRI's laboratory in Reno to be inventoried and analyzed for BC concentration and particle-size distribution using a revolutionary new analytical technique developed in 2007. A series of BC stability limit experiments have been performed this past fall, under supervision of Ross Edwards, to understand how BC concentrations change when samples are re-frozen after being melted. Soluble ions were measured to understand flushing in the snowpack. Selected samples will also

be analyzed to determine the type and amount of continental dust since impacts on snow pack radiation depend on dust mineralogy.

Principal findings and significance:

Research objectives were designed to answer the following hypotheses.

-We expect black carbon to accrue within the snowpack during snow accumulation because there is no melt occurring and therefore all deposition is preserved and compacted. During accumulation, black carbon remains constant within the snowpack layers because the snowpack is frozen.

-We expect black carbon concentrations (and the total black carbon in each pit) to decrease immediately after the onset of melt because the black carbon is flushed (hydrophilic), and removed by melt water and flow fingers. During melt, as the temperature increases, the flushing of black carbon increases.

-We expect high black carbon concentrations to correlate negatively with spectral albedo measurements because black carbon absorbs incoming radiation, and thus decreases the albedo of snow. We hypothesize the relationship between black carbon concentrations and albedo will be negatively correlated.

Principal findings are still being evaluated as part of Kelley Sterle's Master's Thesis. Thus far, the following findings have been made:

-BC is highly variable in space and time, as seen through differences in regional measurements throughout the Sierra Nevada and local measurements within the Cooperative Snow Study Site on Mammoth Mountain. Differences among measured amounts exceed estimated errors and imply real variability.

-Sagehen Creek samples revealed lower concentrations than Mammoth samples, and melt began much earlier (April versus May). Surface snow measurements taken in April 2009 near the Mt. Rose SNOTEL site revealed similar concentrations near Sagehen.

-Surface snow samples that were collected across a 250 meter transect off the Mt. Rose Highway, at 50 meter intervals to compare the concentration to the distance from the road. Samples closest to the road did not reveal greater concentrations to that those farther into the meadow, suggesting that the source and sample collection distance are independent. Further investigations of source distribution and atmospheric transport would provide more clarification for the observations made.

-Low concentrations of black carbon found in lysimeter melt water during the ablation season suggests that BC is not flushing, but remaining within the snow pack until the final melt stages. The significance of this is still being investigated; however it may prove that BC is hydrophobic during the initial stages of melt, and eventually flush through the snowpack under later conditions.

-Aged summer snow samples that were collected near the Conness Glacier showed higher concentrations than we expected, based on our hypothesis that BC flushes through the snowpack. Spectral albedo data will be compared to the concentrations made to determine if a correlation exists.

-We have measured soluble ions in Mammoth snow pits and are currently in the process of interpreting how these concentrations explain the elution of solutes through the snow pack. Furthermore, we aim to gain an understanding to whether or not the BC remains in the snowpack after flushing, or if it leaves the snowpack differently than ions.

-We will evaluate the significance of the observed concentrations in the top 50 centimeters of snow, and send BC data to Mark Flanner for forcing interpretation in Snow, Ice and Aerosol Radiative Model (SNICAR).

Information Transfer Activities:

Presentations:

Sterle, Kelley M., Joseph McConnell, Jeff Dozier, Ross Edwards, and Marion Bisiaux (2009), Black Carbon in the Eastern Sierra Nevada, *American Geophysical Union*, Fall Meeting, Abstract H33E-0933, San Francisco, CA.

Sterle, Kelley M., Marion Bisiaux, Cassandra Hansen, KC King, and Joseph McConnell (2009), The Sources, Distribution, and Effect of Black Carbon in Annual Snowpack of the North Lake Tahoe Region, *Truckee River Symposium*, Desert Research Institute, Reno, NV.

Student Support

This grant largely funded the research endeavors (field work, travel, analysis) during Kelley Sterle's M.S. degree, and will continue through her graduation in August 2010. The grant also provided funding for field assistance in Mammoth, CA from undergraduate students at the University of Nevada, Reno (Tommy Cox & Orion Ashmore). This grant also enabled collaborative research with UCSB professor Jeff Dozier and his students Ned Bair & Mike Colee. Sampling at Sagehen Creek Field Station was done in cooperation with the Sagehen Creek Experimental Forest Staff and UNR's 2009 Snow Hydrology Class. Additional sampling for aged summer snow was done in collaboration with University of Utah's professor Thomas Painter.

Information Transfer Program Introduction

None.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	1	0	0	0	1
Masters	4	0	0	1	5
Ph.D.	5	0	0	0	5
Post-Doc.	0	0	0	0	0
Total	10	0	0	1	11

Notable Awards and Achievements