# Climate Variability, Fire, Vegetation Recovery, and Watershed Hydrology

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## Abstract

The San Dimas Experimental Forest was established in 1934. A large database of fire history, and stream flow exists for several locations within the forest. San Dimas was selected as a perfect example of the hydrology, geology, and ecology of the mountains of southern California. As such the long-term data set provides the best examples available of rainfall-runoff relationships in a mountainous Mediterranean climate. One of the most important ecological processes operating at San Dimas is the frequent stand replacing fires that occur approximately every 40 years. The effect of fire on streamflow is a pertinent topic considering the current national discussion about changes in fire policy in the western United States. The data sets at San Dimas provide an opportunity to investigate what the short and long term impacts of fire are on water resources in chaparral ecosystems. In particular the fires of 1938 and 1960 provide an opportunity to investigate the effect of fire on streamflow response. Immediately after the fires the well-known fire-flood response of chaparral watersheds is noted with extremely large flood peaks possibly due to the combined effects of removal of vegetation and litter by fire as well as the presence of hydrophobic soils. However longer term impacts of fire are noticeable, lasting as long as 20 years and are most likely related to aggrading vegetation coverage and the linked increase in evapotranspiration. Around 1960 several watersheds were type converted to annual and perennial grasslands from their native chaparral, this increased streamflow to the present day and offers insight into the importance of deeply rooted vegetation on summer streamflow in seasonally dry climates.

**Keywords:** Mediterranean climate, fire, streamflow, water yield, baseflow recession

## Introduction

Fire and its effect on watershed hydrology and water quality has been a well studied process for many decades now (e.g. Hoyt and Troxel 1934, Loaiciga et al. 2001). These studies have typically focused on the immediate post-fire period and the large increases in flooding, sediment production and nutrient export (DeBano et al. 1998). While these processes are of obvious importance to assist decision makers in hazard avoidance during the post-fire period they are not the end of the story.

Ecosystem disturbances, such as fire, have short and long term impacts on ecological processes. Several studies in the last several decades have shown that while clear-cutting or stand replacing fires can cause immediate large increases in streamflow the longer term impacts of either disturbance are longer term decreases in annual streamflow (Kuczera 1987, Hornbeck et al. 1997). Additionally, vegetation type conversion experiments offer an important contrast to fire effects studies and permit a direct investigation of vegetation effects on ecological processes. Thus they offer a way to understand how fire influences watershed hydrology in the short and long terms (Bosch and Hewlett 1982).

In this study we investigate the following three questions:

1) What are the short and long-term effects of fire and vegetation type conversion on watershed hydrology?
2) What can these experiments tell us about the importance of the deeply rooted vegetation that is native to the chaparral and similar Mediterranean ecosystems?
3) In moving to a scale larger than those studied at San Dimas, what problems might be confronted?

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# Methods

## Site description

The San Dimas Experimental Forest (SDEF) ($34^o$ 12’ N, $117^o$ 40’ W) was established in 1934 to study the interaction between chaparral ecosystems and water availability (Figure 1). The Forest originally gauged a total of 17 catchments with area larger than 10 ha. Most of the stream gauging network was destroyed in a catastrophic wildfire in July 1960. Of the original gauged catchments, 5 catchments have been gauged continuously since the inception of the experimental forest. The forest is subject to dramatic variation in annual precipitation (Figure 2) and frequent wildfires. Chaparral watersheds supply much of the water that recharges to groundwater in southern California and it is one of the most extensive ecosystems in California. In 1984 several prescribed burns were conducted that were intended to study the effect of fire on watershed hydrology, water quality and sediment transport (Riggan et al. 1994).

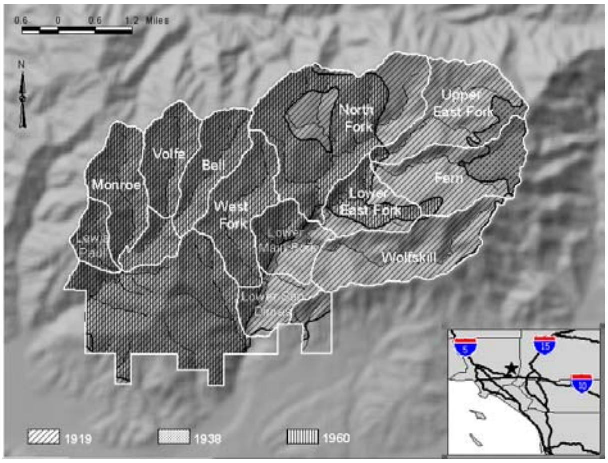

Figure 1. Location, catchment delineation and fire history for the San Dimas Experimental Forest.

## Experimental framework

This paper focuses on comparing annual water yield and daily streamflow for several different natural and human induced experiments that have been conducted at SDEF (Table 1). First, the effect of a 1938 fire that only burned the three small Fern watersheds are assessed by comparing annual runoff from these catchments to the Bell 2 catchment that was not burned. Second, the Bell 1 and Bell 2 watersheds were type converted from native chaparral to grasslands in 1960 and 1958 respectively. The effect of this type conversion on water yield and daily baseflow recession will be analyzed by comparison to the Volfe catchment. Third, Volfe catchment streamflow prior to and following the 1960 fire was used to investigate the impact of the fire on annual water yield and baseflow recession. Fourth, we will look at the impact of a controlled burn conducted in 1984 on annual water yield in the Bell 4 catchment, which was burned, to annual water yield in the Bell 3 catchment which serves as a control for this experiment (Riggan et al. 1994). Finally, annual runoff from the SDEF catchments is compared to annual runoff from nine neighboring USGS gauges to assess the effect of scale on annual runoff (Table 2). Between catchment comparisons used runoff depth and similar time periods.

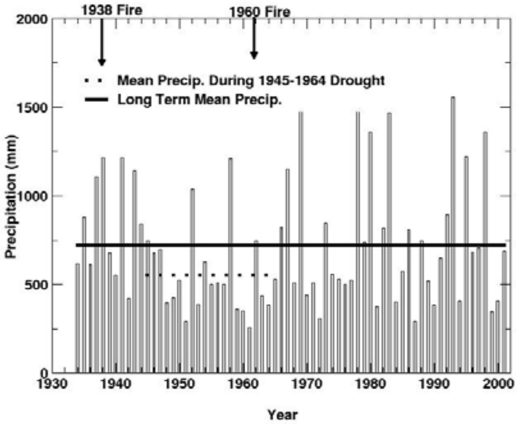

Figure 2. Annual Precipitation for SDEF. Note extended drought from 1945 to 1965.

Table 1. SDEF Catchment Descriptions

| Catchment | Area (ha) | Burned | Treatment, year |
|---|---|---|---|
| Bell 1 | 31 | 1960 | Grassland, 1960 |
| Bell 2 | 40 | 1960 | Grassland, 1958 |
| Bell 3 | 25 | 1960 | Chaparral |
| Bell 4 | 16 | 1960, 1984 | Chaparral |
| Volfe | 299 | 1960 | Control |
| Fern 1 | 14 | 1938 | No Treatment |
| Fern 2 | 16 | 1938 | No Treatment |
| Fern 3 | 21 | 1938 | No Treatment |

# Results

Unfortunately there is no available data for the pre-fire period for the Fern catchments but considering the similar size of the Fern catchments to the Bell 2 catchment they are expected to have similar or slightly lower annual runoff. The 1938 fire caused a significant increase (as much as 7 times) in annual streamflow from the three small Fern watersheds as compared to annual water yield from the Bell 2 catchment. This initial post-fire increase in water yield was short lived and disappeared by 1942. From 1942 until the end of the gauging record in 1957 the ratios of annual runoff indicate that runoff from the Fern's during this longer post-fire period was below what it would otherwise have been.

Table 2. USGS Gauges Used for Comparison

| USGS Gauge | Area, ha |
|---|---|
| Fish Canyon | 1647 |
| San Antionio Canyon | 4274 |
| Sawpit | 1373 |
| Santa Anita | 2515 |
| Arroyo Seco | 4144 |
| Devil Canyon | 1422 |
| Little Dalton | 705 |
| San Dimas Canyon [1] | 4740 |
| Dalton Canyon | 1875 |

[1] San Dimas Canyon record combines records from above and below the San Dimas Canyon Dam.

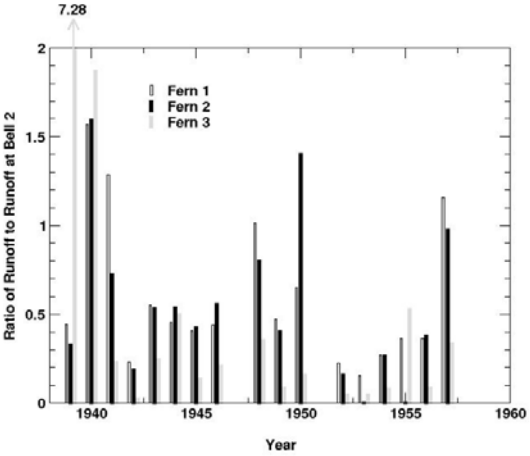

Figure 3. Ratio of annual runoff (mm) between three Fern catchments, burned fall of 1938, to annual runoff in the Bell 2 catchment.

The long-term impact of type conversion at SDEF was a persistent effect on annual water yield into at least the 1980s (Figure 4). Additionally the type-conversion has had its biggest impact on water yield in years with relatively low precipitation (less than 700 mm). Dry years such as these typically produce no runoff in mature chaparral watersheds (Figure 5). Further the effect of the type conversion is not isolated during the wet winter rainy season but is most prominent in increased streamflows during the summer and by a notably more gradual streamflow recession (Figure 6).

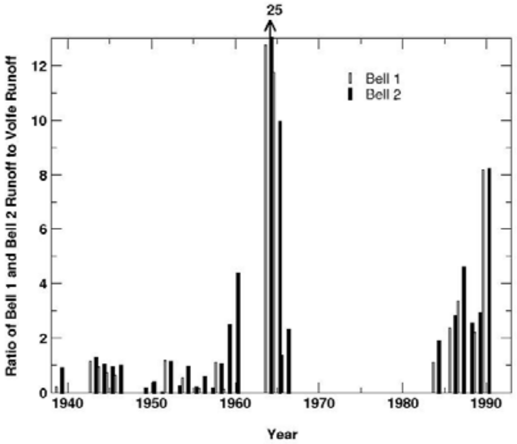

Figure 4. Ratio of annual runoff in Bell 1 and Bell 2 catchments to runoff from long-term control Volfe catchment.

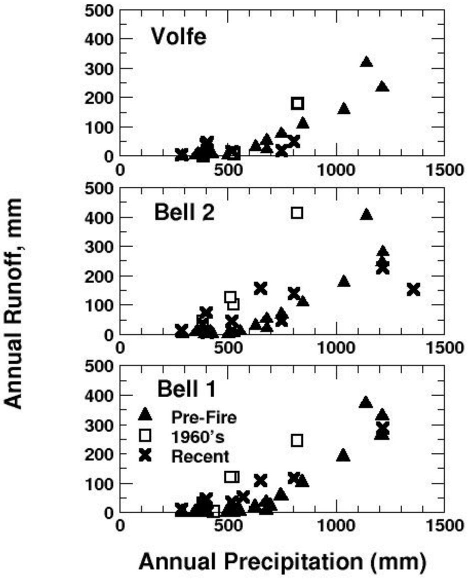

Figure 5. Annual runoff vs. annual precipitation for Volfe and Bell 1 and Bell 2 catchments

The response of streamflow in the Volfe catchment to the 1960 fire indicates an increase in water yield that is in part due to more gradual streamflow recession during the summer period (Figures 5 and 7). The cause of this increased summer streamflow is likely decreased evaporation due to decreased vegetation following fire or type conversion. The increase in streamflow is short lived and by the 1980s Volfe catchment streamflow returns to pre-1960 conditions.

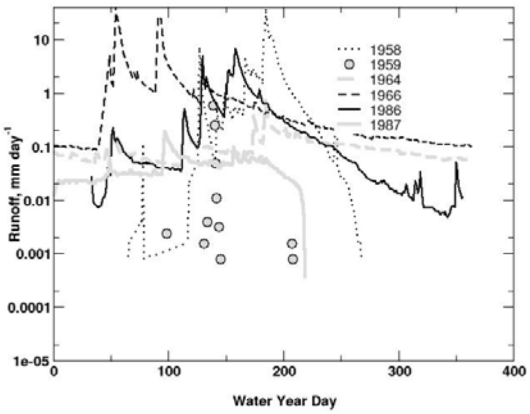

Figure 6. Daily streamflow for Bell 1 catchment (water year starts on October 1st). The years 1959, 1964 and 1987 were dry while 1958, 1966 and 1986 were wet years. Note more gradual streamflow recession in 1964 and 1966 as compared to 1958. Note that in 1986 and 1987 recession rates fall between pre-conversion conditions (1958 and 1959) and immediate post-conversion streamflow recession (1964 and 1966).

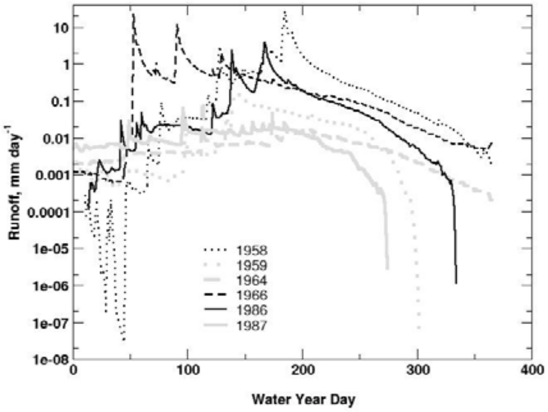

Figure 7. Daily streamflow for Volfe Catchment(water year starts on October 1st). Years are the same as for Figure 6.

The long pre-fire runoff data for both catchments indicates that runoff depth on Bell 4 is typically about 10% greater than runoff on Bell 3. After the 1984 prescribed burn in the Bell 4 catchment streamflow is greatly increased compared to the control Bell 3 catchment for 1985. The late 1980s and early 1990s indicate that this increase in water yield lasts until 1997. In 1998 annual runoff is greater in the control catchment (Bell 3) and this pattern persists and grows larger through the end of the data set.

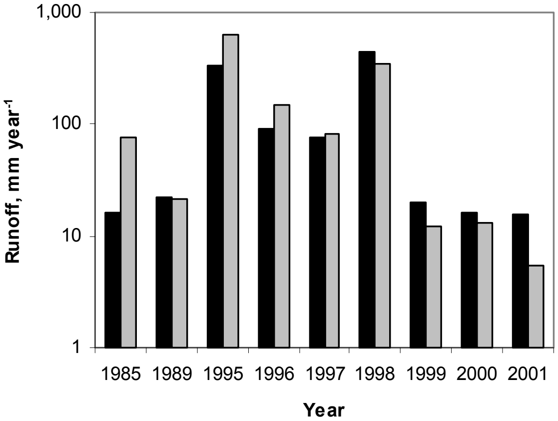

Figure 8. Annual runoff from Bell 3 (control, black) and Bell 4 (burned 1984, gray) catchments.

Annual runoff from the catchments of the SDEF increases with watershed area. The USGS gauges generally measure streamflow at a larger scale, but their streamflow records show an increase in streamflow with increasing watershed area but the runoff volume is significantly smaller than the SDEF catchments. The one USGS gauge that plots with the SDEF gauges is Little Dalton Canyon. This gauge is immediately adjacent to the SDEF with similar landscape position and geology to the catchments of the SDEF.

## Discussion

### Long-term effects of fire

The results indicate that fire, as reported many times previously, increases streamflow at daily and annual time scales e.g. (Hoyt and Troxel 1934). In this behavior fire as an ecosystem disturbance is not very different from other ecosystem disturbances such as clear cutting (Hornbeck et al. 1997). The results show that while the short-term impact of fire is to increase streamflow the longer-term affect is to decrease streamflow. This was evident in the results from the Fern catchments and from the recovery of the Bell 4 catchment from the 1984 fire (Figures 3 and 8).

The short-term increase in streamflow is due to decreased evapotranspiration (ET) losses and perhaps increased runoff during winter rain storms. Decreased ET is due to the loss of vegetation in the post-fire environment (Kuczera 1987, Hornbeck et al. 1997). The increase in winter runoff is possibly due to the loss of vegetation, surface cover and post-fire soil hydrophobicity (Letey 2001).

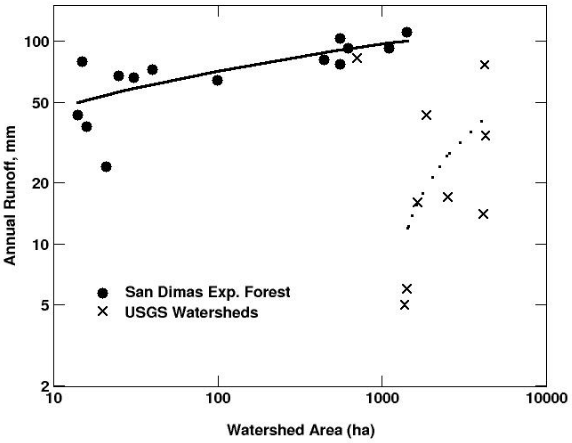

Figure 9. Annual runoff versus watershed area for San Dimas and USGS watersheds.

The results from the type-conversion experiments indicate that the type conversions induce an increase in flow during summer periods that is similar to the increases in stream baseflow due to a fire. Furthermore the type-conversions have caused a persistent increase in streamflow for well over 40 years but at a level somewhat decreased from the initial period. This result indicates that the large number of type-conversion experiments conducted globally during the 1950s and 1960s (Bosch and Hewlett 1982) should be revisited to see if the effect of conversion has persisted. The persistence of the type-conversion effect is likely dependant on ecosystem properties such as the ability of the original vegetation species to reinvade after the conversion. Native chaparral species have been slow to reinvade the converted catchments due to low seed dispersal and the dependence on fire for germination of many of the species (R.A. Minich, personal communication, Thanos and Rundel 1995).

## Importance of deeply-rooted vegetation

The increase in summer streamflow from both the type conversion and after fires indicates that some process related to the vegetation is removed from affecting streamflow under the post-fire and post-conversion conditions. Most notably streamflow recession is more gradual with the absence of vegetation. Theoretically streamflow recession is treated as the draining of an aquifer. A given streamflow is associated with a given storage in that aquifer (Wittenberg and Sivapalan 1999). The implication of the more gradual baseflow recession observed is that there must be another mechanism draining aquifer storage when chaparral vegetation is mature. The most likely alternative draining mechanism to streamflow is ET. Others have shown that adding ET losses to the theoretical equations that model baseflow recession would cause more rapid decreases in streamflow than in the absence of ET (Weisman 1977). The vegetation of Mediterranean climates is widely noted for its deep roots that are used to survive the long hot, dry summers (Schenk and Jackson 2002). The data at SDEF offers a way to investigate the water demand of this vegetation; by comparing baseflow recession rates in the type converted systems to those in the control catchments.

## Scale effects on water yield

The original work on paired catchment studies instigated much debate about whether the results at the ~100 ha scale would be observable at larger scales (Hoyt and Troxel 1934). The results here indicate some hazard in extrapolating from the results at SDEF to the larger southern California region and chaparral and Mediterranean ecosystems in general. The larger gauged catchments of the USGS gave reduced annual runoff amounts as compared to the headwater catchments of the SDEF (Figure 9). The reason for this difference may be increased recharge to deep hard rock aquifers, the USGS gauges are located on top of valley alluvial deposits, and losses of stream water to ET by riparian vegetation.

## Relevance to California water resources

The results of this study are of critical importance to water resources management in California. Chaparral ecosystems are large in their extent and critical for groundwater recharge in southern California. Fire plays such a central role in chaparral ecosystems that even small hydrologic effects of fire and fire recovery would be felt throughout the water resources infrastructure of southern California. Past studies on the effect of fire on water yield in the chaparral have focused on the immediate increase in annual water yield (Turner 1991, Loaiciga et al. 2001). While relevant, the short-term positive of fire may be drowned out by the long-term effect of vegetation recovery noted here. This long-term loss of water from chaparral watersheds represents an adverse impact of fires in chaparral that is not well recognized and it could jeopardize water resources system reliability (Kuczera 1987, Watson et al. 1999). Additionally, it is likely that larger chaparral fire patterns of today have different catchment scale water yield effects than the more patchy nature of chaparral fires prior to large scale suppression during the last century (Minnich and Bahre 1995).

## Conclusions

The results from this study indicate that type conversion has a long lasting positive effect on water yield from chaparral watersheds. This result may be ecosystem specific. While fire has a short term positive effect on water yield, longer term it causes a decrease in water yield. These two results indicate that fire suppression policy could have a beneficial impact on water resources through increasing return periods of fire or a negative impact due to the large scale of chaparral wildfires under suppression regimes. Finally, the research results at San Dimas need to be investigated from a broader regional perspective since comparisons with USGS gauges indicate a difference in process at the larger scales that are most relevant to water resources decision makers.

## Acknowledgments

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