# ROCKY MOUNTAIN HYDROLOGIC RESEARCH CENTER

## MEETING PROGRAM AND ABSTRACTS

**53RD ANNUAL MEETING**

**AUGUST 28, 1998**

**NCAR MESA LAB**

**BOULDER, COLORADO**

## MEETING SCHEDULE

8:20 Welcome (Flug/Pitlick)
8:30 Rense, W.C., Hydrologic impact of climatic change in the Colorado Front Range: Global warming and Little Ice Age scenarios
9:00 Clark, M., Sensitivity of United States snowfall to changes in the phase and amplitude of the PNA wave train
9:20 Woodhouse, C.A., Preliminary tree-ring reconstructions of streamflow for the N. Platte, S. Platte and Arkansas Rivers
9:40 Wright, K.R. and Schaper, L.F., Mummy Lake: A Mesa Verde paleohydrologic enigma
10:00 Doesken, N., The Fort Collins flood of July 28, 1997 in comparison with other extreme rainstorms in the Front Range

**10:20-10:40 (Break)**

10:40 Waters, S., Phytoplankton populations at high elevations
11:00 McCutchan, J.H., Lewis, W.M., and Saunders, J.F., Accuracy and precision of open-channel estimates of stream metabolism
11:20 Kaushal, S., McCutchan, J.H., and Lewis, W.M., Natural abundance of Nitrogen isotopes in algae as an indicator of Nitrate pollution to Colorado rivers
11:40 Tyus, H.M., Determining streamflow requirements of endangered fishes: Another lesson in the "Arrogance of Humanism"

**12:00-1:30 (Lunch)**

1:40 Niyogi, D.K., McKnight, D.M., Lewis, W.M., and Kimball, B.A., Collection and remediation of acid mine drainage and the effects on a headwater stream
2:00 Hamann, H.A., Snowcover Control on Alpine Soil Surface Temperatures and Basal Ice, Niwot Ridge, Colorado
2:20 Milhous, R.T., On the median size of armour in a gravel-bed river
2:40 Morehead, M.A. and Syvitski, J.A., The ABCs of a River's Sediment Load: Predicting the Rating Coefficients

**3:00-3:20 (Break)**

3:20 Martin, D.A., J.A. Moody and M. Richards, Hillslope response of a burned watershed
3:40 Moody, J.A. and Martin, D.A., Sediment transport in a discontinuous stream channel after a forest fire
4:00 Trustees Meeting

ABSTRACT

**Hydrologic Impact of Climatic Change in the Colorado Front Range: Global Warming and Little Ice Age Scenarios.**

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The Thornthwaite Water Budget technique has been proven as effective in calculating streamflow if basic climatic data is available. Data have been collected in the Colorado Front Range by the Institute of Arctic and Alpine Research in each of the four major ecosystems-- the Lower Montane, Upper Montane, Subalpine and Alpine zones. Using these data it is possible to calculate a water budget for each elevation zone in the Front Range and thus estimate streamflow with considerable accuracy, within 5% of the gauged flow on Boulder Creek, for example. This paper uses the Thornthwaite method and the INSTAAR data to calculate runoff in the Front Range under a variety of climatic scenarios. The data furthermore allow runoff and contribution to streamflow to be calculated for each of the altitudinal ecological zones. For this paper, runoff was calculated for the modern climate, then estimated for a "global warming" scenario assuming a 2°C. increase in mean monthly temperature and three conditions of precipitation-- no change from moden values, a 10% increase above modern values and a 10% decrease below modern values. A "Little Ice Age" hydrologic condition was then estimated assuming a decrease in temperature of 1.5°C. with the same three assumptions concerning precipitation. The findings indicate that streamflow would decrease under a global warming scenario to values of 86.5% of the modern flow with no change in precipitation, and 67.5% with a 10% decrease in precipitation. However, global warming plus a 10% increase in precipitation would elevate stream discharge in the Front Range to 105.6% of the modern value. During the Little Ice Age, significant increase in streamflow is indicated except for the condition of decreased precipitation.

# Sensitivity of United States Snowfall to Changes in the Phase and Amplitude of the PNA Wave Train

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## Abstract

Through composite analyses, daily data from a network of cooperative climate stations distributed throughout the United States are used to provide a general description of the large-scale atmospheric controls on snowfall over the country. Composites of snowfall, precipitation and maximum temperature are constructred for cases when the ridge axis of the Pacific-North American wave train is located in each of the 10 deg longitude bins between 160 deg W and 100 deg W, with high amplitude and low amplitude situations examined separatly.

In the high amplitude composites, situations when the wave train is located just west of its preferred position are characterized by increases in precipitation and decreases in temperature throughout the country, with corresponding increases in snowfall. as the wave train is shifted a few degrees east (nearer to its preferred position) the precipitation signals are slightly negative, but positive increases in snowfall still prevail over the eastern United States where temperatures are below normal. In cases when the wave train is located east of its preferred position the above normal air temperatures and below normal precipitation is manifested in negative snowfall signals throughout the country.

Turning to the low amplitude composites, the tighter height gradients over the western two-thirds of the country (implying a southward shift in baroclinicity) are associated with positive precipitation anomalies through large areas of the country in every longitude bin. Positive snowfall signals are evident in the western United states in the three western longitude bin where air temperatures are near average or below normal. Consistent with the precipitation signals, no significant decreases in snowfall are apparent in any longitude bins.

This study draws attention to two important points. First, the most remarkable snowfall and precipitation signals are evident under atmospheric situations that occur less frequently. Since, particularly in arid regions, the seasonal snowpack may be shaped by only a few extreme events, understanding the mechanisms that force such situations will be important for seasonal water supply forecasts. The second point is the contrasting significance of temperature on snowfall between the western and eastern United States, implying there may be relatively lesser impacts on snowfall and surface hydrology in the western United States when compared to the eastern part of the country.

ABSTRACT

Preliminary tree-ring reconstructions of streamflow for the N. Platte. S. Platte, and Arkansas River

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Water supply issues are becoming increasingly critical in the arid to semi-arid western United States. In Colorado, population increases and changing water needs along the Front Range urban corridor are placing greater demands on limited water resources. These changes, in concert with the natural climate variability and potential anthropogenically-induced climate changes, make water resource management tasks challenging and difficult. An important source of water in the Front Range is the precipitation that falls in the headwaters of the South Platte and Arkansas Rivers. Year-to-year variations in the mountain water supply are measured by streamflow, but streamflow records in this region are commonly less than 100 years in length. This limited period of time does not well reflect decadal- to century-scale variations in climate, and represents only a small subset of the extreme events possible.

Proxy data offer a way to extend records of climate and hydrologic variability. Although no reconstructions of hydrologic variability have been generated for the Front Range region to date, a large number of moisture sensitive tree-ring chronologies exist that are suitable for dendrochronological reconstructions. In this study, I have generated three preliminary reconstructions for streamflow on the Laramie R. (N. Platte R. Basin), on Middle Boulder Ck. (S. Platte R. Basin), and on Grape Ck. (Arkansas R. basin), extending records back to 1726. Reconstructions explain 47-58% of the variance in the observed records and have been validated with independent data.

The instrumental records indicate that flow at these three sites varies along a north/south gradient, which may be due to the spatially variable influence of atmospheric circulation patterns such as those generated from the El Niño/Southern Oscillation (ENSO) or the Pacific Decadal Oscillation (PDO). A comparison of the temporal patterns of flow over the past 300 years from these sites shows changes in coherence between sites that may be related to the behavior of these circulation patterns. Streamflow reconstructions for this region also indicate that periods of extreme low flow in the 20th century have been exceeded by low flow events in the past 300 years.

# MUMMY LAKE: A MESA VERDE PALEOHYDROLOGIC ENIGMA

**By: Kenneth R. Wright and Lynnette F. Schaper**

## ABSTRACT

Mummy Lake is an important archaeological ruin on Chapin Mesa of Mesa Verde National Park. Opinions of respected and seasoned scientists differ on the original function of Mummy Lake which has created a Park Service enigma. The opinions of the function vary from it being an ancient dance pavilion or religious site to it being a reservoir for irrigation and domestic water supply.

The 30-meter-diameter structure is adjacent to Coyote Village and the Farview ruins. Mummy Lake is on a narrow ridge of Chapin Mesa where collection ditches could control an upstream drainage basin of about 10 hectares. A seasonal perched water table may have contributed groundwater to Mummy Lake.

A comprehensive scientific research effort has been undertaken in 1998 for completion in 1999 which is aimed at defining the ancient site hydrology including the likelihood of a seasonal perched water table and whether or not ancient "ditches" are actually modern cattle and horse trails. Study of the documents available from earlier investigations dating back 100 years or more will supplement new field evidence and findings.

Described is a summary of findings by previous investigators coupled with initial field data by the authors and a tabulation of research objectives.

# The Fort Collins Flood of July 28, 1997 in Comparison With Other Extreme Rainstorms Along the Colorado Front Range

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## ABSTRACT

The heaviest rainfall ever documented over an urbanized area in Colorado fell over portions of the City of Fort Collins on July 28, 1997. The resulting flash flooding claimed five lives and caused more than $150 million in damage. At the center of the storm, more than ten inches of rain fell in less than five hours after four inches had already fallen during the previous 24 hours. This paper provides a detailed description of rainfall patterns and timing from the Fort Collins storm. Comparisons will then be made with other extreme rainfall events along the Colorado Front Range such as the 1976 Big Thompson flood. In particular, the important role that Front Range topography plays in storm development and maintenance will be discussed. The relationship between elevation and extreme rainfall potential will also be assessed.

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# Abstract

*Phytoplankton Populations at High Elevations*

The Green Lakes Valley is a high altitude catchment located below Niwot Ridge at 3500 meters above sea level in the Rocky Mountains. The catchment and surrounding watershed are responsible for 40% of the water supplied to the city of Boulder. Concern over water quality in response to anthropogenic influence has been a focus of ongoing research in the watershed area. The purpose of this research is to determine the health of the freshwater ecosystems located within the Green Lakes Valley, using biological organisms as indicators. As primary producers phytoplankton are sensitive to small changes in abiotic conditions. Phytoplankton productivity influences nutrient cycling, dissolved oxygen, trophic composition, and freshwater ecosystem stability. Phytoplankton have varying tolerances for temperature, light, acidity, and nutrient availability depending on the species. Thus, changes in climate, pH, and nutrient influx can be inferred by observing changes in phytoplankton species distribution. Furthermore, hydrologic conditions influence seasonal patterns of maximum population density. As part of the Niwot Ridge LTER program phytoplankton abundance and species composition in the Green Lakes Valley are currently being studied. Water samples from the Green Lakes Valley were collected once per month under winter ice cover, and once per week during the summer season. Samples were analyzed for total chlorophyll *a* as a representation of phytoplankton abundance, and species composition was observed using inverted microscopy. Samples were taken at multiple depths in order to determine response to solar irradiation. Results provide a foundation for understanding changes in the health and stability of freshwater ecosystems, and subsequent effects on water quality.

# Accuracy and Precision of Open-Channel Estimates of Stream Metabolism

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The open-channel oxygen method for estimating photosynthesis (P) and respiration (R) in streams avoids many of the problems associated with chamber techniques and its use has become widespread since the advent of recording field oxygen meters. Bias, resulting from assumptions implicit in previous applications of the open-channel method, and the overall precision of the method, however, have not been rigorously quantified.

Standard calculations of metabolism by the open-channel method assume that effects of groundwater on oxygen concentration are negligible. In streams with significant net accrual of groundwater, this assumption may not be correct. A model that includes accrual rate, concentration of oxygen in groundwater, respiration rate, temperature (T), and reaeration rate coefficient ($k_{20°}$) shows that the estimation of P is not significantly affected by accrual, but that rates of R will be greatly overestimated where accrual rate is high (> 20% /d) and the concentration of oxygen is substantially lower in groundwater than in the channel. Accurate open-channel estimates of R are possible in streams with high accrual rates and low concentrations of oxygen in groundwater if accrual is measured, the concentration of oxygen in groundwater is known, and the mass-balance equation for oxygen is modified to account for accrual.

Uncertainty in open-channel estimates of P and R can be quantified by use of a Monte Carlo approach incorporating uncertainty in each of the terms affecting error in estimates of P and R. The distributions derived from the Monte Carlo simulations provide confidence limits for estimates of P and R. Use of this approach along with simulation of a range of stream conditions indicates that: 1) given equivalent metabolic rates and physical conditions, estimates of R are subject to greater uncertainty than are estimates of P, especially in high-gradient streams, and 2) uncertainty can be minimized by special attention to the precision of measurement for factors affecting the saturation concentration of oxygen. Reasonable precision (95% CL within 30% of mean) can be achieved for estimates of P in most streams, but in turbulent streams ($k_{20°}$ = 100 /d), rates of R must be nearly 15 $mgL^{-1}d^{-1}$ to achieve similar confidence limits.

The computational methods described here improve the accuracy of open-channel estimates of metabolism and provide information on the suitability of the open-channel method to a particular location.

# Natural Abundance of Nitrogen Isotopes in Algae as an Indicator of Nitrate Pollution to Colorado Rivers

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The purpose of this project was to identify major sources of nitrate to the St. Vrain River and rivers entering Lake Dillon, CO. Nitrate levels are abnormally high in these rivers wherever septic systems or sewage outfalls are present. Nitrate concentrations in drinking water are regulated for protection of human health, and nitrate has the potential to stimulate excessive levels of algal productivity in high elevation lakes leading to diminished water quality and the impairment of aquatic life.

Nitrogen isotope ratios of algae, often expressed in $\partial$ notation (which is the parts per mil difference in the ratio of the sample compared to a standard ratio designated as 0), were used to identify major sources of nitrate to the Snake River, Blue River, and St. Vrain River. Nitrate from sewage and precipitation has different $\partial^{15}N$ values which allows the delineation of these two sources. Nitrate from atmospheric deposition usually has a $\partial^{15}N$ value close to 0 and nitrate derived from animal waste has much higher $\partial^{15}N$ values (+10‰ and +20‰). The $\partial^{15}N$ of algae closely reflects the isotopic signature of nitrate in streamwater because plants can take up nitrate directly. Consequently, the $\partial^{15}N$ of algae can be indicative of uptake of nitrate derived primarily from animal waste or precipitation.

We found that algae collected from unpolluted streams with nitrate concentrations ranging from 25 µg/L to 125 µg/L had $\partial^{15}N$ values that were significantly lower than those of polluted streams with much higher nitrate concentrations (up to 24,000 µg/L). Algae from unpolluted streams draining into the Snake River and St. Vrain River had $\partial^{15}N$ values close to 0‰, whereas algae from polluted sites farther downstream generally had higher values (at or above +10‰). The $\partial^{15}N$ values of algae in the St. Vrain River increased as elevation decreased and population in the watershed increased, indicating enhanced contributions to nitrate loading from anthropogenic sources farther downstream.

# Determining Stream Flow Requirements of Endangered Fishes: Another Lesson in the "Arrogance of Humanism"?

By

Harold M. Tyus
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Abstract.–Anthropogenic effects of the last century have resulted in worldwide decline in freshwater fishes. In North America, 25% of freshwater fishes have suffered major reductions in distribution and abundance and over 100 species are now protected by the Endangered Species Act. Endangerment of native fishes has reached an alarming proportion in the American Southwest, and especially in the Colorado River system where drastic and widespread habitat changes have affected the entire fauna. Four fishes, once abundant in mainstream rivers, are now endangered and the entire big river fish community is considered at risk. There, as elsewhere, efforts to recover fishes to a less-endangered status have been primarily directed at restoring instream flows. However, although physical habitat change has a primary factor, change in the biological component of habitat also has played a major role in the decline of these fishes. As a result, efforts to determine instream flow requirements using only physical habitat use is problematic, ignoring the premise that an endangered fish would not be occupying optimal, or perhaps even acceptable habitats. Finally, the native Colorado River fishes are exceedingly complex organisms that have developed complicated life history strategies. It is argued that past approaches used to determining stream flow needs have been overly simplistic due, in part, to the "arrogance of humanism." Future recovery efforts for endangered fishes should be based on sound ecological principles that consider not only requirements for all life history stages of a fish species, but also maintenance of its community.

**Collection and Remediation of Acid Mine Drainage and the Effects on a Headwater Stream**

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St. Kevin Gulch, a headwater stream located near Leadville, Colorado, receives acid mine drainage from an abandoned mine in the watershed. In 1994, we set up a collection system for the acid mine drainage, and diverted this water 100 meters downstream. We present here data on the efficacy of the collection system, the recovery of the 100 meter "experimental reach," and problems with passive treatment of mine drainage.

We used a natural tracer approach to estimate flows of mine drainage entering St. Kevin Gulch through our collection system and through groundwater (uncollected) seepage. Zinc and manganese proved to be the best cations to use in this approach, as they behave conservatively in the low pH streamwater. By use of this approach, we estimate that the collection system captured about 85% of the mine drainage during late summer base flow.

Water quality improved in the "experimental reach," the section of stream around which the mine drainage was diverted. In 1994, the pH increased from 3.7 before the diversion to 4.5 afterwards, and concentrations of dissolved zinc decreased from 10 mg/L to 5 mg/L. A filamentous green alga, *Ulothrix* sp., quickly colonized this area and reached high biomass. In 1995 and 1996, water quality in the experimental reach improved still further, but little algal biomass accumulated during the summer. A change in substrate quality during this period may have affected stream algae.

The collection system at St. Kevin Gulch may one day become part of a treatment system. Acid mine drainage can present several hindrances to the goal of designing a passive treatment system in remote watersheds such as St. Kevin Gulch. Small-scale experiments in treating the mine drainage at St. Kevin Gulch highlight these difficulties.

# Snowcover Control on Alpine Soil Surface Temperatures and Basal Ice, Niwot Ridge, Colorado

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## ABSTRACT

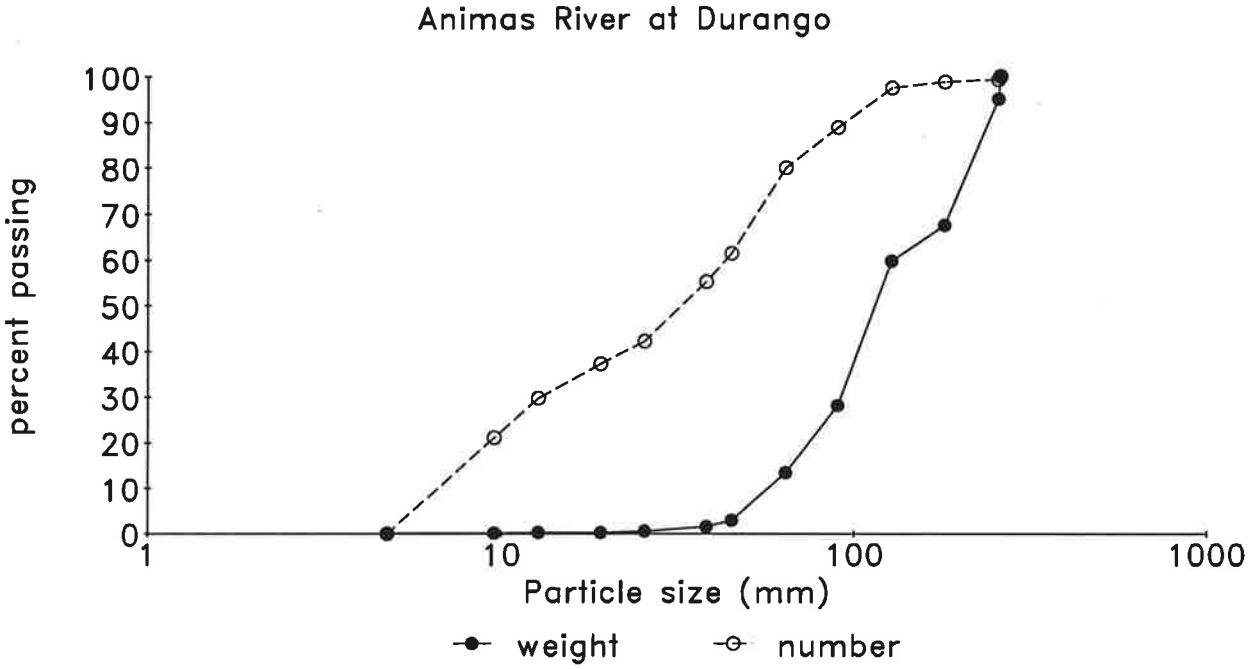
Seasonally frozen soils play an important role in many hydrologic, biologic, and hydrochemical processes. In the alpine, heterogeneous vegetation, topography and snow conditions during the winter should affect spatial and temporal variations in soil temperatures. In 1996-97 a network of soil temperature recorders were installed at 3500 m on Niwot Ridge to evaluate variations in surface soil temperatures and the primary controls on spatial and temporal variability of ground surface conditions. The study utilized a constructed snowfence on the Ridge as well as naturally occurring shallow, moderate and deep snow deposition sites. Snow depth was monitored throughout the winter season, and a reconnaissance of ground surface conditions was carried out prior-to and after snowmelt to look for basal ice at the snow-soil interface. Available data was utilized to examine soil moisture, vegetation and snow cover as primary controls on temperatures and temperature variations in the soil. Results indicate that although interactions occur between vegetation, soil moisture and soil temperatures, snow cover maximum depth and timing information can be used as a simple and effective predictor of general soil surface temperatures and variations. Maximum snow accumulations at the study site ranged from 10 cm to 560 cm and occurred in late April, 1997. Results from the 1996-97 snow year show that as seasonal snow cover depth and duration increase, short term temperatures variations are delayed and dampened. Sites with early snow accumulation less than 30 cm showed the greatest and fastest response to synoptic temperature changes. At sites where the early season snowpack ranged from 30 to 90 cm, response to general synoptic temperature trends was evident, though temperatures and range were dampened by up to 10 degrees C. The depth and timing of the snow cover also influenced minimum temperatures, the timing of minimum temperatures and the duration of an isothermal period at the end of the snow season. Snow cover and soil temperatures also appeared to affect the occurrence of basal ice and snowmelt flowpaths. Results of the basal ice survey point to antecedent soil moisture in the fall and spring meltwater supply as primary conditions necessary for basal ice formation on Niwot Ridge.

# ON THE MEDIAN SIZE OF ARMOUR IN A GRAVEL-BED RIVER

**Robert T. Milhous**[1]

## ABSTRACT

At least two general procedures are used to determine the grain size distribution of the armour (surface-layer) of a gravel-bed river. These are 1) the Wolman procedure with size analysis by number; and the 2) geotechnical procedure with removal of a sample of the armour and size analysis by weight. There a number of variations of each procedure. The two procedures can result in significant differences in the median size. For the Animas River at Durango the median size determined using the Wolman procedure is 32 mm while the geotechnical procedure gives 115 mm. This difference is significant and important. The grain size distribution determined from each procedure is given in the diagram below.




The correct distribution to use in any riverine analysis depends on the type of analysis being made and the source of the empiricisms used in the analysis. For instance, size distributions for Oak Creek (Western Oregon) were determined using the geotechnical procedure. Oak Creek results have been compared to results from other streams where the Wolman procedure was used. Not a good idea.

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# THE ABCS OF A RIVER'S SEDIMENT LOAD: PREDICTING THE RATING COEFFICIENTS

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## ABSTRACT

A continual problem for mankind is the prediction of sediment loads for rivers being used or altered for our purposes. The lack of long term data for most of the world's rivers makes the prediction of sediment load a difficult problem. Discharge measurements have been made on many rivers but are typically of short duration. Even fewer measurements of sediment load exist for most of the rivers, particularly in third world countries.

Using a large data set of the world's rivers we have studied the relationships among the various river basin parameters (drainage area, relief, sediment load and yield, mean discharge) and the sediment rating coefficients (a and b in the rating equation Cs = aQ^b, where Cs is the sediment concentration and Q is the discharge). Through the use of these relationships we have developed a method to predict the sediment rating coefficients for most rivers. The rating coefficient "a" (the theoretical sediment concentration in a river at a discharge of Q = 1 m^3/s) is directly related to the mean discharge of a river. The mean discharge can be obtained from direct measurements or through modeling with precipitation data and basic basin relief information. A very strong negative correlation exists between the rating coefficient "a" and the rating exponent "b" over a large range of time scales and rivers. Through the use of these relationships and the basin area and relief we are able to predict to a reasonable level the rating coefficients.

## *Hillslope Response of a Burned Watershed*

### *(Abstract of a talk to be presented at the Rocky Mountain Hydrologic Center Meeting, August 28, 1998)*

Deborah A. Martin, John A. Moody and Mark Richards, U.S. Geological Survey

In 1996 the Buffalo Creek Fire burned approximately 4820 hectares of national forest land. Most of the burned area is on the Pikes Peak Batholith and over 50% is on slopes having greater than 30-degrees. A major consequence of the fire has been increased sedimentation into Strontia Springs Reservoir which supplies over 80% of Denver's water. From July through September, 1997, we monitored the production of sediment from two hillslopes located in a severely burned area of the fire using eight hillslope traps. A hillslope trap is a 4"-diameter PVC pipe which has a 1 meter long by 0.1 meter wide slot. The slot is interfaced to the hillslope using aluminum flashing and the contributing area of hillslope is delineated by edging. The trap is connected to a series of buckets by tubing. In addition to sediment, the buckets collect overland flow which we term runoff. Particle size separations, including the silt and clay fractions, were performed on all the sediment collected from the hillslope traps.

The hillslope response of the south-facing and north-facing slopes has been different. The particle size distribution of surface soil on the south-facing slope is coarser than that of the north-facing slope. The coarser material occurs as a pebble armor covering the south-facing slope. Runoff is significantly greater ($p=0.06$) from north-facing slopes than from south-facing slopes. From the rainfall record we identified a maximum 30-minute rainfall intensity during each collection period, $I_{30}$. For an $I_{30}$ of about 5 mm/hr, runoff from the hillslope traps was about the same for the north- and south-facing slopes, averaging about 0.1 mm. At an $I_{30}$ of about 20 mm/hr, the runoff

from the north-facing slope averaged four times that of the south-facing slope (1.2 mm versus 0.3 mm). We have two hypotheses to explain the runoff observations: 1) the antecedent moisture of the soil on the north-facing slope is greater than the south-facing slope which means that the soil is more quickly saturated during a rainstorm event, 2) north-facing soils have greater amounts of fine-grained material and organic matter and thus the infiltration rate is more quickly exceeded, leading to infiltration excess overland flow. The runoff characteristics of the hillslope affect the production of sediment and its particle size distribution. For a given $I_{30}$ below 20 mm/hr, the average production of sediment from both north- and south-facing slopes was about the same. At $I_{30}$ values greater than 20 mm/hr, average sediment production was always greater from the north-facing slope than from the south-facing slope. A high intensity storm having an $I_{30}$ of 90 mm/hr resulted in at least 800 g/m$^2$ of sediment production from the north-facing slope versus 100 g/m$^2$ from the south-facing slope. The $D_{50}$ of the sediment collected from hillslope traps on the south-facing slope is significantly ($p=0.006$) coarser (2.4 mm) than the sediment from the north-facing slope (1.0 mm), partly due to the coarser surface material available for transport. We are in the process of examining the factors that promote infiltration and overland flow on the study slopes. Understanding the factors that lead to erosion on burned slopes will allow more careful allocation of resources for rehabilitation and restoration and better management of water supplies.

# *Sediment Transport in a Discontinuous Stream Channel after a Forest Fire*

John A. Moody and Deborah A. Martin, U. S. Geological Survey

Mostly coarse sand and gravel were deposited in the channel of Spring Creek, Colorado, by a flood in July 1996 following the May 1996 Buffalo Creek forest fire creating an aggraded, seasonally discontinuous stream channel. Sediment transport in Spring Creek, during the two years since the fire, has varied in time and space along a 1500-m study reach (beginning at the mouth and consisting of 150, 10-m subreaches bounded by two cross sections). Spring Creek has an average stream gradient of 0.04 m/m. Bedload measurements in Spring Creek have ranged between 0.0003 and 1.0 kg/s/m corresponding to water discharges of 0.0036 to 0.16 $m^3/s$, and the $D_{50}$ ranged between 2.9 and 5.7 mm. Sediment transport is related to the type of runoff and bed conditions. Runoff was from cyclonic storms, convective storms, snowpack, or baseflow. Bed conditions depend on the degree of "cohesiveness" and armouring.

In the spring of 1997, rainfall associated with cyclonic storms caused erosion in several subreaches and subsequent deposition downstream that created a series of channel fans with braided morphology alternating with incised channels armoured by material ~20-60 mm in size. The resulting pattern was a wavelike form of erosion and deposition with the maximum net erosion and deposition rates of 1.3 $m^3$/day per meter of channel. Convective storms in July and August 1997 created both small and large flash floods that resulted in both erosion and deposition within each cross section. Small flash floods caused equivalent amounts of erosion and deposition (maximums of 2.6--5.5 $m^3$/day/m) at every cross section, whereas a large flash flood (31 August 1997) caused much more deposition (maximum of 161 $m^3$/day/m) than erosion (maximum of 55 $m^3$/day/m) at every cross section. Consequently, the channel aggraded 1-2 m during the summer of 1997. After the large flash flood of 31 August, baseflow on top of the elevated surface of the bed eroded essentially every cross section (maximum erosion of 3.1 $m^3$/day/m) and deposited sediment at only a few cross sections (maximum deposition of 0.5 $m^3$/day/m). The snowpack during the winter of 1997-98 was much greater than during the winter of 1996-97 and consequently yielded more runoff from south-facing slopes during the winter months. Frozen-bed conditions created essentially a cohesive bed and the winter runoff resulted in erosion that was predominantly vertically downward, with little lateral migration, creating a narrow channel in the upper half and random levees of mixed layers of gravel and ice in the lower half of the study reach. As the bed thawed in the spring, the snowmelt runoff in 1998 caused rapid lateral erosion. Sediment was deposited in the lower half of the study reach to form a braided channel that filled the valley. Maximum erosion rate in the upper half (averaged over the 211 day period from 2 October 1997 to 1 May 1998) was 1.0 $m^3$/day/m and the maximum deposition rate in the lower half was about 0.7 $m^3$/day/m. As the channel in the upper half eroded it became armoured with boulders and rocks which were apparently transported by the 31 August 1997 flash flood. The channel is still (summer 1998) about 0.5 m above the channel that existed in June 1997. We initially expected runoff to flush out the sediment stored in the channel network thereby degrading the channels, but in fact the study reach so far has experienced aggradation.