4.3) 1999 Annual Sequoia Watershed Report

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INTRODUCTION

The Sequoia and Kings Canyon (SEKI) watershed program is a long-term cooperative study of anthropogenic effects on Sierran ecosystems. The SEKI program was designed to collect a set of core baseline measurements on surface water chemistry, vegetation dynamics, precipitation inputs, meteorology, and soil mapping. Initially, the SEKI program focused exclusively on sites along an elevational gradient in the Middle Fork drainage of the Kaweah River. In 1990, the Tharp's watershed was burned as a pilot study to determine the effects of fire on biogeochemical and hydrologic processes in a mixed-conifer forest. Coinciding with the start of the Mineral King Risk Reduction Project in 1995, the SEKI watershed program expanded its efforts to determine the effects of fire on stream chemistry and hydrology. Two first order watershed sites were established in the East Fork drainage and sampling was initiated in the East Fork at Lookout Point.

The present goal of the watershed program is to build upon our long-term research base to understand the interacting effects of fire and fire exclusion, air pollution and climatic change on key ecosystem elements and processes in Sierran watersheds. In recent years the program has been plagued by budget cuts, so much of this year was spent writing proposals to augment current funding.

This report presents results from ongoing work conducted in both the Middle Fork and East Fork. Results from the analysis of post-fire hydrologic and forest structure changes observed Tharp's Creek following the 1990 burn are presented. Comparisons in runoff are made between a manipulated and control catchment for a sixteen year period (pre-burn n=7, post-burn n=9). Annual precipitation totals and the influence of antecedent moisture conditions on stream discharge are discussed. Reference forest stand data are also presented to document changes in post-fire forest structure and are related to observed changes in post-fire hydrologic responses. The discussion of Mineral King includes the results of the 1999 large woody debris survey, annual runoff coefficients for the study catchments, and annual volume-weighted mean (VWM) solute concentrations. Previous reports and publications (Williams and Melack 1997a, Williams and Melack 1997b, Chorover et al. 1994) summarize the effects of fire on biogeochemistry in the Tharp's catchment following the 1990 prescribed fire and the seasonal variation in pre-burn stream chemistry in the East Fork study sites (Moore 1999).

STUDY SITES

Watershed research is conducted in Middle Fork Kaweah and the East Fork Kaweah, large adjacent drainages (**fig. 4.3-1**). Vegetation in both drainage areas is diverse, ranging from chaparral and hardwood forests at the lower elevations to mixed-conifer and giant sequoia forests at mid elevations. Alpine vegetation is found above 3,100 m.

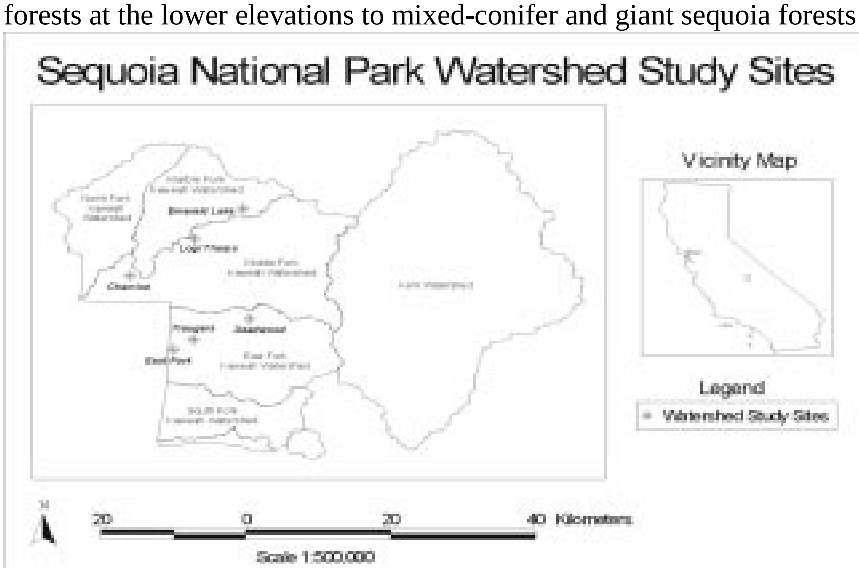

Figure 4.3-1 Location of watershed sampling sites in Sequoia National Park.

Middle Fork

The Middle Fork study sites were part of a larger program established in 1982 to study atmospheric deposition along an elevational gradient in the Middle Fork Kaweah River drainage in Sequoia National

Park. Selected areas were located in low elevation chaparral and mid elevation mixed-conifer forest communities.

Log Meadow is dominated by white fir (*Abies concolor*) and giant sequoia (*Sequoiadendron giganteum*). Precipitation averages 100 cm annually, with half falling as snow during the winter months. **Tharp's Creek** (13.1 ha) has a southeast aspect and ranges in elevation from 2067 – 2397 m. **Log Creek** (49.8 ha) has a northwest aspect and ranges in elevation from 2067 – 2255 m. These creeks are sampled as paired first- and second-order watersheds.

East Fork

The East Fork is sampled at Lookout Point (4,200 m) as a representative of downstream accumulation from a large-scale watershed. In addition two first order watersheds are sampled as representatives of the different vegetation types found in the East Fork drainage.

Trauger's Creek (106 ha) is in a transition zone between the lower mixed-conifer zone and the upper chaparral-hardwood zone. The dominant species is canyon live oak (*Quercus chrysolepis*). Average annual precipitation based on available records is 92 cm. Elevation ranges from 1390 m to 1970 m and aspect is south facing.

Deadwood Creek (100 ha) is characterized by white fir (*Abies concolor*), red fir (*Abies magnifica*), giant sequoia (*Sequoiadendron giganteum*), and incense cedar (*Calocedrus decurrens*). Annual average precipitation based on available records is 136 cm. Elevation ranges from 1985 m to 2660 m and aspect is south facing.

METHODS

The watershed approach requires that many key aspects of the hydrological and biogeochemical cycles be measured and sampled to get a full understanding of the variability in watershed processes. The Sequoia watershed program has used a holistic approach by establishing co-occurring sites to measure meteorology, stream discharge, and hydrochemistry.

Meteorology

Meteorological data were collected at established sites in the Middle Fork and East Fork watersheds. These stations were co-located with primary study sites, providing more accurate climatic data for the individual study sites, and whole watersheds, than could be obtained by a single station within a watershed. Meteorological stations were managed by several federal agencies including: USGS/BRD, NPS, NOAA, and the U.S. Army Corps of Engineers. Most stations measured precipitation, temperature, relative humidity, wind speed and direction, and solar radiation.

Precipitation Chemistry

Precipitation depth and chemistry samples were collected weekly in accordance with National Atmospheric Deposition Program (NADP) protocols in Aerochem Metrics Model 201 samplers located at Lower Kaweah in the Giant Forest area and at Ash Mountain (Dossett and Bowersox 1999). Belfort rain gauges were located at each site. Samples were shipped to California Air Resources Board (CARB) and NADP labs for chemical analysis. Deposition chemistry was used to determine mass balances for solutes entering Sierran catchments -- information needed for understanding fire, air pollution, and climatic change.

Hydrology

The study catchments were equipped with Stevens type A/F records and Omni Data loggers and/or chart recorders to record hourly discharge. The Middle Fork sites were fitted with weirs that provided direct stage-discharge relationships, which were established by USGS/WRD. Discharge data for the East Fork was obtained from Southern California Edison Power Company, which maintains several gauging stations in the Southern Sierra. Stage-discharge relationships were developed for Trauger's and Deadwood Creeks using dilution methods developed by Kilpatrick and Cobb (1985).

Hydrochemistry

Stream samples were collected weekly throughout the year. Additional samples were collected during periods of high flow (storm events and snowmelt runoff). This sampling frequency allowed us to look at both inter- and intra-annual variation. Samples were collected and processed according to protocols outlined by Dr. Stottlemeyer (1987). Samples were filtered at the Ash Mountain Water Lab (AMWL) and shipped to the Biogeochemistry Laboratory at the Rocky Mountain Station Experiment Station in Fort Collins, Colorado, for analysis of base cations, ammonium, nitrate, sulfate and phosphorus. Alkalinity, pH and conductivity were measured at the AMWL.

Stream Morphology

A large woody debris (LWD) survey was conducted following protocols outlined by Robinson and Beschta (1990). These measurements were compared with LWD measurements made by Chan in 1996 to determine the effects of the January 1997 flood. We thought that this event would decrease the total volume of woody debris in the creeks. The 1999 woody debris survey also included photo points and stream mapping for post-burn follow-up.

RESULTS and DISCUSSION

Tharp's Creek Post-Burn Runoff Analysis

Pre- and post-burn stream discharge was analyzed for data collected between 1983 and 1999 in Tharp's Creek and Log Creek, and runoff coefficients were calculated for each catchment. Runoff was expressed as (1) a coefficient of annual precipitation using the equation:

$$RC = \frac{[Q\ (m^3) \div a\ (m^2)] \times 1000\ (mm)}{ppt\ (mm)}$$

where RC = runoff coefficient, Q = total annual discharge, a = area of catchment, and ppt = total annual precipitation. Total annual values were given by water year (10/1 – 9/30); and (2) as the runoff ratio of Tharp's:Log. During the analysis, the importance of antecedent precipitation patterns became apparent in explaining runoff totals for any given year. Thus, a discussion of pre- and post-burn runoff responses during wet and dry years is also presented.

Runoff Patterns

Average runoff coefficients increased 325% and 139% in post-burn dry and wet years, respectively, in Tharp's catchment (**fig. 4.3-2**). In Log catchment, average runoff coefficient decreased by 20% in the post-burn wet years. The decrease is a likely response to the seven-year drought. In the post-burn years, annual runoff in Tharp's Cr. has increased steadily. In 1998 the runoff ratio exceeded 1.0, and was 1.32 in 1999, the fourth driest year of the study period. By comparison, in 1985 – a drought year, preceded by a four year wet period, the runoff ratio was 0.43. This increased runoff has led to a major shift in the post-fire runoff relationship between the two catchments (**fig. 4.3-3**).

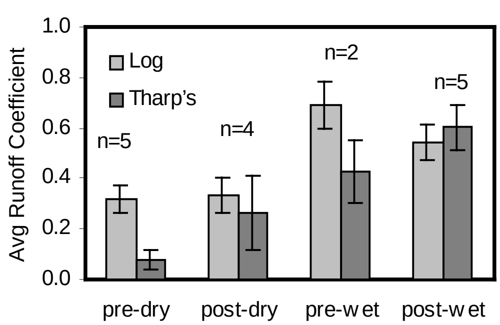

Figure 4.3-2. Average runoff coefficients before and after fire in Tharp's and Log Creeks.

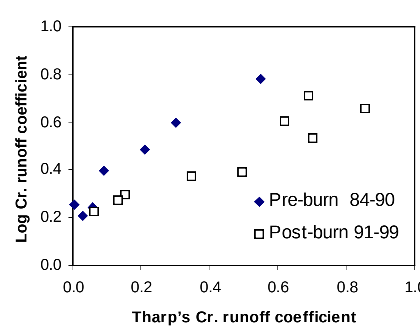

Figure 4.3-3. Increases in Tharp's Cr. runoff following the 1990 burn resulted in a dramatic shift in the runoff relationship between Tharp's and Log Creeks.

Prior to the burn, base-flow discharge contributed the least to the annual runoff in Tharp's Creek, and the creek was dry for much of the summer and fall. In 1990 after four consecutive years of moderate to severe drought, the creek was dry for a record 299 days (**fig. 4.3-4**). In the post-burn years, the contribution of base-flow increased corresponding to an increase in the number of flow days in the summer months. Tharp's Cr. was dry for a record low of 28 days in 1999 despite moderate drought conditions.

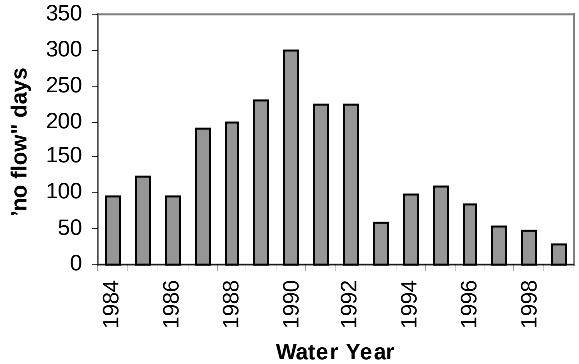

Figure 4.3-4. Following the 1990 prescribed burn the number of "no flow" days has decreased

Post-fire Changes in Forest Structure

The paired watershed analysis revealed that in post-fire years the burned and control catchments both had an increase in annual runoff, and that much of the increase can be explained by an increase precipitation. However, there was a much greater response from the Tharp's catchment. The results of a companion study on forest mortality and recruitment in these catchments between 1986 to 1995 provide a unique opportunity to correlate post-fire changes in forest structure as a means of explaining some of the observed increases in annual runoff.

In the pre-burn years mean annual mortality for all tree species and size classes was <1% in both catchments. In the post-burn period (1991-1995) annual mortality increased slightly to 1.4% in Log Cr. catchment, whereas Tharp's Cr. catchment had an annual mortality of 17.2% (Mutch and Parsons 1998). The highest mortality in Tharp's catchment occurred in 1992 and 1993 (**fig. 4.3-5**). The increase in

mortality in Log Cr. catchment was attributed to drought stress, which reduced tolerance to pathogens and insect outbreaks. Tree mortality in Tharp's catchment was significantly correlated with fire-caused crown scorch, which resulted in a 75% decrease of the trees ≤50 cm dbh (diameter at breast height) and a 25% decrease of trees >50 cm dbh. Although the highest morality averages occurred in the subcanopy class

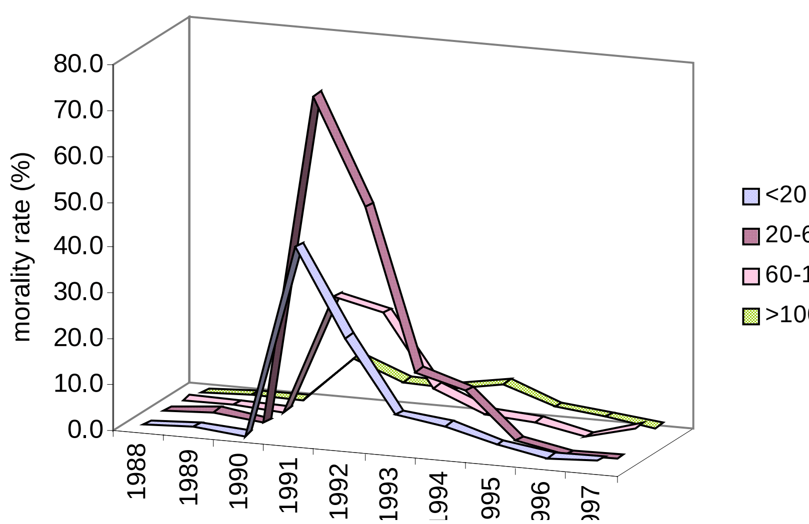

Figure 4.3-5. Sharp increases in mortality rates were observed in Tharp's catchment following the 1990 prescribed burn. Rates remain elevated eight years after the burn.

(28%), dominate and co-dominate trees had average mortality rates of 7% a year from 1991-1995. In 1997, mortality rates for the dominate and co-dominate size classes were 1.45% and 4.23% and 0.0% and 1.89% in Tharp's and Log catchments, respectively (unpublished data).

Management Implications
Interception measurements were not made during either study, but results from the forest study strongly suggest that tree mortality in the large size classes resulted in a decrease in interception and evapotranspiration losses in Tharp's catchment. Other studies have shown that these losses can be substantial, ranging from 15 to 30% annually (Fujieda et al. 1997, Cienciala et al. 1997, Llorens 1997). In the post-burn years, source contributions from snow-melt and base-flow in Tharp's Creek were 10 to 15% greater than in pre-burn years.

The overall mortality rate in Tharp's catchment between 1996 and 1998 was 3.9% (unpublished data), which was more than twice the rate of 1.5% observed in Log catchment. Increased runoff coefficients in Tharp's catchment suggest that the continued mortality is contributing to the additional annual runoff. The continued trend of elevated mortality eight years following the prescribed fire indicates that severe fire behavior can have a prolonged effect of forest structure and hydrologic response.

Results of this analysis indicate that the effects of fire on the hydrologic response of a small mixed-conifer catchment are a complex interaction of biological and physical factors. Paired watersheds and long-term precipitation data are necessary to understand the variation in hydrologic before and after fire. The benefits of companion studies such as the forest mortality study are clearly seen here where detailed information on the changes in forest structure following a prescribed fire provided the information necessary to explain the continued increase in Tharp's catchment annual runoff. The results of this analysis also suggest the need for long-term monitoring in catchments where fire intensity is severe.

Mineral King Pre-Burn Analysis

Runoff Coefficients
Annual runoff coefficients were calculated for each catchment for water years 1996 – 1999 using the above equation. The East Fork coefficient values were under estimated due to the lack of data for the alpine area of the catchment. Trauger's Creek had the highest values overall for the pre-burn period for the four-year period (**fig. 4.3-6**). Runoff in the small catchments did not seem to be affected by the low precipitation totals for WY 1999. Runoff coefficients are expected to increase in the initial years following the application of fire. Much of the burning in the Mineral King Project has been light to moderate in intensity, thus, we expect that increases in runoff will be slight and short-term. We don't expect to see significant changes in East Fork runoff due to the patchy nature of burning within the watershed and the time span of the burns.

Stream Chemistry
Annual volume-weighted mean (VWM) solute concentrations show little inter-annual variability for most anions (H^+, SO_4^{2-}), base cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) and nutrients (PO_4^{2+}) with standard error (SE)

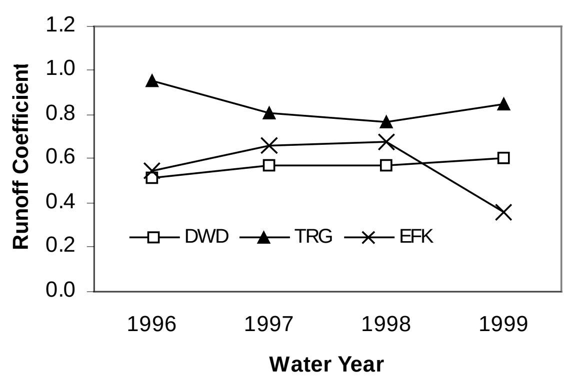

Figure 4.3-6. Annual runoff coefficients for East Fork study sites. The East Fork was most affected by the lower precipitation total in 1999

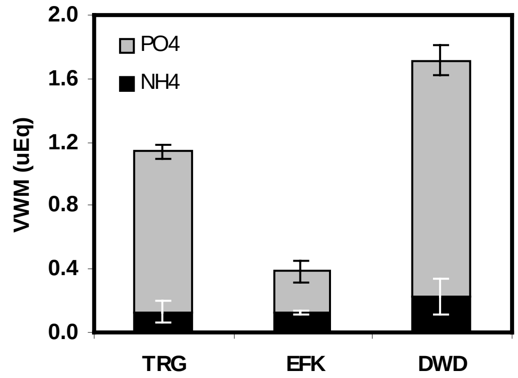

Figure 4.3-7. Phosphate exceeds ammonium in all catchments. Ammonium in undetectable for much of the year

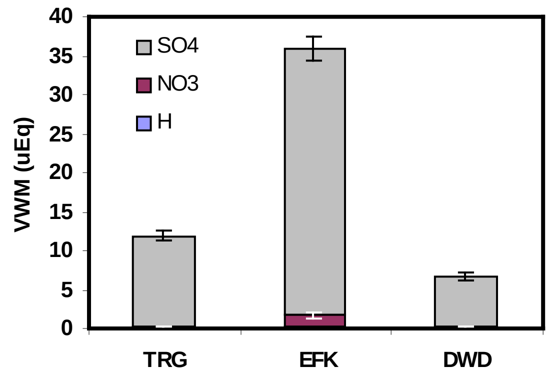

Figure 4.3-8. Sulfate is the dominant acid anion in all catchments.

values ranging from 0.00 to 0.10. Due to the highly variable concentrations of NH_4^+, and NO_3^- , higher SE values were observed. The Mineral King catchments appear to be nitrogen limited as annual VWM ammonium concentrations were significantly less than phosphate concentrations (**fig. 4.3-7**). Phosphate VWM concentrations were highest in Deadwood Cr. Sulfate contributed the highest acid anion VWM concentration in all catchments (**fig. 4.3-8**). High concentrations in the East Fork were correlated with mineral springs in the upper canyon. Nitrate and hydrogen ion accounted for <2.0 µEq in any of the study catchments. These concentrations were contra-indicated by atmospheric deposition patterns where average nitrate concentrations were 25% greater than sulfate concentrations (NADP 1998). The study sites appeared to be well buffered with alkalinity concentrations > 500 µEq. Slightly lower alkalinity concentrations were observed in the East Fork, which may be due in part to higher sulfate concentrations. The dominant cation order was Ca>Na>Mg>K (**fig. 4.3-9**), which is typical of Sierran systems with metamorphic terrain and granitic geology (Melack et al. 1987). Sodium and calcium were reversed in Trauger's Cr., which also had higher chloride concentrations. This may be due to the influence of marine onshore air-flow during the winter, when most of the rain falls.

Large Woody Debris

The LWD survey indicated that most of the downed wood is suspended across the creeks – extending up onto the stream bank; <10% of the woody volume was within the bankfull zone - stage height during the 2 year flood (**fig. 4.3-10).** This finding was consistent with results from similar-sized catchments in the northwest (Robison and Beschta 1990).

In 1996 Chan conducted a LWD survey as part of his aquatic invertebrate study. Starting from the road, he walked up stream and measured the first 50 pieces of wood meeting his standards for minimum length and diameter. He traveled 114m and 111m in Deadwood and Trauger's creeks, respectively, to measure 50 pieces of downed wood. Assuming cylindrical shapes the following equation was used (Lienkaemper

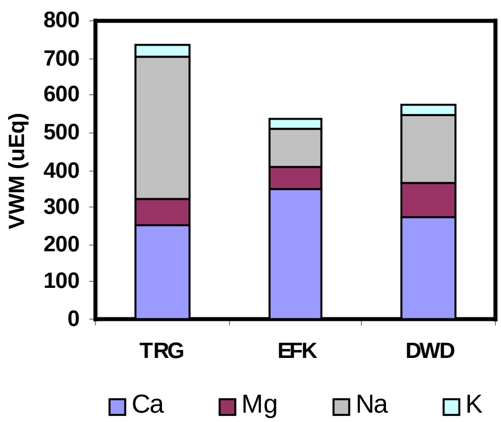

Figure 4.3-9. Calcium and sodium are the dominant base cations. Concentrations did not vary much from year to year

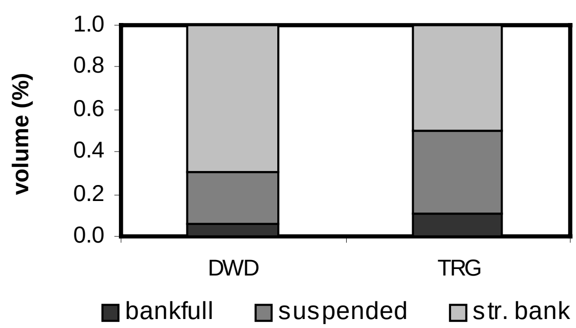

Figure 4.3-10. Percent of LWD by zone.

and Swanson 1987):

$$Volume = \frac{\pi(D_1^2 + D_2^2)L}{8}$$

We followed his protocols in Trauger's (1998) and Deadwood (1999a) to compare results following the Jan 1997 flood, which was rated as a 35-40 year event by the California Water Resources Dept. Comparisons with the 1996 survey showed a substantial decrease in total volume, and an increase in bankfull width (**table 4.3-1**), suggesting that the 1997 flood waters eroded stream banks and carried away much of the wood measured in the lower 100 m of Trauger's and Deadwood Creeks.

As the creeks were surveyed, we realized that slope influences how wood is positioned in the creeks. In the lower portion of the creeks the gradient is lower, increasing the potential for woody debris accumulation within the bankfull area. To account for this we randomized 50m surveys (1999b) for a more accurate representation of the entire stream. Results of the 1999b surveys were mixed. In Trauger's Cr. where is upper 2/3 of the creek is very steep (slopes range from 20% – 35%), the total volume of woody debris was only 0.69 m^3 - much lower than the 1996 and 1998 results. In Deadwood Creek, where slopes are less steep overall and more varied throughout the short stretch of stream (≈ 400 m), the results showed an increase in total volume over the 1999a survey, but were still significantly lower than the 1996 results. The increased volume was due to a number of large downed trees that were located in the upper 50m survey, where the slope was less than 10%. The results of the randomized survey suggest that more accurate total volumes of LWD are obtained because the slope affects on woody debris accumulation are better represented in the sampling.

Table 4.3-1. Results of Large Woody Debris surveys comparing pre- and post-flood volumes and randomized versus non-random surveys.

	Bankfull	Dist.	Dia.	Length	Vol/dist	totVol
DWD			**Avg.**	**Avg.**		
1996	1.28	114	0.32	2.34	0.17	19.36
1999a	1.26	111	0.17	1.46	0.01	0.64
1999b	1.33	100*	0.28	4.86	0.02	2.08
TRG						
1996	0.69	111	0.22	3.23	0.11	12.26
1998	1.22	167	0.17	2.22	0.02	3.84
1999b	1.06	200*	0.15	3.60	<0.01	0.69

* sum of 50 m random surveys in each creek.
All measurement in meters, volume in m^3

Management Implications

Approximately half of the Deadwood catchment and a much smaller portion of the Trauger's catchment were burned in late 1999. Increased phosphate and conductivity values were observed almost immediately in Deadwood Creek. We have not observed changes in stream chemistry in the East Fork, despite all the burning that has taken place. It may be that the effects of mosaic burning over time in large drainage areas does not alter the seasonal fluctuation in stream solute concentrations. Every effort should be made to continue the sampling through the burn and post-burn phase of the MKRRP. These watershed results are extremely valuable in understanding the variation in watershed response to fire. For instance, as we observed in Tharp's catchment precipitation patterns can strongly influence post-burn watershed response to fire. The Mineral King pre-burn data were collected during a period of wet years – completely opposite the dry years that dominated the pre-burn data collection in Tharp's catchment. This shift pre-burn in precipitation patterns will likely influence the magnitude and duration of the fire effects in the East Fork sites.

We are fortunate to have a long-term data base on stream chemistry, hydrology and meteorology from the Log Meadow catchments. These data allow us to understand how long-term anthropogenic influences affect watershed function and help us to tease out the affects of short-term disturbance such as fire. We should continue to build upon this knowledge base by funding studies such as the Mineral King project.

1999 ACCOMPLIMENTS

- Conducted Large Woody Debris survey in Trauger's and Deadwood Creeks, and compared results with 1996 pre-flood survey.

- Submitted paper entitled "Hydrologic Response of a Forested Catchment before and after Fire" to American Water Resources Association conference: Water Resources in Extreme Environments. Paper will be presented at the May 2000 meeting in Anchorage, AK.

- Submitted proposal to CalFed entitled "Effects of Fire on Sediment Processes in Sierra Nevada Forested Watersheds". This proposal presented an experimental approach to studying fire effects on sediment transport and storage, and hillslope erosion in small (<100 ha) forested catchments in the Sierra Nevada in various stages of fire reintroduction. (not funded)

- Submitted proposal to U.S. Geological Survey entitled "Effects of Fire on Sediment Processes in Sierra Nevada Forested Watersheds". This proposal presented a scaled down version of the CalFed proposal to study fire effects on sediment transport and storage, and hillslope erosion in the East Fork study sites. This was a joint proposal with co-authors from Water Resources and Geologic Divisions. (not funded)

- Submitted proposal to NPS Resources Management unified call for FY 2000 entitled "Effects of Fire on Watersheds". This proposal sought funds to continue long-term stream and precipitation sampling with an emphasis on fire effects. (not funded)

2000 PLANS

The watershed account will be zeroed out for FY2000 and all monitoring will be phased out. A three-phase plan is underway to close out the program. In Phase I sampling will cease at all Middle Fork sites as of Feb. 2000. Sampling will continue in the East Fork through April 2000 to capture the winter/snowmelt runoff period in the recently burned watersheds. Final chemistry analysis will be performed for all remaining stream and precipitation samples. In Phase II equipment will be removed from the field, including all data loggers and meteorological stations. During Phase III equipment will be inventoried and stored, all data sets will be updated and reviewed, and all metadata will be completed.

Plans are also underway to complete a draft synthesis of the watershed program. This document will summarize all research and monitoring in the Middle Fork (1984-1998), and will include an overview of fire effects in the Tharp's catchment, and a trends analysis on the long-term stream chemistry and hydrology data sets.

REFERENCES

Chan, I. A. 1998. *Aquatic Macroinvertebrates of Small Streams in Mineral King Region of Sequoia National Park: Baseline Communities and Response to Prescribe Fire.* Thesis. University of California, Berkeley. 111 pp.

Chorover, J., P. M. Vitousek, D. A. Everson, A. M. Esperanza and D. Turner. 1994. Solution chemistry profiles of mixed-conifer forests before and after fire. *Biogeochem*. 26:115-144.

Cienciala, E.; J. Kucera, A. Lindroth, J. Cermak; A. Grelle, S. Halldin, 1997. Canopy transpiration from a boreal forest in Sweden during a dry year. Agricultural and Forest Meteorology, v. 86, n. 3-4:157-167.

Dossett, S. R. and V. C. Bowersox. 1999. National trends network site operation manual. National Atmospheric Deposition Program Office, Illinois State Water Survey. NADP Manual 1999-01. Champaign, IL

Fujieda, M.; T. Kudoh,, V. De Cicco,; and J. L. De Calvarcho. 1997. Hydrological processes at two subtropical forest catchments: The Sierra do Mar, Sao Paulo, Brazil. J. of Hydrology, v. 196, n. 1-4:26-46

Lienkaemper, G. W. and F. J. Swanson. 1987. Dynamics of large woody debris in streams in old-growth Douglas-fir forests. *Can. J. For. Res*. 17:150-156.

Llorens, P. 1997. Rainfall interception by a *Pinus sylvestris* forest patch overgrown in a Mediterranean mountainous abandoned area: II. Assessment of the applicability of Gash's analytical model. J of Hydrology, v. 199, n. 3-4:346-359.

Melack, J., S.D. Cooper, R.W. Holmes, J.O. Sickman, K. Kratz, P. Hopkins, H. Hardenbergh, M. Thieme and L. Meeker. 1987. Chemical and biological survey of lakes and streams located in the Emerald Lake watershed, Sequoia National Park. Final Report to the California Air Resources Board, Contract A3-096-32, Sacramento, CA. 345 pp.

Moore, C. M. 1999. 1999 Annual Sequoia National Park Watershed Report. U.S. Geological Survey. Three Rivers, CA. Unpublished report. 15 pp.

Robison, E. G. and R. L. Beschta. 1990. Characteristics of coarse woody debris for several coastal streams of southeast Alaska, USA. Can J. Aquat. Sci. 47:1684-1693.

Williams, M. R. and J. Melack. 1997a. Effects of prescribed burning and drought on the solute chemistry of mixed-conifer forest streams of the Sierra Nevada, California. *Biogeochem*. 39:225-253.

Williams, M. R. and J. Melack. 1997b. Atmospheric deposition, mass balances, and processes regulating streamwater solute concentrations in mixed-conifer catchments of the Sierra Nevada, California, *Biogeochem*. 37: 111-144