The History of Water and Vegetation in Bears Ears National Monument, Southeastern Utah

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Abstract. On December 28, 2016, President Barak Obama created Bears Ears National Monument on 1.35 million acres in southeastern Utah, primarily to protect its archaeological heritage. One of the primary archaeological questions is the cause of the migration of the Ancestral Pueblo from southern Utah to the Rio Grande valley of New Mexico about 1300 AD. Climate change is often invoked as a cause, but understanding migration involves combining the occurrence of climate change with the resilience of the ecosystem and social system. The objective of this study is to predict the hydrography and vegetation of Bears Ears National Monument under various levels of and seasonality of precipitation. The ultimate goal is to create a series of hydrographic and botanical maps of Bears Ears for the centuries leading up to the abandonment of Bears Ears by the Ancestral Pueblo. The objective has been addressed thus far by measuring discharge and collecting water samples from 18 springs in Bears Ears, and analyzing the samples for stable isotopes of water and for concentrations of the anthropogenic gas CFC. The stable isotopes indicate that the springs are recharged by local precipitation and that most recharge results from summer monsoonal and fall rains with very little contribution from snowmelt. The CFC concentrations indicate that the groundwater emerging from springs has residence times as long as 65 years, so that these springs could remain as viable water sources even after severe mega-droughts lasting for over half a century. Further results will be reported at the meeting.

Distribution of Soil Water Salinity and Impacts on Maize Yield in Gypsiferous Irrigated Fields with Subsurface Drainage

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Abstract: About 20% of irrigated land worldwide is considered salt-affected, resulting in many billions of dollars of annual loss in global crop yields. A project funded through the US-Pakistan Center for Advanced Studies in Water aims to jointly develop techniques for quantifying severity of soil salinity and impacts on crop production on surface-irrigated fields in Pakistan's Indus River Valley and in the Lower Arkansas River Valley (LARV) in Colorado. As part of this project, the objective of this preliminary study was to characterize the spatial variability of soil salinity and maize yield in a furrow-irrigated, tile-drained (1.2 m depth) field (14 ha) in the LARV during 2016. Electromagnetic induction was used to map apparent soil electrical conductivity (EC_a; 0 – 1.5 m depth). The spatial EC_a values were inputted into the Electromagnetic Sampling Analysis and Prediction (ESAP) program to identify soil sampling points for saturated paste soil extract conductivity (EC_e). A calibration equation was used to convert EC_a to EC_e values that were used to create a spatial map of salinity. Applied irrigation water and salt loading (TDS) on the field was measured. At selected low (0 – 4 dS/m), medium (4 – 6 dS/m), and high (6 – 12 dS/m) EC_e (dS/m) zones, volumetric water content (θ_v) at 10, 50, and 100cm depths, maize growth, and yield were monitored over the growing season. Water table levels were monitored via monitoring wells installed at the perimeter of the field. The θ_v time series indicated that the high EC_e zones had prolonged exposure to saturated root zone conditions. This indicated that high EC_e zones were more severely affected by shallow water table depths (0.34 – 2.85 m). Average grain yields were 16000, 12000, and 8000 kg/ha at the low, medium, and high EC_e zones, respectively. Maize yields varied spatially with severity of soil salinity and water logging, diminishing by as much as 50% in the high salinity zones. Future work will focus on characterization of salt species in the root zone, soil salinity effects on water potential and evapotranspiration, and calibrating remotely-sensed imagery with ground-based EC_e measurements to develop algorithms for regional salinity mapping.

Vulnerability of water resources to nutrient pollution: The usual suspects, urban development and agricultural activities

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Abstract. The main goal of this study was to characterize the vulnerability of water bodies to nutrient pollution as a function of upstream land use under different climatic conditions. Multiple linear regression models were developed across 23 subbasins within Jordan Lake Watershed in North Carolina between 1992 and 2012 to explore land use-water quality relationships. Percentage of urban land use and wastewater treatment plant capacities showed significant ($p < 0.01$) and strong ($R^2 > 0.7$) positive correlations with annual concentrations and loads in all models. There was a negative correlation between percentage of agriculture and TN in most years, but positive for TP in some years. Analysis of covariance was used to explore the impact of inter-annual precipitation variations on land use-water quality relationships. Significant difference ($p < 0.01$) was determined between models developed for urban land use with TN or TP loads based on annual precipitation. This is while; using concentration data resulted in insignificant difference between models for average and wet years. Vulnerability computed as probability of exceeding the nutrient standard limits (targets) changed substantially with land use and climatic conditions. The vulnerability to nutrient pollution as a function of urban land use was significantly higher in dry years than the conditions in average and wet years.

Estimation of Flood Zones along Ungauged Gravel-Bed Braided Rivers

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Abstract. With regard to river engineering projects along a gravel-bed river in an ungauged watershed, experience-based engineering and engineering judgment is shown to be important part of the procedure needed for determining flood-hazard zones. This paper presents a case study of a flood-hazard delineation project along a reach of the Dehbakri River in Kerman province, Iran. After following the usual routine procedure involving a widely used one-dimensional numerical model to estimate the 100-year recurrence for defining the flood hazard area, it was found that the estimated flood levels along a gravel-bed channel did not match well-delineated watermarks formed during earlier flood flows. Because there was no substantial data or observations regarding the flood's peak discharge or stage, it was found that experience and judgment had to be used. The observations use the limited observational data available (water-level marks) and insight from studies at similar channels, to reach a reasonable estimation that match observed water levels. This paper describes the experience and judgement used to estimate flood levels and a flood zone for the reach along the Dehbakri River. In particular, this paper points out that, for steep, braided gravel-bed rivers, critical depth of flow acts as a form of constraint causing the channel-bed characteristics to change, switching from sub- to super-critical flow; and, relatedly altering bed forms and flow resistance. The typical fixed-bed numerical models sometimes (e.g. this study) inaccurately estimate the flow characteristics in steep loose-bed channels. Indeed, there is no alternative at present other than to make use of observed water-levels associated with earlier floods. Therefore, experience and engineering judgment emphasize the importance of determining water levels associated with the loose, deformable beds of ungauged gravel-bed rivers.

Some insights for parameterizing mixing in stably stratified turbulence

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Abstract. In this study, some new insights for inferring turbulent mixing in stably stratified flows are provided based on physical scaling arguments and tested using high resolution direct numerical simulation (DNS) data. It is shown that in the weakly stratified regime ($Fr \geq 1$), the diapycnal (eddy) diffusivity $K_\rho \sim w' L_E$, and for the strongly stratified regime ($Fr < 1$), $K_\rho \sim (w' L_E) \times Fr$. Here, w' is the vertical (fluctuating) velocity scale, L_E is the Ellison length scale and $Fr = \epsilon / Nk$ is the turbulent Froude number wherein N is the buoyancy frequency, k is the turbulent kinetic energy and ϵ is the rate of dissipation of turbulent kinetic energy, respectively. The comparison between the modeled and exact diffusivities using DNS data is remarkable and highlights the strength of the proposed new model in its ability to predict turbulent mixing in stably stratified flows.

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Added Sediment Concentration in The Porong River, Indonesia, from the Sidoarjo Mud Volcano Diversion

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Abstract. The Sidoarjo mud volcano is a disaster that started on May 29, 2006 at the drilling point of Lapindo Brantas Inc. in East Java, Indonesia. The mud volcano itself is predicted to have a 50% chance for lasting more than 41 years (Rudolph et al., 2011) with an average discharge of 50,000 m^3/d (Harnanto, 2011) and a 35% average concentration of silt and clay. Since 2007, 95% of the solids have been contained in mud reservoir with a 650 ha of area. To mitigate the damage to surrounding regions, the Government of Indonesia took an action to discharge the mud to Madura Strait through the Porong River (Hadimuljono, 2012). The Porong River is a tributary of the Brantas River, which starts from Lengkong Baru Weir at Mojokerto to Madura Strait with an average bed slope of 0.0003 m/m. Bed materials of the river are 4% of sand, 35% of silt and 61% of clays. Based on the recent available water level record from January 2012 to December 2016, the highest average monthly discharge can reach up to 690 m^3/s and the lowest is about 20 m^3/s. The pipe outlets of the mud diversion are located on the left bank, about 15 km from its estuary, with an average mud discharge of 615 thousand m^3/month. From HEC-RAS and the analytical solution of the advection – diffusion equation for a steady point source, the sediment concentration for 15 km reach of the Porong River can be modeled. The results for the model with a flow discharge of 530 m^3/s are: at 15 km, the maximum concentration on the left bank side is 37% by the initial concentration of the point source and the concentration on right bank is approximately half the concentration on the left bank.

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Lessons Learned and Future Directions in Large Scale Hydrologic Assessment

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Abstract. USDA Agricultural Research Service, Texas A&M University and USDA Natural Resources Conservation Service have led national conservation and environmental assessments since the early 1980's. USDA sponsored CEAP (Conservation Effects Assessment Project) to determine the environmental impacts of USDA conservation programs while USEPA sponsored HAWQS (Hydrologic and Water Quality System) for EPA contractors to perform environmental assessments across the U.S. Development of models and tools to perform the assessments have been accomplished through collaboration with other universities and agencies across the globe. While undertaking these national assessments, we have learned several lessons on developing national input data, calibration, scenario analysis, and presentation of model output to decision makers. In addition, we are developing plans for future assessments by improving spatial representation and detail, utilizing advances in satellite and remotely sensed data, and providing web-based tools for decision makers.

Small-scale Spring and Summer Precipitation Variability

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Abstract. Temperature and precipitation are the most ubiquitously measured hydrometeorological variables. However, measuring precipitation can be difficult. In the winter wind and other influences can create an environment where a gauge under-measures the actual precipitation while in the summer convective storms often yield much spatial variability. From mid-May through early August in 2015, 2016 and 2017, we measured daily precipitation at 20 locations over a 25-hectare area at the Colorado State University Mountain Campus. During this time period, the site encounters both snowfall and convective precipitation. We used several geospatial analysis techniques to identify the nature of the spatial variability in precipitation over the three partial years, as well as an optimal strategy to identify this variability on a daily time step. Using 20 precipitation gauges is unrealistic in an operational setting, but the use of several gauges can yield improved precipitation estimates for individual storm events.

An Initial Investigation of the Long-term Use of Random Packing Material (RPM) in Contact Tanks

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Abstract. In the US, the Environmental Protection Agency (EPA) has set certain drinking water standards to ensure the safety of water distributed from our water supply systems. However, there are still areas where these standards are not being met, largely due to lack of financial and managerial resources. For instance, small-scale systems (less than 5,000 gallons operating up to 50 GPM) account for 93% of these EPA violations. CSU's Department of Civil and Environmental Engineering collaborated with the Colorado Department of Public Health and Environment to conduct research for small-scale water systems, which resulted in cost-effective pre-engineered small-scale tanks and system modifications proven to increase the hydraulic disinfection efficiency presented in the *Baffling Factor Guidance Manual* (2014). One of the suggested modifications is to add random packing material (RPM) into a contact tank. Lab-scale studies indicated a 300-400% increase in baffling factor reaching near plug flow conditions (BF≈0.9; plug flow: BF=1) (Barnett 2013). Despite the exceptional impact the RPM had on the internal hydraulics, the long-term use of this RPM in a contact tank is a concern when considering the water quality entering the contact tank (i.e. not yet disinfected) in combination with the high surface area of the RPM. These conditions are favourable for the formation of a biofilm. The hypothesis is that the presence of the disinfectant in the contact tank, though the water is not yet fully disinfected, will mitigate any biofilm growth. A pilot study was conducted in the Environmental Fluid Mechanics Lab to address this concern. Preliminary results support this hypothesis.

Characterization of urban water use and water demand forecasting using the Integrated Urban Water Model in Sao Paulo, Brazil

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Abstract. The pressure over water resources in urban areas, especially in developing countries, is of great concern when considering population growth, climate change and land use changes. Sao Paulo is one of the largest urban agglomerations in the world and is located in Southeastern Brazil. Reservoir levels used for water supply to over 12 million people in the city, not including the Metropolitan Region, suffered a severe drop, particularly in 2014 and 2015. The magnitude of this event served as warning for society, government and utilities and raised discussions about strategies for demand compliance in urban areas and enhanced water resources management. The Integrated Urban Water Model (IUWM) is a web-based tool with a mass balance approach and a GIS interface that uses land use, climate and demographics data for water demand forecasting and evaluation of conservation scenarios that could reduce demand of potable water, such as graywater reuse, stormwater harvesting and increase in irrigation efficiency. IUWM applicability to Sao Paulo aims to characterize urban water demand, estimate the impact of conservation strategies and forecast demand driven by changes in demographics and climate until the end of this century. Initial results show the possibility of the model application outside of the United States, presenting a good model performance at estimating water demand.

Can water conservation save agriculture?

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Abstract. Rapidly growing populations in many semi-arid regions of the world intensify competition over scarce water resources, injuring the livelihood of vulnerable populations. Specifically, rural economies that rely on irrigated agriculture suffer negative consequences from lost economic activity as farmers sell water rights to growing municipalities. In this talk, we pose a critical and relevant question: can improved management practices save rural communities from impending decline? Applying a hydroeconomic modeling framework in a representative semi-arid river basin reveals that a mix of conservation techniques and new supplies will likely extend the life of irrigated agriculture in semi-arid regions. Adoption of these strategies can increase the magnitude of irrigated acreage by nearly 70% as compared to baseline conditions. Further, urban conservation and lower water acquisition prices significantly decrease costs to municipalities. However, loss of irrigated agriculture is imminent near the end of the century as city populations exceed a critical threshold between urban water demand and irrigated cropland. This talk examines how water transfers affects rural economies and investigates strategies to protect such economies. Results are of widespread interest for the future health, security, and livelihood of agricultural communities throughout the world and the populations that depend on their productivity.

How often does Frost Occur?

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Abstract. The majority of California, Arizona, New Mexico, and parts of Nevada get their water from the Rocky Mountain Headwaters. Snow melt in the mountains contributes to the largest amount of water recharge in Colorado reservoirs and for water allocation to other states. To better understand how snow impacts the water budget, we must consider what is lost in semi-arid regions. Sublimation is an important process where vapor pressure fluxes can be measured as losses from the water storage, as well gained by deposition of frost. However, the amount of water that is lost or gained due to sublimation is still largely unknown. We used small scale, close-to-the-surface measurements of wind speed, air temperature, and relative humidity to determine downward sublimation flux as frost. We determined that frost occurs often in Colorado, and this downward flux of negative energy remains relevant to the Global Energy Budget in Colorado's watersheds.

The Interaction between Gravity Currents and Breaking Internal Waves

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Abstract. Gravity currents moving along the continental slope, such as cold river inflows into lakes or brine effluent from desalination plants, can be influenced by internal waves shoaling on the slope resulting in mixing between the gravity current and the ambient fluid. Whilst some observations of the potential influence of internal waves on gravity currents have been made, the process has not been studied systematically. I will present the results of laboratory experiments, and some initial numerical simulations, in which a gravity current descends down a sloped boundary through a pycnocline at the same time as an internal wave at the pycnocline shoals on the slope. The waves are generated in a two-layer thin-interface ambient water column under a variety of conditions characterizing both the waves and the gravity currents. I will present results over a full range of Froude number (characterizing the waves) and Richardson number (characterizing the gravity current) conditions, and will discuss the mechanisms by which the gravity current is mixed into the ambient environment including the role of turbulence in the process. Measurements of the downslope mass flux of the gravity current fluid in cases with different amplitudes of the incident internal wave will also be discussed. For the parameter regime considered, the mass flux in the head of the gravity current was found to reduce with increasingly larger incident amplitude waves. This reduction was effectively caused by a "decapitation" process whereby the breaking internal wave captures and moves fluid from the head of the gravity current back up the slope. The significance of the impact of the internal waves on gravity current transport, strongly suggests that the local internal wave climate may need to be considered when calculating gravity current transport.

Seasonal Streamflow Effects of Lateral Connectivity in Unconfined Mountain Valley Bottoms

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Abstract. Fluvial networks of historically glaciated mountain landscapes alternate between confined and unconfined valley segments. In low-gradient unconfined reaches, river-connected floodplains are thought to attenuate extreme flooding. Less clear is how this lateral connectivity affects seasonal snowmelt hydrographs characteristic of mountain streams. Here, we present preliminary approaches using water balance and recession curve analysis to quantify the effect of floodplain connectivity on stream hydrologic regimes. Our analysis incorporates sites that vary in the extent of lateral exchange and degree of valley confinement. This study will provide insights into future work on cumulative network effects of unconfined valley bottoms. In doing so, we aim to provide insight into hydrologic effects of floodplain restoration efforts.

Bedload traps and Helley-Smith samplers yield different transport rates and particle sizes of gravel bedload

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Abstract. Samplers used to collect gravel bedload differ in their opening size, the degree of sampler body flaring, in the size, shape and mesh width of the sampler net, in sampler deployment (on the channel bed or a fixed sill or ground plate), and in sampling time. Those differences affect sampling results. Not much is known about the details of how those sampler and deployment characteristics affect sampled gravel transport rates and the largest bedload sizes ($D_{QB,max}$). Hence, many studies base their choice of a gravel bedload sampler on availability or convenience and might use results from studies with diverse samplers indiscriminately.

This study sampled gravel transport with bedload traps and a 0.076 m Helley-Smith sampler in mountain streams to tease out why and by how much sampled gravel transport rates and particle sizes differ. Bedload traps have a 0.3 m by 0.2 m opening size and an unflared body, to which nets >1 m long with a 3.6 mm mesh width are attached. Bedload traps were deployed on ground plates, spaced 1-2 m apart and typically collected bedload for about an hour per sample (unless transport is very high). The Helley-Smith sampler (HS) with its 0.076 by 0.076 m opening has a strongly flared body and a net about 0.4 m long with a 0.25 mm mesh width. The HS was placed onto 10-20 even-spaced locations across the channel bed, collecting for 0.2 - 5 minutes per location.

Gravel transport rates collected with a HS exceeded those from bedload traps by orders of magnitude during low transport rates, but fell below those from bedload trap during high transport when coarse gravels were moving that did not fit into the small HS opening size. When the HS sampler was deployed for 5 minutes on each of the ground plates—which avoided inadvertent particle pick up during sampler placement on the bed—its transport rates generally exceeded those from bedload traps by a factor of 3 to 20. This oversampling resulted from the HS's high hydraulic efficiency. When the HS deployment time was set to 2 minutes, both samplers collected similar bedload rates. The reason for no longer oversampling lies in the fluctuating nature of gravel transport. Short sampling times have less chance to catch rare high-transport rates or the largest mobile particles; i.e., short sampling times reduce sampled transport rates and $D_{Qb,max}$ sizes. Compared to 1-hr sampling with bedload traps, bedload $D_{QB,max}$ sizes sampled with a HS were generally smaller: about ½ to ¾ of the actual $D_{QB,max}$ size for 5-minute sampling but only ⅓ of the actual $D_{QB,max}$ size when sampling for 2 minutes. Those results show that there is no optimal deployment time for a HS on ground plates to attain general similarity with bedload trap result: A 2-min. deployment of the HS produced similar transport rates, but left sampled $D_{QB,max}$ bedload sizes severely underrepresented, while 5-min. deployment moderately underestimated $D_{QB,max}$ sizes but overestimated gravel transport rates by almost an order of magnitude.

Flow velocity measurements in a laboratory flume with ADV and LDA: a comparative study

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Abstract. Point velocity measurements in moving fluids are relied on in numerous scientific fields including hydrology, hydraulics, oceanography, and fluid mechanics. Although the Laser Doppler Anemometer (LDA) is widely regarded as one of the most accurate flow measuring devices due to high temporal resolution, its complexity, cost and sensitivity render it difficult to use in field applications. On the other hand, the Acoustic Doppler Velocimeter (ADV) is a more durable and user friendly device, and hence, it is widely used for flow measurements in the field. However, the ADV is semi-intrusive, known to be less accurate than the LDA, and is not feasible for measurements near boundaries. In this work, a comparative study of both the LDA and ADV is performed in a smooth laboratory flume. Flow conditions are varied by changing slope, discharge, and/or depth. Velocity components are measured with both instruments at a coincident sample volume concurrently in time along the wall-normal (vertical) direction to yield velocity profiles. The LDA is also used to compare flow conditions at the ADV's sample volume with and without the ADV present. The LDA and ADV used in this experiment measures two and three dimensional point velocity, respectively. This study will provide a basis for data quality analysis of ADV measurements for laboratory and field scientists.

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Uncertainty in flood routing: Diffuse wave models by fuzzy set theory approach

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Abstract. Impacts caused by flood routing affect families, economic activities, public and private systems. Impacts and economic losses has increased considerably, because these areas, in general, there is a growing concentration of people and economic activities present in the region. Flood routing is a problem, both developed and developing countries. Many hydrodynamic problems that involve of the propagation flood waves along the length in natural channels are solved by Saint – Venant equations. In most practical applications of flow routing in open channels, inertia terms are negligible, thus the system of Saint – Venant equations is reduced to a parabolic equation, known as the diffusive wave equation. This research aims to apply the fuzzy set theory in diffusive wave models at natural channels, in order to verify the uncertainties related to the hydrodynamic parameters present in these models. Through the implicit finite difference schemes was solved partial differential equations present in Saint - Venant equations. Simulations were carried out for different scenarios in the water body. It was developed a computer program, coded in Fortran. Results allowed establishing some interesting analysis with regard to the behavior of diffusive wave flood routing, it is strong influence of hydraulic parameters, the slope feature and Manning roughness coefficient. Results allowed concluding that the application of the fuzzy set theory in the hydrodynamic systems, it is a viable alternative for determining the uncertainty in flooding and thus be more a support tool in water resources management programs.

Baseflow response to stormwater infiltration: Exploring feasibility of using spatial arrangements of infiltration sites to manage baseflow

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Abstract. Urban development negatively impacts receiving streams by altering natural flow regimes. The importance of baseflow in urban flow regimes has only recently been widely acknowledged with respect to stream ecology, water quality, and geomorphology leading to evolving water management strategies. Recent stormwater management approaches focus on infiltrating stormwater near its source. It has been shown that different spatial distributions of stormwater infiltration sites can lead to varying responses in water table elevation, but the connection to baseflow has not been adequately explored. This project aims to identify under what physiographic and climatic scenarios spatial arrangements of stormwater infiltration sites can be used to manage baseflow magnitude and timing. ParFlow, a physically based, integrated surface-subsurface finite difference model that takes advantage of parallel processing is being used for this research. ParFlow is especially appropriate for this research as vadose zone behavior is expected to be a primary factor driving varying responses to spatial distributions of infiltration sites and ParFlow solves three-dimensional Richard's equation for variably-saturated flow. We hypothesize that stormwater infiltration sites distributed over larger areas will reduce subsurface saturation during precipitation events leading to lower hydraulic conductivities and increased vadose zone storage. Therefore, groundwater recharge is expected to occur more slowly and be reduced, decreasing time to observed responses in event-based baseflow response and magnitude of baseflow. Varying physiographic and climatic scenarios will alter how impactful spatial distributions of infiltration sites are on baseflow response. This work will contribute to recommendations on most appropriate spatial distributions of stormwater infiltration sites.

Technical and Administrative Feasibility of Alluvial Aquifer Storage and Recovery on the South Platte River of Northeastern Colorado

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Abstract. Increasing population and climate change are causing water managers to reassess water storage. In this context, alluvial aquifer storage and recovery (ASR), in which excess water is stored in the alluvium near a river, offers a plausible option. To investigate this option, a coupled technical-administrative analysis was conducted to investigate the feasibility of alluvial ASR in the semi-arid American state of Colorado, where water rights are governed by the doctrine of prior appropriation. A hypothetical alluvial ASR facility near Brighton, Colorado with a storage capacity of 118,500 cubic meters (96 acre-feet) was considered. This analysis comprises both technical feasibility, using a groundwater model that explicitly accounts for clogging, and administrative feasibility, using a first-of-its-kind analysis of the legal availability of water including both free river and reusable effluent water. This coupled technical-administrative analysis suggests that alluvial ASR facilities present a viable option to meet rising demand for water storage, preventing water loss due to evaporation, reducing the effect of climate stress on water resources, and avoiding the need to purchase land for above-ground water storage facilities. More generally, this study illustrates the crucial importance of placing hydrologic analysis in the broader context of policy constraints.

Research on Characteristics of Groundwater Recharge in Weishan Irrigated District Based on Bromide Tracer

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Abstract. It is of great theoretical and practical significance to determine the vertical infiltration recharge of groundwater by Bromide tracer technology, which reveals the spatial variation rule of groundwater recharge and improves the theory and method of groundwater resource evaluation. Bromide was used as tracer in Weishan Irrigated District to determine the groundwater recharge as well as to evaluate the impacts of different irrigation basin location, irrigation regime and crop types on the recharge. The comprehensive recharge coefficient and the Kringing Spacial Interpolation methods were used to distinguish the effects of precipitation and surface water irrigation on groundwater recharge rate. The results showed that the recharge rates ranged from 85.8 to 243 mm/a, with an average of 168 mm/a; the average recharge rate in the upstream district was greater than that in the downstream; the average recharge rate of irrigated land (193 mm/a) is greater than that of non-irrigated land (110 mm/a). The recharge rate of winter wheat-summer maize and cotton fields with irrigation was 210 mm/a and 140 mm/a, respectively while it was 115 mm/a and 94.1 mm/a under no irrigation conditions. The comprehensive recharge coefficient of groundwater in the upstream irrigation area was larger than that in the downstream. By comparing the spatial distribution of groundwater level and comprehensive recharge coefficient, it was found that there was an inverse relationship between the groundwater level and the comprehensive recharge coefficient.

Remote Sensing of Soil Salinity for Use in Irrigation Water Management

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Abstract. Approximately 70 percent of consumed fresh water in the Western United States is used for crop irrigation, and worldwide irrigated agriculture supplies 35 to 40 percent of the demand for food and fiber. As the world's population continues to grow, irrigated agriculture must provide an even larger amount of food and fiber, with a smaller amount of water. In the face of this demand, salinization of water and soils has reduced crop yields in many irrigated areas because dissolved salts limit a plant's evapotranspiration (ET) and photosynthesis processes. Remote sensing (RS) derived ET maps can be used to monitor spatially and temporally-distributed crop water use and related salt effects, providing foundational information to develop strategies to improve irrigation management. Furthermore, indices derived from remotely-sensed vegetated surface reflectance, combined with multi-year ground-based micrometeorological data have been used to directly estimate soil electrical conductivity, a common measure of salt concentration. In this study, we use land surface energy balance (LSEB) models to estimate actual ET in conjunction with refined vegetation indices for effective mapping of soil water salinity in corn fields in southeastern Colorado. These data sets are compared with seasonal ground-level data, including soil electrical conductivity, soil volumetric water content, and total corn yield to determine what remote-sensing model has the best potential to effectively map distributed salinity levels. Preliminary results indicate that many of the calibrations within LSEB models vary with salinity, thus complicating the model's predictive ability.

Certified Floodplain Managers: What it is and why it can benefit Hydraulic Engineers!

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Abstract. Hydraulic engineers, specifically those working in river restoration, will often encounter situations where their design may impact a FEMA-regulated floodplain. Designs that will change either (1) the boundaries of the floodplain or floodway, or (2) the water-surface elevation of the base flood (the peak flow of the 1% annual exceedance, or the 100-yr average annual recurrence) may be subjected to permitting requirements of local floodplain administrators, the state, and FEMA. Hydraulic engineers that are Certified Floodplain Managers (CFM) become familiar with the steps and intricacies required to guide a project through permitting to successfully obtain local, state, and federal approval. The CFM certification process introduces many parties and avenues involved in the National Flood Insurance Program and certification makes the hydraulic engineer more marketable to firms that specialize in river restoration projects. The 2013 Colorado floods opened the doors for the design (including permitting) and implementation of numerous river restoration projects along the Front Range. These restoration projects were largely successful because CFM's facilitated the floodplain permitting.

Curvature effects on flow dynamics in river bends

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Abstract. Natural rivers and manmade channels are common conveyance systems that typically have meandering geometries with varying degrees of curvature. A better understanding of the flow dynamics as well as the associated complex flow structures in river bends is critical for developing improved engineering design methods for protecting such conveyance systems from erosive degradation. This research focuses on understanding the effect of curvature on the flow dynamics in the channel bend using large-eddy simulations. One of the most important non-dimensional geometric parameters that influence the flow dynamics in a bend is the ratio of the radius of curvature to the top width of the uniform flow upstream of the bend R/T_w. Four highly-resolved simulations of flow through a U-shaped ($180^{o)}$ bend were performed with R/T_w. ranging from 1.25 to 8.7, which encompasses tight to mild bends. The results show that, on average, the maximum shear stresses for tight bends are closer to the inner bank and shifts closer to the outer bank in the interior of the channel bend. Furthermore, it is clear that the flow evolves from the beginning of the bed to a more developed condition beyond 90° into the bend.

Statistical Analysis of Soil-Moisture Patterns for Probabilistic Downscaling

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Abstract. Soil moisture is a key variable for a variety of applications ranging from vector-borne disease-outbreak prediction to off-road vehicle trafficability. These applications require not only accurate, fine-resolution soil-moisture estimates across regions but also soil-moisture patterns that exhibit realistic statistical properties (e.g., variance and spatial correlation structure). Many existing downscaling models provide deterministic soil-moisture estimates using soil moisture's dependence on topographic, vegetation, and soil characteristics. However, observed soil-moisture patterns also contain stochastic variations around such deterministic estimates. The primary objective of this research is to analyze these stochastic variations in soil moisture and include them when downscaling to produce more realistic spatial patterns and statistical properties. Extensive soil-moisture observations from two catchments (Tarrawarra in Victoria, Australia and Cache la Poudre in Colorado, USA) are used for the analysis and model development. The Equilibrium Moisture from Topography, Vegetation, and Soil (EMT+VS) model is used to obtain deterministic soil-moisture estimates from the catchment attributes, and the resulting residuals are considered to be the stochastic variations. Using semivariogram analysis, the stochastic variations are found to contain substantial spatial variance and correlation (i.e., they are not simply white noise). These patterns also include both temporally stable and unstable components. Moreover, the spatial variance of the stochastic variations increases with the spatial-average soil moisture. The EMT+VS model can reproduce these features if it is generalized to include stochastic deviations from the equilibrium state, stochastic variations in porosity and precipitation, and stochastic variations to account for measurement error. The generalized model produces realistic spatial patterns and extreme values of soil moisture, which are beneficial for the aforementioned applications.

Climatology of Floods in the United States as Observed by Storm Reports and TRMM Rainfall Data

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Abstract. Floods are the second deadliest weather-related natural disaster in the United States (Ashley and Ashley 2008) and have resulted in $120 billion worth of losses since 1980 (NCEI 2018). The risk of flooding is expected to increase in the future, due to increased heavy precipitation in a warmer and moister climate (Trenberth et al. 2003, Ban et al. 2015, Dai et al. 2017, Prein et al. 2017, Rasmussen et al. 2017). Before understanding how floods may change in the future, it is first critical to understand the characteristics of floods across the continental United States (CONUS) from a climatological perspective. Numerous flood-related climatologies across the CONUS have been performed before, but they have been either from a purely meteorological standpoint through the examination of extreme rainfall (Maddox et al. 1979, Schumacher and Johnson 2006) or from a hydrological perspective through the examination of stream discharge (Michaud et al. 2001, Saharia et al. 2017). However, no prior studies have performed a comprehensive flood climatology over the entire CONUS from a hydrometeorological perspective. The goal of my research is to address this gap by developing a hydrometeorological climatology of floods over the CONUS from 2000–2013, utilizing the National Centers for Environmental Information (NCEI) Storm Events database to identify floods and the Tropical Rainfall Measuring Mission Multi-Satellite Precipitation Analysis 3B42 version 7 (TRMM 3B42) to characterize the associated rainfall.

The NCEI database was used to identify the location, duration, and frequency of slow-rise, flash, and hybrid (a category created for floods labeled as both slow rise and flash flood) flood episodes. After excluding flood episodes with only a single report (which are more likely to be spurious data points), this resulted in approximately 2000 slow rise, 3700 flash, and 1300 hybrid floods over the 13-year period across the CONUS. Since the NCEI Storm Events database does not provide information on the amount of precipitation causing the flood, TRMM 3B42 3-hourly rainfall data was utilized to quantify the rainfall associated with these floods. For each flood episode, rainfall metrics were calculated at the 25th, 75th, and 90th percentiles, such as the total accumulated rainfall and volumetric rainfall. The average accumulated rainfall exceeding the 75th percentile threshold in each county was calculated, as well as the average duration, area, and number of these flood per county in order to understand the characteristics of high-impact flood events across the CONUS. The characteristics and spatial distribution of high-impact floods was found to differ based on flood type and is hypothesized to be due to different underlying atmospheric and hydrologic causes. Such a comprehensive hydrometeorological climatology of floods across the CONUS is unprecedented and the results could aid water resource managers and city-planners in developing more water-resilient communities.

Newcomers have subsidized water in the South Platte River Basin

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Abstract. Cities in the South Platte River Basin have been growing rapidly while water resources are already allocated. As a result, the right to divert and store water must be acquired from agriculture or transbasin imports. Cities in the region have predominantly required land developers to either purchase water rights or pay cash-in-lieu when developing a piece of land. Most cities have developed these water rights purchase requirements without updating them despite recent water efficiency requirements and gains. Thus, land developers and ultimately the new home buyers are purchasing more water or paying the city for more water than needed on site. This revenue or water rights assets add value to existing water consumers in the utility. This presentation estimates the extent to which this is occurring across the basin.

Dirty Snow: Constructing a Model for Emergence of Dust Layers in the Colorado Snowpack to Improve Melt Prediction

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Jeff E. Derry
Center for Snow and Avalanche Studies

Abstract. Mountain snow cover provides most of the fresh water resources of the Western US. The rate and timing of snow melt directly influences downstream storage decisions by water resource managers. Melt rates are influenced by changes in snow albedo, with any decrease in reflectivity resulting in an increased melt rate. Disturbed desert dust layers, deposited during the snow accumulation cycle and persisting as hidden layers within the snowpack, emerge at the surface during the melt season. The change in albedo associated with dust emergence can accelerate melt rates and shorten snow cover duration by as much as 35 days. Currently, a NASA remote-sensing product (MODIS-Dust-Radiative-Forcing-on-Snow, or MODDRFS) approximates snow-surface albedo changes as changes in absorbed solar radiation energy. That dataset is used by agencies such as Colorado Basin River Forecast Center to adjust modeled snow melt rates. However, remote-sensing assessments of surface conditions are limited to short timescales (1- or 2-day) and good weather (visibility). These limitations could be mitigated by development of a physically-based model that relates snowpack conditions and meteorological forecasts to rates of dust layer emergence. This presentation will address how to construct and calibrate such a model with the 12-year record of snow conditions and solar radiation measurements collected by Center for Snow and Avalanche Studies at a high-elevation site near Silverton, Colorado.

Tracking the Fate of Sediment After an Extreme Flood

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Abstract. Assessing the ongoing sediment remobilization and deposition following an extreme flood is important for understanding disturbance response and recovery, and for addressing the challenges to water resource management. From September 9-15, 2013, a tropical storm generated over 350 mm of precipitation across the Colorado Front Range. The resulting 200-year flood triggering landslides and extreme channel erosion along North St. Vrain Creek that feeds Ralph Price Reservoir, an important water supply for the Cities of Lyons and Longmont, CO. The flood resulted in 10 m of aggradation upstream of the reservoir, transforming the inlet into an approach channel. Four years after the flood, downstream transport of flood sediment and deposition in the reservoir continues. This research tracks the fate of flood-derived sediment to understand the evolution and progradation of the delta as well as to inform reservoir management practices. Bathymetric DEM differencing from April 2014, April 2016, May 2017 and August 2017 (years 1, 2, 3 and 4 post-flood, respectively) demonstrates a constant rate of delta progradation of ~50 m per year since 2014. Between April 2016 and May 2017, the reservoir level was dropped approximately 10 m during reconstruction at the spillway. Despite the change in base level, year 4 pre-snowmelt runoff measurements indicate that the rate of progradation has remained comparable to the two years following the flood. Assuming that most sediment is transported during snowmelt runoff, year 4 post-snowmelt runoff bathymetry suggests a decline in progradation rate. However, an additional bathymetric survey in spring 2018 is needed to confirm this interpretation. Bathymetric differencing further indicates net deposition of 67,000 m^3 over 14,000 m^2 (an area covering 94% of the 2017 delta and common to all surveys) of the inlet between years 1 and 3. The drop in base level associated with the lower reservoir level (years 3 to 4) produced visible incision and erosion of 16,000 m^3 and deposited 6,000 m^3 of sediment over the same area. Future analysis of Structure-from-Motion differencing of the approach channel, analysis of sediment thicknesses in reservoir cores, and morphodynamic modeling using measured discharge values will further quantify the post-flood sediment budget. Grain size, loss on ignition, and XRF analyses of cores collected from the delta will additionally enhance our understanding of stratigraphic changes and delta progradation within the reservoir.

Analysis of Sediment Transport Formulas using a Data Mining Technique with Applications to South Korean Rivers

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Abstract. This research explores new ways to improve the applicability of sediment transport formulas to field conditions. Several formulas derived from laboratory measurements are often applied to rivers with very high annual maximum to minimum discharge ratios. For instance, it is particularly difficult to find appropriate sediment transport formulas for South Korean rivers where very low flow periods are frequently followed with massive floods from typhoons during the summer months. This study uses data mining techniques to derive the statistical pattern for the development of site-specific sediment discharge formulas based on a combination of 14 dimensionless and dimensional variables. For each case, the mean discrepancy ratio, the correlation coefficient, the root mean square error and the mean absolute percent error were calculated and used to review the accuracy of the predictions. As a result, the best fit was obtained after data mining from a sediment discharge formula using five-dimensional variables: flow velocity, flow depth, bed slope, river width, and the median diameter of the bed material. Also, the results of the data mining formula were compared with several original formulas from: Engelund and Hansen, Ackers and White, Yang, Brownlie and van Rijn. The evaluation has been made through comparisons with field measurements of discharge and sediment transport at 28 rivers stations in South Korea. Among the accuracy predictors for the comparison, the mean discrepancy ratio by data mining was 1.42. This shows improved discrepancy ratios compared to the original formulas of Engelund and Hansen (2.72), Ackers and White (1.44), Yang (1.65), Brownlie (1.55) and van Rijn (1.64), respectively.

Combined effects of snow and land cover change on mountain hydrology

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Abstract. Colorado's water supply depends on snowpack as a natural storage and release mechanism, without which streamflow is dramatically reduced. In addition, insect-induced tree mortality, increased wildfire activity, agriculture, and expanding urbanization all affect streamflow. An analysis that emphasizes the impacts of both climate warming and land cover change on hydrologic response is needed to understand the interactions of these effects. This research will investigate (1) how landscape alterations impact streamflow across an elevation gradient and (2) how these stressors interact with each other and with climate to affect regional water supply. This research is motivated by our marginal understanding of the hydrologic response to combined climatic and land cover changes throughout Colorado and the need to be able to accurately and consistently predict streamflow. Snow persistence (SP) is the fraction of time snow is present on the ground from Jan-June and is highly correlated with discharge in semi-arid environments. Prior research developed a mean annual curve of Q/P vs. SP for reference watersheds with little land cover change. I propose using deviations from this reference curve to examine how land cover affects streamflow within the context of climate variability. I will use statistical analyses to identify connections and interactions between changing climate, landscape changes, and streamflow at mean annual to sub-annual time scales.

Hydrogeologic characterization of the Todos Santos Aquifer, Baja California Sur, Mexico

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Abstract. Overuse of coastal aquifers is detrimental to coastal communities due to the consequence of seawater intrusion, especially in arid areas where recharge rates are extremely variable. Todos Santos, a coastal town of over 5,000 residents located on the southwestern coast of Baja California Sur (BCS), Mexico, receives mean annual precipitation of 150 mm and has experienced years with as little as 8.5 mm. Previous studies have shown concern regarding aquifer overexploitation, and additional water requirements are expected. This study employs field data to create and calibrate a three-dimensional variable-density groundwater flow model, SEAWAT, to analyze and predict the long-term anthropogenic and climatic impacts on the Todos Santos Aquifer. The model is calibrated to published records from 2007 and field data acquired from 21 wells in 2017. Stable isotope, major ion, and minor element analysis were performed on these water samples.

Stable isotope analysis shows $\delta^{18}O$ and $\delta^{2}H$ values that vary from approximately -12 to -6‰ and -77 to -67‰. This range of isotopic signatures is relatively depleted compared to typical values of this latitude. These depleted compositions are attributed to recharge from tropical cyclones. Major ion analysis shows an increase in chloride concentration with proximity to the coast. Compared with data published in 2007, current data shows a notable increase in chloride concentration and specific conductance, indicating a strong possibility of seawater intrusion. Modeling will help understand the effects of increased water demand on available water for use and maintenance of a local estuary.

New Module to Simulate Groundwater-Surface Water Interactions in Small-Scale Alluvial Aquifer Systems

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Abstract. When a pumping well lowers water table elevations adjacent to a nearby stream, a strong hydraulic gradient develops which results in a process referred to as streamflow depletion. Being able to accurately model the severity of this process is of critical importance in semi-arid regions where understanding groundwater-surface water interactions is crucial for sustainable water resource practices. The U.S. Geological Survey's modular finite-difference flow model, MODFLOW, is currently the standard for modeling groundwater flow. However, certain limitations persist when the program is applied on local, fine scales with dynamic interactions between an aquifer and a stream. To address these limitations, we present a new module for MODFLOW that (1) allows for multiple computational grid cells over the width of the river to allow for a finer mesh; (2) computes streamflow and stream stage along a stream reach using 1D steady shallow water equations, which allows for more accurate stream stages when normal flow cannot be assumed or a rating curve is not available; and (3) incorporates a process for computing streamflow loss when an unsaturated zone develops under the streambed. The new modeling code is tested against stream and groundwater data collected in a stream-aquifer system along the South Platte River in south Denver, Colorado. The model is being used to estimate streambed hydraulic conductivity and to estimate the impact of nearby pumping wells on streamflow. The new module can be applied to other small-scale stream-aquifer systems.

Simulating snowmelt-driven streamflow in small mountain catchments with the GEOtop model using a novel calibration method

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Abstract. The integrated watershed model GEOtop describes the canopy and surface energy balances, snow accumulation and melt, and soil freeze-thaw. In this study, GEOtop was applied to two mountain catchments with heterogeneous soils overlying bedrock. The model was calibrated using bulk density optimization supported by field data on gravimetric water retention and soil texture. This resulted in layer-wise predictions of soil fraction, coarse fragment/fraction, and hydraulic properties. The method was first tested in point-scale simulations (one-dimensional) to predict soil-water content timeseries for locations in the Dry Creek Experimental Watershed (DCEW) in the Boise Front, Idaho, and in the Libby Creek Experimental Watershed (LCEW) in the Medicine Bow Mountains, Wyoming. The results of the point-scale simulations showed that a single bulk density can be optimized for the entire profile using pooled depth-wise soil information. The calibration method was then used on the same catchments for three-dimensional watershed simulations to predict both soil-water and stream discharge timeseries. Profile-averaged soil-water content modeling efficiencies (ME) were reasonable, between 0.55 and 0.77. Stream discharge ME values were lower (0.23-0.24). For the DCEW, hydrograph trends were reasonably predicted, while in the LCEW, hydrograph trends were poorly predicted but cumulative discharge was well predicted. Snow depth was well predicted for both catchments.

Evaluation of multispectral remote sensing derived vegetation indices to estimate reflectance-based crop coefficients and seasonal evapotranspiration rates for grass pastures in western Colorado

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Abstract. Knowledge of crop evapotranspiration (ETc) is important for effective irrigation water management. Among the various methods used to estimate ETc, the standardized FAO56 Penman-Monteith approach, using tabulated generalized Kc values, has been widely adopted to estimate crop evapotranspiration. This research project aims to develop quantitative relationships and to improve the estimation of actual crop coefficients from remotely sensed data for and grass pastures in the western slope of Colorado. Remote sensing techniques are growing rapidly as a way to monitor actual crop water use. Remotely sensed data are used in algorithms to measure the spectral reflectance of the crop canopies. The differences in reflectance values, at different bandwidths from typical multispectral signatures, help determine the current or actual canopy properties like crop fractional cover, water stress, nutrient level, etc. The actual crop coefficients (Kca) values were calculated using ETc and alfalfa based reference crop evapotranspiration (ETr). The soil water balance approach was used to estimate the ETc for grass during the 2016 and 2017 growing seasons. A handheld multispectral radiometer was used to collect surface/canopy reflectance data. Vegetation indices (VI) were calculated using those surface reflectance data. Vegetation indices are the mathematical combination or transformation of surface reflectance in different spectral bands. These VI were then related to actual crop coefficients to develop the VI-Kca models. Among the 11 different vegetation indices evaluated, the soil adjusted vegetation index (SAVI) model performed better. The difference between estimated ETc and actual ETc for one cutting cycle (7/11/1017 to 9/3/2017 for days free from irrigation event) were under 20% for most indices evaluated. This approach can be a promising tool to estimate the seasonal as well as near real-time ETc rates for grass pastures. The following will be discussed: the vegetation indices used in this study, the models developed, results, and the performance evaluation of the models.

The Use of Finite Element Modeling to Increase the Efficiency of Low Environmental Impact Hydropower

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Abstract. In low environmental impact hydropower, fluvial energy is converted into rotational energy of a turbine by placing the turbine directly into a river without the creation of a dam. The central problem of low-impact hydropower is its low efficiency, meaning that only a small fraction of fluvial energy is converted into rotational energy. Most approaches to improving efficiency have involved reducing frictional losses and forcing more of the water to come into contact with the turbine. However, the major source of inefficiency follows from conservation of mass. As the turbine extracts energy from the water, it reduces the stream velocity. Therefore, the water downstream from the turbine must become significantly deeper, which causes the water to flow back upstream toward the turbine. The objective of this study is to use finite element modeling to determine the improvements in efficiency that would result from the following innovative features for preventing backflow:

1) The water exiting the turbine will be forced to rise up a step, which will drive the flow into the supercritical state in which pressure energy will be converted into kinetic energy that will accelerate the water away from the turbine.
2) Some of the turbine energy or other source of energy will be used to drive the low-energy water downstream and away from the turbine.
3) In contrast to the usual open-paddle design, the turbine will be enclosed and the low-energy water will be forced to exit through a vertical tube.

Results will be reported at the meeting.

Understanding carbon nanoparticle transport in heterogeneous porous media: Influence of particulate and dissolved organic matter

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Abstract. The environmental prevalence of harmful nanoparticles (NPs) and limited understanding of NP fate and transport behavior threatens ecosystems and human health. Yet, little is known about NP transport through heterogeneous porous media, and no *reference NP* capable of mass-conservative transport has been identified. This reference NP would enable future studies to better explain transport behaviors of NPs that are more prone to sorption, diffusion, settling, and pore-throat filtering. Carbon nanoparticles (CNPs) are reference NP candidates due to their inert, hydrophilic, and submicroscopic qualities. Furthermore, CNPs are non-toxic, inexpensive, and detectable at low concentrations. Such qualities also imply their potential value as applied groundwater tracers. Recent one-dimensional (1D) column experiments suggest that CNPs transport conservatively through homogeneous quartz sand, surface modified zeolite, and soda lime. However, additional column experiments should independently examine relationships between natural conditions and CNP transport. This study employs 1D columns to investigate CNP transport (1) through porous media incorporating natural particulate organic matter and (2) in ionic solutions containing dissolved organic matter. Considering natural organic matter's ubiquity in soils and waters and ability to affect NP surface properties, this study aims to clarify the appropriateness of characterizing CNPs as reference NPs. This presentation will discuss results of such 1D column experiments and whether findings support or reject the general hypothesis that CNPs will exhibit mass-conservative transport under natural conditions.

Temporal Information Partitioning Networks reveal ecohydrologic responses to rainfall pulses and drought

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Abstract. Ecohydrologic fluxes within atmosphere, canopy and soil systems exhibit complex and joint variability. This complexity arises from direct and indirect forcing and feedback interactions that can cause fluctuations to propagate between water, energy, and nutrient fluxes at various time scales. When an ecosystem is perturbed in the form of a single storm event, an accumulating drought, or changes in climate and land cover, this aspect of joint variability may dictate responsiveness and resilience of the entire system. A characterization of the time-dependent and multivariate connectivity between processes, fluxes, and states is necessary to identify and understand these aspects of ecohydrologic systems. We construct Temporal Information Partitioning Networks (TIPNets), based on information theory and information decomposition measures, to identify time-dependencies between variables measured at flux towers along elevation and climate gradients in relation to their responses to moisture-related perturbations. Along a flux tower transect in the Reynolds Creek Critical Zone Observatory (CZO) in Idaho, we detect a significant network response to a large 2015 dry season rainfall event that enhances microbial respiration and latent heat fluxes. At a transect in the Southern Sierra CZO in California, we explore network properties in relation to drought responses from 2011 to 2015. We find that high and low elevation sites exhibit decreased connectivity between atmospheric and soil variables and latent heat fluxes, but the high elevation site is less sensitive to this altered connectivity in terms of average monthly heat fluxes. This work presents a novel use of information theoretic measures to gage the responsiveness of ecosystem fluxes to shifts in connectivity, and aids our understanding of ecohydrologic responses to disturbances. This study is relevant to ecosystem resilience under a changing climate, and can lead to a greater understanding of shifting behaviors in many types of complex systems.

Soil moisture dynamics in a Colorado field: Stability and threshold crossing times under annual crops and perennial vegetation

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Abstract. Soil moisture is a key state variable in many landscapes and varies in space and time. Within an agricultural field, soil moisture dynamics may be similar at many positions but can also vary with landscape topography, soil characteristics and land use/management. Different process models were used previously to simulate space-time soil moisture in a well-monitored agricultural field (106 ha) in northeastern Colorado. The simulated periods comprised primarily a wheat-fallow rotation managed in alternating strips (~120 m wide). In all simulations, the model dynamics of near-surface soil moisture did not fully capture the more stable features of field measurements. That is, simulated responses to infiltration events were more peaked with sharper wetting fronts and often faster drying (recession) than measured moisture contents. While much of the soil-water dynamic behavior is driven by weather patterns from event to inter-annual time scales, land management is an important driving factor. The wheat-fallow field was converted to a Conservation Reserve Program (CRP) in two stages based on alternating crop strips starting in 2013. The current objective is to characterize measured soil moisture dynamics at different landscape positions including changes in these dynamics associated with periods of cropping and the multi-year transition to perennial vegetation. Soil moisture contents were measured hourly with capacitance sensors centered at depths of 30, 60 and 90 cm at 18 landscape positions since 2002, and using two cosmic ray sensors installed in 2015 and 2016 at summit and toe-slope positions, respectively. In addition to conventional temporal statistics for each sensor, we evaluated "crossing times" of when moisture content crossed given thresholds for both wetting and drying. The experimental data were compared with a theoretical model of the distributions of first return times. The data and conceptual model results have implications for potential quantitative assessments of CRP as a program of payments for ecosystem services.

Hydro-epidemiology: modeling the water-health nexus

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Abstract. With ongoing global change, water managers are facing problems of broader scopes and larger scales than in the past. While global incidence of bacterial waterborne disease has declined, surveillance of all water-related diseases has also declined, thus creating uncertainty about how emerging threats will affect human health. On an overall basis, waterborne disease threats seem poised to change and increase because of pollution, chaotic living conditions and emerging pathogens. Facing these threats requires more actions than water management alone, but water managers can make a difference by advising on policy and going beyond minimums in their work. To explain the situation, the presentation will describe the threats and state of knowledge by outlining the water-health nexus and the pathways from water management actions to different disease types. It will include a summary of the state of knowledge about links between water issues, regulatory actions and disease occurrences, and it will outline a research agenda to address the water-health nexus.

An Analytical Framework for Assessing Municipal Vulnerability to Water Shortage and Drought Characteristics under Nonstationary Supply and Demand Conditions

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Abstract. Rapid urban growth places additional demands on water supplies and rising temperatures may decrease surface water yield through increased evapotranspiration. Comparison of supply and demand under nonstationary conditions within an analytical framework yields a measure of the vulnerability of the municipal water supply system and change in drought severity-duration-frequency. The purpose of this research is to develop a methodology to assess vulnerability of municipal water supply system to shortage and drought conditions through coupling a hydrological model with bias-corrected climate simulations and water use scenarios. As a case study, the approach was applied to assess the vulnerability of City of Fort Collins to water shortage under current and future climate, population growth, and land use scenarios.

Fort Collins receives native water from the Cache la Poudre River and imported water from the Horsetooth Reservoir (the Colorado Big Thomson Project). Changes in water yield in the Cache la Poudre River were evaluated using the Soil and Water Assessment Tool (SWAT) with projected alternative future climates scenarios for the region throughout the 21st century. The future climate data was obtained from the CMIP5 dataset, and was subsequently downscaled for meteorological stations in the region using the Quantile Mapping technique combined with a rigorous temporal (i.e. monthly to daily) downscaling approach. Municipal water demand under alternative climate, population, and water demand management scenarios was estimated using the Integrated Urban Water Demand Model (IUWM). The results will enable assessments of alternative mitigations and adaptation strategies to improve current and future water shortages.

How Clean is Clean Enough? Assessing Edge-of-Field Nutrient Runoff

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Abstract. Excess nutrient loading from numerous sources (e.g., agricultural and urban runoff, treatment plant discharge, streambank erosion) continue to adversely impact water resources, and determination of the cause(s) of accelerated nutrient enrichment has become a contentious and litigious issue in several US regions. This paper addresses one fundamental question "What are acceptable levels of nutrients in runoff from agricultural fields?" focusing on the field-scale where farmers and ranchers make management decisions. Not answering this question limits the effectiveness of on-farm management and policy alternatives to address agriculture's contribution. To answer the question, some might suggest "direct comparison" with reference site data, existing criteria/standards, or measured data compilations. Alternatively, "indirect assessments" using soil test P levels, P Indices, field-scale models, or certainty programs might be suggested. Thus to provide a scientific basis for policy debate and management decisions related to nutrient runoff from agricultural fields, we evaluated "direct comparisons" with measured data from case studies and evaluated "indirect assessment" alternatives. While acknowledging that scientific challenges and practical realities exist for each alternative, we concluded that certainty programs offer the most promise for ensuring acceptable nutrient runoff and that field-scale models linked with watershed decision support tools are the most promising for assessing impacts on downstream water quality. Recognizing the reality that some nutrient loss is unavoidable from natural and anthropogenic sources, thus agriculture, industry, and municipalities are each encouraged to commit to implementing enhanced management where needed to minimize their sector's contribution to excess nutrients in our Nation's waters.

Assessing the Impacts of Wildfire on Sedimentation and Runoff in the Colorado Front Range

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Abstract. The complex effects of wildfire disturbances on the quality and availability of water are far-reaching and often difficult to anticipate, thus proving a challenge for prediction. Many studies have documented wildfire on either continental or hillslope scales, yet most critically overlook the interaction of local-scale processes across entire watersheds following a fire disturbance. In this study, we explore modifications to a hydrologic model to portray the effects of wildfire disturbance at the basin scale on streamflow and suspended sediment loading (SSL) in a disturbed, mid-sized (approx. 1,056 mi^2) watershed on the Colorado Front Range. The Variable Infiltration Capacity (VIC) model, a semi-distributed hydrologic model that solves land surface-atmosphere exchanges of moisture and energy, was upgraded to include five hillslope erosion algorithms in order to quantify uncertainties in SSL estimation under a unified framework. Wildfire disturbance is simulated through modification of soil and vegetation characteristics based on a diverse set of historical in-situ and remotely sensed observations of basin features that become perturbed following a wildfire event, using the 2012 High Park Wildfire in the Cache La Poudre basin as a case study. One such feature is Leaf Area Index (LAI), a characterization of the plant canopy, as observed by the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite. Model parametric modifications are optimized with multiple objectives to evaluate the robustness of simulated sediment loading and runoff in the immediate aftermath of a wildfire. The results from this study have implications for water management and reservoir operations in the West.

Estimation of Soil Erosion Risk of the Euphrates River Watershed Using RUSLE Model, Remote Sensing and GIS Techniques

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Abstract. The average annual soil erosion is the main problem of natural water resources and the agriculture, the most dominant factor that effect on the soil erosion is water. The aim of this study was estimated the average annual soil erosion by using RUSLE model and the ArcGIS software of the Euphrates river watershed, this model was based on five factors for calculation soil erosion map of the watershed. The rainfall-runoff erosivity (R) factor map was computed for precipitation data that content from thirty-one stations scattered within and outside the watershed area to assist in the interpolation estimation. The soil erodibilty (K) factor map of topsoil was derived based on data that provided from UN-FAO (Food and Agriculture Organization of the United Nations). The topographic factor map can be depended mainly on the raw images of the Digital Elevation Model (DEM) of the watershed which DEM of Euphrates watershed consisted of sixteen images with a spatial cell size 30m*30m. The cover/crop management (C) factor map can be calculated based on the NDVI (Normalized Difference Vegetation Index) map of the Euphrates basin, the NDVI map can be derived based on remote sensing of the data available in the United State Geological Survey (USGS) for multi-images of the study area. The support practice factor (P) can be assumed equal to 1 because the bare land area occupied about 92% of the total area for computational years 2013 and 2017. The average annual soil loss for the year 2017 was ranged from 0 to 2995.614 tons/ha/year, 99.69% of the watershed area had the slight soil erosion loss while 0.17% of the watershed was represented the soil erosion of the slight to moderate type. For the year 2013, the soil loss estimated from 0 to 2610.47 tons/ha/year, 99.7% of watershed had the slight soil erosion loss while 0.16% of the watershed was classified into the slight to moderate soil loss type. Furthermore, the other soil loss types such as moderate to extremely high were found in the riverbed of the Euphrates. The sediment delivery ratio can be computed for upstream of Al Shamia barrage based on the field value of sediment yield for the year 2013. The observation value equaled to 25.62% while it's equal to 26.12% based on the Renfro equation.

Interference of Dual Spillways Operations

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Abstract. Dual spillway interference refers to the loss of hydraulic performance of spillways when they are placed close together. Spillway interference is examined using both physical experiments and numerical simulations. Stage and discharge measurements from four physical models with dual spillways configurations are compared to the Flow-3D computational results at four dam sites in South Korea. The conjunctive use of two spillways is compared with the singular operation of each spillway. When both spillways are operated at the same time, the total flow rate through the two spillways is reduced by up to 7.6%. Interference coefficients are most significant when the stage H_e exceeds the design stage H_d and when the distance D separating two spillways is short compared to the spillway width W. The parameter DH_d/WH_e correlates very well with the calculated and measured interference coefficients. A flood routing example for the design discharge at Andong dam shows a 42cm difference in reservoir water level with and without application of the interference coefficient. Consequently, to include the effects of spillway interference, the width of additional spillways (emergency and auxiliary spillways) should be increased for dam safety.

Modelling the Distribution of Major Salt Ions in Agricultural Surface Water and Groundwater Systems

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Abstract. Excessive irrigation and canal seepage, along with insufficient drainage, has contributed to the salinization of much of the world's productive irrigated land. Through processes of dissolution, transport, and evaporative concentration, salts build up in groundwater and soils and return to streams which in turn supply salty water to areas further downstream. The development and preliminary application of a numerical model (RT3D-OTIS), capable of simulating the multispecies reactive transport of solutes in coupled surface and groundwater systems, is described for the problem of salinization in irrigated agricultural regions. The subsurface component of the model is already tested at local and regional (500 km^2) scales in Colorado's salinity-affected Lower Arkansas River Valley (LARV). For this study, the model is modified and linkage to surface water is also included, permitting simulation of the cycling and transport of major salt ions (sodium, magnesium, calcium, potassium, sulfate, chloride, bicarbonate, and carbonate), salt ion equilibrium chemistry, precipitation-dissolution processes, advection, and dispersion. First-order kinetic reactions; source sink mixing such as irrigation water loading, canal seepage, crop uptake, and groundwater pumping; along with mass loading to/from the river network are included. The model is being calibrated and tested against targets of groundwater salinity, soil salinity, salt loading to streams, and stream salinity. The initial results of spin-up simulations for 40 years, applied to a monitored study region in the LARV, are presented. The model is designed not only as a tool to characterize spatial and temporal salinity levels in salinized irrigated regions but also for predicting the outcome of alternative land and water best management practices to lower salinity and increase crop productivity.

Simulating the nonlinear response of alpine and subalpine snowpacks to climate warming

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Abstract. It is well known that climate warming invokes nonlinear responses in snow accumulation and melt within the seasonal snow zone. Previous research has shown that higher, colder sites are generally more resistant to warming-driven reductions in peak snow water equivalent (SWE) and snowmelt rate. While prior work has examined the proximate empirical causes (e.g., elevation and air temperature) behind this phenomenon, little research has been done on the physical mechanisms behind the differential response. Here we explore the energy balance processes controlling the nonlinear effect of climate warming on alpine and subalpine snowpacks in order to identify the underlying physical, not empirical, causes. To do this we performed a series of physics-based snow simulations using the SNOWPACK model at an alpine (3500 m) and subalpine (3000 m) site in the Niwot Ridge LTER in Colorado's Rocky Mountains. Baseline runs utilized a 23-year quality controlled, serially complete forcing dataset and model output was validated on SWE, depth-weighted snowpack temperature, and cold content from a long-term snow pit record. We then utilized a pseudo global warming approach where we increased air temperature from 0.5°C to 4.0°C in 0.5°C increments with associated increases in downwelling longwave radiation. The subalpine site was more sensitive to air temperature increases, experiencing significant reductions in snowmelt rate (-20.3%) and peak SWE (-57.0%) over the 4.0°C range, while the alpine exhibited a non-significant snowmelt response and a significant reduction in peak SWE (-17.1%). We found two physical mechanisms behind the nonlinear response: 1) A significant decline in subalpine net energy exchange (Q_{net}) during the primary snowmelt period; and 2) A step change in the relationship between cold content (CC) and Q_{net} throughout the winter in the subalpine, whereby Q_{net} became consistently greater than CC, enabling persistent snowmelt. There was no evidence of the above two processes in the alpine simulations.

A Method for Efficient Assessment of Parameter Uncertainty in Numerical Model Simulations

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Abstract. Numerical models are widely used to forecast the potential changes in water resources systems that might result from natural and/or human influences. The predictions from those models always possess uncertainty, and one major source of uncertainty is the parameter values. Bayesian methods, such as Generalized Likelihood Uncertainty Estimation (GLUE) and Markov Chain Monte Carlo (MCMC) approaches, have been developed to assess the uncertainty in model predictions that results from uncertainty in the parameter values. However, these methods require large numbers of model simulations, which makes them difficult to use with complex models that require long computation times for each simulation. The objective of this study is to develop a new method that can estimate the parameter uncertainty and its contribution to prediction uncertainty using fewer model simulations. To reduce the required simulations, the new algorithm replicates more likely parameter sets that have already been used for model simulations rather than generating many new but similar parameter sets that require additional model simulations. The new method is evaluated by application to a one-dimensional sediment transport model with nine uncertain parameters. The model is used to simulate a natural river in Taiwan. The results indicate that the new algorithm requires only 45% of the model simulations required by an existing MCMC method, and it still provides similar estimates for both the parameter uncertainty and the model prediction uncertainty.

On economy-hydrology effect of water price adjustment in the Wohu basin

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Abstract. Water price is an important measure to regulate water resources utility in current China. To find the feasible water price which considers both the economy effect and the hydrology effect caused by water price adjustment, Input-Output analysis and physical hydrology model are used, and the Wohu basin in Jinan is studied. Using latest 43 divisions I-O table of Shandong province, a special 15 divisions I-O table contained an independent division of water resources production is deduced, so that the I-O price model can be used to calculate the increases of prices of different economy divisions such as industry and agriculture when water price is raised. With the same rising of water price, the water consumption in basin also will decrease and the runoff in basin outlet will increase which is so called hydrology effect. Using the elasticity of demand of water resources the decease of water consumption is estimated through and physical hydrology model SWAT is used to simulate the hydrology response to this decrease in basin outlet. The result showed that when the water price is raised 50% and 100%, the average social price will increase 0.044% and 0.088%, the outlet runoff will increase 0.19% and 0.44%. It is can be concluded that the water price in basin has wide space of adjustment in the Wohu basin.
Keywords.water price; I-O analysis; economy-hydrology effect; SWAT ; Wohu basin

Snow depth measurement via time-lapse photography and automated image recognition

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Abstract. Seasonal snow measurements are critical to water management in many watersheds in the mountain west and in arid regions around the world. The Natural Resource Conservation Service's SNOTEL network provides daily measurements of depth, density, and snow water equivalent (SWE) at over 800 sites across the western United States. Whole watersheds are often served by a single SNOTEL station, meaning the data has limited spatial representativeness. In the past, time lapse photography of depth staffs has been used to obtain low-cost snow depth measurements over a large area but the temporal resolution has been limited by time-consuming manual image reading. We are developing an automated process to read snow depths from images of multiple snow depth staffs arrayed over scales of 1-50 meters in a variety of configurations. Previous studies have examined snow depth variability at a monthly or biweekly interval, but this technique will provide more frequent data points. The low cost and versatility of the setup means it can be deployed in locations inaccessible for conventional measurement techniques. This will further our understanding of how snow behaves in different areas over a large basin to better quantify accumulation and melt. At this stage, we will present progress made on this measurement technique and discuss data collected over this winter.

Dilemmas of State-led Environmental Conservation in China: Environmental Target Enforcement and Public Participation in Minqin County

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Abstract. This paper examines the acute socio-ecological crisis in the Minqin region of China's Gansu Province beginning in the 1980s and the multi-level, governmental response to that crisis in the first two decades of the 21st century. Drawing on extensive field research and interviews in the area, supplemented by analysis of available data, the paper presents a detailed case study of the development and implementation of the Shiyang River Watershed Restoration Plan in the period 2007-2015. The case illustrates how conflicting policy objectives of the central state-led conservation project shaped patterns of interaction between local government officials, cadres, and farmers in Minqin County, as well as ensuing outcomes and challenges in policy implementation. The study finds that top-level declaration of ecological and social issues in the watershed as a national security issue incentivized local government officials and cadres to overlook the Plan's provision for local consultation, in favor of meeting binding ecological and economic targets. It contributes to scholarship on environmental authoritarianism, illuminating structural factors and institutional constraints that shape local government officials' and cadres' behavior in a centrally-administered environmental policy context.

Applications of Satellite Moisture Products to Help Forecasters Enhance Their Forecasts: The West Coast Winter of 2016-17

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Abstract. Use of satellite-derived moisture products are an important source of value-added information to base a forecast on. The West Coast of the United States 2016-2017 cool season will be known for having the most widespread and heaviest amount of precipitation in over a decade and maybe even back to the 1990's. The winter provided a laboratory-like setting to expand and refine satellite moisture applications for both old and new satellite moisture products, while developing new ones for the analysis and forecast of heavy precipitation. Blended Total and Layered Precipitable Water satellite products will be highlighted when discussing events that occurred this past October to March from southern California to Washington State. Applications using these products will be discussed in the context of how they can be used to help forecasters identify and locate potential hazards up to 36 hours in advance.

Discharge Rating Equations for Pneumatically-Automated Overshot Gates

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Abstract. Adjustable overshot gates are commonly used to control discharge and water levels in irrigation delivery networks. The degree to which this control can be achieved depends upon reliable relationships between discharge and the hydraulic head upstream and downstream of the gate. This study aims to develop discharge rating equations for free and submerged flow over Obermeyer-type pneumatically-automated overshot gates. These structures are hinged across the bottom and there is an air bladder that controls the motion of the gate to set the crest at a desirable elevation. Their hydraulic behavior is comparable to that of sharp-crested weirs and pivot weirs. Some previous research on the flow characteristics of overshot gates has been performed in laboratories but there is very little investigation of their performance in the field. This paper provides a progress report of a field study conducted on overshot gates in a canal in northern Colorado. Utilizing the form of the classical sharp-crested weir equation, Buckingham-Pi dimensional analysis, and incomplete self-similarity theory, a discharge coefficient for free flow is developed as a function of gate inclination angle. To estimate the discharge coefficient, three suppressed Obermeyer-type overshot gates with crest widths of 22 ft., 20 ft., and 15 ft., and respective lengths of 5 ft., 6.3 ft., 6.1 ft respectively, were inspected for six different inclination angles (α = 22.84°, 23.58°, 29.74°, 34.61°, 35.29°, 38.94°). The resulting equation can be used to relate discharge to upstream hydraulic head, within ± 9.7 % accuracy.

Four-year Oleophilic Bio-Barrier demonstration results

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Abstract. With the vision of mitigating the formation of hydrocarbon sheens due to upland releases of petroleum products, Colorado State University (CSU) has been researching the Oleophilic Bio-Barrier (OBB) as a low-cost alternative to traditional sheen remedies. This technology utilizes an oleophilic (oil-loving) plastic geocomposite which retains hydrocarbon contamination, remaining bioavailable for microbial degradation. A transmissive geonet core delivers oxygenated surface water and atmospheric air to the microbes to promote degradation on the OBB and in the underlying sediment. By utilizing both sorption and degradation, the OBB is not limited to a finite sorption capacity and can help mitigate sheen formation until the source zone is remediated. A field demonstration of this technology has been ongoing on the Hudson River for four years. The primary objective of this demonstration was to validate the use of an OBB to prevent the release of sheens to the surface water. In October of 2017, the demo barrier was removed, sampled, and replaced with a full-scale OBB. Removal of the demonstration OBB provided CSU the unique opportunity to analyze an OBB system after four years in the field. Sample analysis indicates that there was negligible sediment intrusion or biofouling in the geonet that would obstruct the flow of oxygen. Visual inspection of the geocomposite under both ultraviolet (UV) and ambient light suggests that no non-aqueous phase liquids (NAPL) permeated the top of the geocomposite. Furthermore, hydrocarbon analysis shows that the OBB system was at less than 0.1% retention capacity. Sheens were observed in holes dug below the OBB, suggesting that hydrocarbon contamination exists under the OBB and is being depleted via biological processes. Sediment from underneath this OBB system will also be used in a laboratory experiment designed to elucidate aerobic and anaerobic degradation rates. Columns loaded with the field sediment will be injected with NAPL at various loading rates to compare the breakthrough times for each column to estimate the biological degradation rates. Nine columns will undergo water cycling designed to mimic tidal fluctuations and establish aerobic degradation rates. Seven columns will have a constant water level to demonstrate anaerobic degradation.

Risk to Assets and Communities from Coastal Flooding: Quantifying the effect of sea level rise and flood adaptation strategies

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Abstract. Coastal communities are increasingly vulnerable to coastal flooding due to rising sea level as a result of climate change. The nonstationary sea level conditions pose planning and management challenges to stakeholders in coastal regions. Estimation of the economic impact of sea level rise on the coastal communities is of utmost importance for policymakers to adopt effective strategies to protect the society from cumulative losses from less extreme coastal flooding besides extreme events. Thus, in this study we develop a decision framework for assessing coastal flood risks due to different coastal flood categories (minor-moderate-major) and evaluating adaptation and mitigation strategies under uncertainty. In order to do this the frequency of extreme values of maximum daily sea water level data are assessed based on the peak-over-threshold (POT) and Generalized Pareto Distribution (GPD) approach using the variable threshold expressed in terms of regression quantile. Usually, a quantile regression is done using time as an explanatory variable. However, in this work, Mean Sea level (MSL) is used instead of time which is more appropriate under unknown future sea level conditions. Then, we demonstrate the application of the framework for assessing risks to assets and communities in the 10 populated coastal cities in the United States across a range of possible management actions under different future sea-level scenarios. By considering the effect of different sea level rise as well as adaptation scenarios we are able to study the development of average annual losses.

Aquatic Ecology in the Upper Yellow River Basin

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Abstract. The ecological and environmental quality of the Yellow River Source Region (YRSR) on the Qinghai-Tibetan Plateau has been a focal issue for decades owing to its unique geographical location and ecological function. To explore the water quality and the ecological status of the waterways, this study investigated the headwater streams, main stem and tributaries in YRSR using multiple traits of macroinvertebrates as biological indicators. It was observed that the headwater streams were characterized by low water temperature, poor aquatic and riparian vegetation, and low runoff. Because of these restrictive environmental conditions, macroinvertebrate assemblages in the headwater region were characterized by low biodiversity and incomplete ecological function. The ratio of pollution-tolerant taxa of the headwater streams was higher than those of the main stem and downstream tributaries. The combined effect of harsh natural conditions and increasing human interference was regarded as the main cause for eco-environmental degradation in the Yellow River Headwater Region, which was believed to have once possessed the best water quality in the Yellow River basin. Potentially, ecological restoration of runoff in the headwater region could be improved using short-term artificial water inputs to reduce nitrogen enrichment and help improve the eco-environmental health of YRSR.
Keywords: functional feeding groups, tolerance values, biotic indices, functional diversity, nitrogen enrichment, bio-assessments

Distribution of velocities in a cross section using the logD method: Application to a cross section of the Wainiha River

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Abstract. The logD method distributes velocities across a transect (cross section) uses the equation $v = C\sqrt{Sd}\,\log(\alpha(d/k))$. In the equation d is the depth at a location in the cross section, S is the slope, α is an empirical parameter, k is the absolute roughness height and C is a constant (32.61 for traditional English, and 18.00 for metric units). Typical value of α is 10.96 (based on theoretical considerations), and 4.70 (based on empirical measurements). The distribution of velocities in a cross section is used in the Physical Habitat Simulation System (PHABSIM) to calculate physical habitat for aquatic animals. The logD method is an effective method for calculation of the velocity distribution and helps reduce problems associated with the simulation of velocities at the edges of a channel. The method requires a consistence approach to the selection of the roughness heights. Roughness heights determined from measured velocities may not have a physical meaning but if roughness heights based on measured heights are used they must be used through out the cross section and not mixed with roughness heights determined from measured velocities.

How We Observe Snow, Winter Weather and Climate Change – A Survey of Northern Colorado

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Abstract. The Front Range of Colorado is a highly populated region with a continental climate, at the interface between the agricultural plains to the east that extend to the Mississippi River and the Rocky Mountains to the west. While many people of the area recreate in the snowy mountains, most live where annual snowfall amounts are low. Snow is a valuable natural resource in this semi-arid landscape for both water supply and the revenue generated from winter recreation. It is also however, the source of large routine cost for snow removal of streets and highways in the populated areas. Weather and climate perception is the process by which society seeks to understand the atmospheric conditions where they live so that they might be able to effectively respond and adapt. Perception of weather and climate can be influenced by direct exposure to those conditions, exposure from a variety of media sources, or cultural and social factors. Existing research has attempted to align perceptions of weather and climate with observed data and has shown that perceptions do not necessarily match observed meteorological data. Through the analysis of two surveys administered to Front Range residents we attempt to 1) understand the perception of snow, winter and hydrologic events, 2) determine how perceptions align with observed meteorological data, and 3) determine how individual characteristics shape perceptions of winter weather and climate. In comparison to meteorological observations, we generally found that most respondents did not have a good understanding of winter conditions regardless of the time they spent recreating in the winter or from the weather data that they regularly accessed. Although the difference was not statistically significant, women had a better understanding of snow, winter weather, and related climate change issues.

Riparian area evapotranspiration with implications on water resource management

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Abstract. Riparian areas are a unique corridor that parallel a riverine environment and contribute to ecosystem function as well as play an active role in consumptive water use in an irrigated alluvial aquifer. It is widely known that over application of irrigated water can lead to progressively shallower water tables. This shallowing effect can contribute to an increase in evapotranspiration from both vegetation transpiration and water uptake by capillary rise through the unsaturated zone. This research and subsequent poster will focus on previous work, model setup and initial results regarding riparian area water usage of irrigated-return flows through evapotranspiration by employing a finite-difference groundwater model on the Lower Arkansas River Valley in southeastern Colorado. We presume that a reference evapotranspiration rate applied to the Tamarisk-dominated riparian corridor can be borne out of a combination of MODFLOW-developed and remotely-sensed estimates of groundwater evapotranspiration. Establishing a baseline evapotranspiration rate for a given riparian corridor will allow for a comparison with similar riparian areas that possess a change in vegetal species or a complete lack of vegetation. Seemingly, with a change in vegetation or no vegetation at all, the rate of evapotranspiration in a riparian corridor will become altered. How the evapotranspiration rate changes with alterations to the riparian corridor can provide insight to water resource managers attempting to increase groundwater discharge to streams or to protect streams for groundwater and land-based pollutants through plant uptake.

Evaluation of CMIP5 precipitation trends across multiple scales

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Abstract. Water resources are changing in response to a changing climate. In order for water managers to make effective long term plans they need guidance about how precipitation trends may change. The degree to which climate models should be used for this guidance, however, is currently unknown. How well climate models can reproduce precipitation across a variety of scales is one aspect, and another is how well do climate models reproduce a significant change in precipitation. Yet the heart of this issue is, can the predicted precipitation changes be trusted? To address this question the precipitation output of climate models from the Coupled Model Intercomparison Project Phase 5 (CMIP5) was compared to observed data. Observed and modelled precipitation were compared using multiple metrics at the global, continental and watershed scale. The best and worst performing models based on this evaluation were then compared to the European Center for Medium Range Weather Forecasting Re-Analysis (ERA Interim) in order to glean some insight into why these models perform the way they do. Preliminary results have shown that models are very good at reproducing average annual mean precipitation and precipitation trends, especially at the global scale. At the watershed scale there is considerably more variability in the model outputs. Climate models generally have more difficulty in reproducing the spatial structure of the precipitation trends, regardless of scale. This holds especially true with reproducing the spatial structure of significant precipitation change at the watershed scale.

Assessing performance of an urban water demand model for a selection of U.S. cities of varying climatic conditions and land use characteristics

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Abstract. Forecasting urban water demand under varying climatic conditions, land use changes and population growth is an important task for city water managers across the United States.
The Integrated Urban Water Model (IUWM) developed by the One Water Solutions Institute at Colorado State University is a mass balance water use and forecasting tool that quantifies indoor residential, commercial and outdoor irrigation demands. IUWM is available as a web-based geospatial information system (GIS) that combines census, USGS land cover and historic weather data to allocate water demand at varying spatial scales.
This work consists of calibrating the IUWM for different cities in the US with varying climatic conditions and water use behaviors. With acquired water meter data, sensitivity analysis is conducted to understand the principal drivers of water use for a region and develop an optimal set of physically based parameters. Applying the model in different cities requires a nuanced approach to representing water use across an urban landscape albeit represented by the National Land Cover Database, USGS. Water demands differ in business districts with high rise buildings and areas with significant commercial and industrial use which require additional representation in the model. Seasonal variations in weather, landscape vegetation demands and behavioral use vary considerably by region and must be appropriately accounted for in the model.
This study also seeks to quantify landscape area more accurately by using high resolution land cover to justify irrigation demand parameters in the IUWM. This analysis has been conducted for Fort Collins, CO and can be repeated with the availability of classified high resolution land cover data for cities across the country.

Response of municipal outdoor water use to climatic variables across the contiguous U.S.

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Abstract. Municipal water demand exhibits seasonal patterns in response to withdrawals for landscape irrigation, particularly in arid and semi-arid regions. Outdoor water use can account for more than half of total annual household use in some locations, and therefore is an important aspect of urban planning as water scarcity persists. Previous studies use statistical methods to estimate the impact of climatic, socio-economic, and landscape factors on residential water use, but commonly focus on a single municipality due to difficulty in acquiring billing records. This nationwide study identifies the impact of climatic variables (e.g. temperature, precipitation, ET) on urban landscape irrigation using monthly water deliveries for 230 cities in the contiguous U.S. Outdoor water use is estimated from total water use seasonality under the assumption that winter deliveries can be used as a proxy for indoor use. Using linear regression, we investigate which climatic variables are important for explaining the variability in outdoor water use, and how responses vary across climate classifications. Preliminary results show that temperature and evapotranspiration are the best predictors of outdoor water use, explaining on average 68% and 48% of the variance, respectively, compared to precipitation explaining only 13%. Climate regions of the western U.S. (e.g., west, northwest, west north-central, and southwest) generally had higher mean R^2 values for all variables compared to eastern and central regions. Climate change and population growth projections amplify the importance of understanding the impact of climate on water demand in the context of urban water supply.

Sediment Wave Propagation Modeling in the Doce River after the Fundão Tailings Dam Break in Brazil

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Abstract. On November 5 of 2015, the collapse of the Fundão Tailings Dam located in the Doce River Watershed in Brazil caused the destruction of the Bento Rodrigues Town, resulting in 19 casualties. Furthermore, the propagation of an estimated 32 millions of cubic meters of mud caused the interruption of water supply in 12 cities affecting 424,000 people. The immediately damage in the environment was the death of nearly 3 tons of fish. After the dam break, the floodwave traveled 100 km through the Gualaxo do Norte and Carmo Rivers until the Doce River. Approximately 27 million cubic meters of hyperconcentrated sediment deposited in this reach and approximately 5 million cubic meters reached the Doce River. The Geologic Service of Brazil and the National Water Agency conducted measurements to keep track of the wave propagation and the sediment concentration along the 650 km of Doce River until the wave reached the Atlantic Ocean. A finite difference modeling using the Crank Nicolson scheme was coded in Matlab to simulate the floodwave propagation, considering the diffusive wave approximation for the Saint Venant Equation. In addition, the analytical solution of the advection-dispersion equation using the complementary error function was successfully applied for the transport of suspended sediment. Both models are in good agreement with the observed flow and sediment concentration along the Doce River. Finally, the analysis of the observed data highlights the difference between the celerity of the wave propagation and the velocity of the sediment along the river. As noticed, the floodwave reached the ocean 16 days before the sediment. This effect gave rise to the counterclockwise hysteresis curve, where the peak sediment concentration lags behind the peak discharge.

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A River-Reservoir Network Model In TensorFlow™

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Abstract. Reinforcement learning is a method of machine learning in which an intelligent agent is able to learn optimal decisions through experience with a simulated environment. RL is able to handle complex non-linear stochastic problems which are common in the field of water resources planning and management. To do this, the agent must be allowed to experience the results of its actions many (possibly millions) of times, which can be a significant part of the computation time of the overall learning process. Computation using graphical processing units (GPUs) has become a popular method for high-speed computing in machine learning particularly for the training of large artificial neural networks. This approach takes advantage of the large number of cores available on a GPU to perform many calculations simultaneously. This technology can also be applied to the gathering of experiences required for a reinforcement learning application. A reservoir network model is developed using the TensorFlow™ library to leverage the speed of GPU computing. The model is able to track thousands of agents through unique sequential experiences as the input vector, reservoir storage, release decision, downstream flows and lagged routing effects are all tracked separately. This network model can be used as the environment module of an agent based reinforcement learning application.

Using snow data assimilation within an Ensemble Streamflow Prediction framework to improve water supply volume forecasting for the Upper Colorado River Basin

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Abstract. The Upper Colorado River Basin (UCRB) alone provides water supply for 25 million people, irrigation water for 3.5 million acres, and drives hydropower generation at Lake Powell. April-July water supply forecasts produced by the National Weather Service (NWS) Colorado Basin River Forecast Center (CBRFC) are critical to basin water management. The primary objective of this project is to improve water supply forecasting for the UCRB by assimilating satellite and ground snowpack observations into a distributed hydrologic model at various times during the snow accumulation and melt seasons. To do this, we have built a framework that uses an Ensemble Kalman Filter (EnKF) to update modeled snow water equivalent (SWE) states in the Hydrology Laboratory-Research Distributed Hydrologic Model (HL-RDHM) with spatially-interpolated SNOTEL snow water equivalent (SWE) observations and products from the MODIS Snow Covered-Area and Grain size retrieval algorithm. We are generating April-July water supply reforecasts for a 20-year period (1991-2010) for several headwater catchments in the UCRB using HL-RDHM and snow data assimilation within the Ensemble Streamflow Prediction (ESP) framework. Existing CBRFC reforecasts provide a baseline for comparison. The final forecasting framework developed during this project will be delivered to CBRFC and run operationally for a set of pilot basins.

Snowmelt runoff timing and snow ablation

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Abstract. Snowmelt timing for high elevation watersheds is important for estimating water availability during dry seasons, especially in regions where a majority of precipitation is in the form of snow. This research seeks to further understanding of snowmelt timing by combining streamflow and snow water equivalent (SWE) data by investigating high elevation watersheds in California and Colorado. An automated streamflow timing method was used with the annual cumulative hydrograph to determine the start and end of snowmelt contribution to streamflow. The total volume of water added to streamflow from snowmelt ($Q_{snowmelt}$) was then computed. Using daily $Q_{snowmelt}$ and SWE data from snow telemetry (SNOTEL) stations, we defined a specific basin-year curves from the percent of peak SWE versus the percent of $Q_{snowmelt}$ during ablation. We also examined the relation between the snowmelt rate (change in SWE after peak) and the rate of response in streamflow (change in $Q_{snowmelt}$ after the start of contribution). The shape of the curve between these two variables is consistent between year to year but magnitude varies as a function of peak SWE.

Morphodynamic numerical modeling of sediment transport and deposition around run-of-river dams

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Abstract.

Low-head or Run-of-River (RoR) dams exist on all types of rivers throughout the United States, yet the exact mechanisms of how sediment moves around the structures have not been well researched. Due to the increasing use of RoR dams in small hydroelectric projects, there is a need to better understand the controlling factors of how sediment passes over these dams. A one-dimensional morphodynamic model was developed to investigate the effects of RoR dams on channel morphology over long time scales. The model solves the energy equation to compute the flow field in the vicinity of the dam, computes grain-size-specific sediment transport rates, and uses sediment mass conservation and vertical storage bookkeeping to calculate the evolution of bed elevation, the bed surface grain-size distribution, and the vertical pattern of stratigraphy. The model's hydraulic calculations were calibrated using data collected from a series of flume experiments preformed with a model RoR dam. Numerical experiments designed to investigate how the grain size distribution, flow rate (steady and unsteady), and dam height act as controls on sediment passage over RoR dams were conducted using parameters reported in the literature for a RoR dam in northern Delaware. Lateral influences on morphology around RoR dams, such as width constrictions, were investigated with a two-dimensional morphodynamic model, Nays2DH, which is distributed with the free and open-source iRIC software interface. The 1D model and a toolbox from the results will be implemented into iRIC for further investigation by other researchers in the field.

Reactive Transport of Selenium and Nitrogen in Groundwater and Surface Water Systems in the Lower Arkansas River Valley, Colorado

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Abstract. Agricultural productivity in the Lower Arkansas River Valley (LARV) in southeastern Colorado has been high over the last 100 years due to extensive irrigation practices. However, these practices has led to high concentration of selenium (Se) and nitrate (NO_3) in groundwater, surface water, and soils. Environmental concerns due to these high concentrations include human health, health of fish and waterfowl, and eutrophication. The aim of this study is to construct and apply a computational model that simulates the fate and transport of Se species and nitrogen (N) species in a coupled irrigated stream-aquifer system for a regional study area within the LARV. Groundwater and surface water flow is simulated with MODFLOW-SFR, and reactive transport of Se and N species is simulated using RT3D-OTIS, a model that simulates solute transport in the aquifer (RT3D), in the Arkansas River stream network (OTIS), and the mass exchange between the two. The model is tested against Se and N concentration measured in a suite of monitoring wells and stream sampling sites, and will be used to investigate the effects of best management practices (BMPs) in decreasing Se and N concentrations and mass loadings within the stream-aquifer system.

Sediment erosion in zero-mean-shear turbulence

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Abstract. Sediment erosion and transport are ubiquitous in nature (in rivers, snow avalanches, turbidity currents, snow/sand transport by the wind, costal morphodynamics…) Since most of the flows have a mean flow, the erosion part due to turbulence is very often hindered and badly reported while it does play a true role in the sediment lifting-up process and needs to be addressed. A stirring grid, in a square tank, located more than 2 mesh sizes away from a sediment layer, has been used to study particle erosion by a zero-mean-shear turbulence. Fluid velocity in the region in between the sediment layer and the stirring grid has been monitored using both ADV and PIV. Converged velocity profiles indicate that the bulk isotropy of the turbulent velocity in the tank is well predicted by a slightly modified Matsunaga et al. (1999) model and then gets broken close to the bed. Particle concentration has been monitored using an OBS technique together with sampling measurements. Particle lift-off and concentration in the tank are shown to rise sharply as the grid frequency is increased. Averaged shear rates due to turbulence are shown to be too small at the bed surface and unable to lift up the sediments. Specific events able of coupling a long enough time of occurrence with reasonable horizontal and vertical velocities are shown to be responsible for the particle erosion. They are related to large structures (vortex like) impact on the bed layer.

Integrated Water Resource System Planning, Design, and Operation using MODSIM-DSS and Particle Swarm Optimization: Application to the Tripa River Basin, Indonesia

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Abstract. Water shortages to agricultural, domestic, and industrial demands are a significant concern in the Tripa River basin of northern Sumatra, Indonesia. Available historical data indicate that the basin has been plagued by monthly shortage frequencies over 50% of the time, with average water supply deficits to meeting demands of 30 m^3/s. There is a need to estimate the design capacity of a proposed reservoir for the basin for reducing shortages in conjunction with possible additional supply from transbasin diversions into the basin. This study uses MODSIM-DSS for accurate hydrologic simulation of the Tripa River basin, with consideration of water use priorities, with linkage to a particle swarm optimization (PSO) algorithm for minimizing construction costs and optimizing reservoir operating rules. Also considered are the impacts on adjacent basins of transbasin diversions to the Tripa basin, and whether such recommended diversions are hydrologically, environmentally and politically feasible based on tradeoff analyses between total diverted transbasin water and shortage frequencies. Tradeoff analysis is also performed between construction cost and shortage frequencies, should the magnitude of construction costs be a significant concern in overcoming the water shortage problem.

Evaluation of soil moisture data assimilation to improve hydrologic partitioning over agricultural areas

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Abstract. As data assimilation is increasingly used to merge Land Surface Model (LSM) estimates of state variables (e.g. soil moisture) with remotely sensed retrievals, it is practical to enhance the strengths of both LSMs and remotely sensed products in assimilation systems. Anthropogenic alterations to the land-surface, primarily through irrigation is frequently neglected from state-of-the-art LSM physics; whereas contemporary remotely sensed products, such as the Soil Moisture Active Passive (SMAP) satellite detects these changes. Importantly, this difference leads to diverging climatologies between observational and model time series and biases the partitioning between evaporation and transpiration. This study explores the benefits of assimilating SMAP soil moisture retrievals with the VIC model via implementing the ensemble Kalman smoother (EnKS) and particle batch smoother (PBS) over one irrigated and one non-irrigated drainage basin covering a 2-year record. The results from PBS and EnKS assimilation runs will be compared with each other using a model run with no assimilation and the resulting streamflow simulations will be validated with gauge data.

Data and Parameter Uncertainty of VIC Model Using GLUE and BMC Techniques: Case Study in Diyala River Basin in Iraq

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Abstract. One of the most challenging issues that hydrologists encounter in water resources planning and management is determining model parameter uncertainty and examining parameter sensitivities to the system response. This analysis can only be achieved if accurate forcing data and basin data are assembled from several different data sources. The main objectives of this study are to (1) implement a complete and accurate forcing data for Diyala river Basin in Iraq and test the validity of Tropical Rainfall Measurement Mission (TRMM) and Variable Infiltration Capacity model (VIC) data sets, and (2) quantify the uncertainty of the VIC model parameters in Diyala River Basin in Iraq. Diyala River is a tributary of the Tigris River in eastern Iraq. Its total length and basin area are about 216.5 km and 16,763.7 km^2, respectively. Due to limited availability of observed daily data, a random temporal cascade method is applied to downscale the monthly precipitation into daily with the aid of a transformation technique. Furthermore, generalized linear regression equations are developed to adjust the VIC temperature data depending on the observation data. The coefficients of the developed linear equations are computed based on each basin grid geometry and utilizing Kriging transformation technique. The sensitivity and identifiability of the VIC model are evaluated using Generalized Likelihood Uncertainty Estimation (GLUE) and Bayesian-Monte Carlo (BMC) techniques. Seven candidate parameters of the VIC model (i.e., B_infiltration, Ds, Ws, Dsmax, and depths of soil layer 1, 2, and 3) associated with the infiltration and surface runoff production processes are examined. The analyses indicated that neither the observations from TRMM nor the VIC modeled data is accurate for gridded precipitation. TRMM tends to underestimate the precipitation amount whereas the VIC data tends to be higher than the allowable observations. Therefore, a temporal downscaling technique is applied. Moreover, the comparison between four different interpolation techniques reveals that the Kriging method is superior. The optimal model performance is found with NSCE values of 0.686 and 0.688 for the calibration and verification period, respectively. The optimal model residuals are also tested for normality, heteroscedasticity, and correlation. In addition, the results of the GLUE and BMC analyses imply that the depth of the second soil layer is the most sensitive parameter, and B_infiltration, Dsmax, and soil depth of the first soil layer are relatively insensitive. The Ds, Ws, and third Soil Depth are insensitive parameters.

Implementation of the parametric CLIGEN weather generator with multisite and multivariate technique: study case in Diyala river basin in Iraq

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Abstract. Assessment and evaluation of risk analysis due to climate change impacts on water resources is of paramount importance for hydrologists and scientists. Testing a water resource system behavior under synthetic future scenarios can help us understand the system performance and suggest mitigation strategies. Such evaluation can be performed by implementing a weather generator model coupled with a hydrology model in order to study future climate scenarios for extreme events. Therefore, the main objective of this study is to develop a weather generator model with capability of producing a wide range of climate scenarios in order to assess future climate variability and its impacts on a water resources system. Herein, CLIGEN model is implemented to achieve this purpose. The proposed model contains different features including: (1) a second-order, two-state Markov chain to simulate the precipitation occurrence; (2) Wilks' technique to produce correlated precipitation occurrences and amounts at multiple sites; (3) conserving the cross-correlation and the auto-correlation between the weather variables and the variable itself; and (4) an ability to alter the variable parameters (i.e., mean, standard deviation and coefficient of variation) to generate realistic scenarios to be used later for evaluation of climate change impacts. The developed model is applied in Diyala river basin in Iraq to demonstrate its validity for the period between 1948 to 2006. Results indicate that the proposed model preserves the statistical properties of the variables as compared to the observation properties. The proposed model also conserves the Auto-correlation of a single parameter, the spatial correlation between each variable, and the cross-correlation between the variables in each site with a good agreement with the observation characteristics. The results also show that the second-order two-state Markov chain is superior over the first-order two-state which demonstrates the importance of using higher order in dry-climate regions.

Modeling the hysteretic relation of a snow-covered area (SCA), snow depth, and a dynamic surface roughness (z0)

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Abstract. Surface roughness (z0) is typically a static component used in hydrologic models, although upon observation, z0 is a dynamic value and should be incorporated into these models as such. Inaccurate representation of snowpack depth due to z0 can lead to miscalculations in hydrologic models. Snowpack surface roughness imitates ground surface roughness, however, at a certain snow depth, this relation between topography and snowpack roughness is decoupled and results in a smooth snowpack surface. A model of this is represented by a hysteretic curve based on the snow-covered area (SCA), snow depth, and z0. This study will explore calculations of z0 at different resolutions, as well as the differences in this relation between periods of accumulation and melt. All snow surface and ground surface data will be found using a FARO terrestrial LiDAR scanner. Modeling this hysteretic relation will help to provide a more temporally and spatially dynamic z0 value in hydrologic models.

Toward Understanding Changes in Large-Scale Floodplain Connectivity Caused by Levees

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Abstract. The widespread construction of levees has reduced river-floodplain connectivity and harmed associated fluvial processes in many river systems. Despite the recognition that levees can alter floodplain connectivity, few studies have examined the role of levees in reducing floodplain areas at large watershed scales. In this research we explore the application of a hydrogeomorphic floodplain mapping approach in the Wabash basin, U.S. to assess floodplain loss in levee-protected areas. We evaluate 10-m and 30-m topographic resolutions and spatially examine the influence of levees on floodplain area in relation to river network attributes within discrete HUC-10 sub-basins. Generally, we found that the floodplains mapped in levee-protected areas were influenced by topographic resolution, stream order, and elevation details of levees found in topography datasets. We show that, when compared to Federal Emergency Management Agency maps, our approach underpredicts floodplain area when using 10-m resolution topography data but only slightly overpredicts when using 30-m resolution topography. After removing details of levees from topography datasets, we found that basin-aggregate results changed little compared to topography datasets that contain levees, though larger floodplain areas were produced in some regions where levees were removed. We anticipate our work will contribute to a growing research emphasis on linking water resource management to river-floodplain connectivity.

Understanding geomorphic response to floods: the role of scale and gradients

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Abstract. Morphodynamic response of channels and floodplains to flooding reflects interactions of erosive and resisting forces with sediment transport capacity and supply at multiple scales. Monotonic relationships between reach-scale channel response to floods with independent variables such as flood stream power and channel confinement can be confounded by longitudinal variations (i.e., gradients) in these variables. In these cases, channel response depends on both local and upstream drivers. Using high resolution pre- and post-flood digital elevation models, we calculate reach-scale (0.5 to 1 km) and segment scale (10 km) longitudinal variations in channel widening and sediment balance as a response to the 2013 Colorado Front Range flood. We relate these responses to longitudinal variations of unit stream power and channel confinement. These streams transition from steep and relatively confined in the canyons of the foothills to less steep and unconfined on the high plains.
The channel widening response is more closely linked with reach scale gradients in unit stream power: abrupt widening typically occurred within reaches where a large drop in unit stream power occurred relative to upstream. Sediment balance exhibited a net degradational trend within the foothills that transitioned to a net aggradational trend within the transition to the plains and was less sensitive to reach-scale fluctuations in unit stream power and confinement. These findings indicate that unit stream power gradients mediate channel response at reach to segment scales. Predictive modeling of stream response to floods and fluvial hazards assessments that only consider absolute values of reach-scale stream power may under-estimate fluvial hazards in some settings by ignoring unit stream power gradients.

Evaluation of an Optical/Thermal Remote-Sensing Method for Root-Zone Soil Moisture that Accounts for Regional Characteristics

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Abstract. Mapping root-zone soil moisture over large regions is valuable for improving crop productivity, managing erosion, and many other hydrologic applications. Remote-sensing methods based on optical and thermal satellite imagery have been proposed to estimate root-zone soil moisture at fine resolutions (e.g., 30 m) over large regions (e.g., 170 km x 185 km). In one such method, multispectral imagery from Landsat8 is processed using a calibrated surface energy balance model ReSET to estimate the evaporative fraction (Λ). Then, the root-zone volumetric water content (θ) is estimated using an empirical relationship with Λ. Although early versions of this approach used a single empirical relationship for all regions, field research has demonstrated that a single Λ-θ relationship does not apply for all regions. Subsequent modeling research proposed a series of Λ-θ relationships that depend on regional climate, vegetation, and soil characteristics. The objective of the present study is to evaluate the optical/thermal estimates for soil moisture when the region-specific Λ-θ relationships are used. Two arid to semiarid regions are examined, which are located in southeastern Colorado and southern Arizona. These regions were selected because they have extensive in-situ soil moisture observations available. Remote-sensing estimates for soil moisture were developed using the universal empirical relationship and the region-specific relationships, and these estimates were compared to the in-situ soil moisture measurements. Overall, the soil moisture estimates using the region-specific relationships were found to outperform those using the original empirical relationship.

Spatial Snow Surface Roughness Across Multiple Resolutions

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Abstract. Accurate assessments of snowmelt timing are critical in the mountainous region of Colorado. Most hydrological and climate models ignore variability in snow surface roughness, though it potentially plays a significant role in the sensible and latent heat fluxes of the energy balance of snow-dominated systems. This paper builds on previous efforts in the development of a standard procedure to estimate snow surface roughness in order to improve accuracy of future hydrologic and climate models.
During the winters of 2002 and 2003, various remote and manual data were collected over a number of intensive study areas (ISA) through the NASA Cold Land Processes Experiment (CLPX). Within each ISA, snow roughness was measured from images of snow roughness boards at resolution finer than 1 mm. For the last measurement period in 2003, airborne LiDAR measurements of the snow surface were taken at a 1.5m resolution. Each board covered an extent of one meter, while the LiDAR data extended over the entire 1 kilometer. Statistical analysis of each dataset allowed for a quantitative comparison of roughness metrics over multiple scales; results were examined to characterize the spatial distribution and scaling properties of snow surface roughness. Such properties may indicate important changes in the physical processes of the snowpack.

Developing a coupled SWAT-MODFLOW model assessing groundwater depletion in the Republican River Basin

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Abstract. The Republican River Basin encompasses approximately 50,000 square miles in eastern Colorado, northwestern Kansas, and southwestern Nebraska, with thousands of farms irrigated by groundwater from the underlying Ogallala Aquifer. This overexploitation of groundwater resources has led to significant decline in aquifer saturated thickness in various parts of the river basin in recent decades. In addition, the duration and intensity of drought periods are expected to increase in the majority of the river basin during the next 50 years. Management strategies are sought that maintain economic prosperity and crop yield in the region while also sustaining groundwater resources, i.e. preventing significant decline in saturated thickness. The overall objective of this study is to identify sustainable management strategies for the Republican River Basin under a changing climate. This will be accomplished using the newly developed hydrologic model SWAT-MODFLOW, which couples the land surface hydrologic model SWAT with the three-dimensional groundwater flow model MODFLOW. Applied irrigation water and associated pumped groundwater volumes will be determined from MODIS evapotranspiration data and spatial distribution of irrigated lands, with model results used to compute historical and future saturated thickness for 1 km^2 cells of the river basin under varying management strategies and climate scenarios. The basin incorporates 16 HUC-8 watersheds, and this project will develop models for several of these watersheds. In this presentation, we show the methodology for developing a SWAT model for one of the HUC-8 watersheds (NHD-10250003), linking it with MODFLOW, and present preliminary results of model testing and application.

Keywords: Ogallala, groundwater, irrigation, drawdown

Fifty Years Observing Issues in Hydrology and Water Resources Engineering

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Abstract. The work we do in hydrology and water resources engineering is influenced by the needs of society and the available tools. I place this presentation in the context of the world geo-political setting starting in 1944. I follow with landmark technological developments during the past sixty years and the resulting follow up technology that has influenced, and will continue to influence, our work. I draw examples from the early- and mid- 20th century that should influence much of our modern activity, highlight key parts of the 1991 NRC Eagleson Committee Report and the 2001 NRC BROES Committee Report that set the course of much modern hydrologic research. Of all the issues in hydrology, solving the water balance for any catchment accurately remains a formidable challenge. I provide an example that shows the importance of using accurate precipitation input to determine the water balance and illustrate some of the shortcomings of existing liquid precipitation measuring networks.

The Spatial Distribution of Fine Resolution Snow Surface Roughness

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Abstract. Variability in snow surface roughness is rarely incorporated into climate or hydrological models, yet it has the potential to have a large impact on both latent and sensible heat for a snow dominated system. We looked at the spatial variability of snow surface roughness using the data collected by the NASA Cold Land Processes Experiment (CLPX) during the winters of 2002 and 2003 for a number of 1 km^2 intensive study areas (ISAs) across northern Colorado. Within each ISA, snow roughness data were derived from 100 images of snow roughness boards at sub-millimeter resolution and from airborne lidar measurements at meter resolution. Each board had an extent of one meter while the lidar data was continuous over the entire 1 kilometer. Roughness metrics were estimated for each dataset and examined geospatially to understand their spatial variability and the driving processes. While the spatial coherence of the roughness board data was limited across each ISA based on the Moran's I statistic, the lidar data was more spatially coherent. However, the roughness metrics could be scaled from the fine resolution boards to the coarser resolution lidar snow surfaces for most of each ISA.

Precipitation Features During a Canonical Southeastern Asian Monsoon Event

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Abstract. Summertime westerly monsoons dominate the hydrological cycle within southeastern Asia, contributing greater than 75 percent of the annual precipitation in regions such as Bangladesh and the Philippines. The summertime monsoons are an interconnected hydrological process, wherein the atmosphere and land-surface interact through a multitude of complex mechanisms. While these feedbacks are important to the evolution of the monsoon, deep atmospheric convection and the precipitation it produces are predominantly tied to the atmospheric environment within which the convection occurs. Identifying atmospheric environments conducive to deep convection is therefore critical to understanding the hydrological response to the monsoon. However, monsoonal process studies are commonly performed at a coarse resolution due to the spatio-temporal expansiveness of monsoonal regimes, which limits the explicit representation of smaller scale processes such as individual deep convective clouds. By including cloud-scale processes, regional monsoonal patterns can be dissected using a scale-aware approach.

Using a cloud-resolving model, we simulate a canonical summertime southeast Asian monsoonal event, wherein an established monsoonal regime is perturbed by atmospheric waves with periodicities ranging from the life span of mesoscale deep convective clouds to regional intra-seasonal oscillations. Within this framework, we can examine the evolution of convective systems within the background monsoonal state as a function of the various extraneous waves. This work therefore offers insights into how convective regimes change throughout the summertime southeast Asian monsoon.

Of related interest is the broad applicability of these results to other monsoonal regimes. While the convective environments identified within this study are predominantly applicable to the southeast Asian monsoon, the methodologies are transferrable to other regions of the world.

A look into the role of public perception on the evolution of wastewater treatment

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Abstract. With global population rising, trends toward migrating to urban areas progressing, and access to a clean, sustainable water resources becoming more limited, it is not surprising that obtaining water security has become a major undertaking to overcome. Mara (2003) reports that "over half the world's rivers, lakes and coastal waters are seriously polluted by untreated domestic`, industrial and agricultural wastewaters." UNEP and UNHabitat (2010) estimate that in developing countries, an overwhelming ninety per cent of all wastewater is discharged into rivers, lakes or the oceans untreated." The management approaches and wastewater treatment technologies utilized fit within the general categories of no treatment at all, conventional treatments, alternative treatments, and emerging treatments. The evolution of wastewater treatment practices used within our societies is strongly linked to people's perception and education of wastewater treatment processes, political structures, public health, and the natural environment. By taking a holistic approach of reviewing wastewater treatment approaches, we can compare and evaluate different technologies and policy that drive the watershed management plans in certain regions ranging from the developing to developed world as well as considering urban versus rural areas. The purpose of this research is to educate people on wastewater management approaches by introducing clear comparisons of wastewater treatment technologies while taking into account social, economic, and environmental factors.

Use of the Manning Equation for Predicting the Discharge of High-Gradient Canals and Natural Streams

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Abstract. The Manning Equation is used to predict stream or canal discharge from hydraulic radius, slope of the water surface, and a Manning roughness coefficient. Jarrett (1984) proposed that, for high-gradient streams ($S > 0.002$), the Manning roughness coefficient could be predicted from the hydraulic radius and the slope alone. The objective of this study was to develop separate empirical formulae, depending upon climate and stream bank lithology, for predicting the Manning roughness coefficient for high-gradient canals and natural streams from hydraulic radius and slope. The objective was addressed by separating the database used by Jarrett (1984) according to stream bank lithology, and by carrying out new measurements of the Manning roughness coefficient at nine high-gradient stream sites with crystalline (igneous and metamorphic) banks and two high-gradient stream sites with carbonate banks in Haiti, nine high-gradient stream sites with carbonate banks in Utah, and 14 high-gradient canals in Utah. The data were used to develop empirical formulae for predicting the Manning roughness coefficient for (1) continental climate, clastic stream bank (2) tropical climate, crystalline stream bank (3) continental/tropical climate, carbonate stream bank (4) continental climate, earthen canal with grassy bank. The Manning roughness coefficient was a negative function of hydraulic radius for the first case and a positive function for the other cases, suggesting that the increase in turbulent resistance is caused by the roughness of the sediment in the first case, but by the increase in the Reynolds number, which is proportional to the depth, in the other cases.

Application of Multiplicative Random Cascades to Spatially Downscale Observed Terrestrial Water Storage Anomalies

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Abstract. Gravity Recovery and Climate Experiments (GRACE) satellite mission has been observing terrestrial water storage anomalies (TWSA) at a monthly scale since 2002. Given its coarse spatial resolution (*i.e.* ≥160,000 km^2), TWSAs have been used in numerous hydrological studies at a regional scale. However, TWSA spatial footprint limits its use in understanding small-scale spatial variability of terrestrial water storage in connection with hydrologic, atmospheric, ecological and socio-economic processes. Therefore, spatial downscaling of observed TWSA is of great interest to hydrological community. In this study we explored the possibility of using the well-known, random cascade models to perform downscaling of GRACE TWSA. Using 0.5 degree GRACE MASCONS dataset for the southwest United States, we first analyzed the TWSA for spatial self-similarity. Near mono-fractal behavior (*i.e.,* simple scaling) of TWSA was observed in the process of spatially upscaling the GRACE TWSA observations from 0.5 degree to 4 degree. Given this behavior of TWSA, random cascades can be used to spatially model TWSA at scales ranging from 0.5 to 4 degrees. However, assuming that a similar scaling structure is present for scales below 0.5 degree, we used multiplicative random cascades to downscale TWSA from the large-scale (4 degree) to the small-scale (1/16th degree). Downscaling was performed using two variants of random cascade generators *i.e.*, i) uniformly distributed cascade and ii) beta log-normally distributed cascade. For each variant of cascade, 1000 realizations were performed to downscale TWSA. By comparing the best realization (realization for which Euclidean distance between modeled and observed TWSA images is minimum at 0.5 degree) for each variant of cascade, we found that random cascade based on uniform distribution better models the TWSA at small-scales. In this paper we present the method to downscale TWSA based on its scaling behavior and results of the described methodology.

Assessing Near Surface Soil Moisture Variability for Improved Sampling

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Abstract. Moisture in the soil is a critical characteristic for the growth of vegetation, hydrology, and atmospheric fluxes. Its variability can influence the biological and physical processes, and can make measurements for the ground-truth of remote sensing difficult. This remote sensing of near surface soil moisture is often with passive microwave, which is typically a 25 km pixel, so variability can be large. While an active microwave pixel is much finer, it often includes different soil types and even different landscapes. We used Time Domain Reflectometry (TDR) as an in-situ technique to measure soil moisture at a high resolution. This study uses soil moisture data collected at a 1-meter resolution with TDR from three 100-meter long transects near the Colorado State University Mountain Campus during May and June of 2016 and 2017, totaling 30 plot-days. Different methods were applied to subset each transect to compare the spatial and temporal soil moisture variability, in part to determine an optimal sampling strategy. These methods are 1) equal spacing sub-setting, which cuts a transect into equal-length segments and select the data points at the same position in each segment, 2) sequent sub-setting, which continually adds the next data point into selection, starting from one end of a transect, and 3) random sub-setting, which randomly selects data points from a transect. For an acceptable difference threshold from the mean of 5%, spacing sampling requires fewer measurements to obtain a reasonable estimation of the true mean than sequent and random sampling in most situations. Sequent and random sampling can also be efficient when the dispersion of data (measured by correlation of variance and autocorrelation) are low.

Combining Ground Penetrating Radar with Terrestrial LiDAR Scanning to Observe the Spatial Distribution of Liquid Water Content in Seasonal Snowpacks

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Abstract. Snow is an important component of the hydrologic cycle for numerous communities around the globe. An important consideration for water resource planning is snowmelt runoff timing. Runoff timing can be determined by the difficult to observe physical process of water movement through a seasonal snowpack. The aim of this study is to present a novel method that combines light detection and ranging (LiDAR) with ground penetrating radar (GPR) to non-destructively observe the spatial distribution of bulk liquid water content in a seasonal snowpack during spring snowmelt. We develop these methods in a manner to be applicable within a short time window, making it possible to spatially observe rapid changes that occur to this property (sub-daily timescale). We applied these methods at three experimental plots across elevational gradients in Colorado, showing the high variability of liquid water content in snow. Volumetric liquid water contents ranged from near zero to 19% within the scale of meters. We also show the rapid changes in bulk liquid water content that occur over sub-daily time scales. Results of this study show the importance of the lateral flow of water in higher elevation snowpacks and how this process may change in a future climate. The presented methods have a reasonable amount of uncertainty in bulk liquid water content (maximum of 1.5%) making this an applicable method for future studies to observe the complex spatio-temporal dynamics of liquid water in snow.

Development of Managed Aquifer Recharge in China

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Abstract. China has a long history in managed aquifer recharge (MAR), the development divided into 4 stages based on the summary combined with typical MAR projects. The first stage is MAR applied in agricultural production, the second is MAR applied in industrial production and alleviation of agricultural, the third is MAR applied in ecological protection and augment of urban water supply, the fourth is multi-source MAR. In addition, geothermal reinjection and ground source heat pump are also effective use of MAR. Nevertheless, the system of MAR is defective, the water quality study is lacking and the recharge rate of most projects is low etc. It is conclude that China has achieved a great effect on industrial and agricultural production, ecological protection, drinking water supply and urban reclaimed water reuse etc. However, there are still many issues. It is suggested to develop a feasible, convenient and economic technique of MAR fitting to local hydrogeological conditions, establish guidelines of MAR and management regulations together to make sure the MAR projects running successfully. MAR will make a great difference on improving potable water quality, alleviating geological hazards, long distance diversion, urban water supply and agriculture irrigation etc..

River-connected mountain meadows: Exploring patterns of biogeochemical change in headwater wetlands

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Abstract. Mountain headwater sources provide humanity with over 50% of its usable freshwater. Fluvial networks of headwaters with historically glaciated mountain landscapes alternate between confined and unconfined alluvial valley segments. In low-gradient unconfined reaches, river-connected wet meadows commonly establish, and have been recognized as regions of high biodiversity and storage in otherwise transport dominated reaches. Despite these benefits, historic and contemporary land-use practices often result in the simplification of these wetland systems, leading to reduced river-floodplain connectivity, lower water-tables, and reductions in hydrologic buffering against dynamic events. In this study, we are exploring water chemistry dynamics across a gradient of valley confinement (n=5) and river-floodplain connectivity (connected, n=3; disconnected, n=4) within the southern Rockies. Our approach includes hydrologic analysis, water chemistry, fluorometric assays, instream metabolic measurements, and land-cover assessment to examine patterns between land-form, carbon quality and quantity, and ecosystem function (e.g. metabolism). Between different meadow types, preliminary results suggest that connected meadows reduce downstream organic matter flux, export lower proportions of ground water, and sustain higher levels of ecosystem productivity and carbon-nutrient processing as compared to disconnected meadows. Building baseline understanding of how the ecosystem dynamics of these unique ecotones shift as a function of land-cover change will help to inform how the physical form of floodplains influences ecosystem function in the Colorado Rockies.

Rainfall thresholds for post-fire runoff and erosion from plot to watershed scale

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Abstract. Colorado's Front Range watersheds provide municipal water supplies for downstream communities. Many of these watersheds have been affected by wildfire and subsequent runoff, erosion and sedimentation of waterways. Resource managers need information on the frequency and duration of post-fire runoff and erosion, so the objectives of this research were to: (1) identify rainfall thresholds for runoff and erosion within three recent Colorado Front Range wildfires, (2) examine whether thresholds changed with time since burn, spatial extent, and post-fire treatments, and (3) develop a tool for Colorado to estimate the frequency of runoff and erosion events in future fire areas. We identified 60-minute rainfall intensity (MI_{60}) thresholds in the range of 0-17 mm hr^{-1} at untreated plots (<0.06 ha), hillslopes (0.07-5.2 ha) and watersheds (100-1500 ha) during the first two years after fire. When all spatial scales and burned areas were merged, thresholds ranged from 7-8 mm h^{-1}. Thresholds predicted 56-100% of post-fire runoff and erosion events (average 93% accuracy). For hillslopes, rainfall thresholds in the first two years post-fire were similar for the High Park, Hayman, and Bobcat Fires, with MI_{60} rainfall ranging from 7-12 mm h^{-1} and prediction accuracy $\geq$85%. Thresholds increased substantially during the third year post-fire up to 8-22 mm hr^{-1}. Mulch and other post-fire treatment effects were not detected at plots, but hillslope thresholds increased on average 1 mm hr^{-1} with treatment relative to untreated areas. Effects of time since burn on thresholds were detected only in the Bobcat and High Park Fires. Results indicate that spatial scale can change thresholds for runoff, but the direction of change was not consistent from plot to watershed-scale. Many identified rainfall thresholds have less than a 1-year return interval, indicating that post-fire runoff and erosion are likely to occur several times per year during the first two years after fire. Frequency analyses indicate that MI_{60} rain storms of 4 mm h^{-1} occur between 6 - $\geq$10 times per summer in Colorado, and events with intensities between 5-7 mm h^{-1} occur between 2-6 times per summer. Understanding the likely frequency of rainfall events that will cause runoff and erosion after fire will help resource managers plan for post-fire runoff and erosion and prioritize treatments in areas with lower thresholds and higher frequencies of threshold exceedance.

GIS-based Analysis of Specific Degradation of South Korean River Basins

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Abstract. The sediment yield and specific degradation of 70 river basins in South Korea is examined using detailed GIS information. Specific consideration is given to watersheds located upstream (35 stations) and downstream (35 stations) of major reservoirs located in mountain regions. The GIS data available includes topography, DEM, soil type with four soil layers, and land use at a 5-10 m resolution. The analysis focuses on physiographical characteristics and particularly on the watershed hypsometric curves. As a result, the hypsometric curves, the degree of urbanization and the percentage of clay correlate particularly well with the specific degradation. In general, the specific degradation of these watersheds shows different trends depending on their location, topography and soil type. Specific degradation can be as high as 1,000 tons/km^2▪yr in steep mountain watersheds upstream of reservoirs, 100 tons/km^2▪yr in large rivers and can be as low as 10 tons/km^2▪yr downstream of reservoirs.

A review of sediment environment of Nansi Lake from Shandong Province, China

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Abstract. With the development of the industry and agriculture in Nansi Lake catchment southwest of Shandong, China,concentrations of heavy metals and nutrients in lakes increase.The spatial distribution and pollution status of heavy metals and nutrients from sediments in different lake areas were studied. The results showed that Nanyang sublake was polluted seriously by TP, Dushan sublake has the highest TOC and TN content, and Zhaoyang sublake had a relatively low contamination with these pollutants. The enrichment degree of metals decreased in the order of Hg>Cd > As >Pb > Cr >Ni>Cu> Zn. The degree of non-residue state of heavy metal elements in rank of Zn> Cu> Cr> Pb> Ni> As> Hg> Cd, and the residue content of Ni, Cr, Zn exceeds 70% of the total amount of heavy metals. Through the risk assessment of heavy metals in surface sediments, it can be seen that the element Hg is moderately polluted with high bioavailability and great potential harm to the environment.The average content of mercury in the sediments of the Nansi Lake was 0.046 mg·kg-1, significantly higher than the environmental background values. Mercury in sediments existed mainly in the residual fraction, accounting for 65.15%. The proportion of non-residual fractions was relatively small, in the order of organic bound fraction (30.61%), extractable fraction (2.93%), and Fe /Mn oxide (1.31%). From the horizontal view, the mercury content in the surface sediments of Nansi Lake had visible difference and the pollution degree was different among sub-lakes.
Keywords. Nansi Lake;sediments;pollution;environment

A New Way to Calculate the Mean Annual Sediment Yield

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Abstract. We are developing a new methodology for the determination of the mean annual sediment load of watersheds. The new method consists of two parts: a hydraulic part and a sediment part. The hydraulic part is based on a double logarithmic transform of the exceedance probability function of the daily discharge. This is equivalent to a double logarithmic fit to the flow duration curve. The new method works well when a straight line can be fitted to this double log plot at high discharges. The second part is based on the sediment rating curve. The method works well when a power relationship can be defined on the sediment rating curve showing the daily discharge and the daily sediment load. The resulting analysis yields a simple gamma function which can be used to quickly estimate the mean annual sediment yield of a watershed.

We tested the method on 35 watersheds in South Korea and 14 basins in Fountain Creek in Colorado and the results are comparable to the calculations by the flow-duration, sediment-rating curve method. The method provides a new, simpler method to estimate the long term mean annual sediment yield.

Flow dynamics through a suspended cylindrical patch

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Abstract. In this study, large-eddy simulations (LES) were performed to determine the near-field hydrodynamics of uniform flow encountering a suspended canopy patch. The patch is circular in shape (with bulk diameter D) and consists of rigid circular cylinders (height h and diameter d). Four different patch densities ($\phi = N_c d^2/D^2$) and four different patch aspect ratios ($AR = h/D$) are considered by varying the number of cylinders in the patch (N_c) and the height of the patch (h), respectively. Using a volumetric-flux budget through the patch surface, the bleeding dynamics inside and in the vicinity of the patch was found to strong functions of not only ϕ, but also remarkably of AR. The relative longitudinal bleeding normalized by the total flux entering the patch ($\hat{Q}_x = Q_x/Q_{\text{influx}}$) was observed to be inhibited by increasing ϕ but insensitive to the variation of AR; the relative lateral bleeding ($\hat{Q}_y = Q_y/Q_{\text{influx}}$) increases with either increasing ϕ or AR; and the relative vertical bleeding ($\hat{Q}_z = Q_z/Q_{\text{influx}}$) increases with increasing ϕ while decreases with increasing AR. However, for patches with a constant ϕ, an increase in AR enhances the absolute strength of the vertical bleeding (Q_z) at the patch free end.