CLIMATE CHANGE, WATER SUPPLY, AND RAINFALL-RUNOFF RELATIONSHIPS FOR SMALL INTERMITTENT STREAMS IN SOUTHERN CALIFORNIA

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Abstract: Changing climates and altered hydrologic regimes have made future southern California water supplies uncertain. Coupled with the enormous expense and potential unreliability of large water conveyance projects, these uncertainties have led to a renewed interest in developing local water sources. Southern California is an area where water resources are scarce yet critical to support both agriculture and burgeoning population centers. The San Dimas Experimental Forest (SDEF), located in the San Gabriel Mountains about 45 km northeast of Los Angeles, experiences a Mediterranean climate with cool wet winters and hot dry summers. Multiple small watersheds 15 to 40 ha in size have been monitored for precipitation and runoff since the mid-1930s in the Bell Canyon study area. Vegetation type strongly controls water yield, presumably reflecting the rooting depth and the water demand of the different vegetation classes. Generally, higher rainfall years produce more runoff than drier years, as expected. However, runoff is also influenced by inter-annular antecedent conditions and the distribution of precipitation throughout the rainy season. An understanding of the rainfall-runoff relationships in these small intermittent streams may help guide the prospects of developing a local water source in southern California.

INTRODUCTION

If the model projections are correct, climate change will profoundly affect global weather patterns. Although there is considerable variability among the many models, the general consensus is that temperatures will increase and precipitation will decrease in most continental areas (Cayan et al., 2008). This will alter the local hydrologic cycle (the disposition of rain and snow, evaporation, transpiration, the timing of snowmelt, water storage) that will in turn affect water supplies. In southern California, the Mediterranean pattern of wet winters and dry summers is projected to continue. However, some models predict that the area could experience periods of up to 30 years where annual rainfall is more than 10 percent below historical levels (Cayan et al., 2008), and the annual precipitation could decrease by 20 to 40 percent by the year 2100 (EPA, 2013).

Water is already a scarce commodity in southern California. Most of the water for agriculture, industry, and domestic use must travel hundreds of kilometers from northern California and the Colorado River in large conveyance projects. However, these engineered water systems are currently at capacity and may be unreliable in the future, as they face issues of aging infrastructure and legal restraints for environmental concerns (Meisen and Phares, 2011). Meanwhile, demand for water is expected to remain high.

Prior to the advent of the large engineering projects that supply water to southern California, local sources had to suffice. However, interest in local supplies declined once the conveyance projects were completed and satisfied most of the regional demand (Freeman, 2008). The disturbing prospects of most climate change scenarios coupled with the potential problems and

expense of large conveyance projects have made future water supplies for southern California uncertain. These uncertainties have led to a renewed interest in developing local water sources. Nearly 40 percent of the current demand for water in southern California is still produced from local aquifers (Freeman, 2008). Moreover, developing local supplies through storm water management, using reclaimed wastewater, and groundwater management is seen as the best new source of water for future southern California needs (Nelson, 2012).

One possible source of water not currently being exploited is the intermittent streamflow from the hundreds of canyons in the mountains that ring the coastal plains and valleys of southern California. While some of this water recharges the groundwater reservoir, both naturally and by being directed into spreading grounds, much of the stormflow is quickly routed by flood control structures to the ocean. Perhaps some of this water could instead be harvested for local water supply.

The USDA Forest Service has been monitoring rainfall and stream discharge in the canyons of the San Gabriel Mountains since the 1930s. This paper explores the lessons learned from these extensive rainfall-runoff relationships that could perhaps help guide the prospects of using intermittent streams from mountainous canyons as a potential local water supply. The objectives of this study are as follows: 1) to synthesize long-term rainfall and runoff records from the San Dimas Experimental Forest; and 2) to determine the influence of rainfall distribution, antecedent conditions, and vegetation type on runoff quantity.

STUDY AREA

The San Dimas Experimental Forest (SDEF) is a nearly 7000 ha research preserve administered by the USDA Forest Service, Pacific Southwest Research Station, and has been the site of extensive hydrologic monitoring for over 80 years (Dunn et al., 1988). The SDEF was originally established in 1933 to document and quantify the hydrologic cycle in semiarid uplands with intermittent headwater streams. With its headquarters at Tanbark Flat (34° 12’ N latitude, 117° 46’ W longitude), the SDEF is located in the San Gabriel Mountains, about 45 km northeast of Los Angeles, California (Figure 1).

Elevations in the Bell Canyon study area range from 750 to 1050 m and topography consists of a highly dissected mountain block with steep hillside slopes and steep channel gradients. Bedrock geology is dominated by Precambrian metamorphics and Mesozoic granitics that produce shallow, azonal, coarse-textured soils (Dunn et al., 1988). The region experiences a Mediterranean-type climate, characterized by hot, dry summers and cool, moist winters. Temperatures range from -8° C to 40° C. Mean annual precipitation, falling almost exclusively as rain, is 715 mm in the SDEF (80-year record), but rain during individual years can range from 252 to 1848 mm.

Native vegetation in Bell Canyon consists primarily of mixed chaparral. Plant cover on south-facing slopes ranges from dense stands of chamise (*Adenostoma fasciculatum*) and ceanothus (*Ceanothus* spp.) to more open stands of chamise and black sage (*Salvia mellifera*). North-facing hillsides are dominated by scrub oak (*Quercus berberidifolia*) and ceanothus, with occasional

hardwood trees – live oak (*Quercus agrifolia*) and California laurel (*Umbellularia californica*) – occurring on moister shaded slopes and along the riparian corridors (Wohlgemuth, 2006).

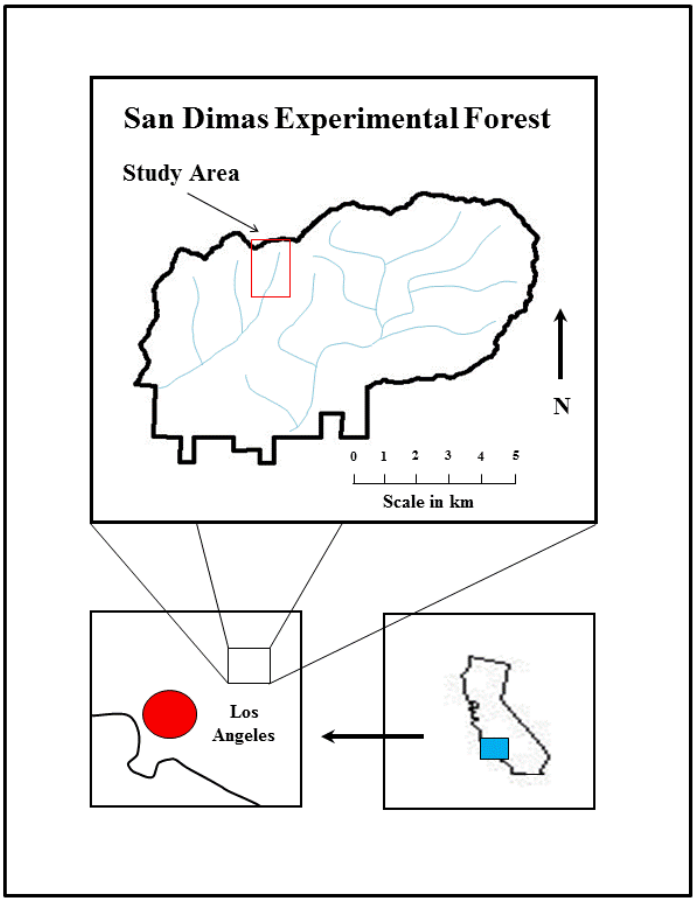

Figure 1 Location map of the San Dimas Experimental Forest.

One of the management treatments following a wildfire in 1960 involved type-converting the native chaparral vegetation in some watersheds to a mixture of perennial grasses. It was thought that type-conversion would aid in future fire control and would enhance water yield by replacing deep-rooted shrubs with shallow-rooted grasses (Rice et al., 1965). These perennials included a variety of wheatgrass species (*Agropyron* spp.), Harding grass (*Phalaris tuberosa* var. *stenoptera*), big bluegrass (*Poa ampla*), smilo grass (*Piptatherum miliaceum*), and blando brome (*Bromus hordaceous*) (Corbett and Green, 1965). Since 1960, many of the seeded grass species have disappeared from the sites and substantial amounts of buckwheat (*Eriogonum fasciculatum*) and black sage have established on the type-converted watersheds.

METHODS

Four small watersheds were selected for study in Bell Canyon (Figures 1 and 2): two in type-converted grass vegetation – Bell1 (32 ha) and Bell2 (41 ha) – and two in native chaparral –

Bell3 (25 ha) and Bell4 (15 ha). Two raingages monitored precipitation inputs across the study watersheds, one at the headwaters and one at the outlets (Figure 2). Although rainfall was very similar between these two gages, total annual rain was computed as the area-weighted average of the two stations. In addition to annual totals, rainfall is also characterized by the amount received during the highest three-month period, or quarter, describing the timing of major rain events throughout the year. Rain was assumed to be spatially uniform across the landscape and was computed as cubic meters based on watershed area.

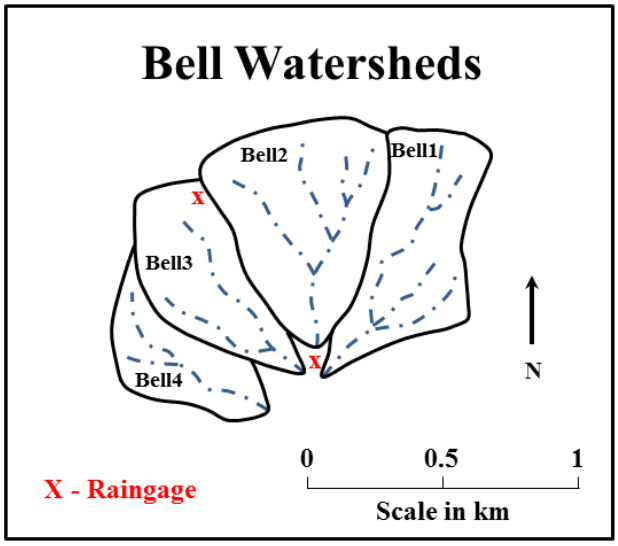

Figure 2 Bell study watersheds.

Prior to 1969, stream discharge for all watersheds was measured in small 90° v-notch weirs for low flows (<50 l s^{-1}) and 0.91 m (3-foot) flumes for higher flows. Following the 1969 floods that destroyed most of the low-flow gaging equipment, all streamflow was monitored in large 120° v-notch weirs in Bell1, Bell2, and Bell3. However, a reconstructed 90° v-notch weir and flume arrangement continued to measure flow in Bell4. Stage height for each instrument was measured in a stilling well by a float-operated recorder to produce a paper chart. In the office, stage heights were manually read from the stream charts at 6 hour intervals and at inflection points during storm events. Discharge was computed from stage height using rating curves developed for each instrument and summed over the time intervals to get an annual water yield in cubic meters. Partial-year records resulting from equipment failure or missing charts were not used in any subsequent analyses.

RESULTS AND DISCUSSION

Rainfall and stream runoff values for each of the Bell study watersheds from hydrologic years (October to September) 1960 to 2000 are arrayed in Table 1. While continuous precipitation records are available from the two raingages over the period of study, stream discharge measurement was sporadic. A wildfire in 1960 and subsequent debris-laden flows prevented continuous stream gaging for three years following the fire. A large flood destroyed the low-flow gaging equipment in all watersheds in 1969. Stream charts are missing for Bell4 from the

Table 1 Rainfall and stream runoff values for the Bell watersheds for hydrologic years 1960 to 2000. First quarter – Oct. to Dec. Second quarter – Jan. to Mar. Third quarter – Apr. to June. Fourth quarter – July to Sep. TC – type converted grass vegetation. NC – native chaparral vegetation. Runoff Ratio = Annual Streamflow/Annual Rainfall. (.) – full-year records not available because of equipment failure or missing stream charts.

			Watershed							
	Rainfall		Bell1 (TC)		Bell2 (TC)		Bell3 (NC)		Bell4 (NC)	
Year	Total (mm)	Highest Quarter (mm)	Runoff $m^3\ ha^{-1}$	Runoff Ratio	Runoff $m^3\ ha^{-1}$	Runoff Ratio	Runoff $m^3\ ha^{-1}$	Runoff Ratio	Runoff $m^3\ ha^{-1}$	Runoff Ratio
1960	377	2nd (215)	0.2	0.01	75.1	0.02	5.9	0.01	.	.
1961	279	1st (175)	.	.	.	.	.	.	.	.
1962	784	2nd (566)	.	.	.	.	.	.	.	.
1963	460	2nd (283)	.	.	.	.	.	.	.	.
1964	410	2nd (188)	370.7	0.09	379.7	0.09	52.0	0.01	.	.
1965	565	3rd (294)	1173.3	0.21	996.3	0.18	181.3	0.03	.	.
1966	859	1st (744)	5230.9	0.61	.	.	2528.1	0.29	.	.
1967	1176	1st (577)	.	.	8846.6	0.75	4632.0	0.39	.	.
1968	510	1st (261)	1207.4	0.24	1242.4	0.24	601.0	0.12	.	.
1969	1617	2nd (1539)	.	.	.	.	.	.	.	.
1970	471	2nd (375)	.	.	1071.4	0.23	620.0	0.13	460.6	0.10
1971	509	1st (340)	.	.	1113.6	0.22	401.7	0.08	297.7	0.06
1972	326	1st (293)	.	.	534.6	0.16	195.1	0.06	81.6	0.03
1973	858	2nd (658)	.	.	.	.	.	.	.	.
1974	563	2nd (436)	.	.	.	.	550.1	0.10	408.9	0.07
1975	518	1st (138)	.	.	609.2	0.12	253.2	0.05	110.7	0.02
1976	525	2nd (304)	.	.	549.8	0.10	131.0	0.02	6.1	0.01
1977	499	2nd (254)	.	.	.	.	140.6	0.03	18.5	0.01
1978	1614	2nd (1220)	.	.	.	.	.	.	7085.8	0.44
1979	744	2nd (548)	.	.	.	.	1219.9	0.16	1070.2	0.14
1980	1379	2nd (1251)	.	.	.	.	6899.7	0.50	5072.0	0.37
1981	378	2nd (289)	.	.	.	.	315.0	0.08	218.5	0.06
1982	839	2nd (266)	.	.	1832.9	0.22	836.0	0.10	809.3	0.10
1983	1463	2nd (798)	.	.	7060.2	0.48	.	.	5179.0	0.35
1984	415	1st (324)	176.0	0.04	718.3	0.17	485.5	0.12	.	.
1985	603	1st (424)	508.6	0.08	725.1	0.12	.	.	.	.
1986	846	2nd (515)	1144.0	0.14	1340.7	0.16	.	.	.	.
1987	285	2nd (190)	88.3	0.03	121.3	0.04	.	.	.	.
1988	759	1st (336)	.	.	432.6	0.06	218.4	0.03	284.9	0.04
1989	531	1st (271)	327.8	0.06	437.8	0.08	183.3	0.03	132.0	0.02
1990	374	2nd (261)	59.6	0.02	53.2	0.01	.	.	30.6	0.01
1991	618	2nd (593)	.	.	709.3	0.11	358.1	0.06	522.8	0.08
1992	800	2nd (792)	.	.	.	.	.	.	.	.
1993	1566	2nd (1215)	.	.	.	.	.	.	.	.
1994	408	2nd (277)	148.0	0.04	.	.	132.0	0.03	.	.
1995	1284	2nd (1128)	4848.1	0.38	.	.	3272.6	0.25	4659.4	0.36
1996	689	2nd (632)	1553.8	0.23	1407.9	0.20	930.2	0.13	906.7	0.13

Table 1 (cont).

			Watershed							
	Rainfall		Bell1 (TC)		Bell2 (TC)		Bell3 (NC)		Bell4 (NC)	
Year	Total (mm)	Highest Quarter (mm)	Runoff $m^3\ ha^{-1}$	Runoff Ratio	Runoff $m^3\ ha^{-1}$	Runoff Ratio	Runoff $m^3\ ha^{-1}$	Runoff Ratio	Runoff $m^3\ ha^{-1}$	Runoff Ratio
1997	718	1st (408)	.	.	.	.	.	.	.	.
1998	1427	2nd (841)	.	.	5981.2	0.42	.	.	.	.
1999	347	2nd (144)	143.2	0.04	244.5	0.07	259.0	0.07	141.0	0.04
2000	511	2nd (382)	.	.	289.2	0.06	177.5	0.03	.	.

1960s and from Bell1 from the 1970s. Miscellaneous missing charts and equipment failures (pen problems, clock stoppages, and float problems) have created additional data gaps for all watersheds throughout the study period. Thus, only half the runoff years were available for analysis.

Average annual rainfall over the study period was 750 mm, slightly more than the mean for the 80-year record on the SDEF. For subsequent comparisons, annual rainfall was divided into three categories: high (> 150 percent of average or 1130 mm; n=8); low (< 50 percent of average or 380 mm; n=7); and normal (between 380 mm and 1130 mm; n=26).

Because of the disparity in watershed size, stream runoff was normalized by area for meaningful comparisons (Table 1). Additionally, the runoff ratio (Ratzlaff, 1994), or the percentage of rainfall that leaves the watershed as streamflow, was calculated. A runoff ratio is a commonly used metric in hydrologic studies to describe basic watershed behavior. For this study, runoff ratios ranged from 1 percent to 75 percent for all watersheds and all years, with an average of 14 percent. These values correspond well with other published runoff ratios for southern California watersheds (Burke et al., 2013; Kinoshita and Hogue, 2015).

There was a distinct difference in stream discharge associated with vegetation type. Both the normalized runoff and the runoff ratio were similar within the vegetation classes of type-converted grass (Bell1 and Bell2) and native chaparral (Bell3 and Bell4). However, considerably more water flowed from the grass watersheds than the chaparral (Table 1; Figure 3). This general trend confirms earlier studies at the SDEF and from similar areas in California and Arizona (Hill and Rice, 1963; Hibbert, 1971; Rich and Gottfried, 1976; Pitt et al., 1978) and supports the rationale for replacing deep-rooted shrub species with shallow-rooted grass to increase water yield (Rice et al., 1965). Higher water yield from grass-dominated watersheds suggests that extensive type conversion of southern California shrubland to grasses could substantially increase local water supplies. However, apart from the wholesale ecosystem changes and effects on native fauna, previous studies have shown that there are serious environmental consequences of type conversion, including increased erosion in the form of soil slips and slope failures (Rice et al., 1969) and degraded water quality (Riggan et al., 1985).

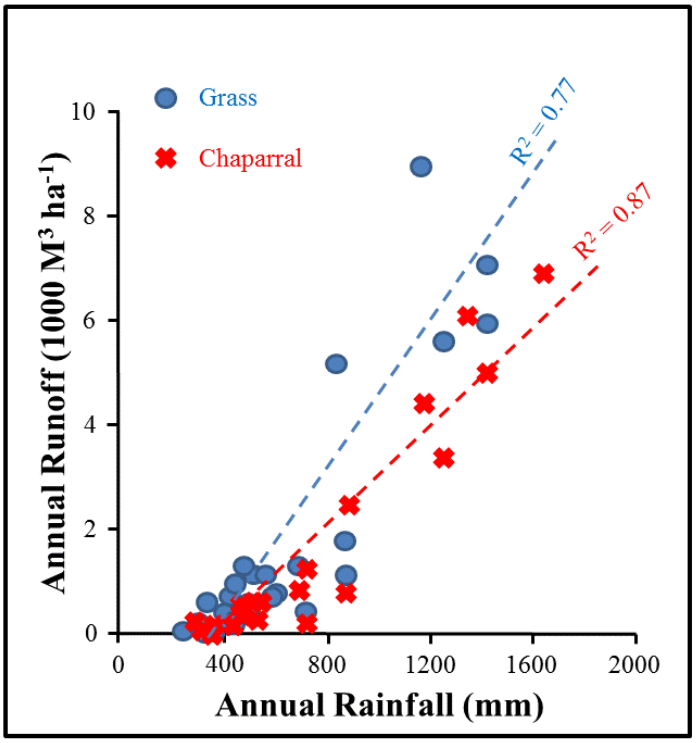

Figure 3 Runoff as a function of rainfall by vegetation type in the Bell Watersheds.

There is a good correlation between stream runoff and precipitation for both vegetation types (Figure 3). However, for the intermittent streams in Bell Canyon, heavy and protracted rainfall can produce streamflow throughout the entire year. In this case, rain from one year could continue to generate surface flow into the following year. This poses a problem with the runoff ratio (Table 1) in that flow is also affected by inter-annular antecedent conditions. So in Bell Canyon, when a high rainfall year is followed by a normal or even a low rainfall year, more runoff is produced in that following year than would otherwise be expected (in Table 1, compare 1968 with 1975 or 1976; compare 1981 or 1999 with 1987 or 1990). In contrast, a high rainfall year is always associated with high runoff, no matter what the prior conditions (1978 or 1995). Therefore, there is a lag in stream discharge from a previous high rainfall year that can enhance flow in the subsequent year.

Another factor that may affect streamflow is the distribution of rain storms throughout the year. Except under the high rainfall lag condition mentioned above, intermittent streams require early season storms to saturate the soil mantle before flow is generated by later storm events. Rainfall amounts for the highest three-month period for each year in Bell Canyon are shown in Table 1. Of the 41 hydrologic years of record, the greatest rain was received 28 times in the second quarter (Jan. to Mar.), 12 times in the first quarter (Oct. to Dec.), and once in the third quarter (Apr. to June). For low rainfall years, low runoff was produced no matter when the rain fell. Similarly, for high rainfall years, the distribution of rain was not a factor in generating the high flows. However, for more average rainfall conditions, those years that had wet second quarters generally produced higher amounts of runoff compared to those years with wet first quarters (in

Table 1, compare 1974, 1976, 1982, and 1991 with 1971, 1975, 1985, 1988, and 1989). Therefore, in normal rainfall years, the timing of storms can affect the amount of streamflow.

SUMMARY

The prospects of reduced rainfall resulting from global climate change and the potential unreliability of large conveyance projects have made future water supplies in southern California uncertain, prompting a renewed interest in developing local sources. One potential source is the intermittent streamflow from the canyons of the local mountains. Long-term research from the San Dimas Experimental Forest in the San Gabriel Mountains shows that stream runoff is strongly correlated with rainfall amounts and that this flow is mildly enhanced when major storms occur later in the rainy season. Streamflow is also greater than expected the year following heavy rains, as a lag component of the high rainfall carries over to the subsequent year. More water is produced from catchments that have been type-converted to grasses than from native chaparral shrublands, presumably reflecting the rooting depth and water demand of the different vegetation classes. While it is tempting to recommend future type-conversion to increase water yield, this must be balanced by the wholesale ecosystem changes and the negative environmental consequences associated with this method of vegetation change.

REFERENCES

Burke, M.P., Hogue, T.S., Kinoshita, A.M., Barco, J., Wessel, C., and Stein, E.D. (2013). "Pre- and post-fire pollutant loads in an urban fringe watershed in southern California," Environmental Monitoring and Assessment, 185(12), pp. 10131-10145.

Cayan, D.R., Maurer, C.P., Dettinger, M.D., Tyree, M., and Hayhoe, K. (2008). "Climate change scenarios for the California region," Climatic Change, 87(Supplement 1), pp. S21-S42.

Corbett, E.S., and Green, L.R. (1965). "Emergency revegetation to rehabilitate burned watersheds in southern California," Research Paper PSW-22, USDA Forest Service, Berkeley, CA.

Dunn, P.H., Barro, S.C., Wells, W.G., II, Poth, M.A., Wohlgemuth, P.M., and Colver, C.G. (1988). "The San Dimas Experimental Forest: 50 years of research," General Technical Report PSW-104, USDA Forest Service, Berkeley, CA.

Environmental Protection Agency. (2013). "Climate impacts in the Southwest," http://www.epa.gov/climatechange/impacts-adaptation/southwest.html.

Freeman, G. (2008). "Securing reliable water supplies," Los Angeles County Economic Development Corporation. 19 p.

Hibbert, A.R. (1971). Increases in streamflow after converting chaparral to grass," Water Resources Research, 7(1), pp. 71-80.

Hill, L.W. and Rice, R.M. (1963). "Converting from brush to grass increases water yield in southern California," Journal of Range Management, 16(6), pp. 300-305.

Kinoshita, A.M. and Hogue, T.S. (2015). "Increased dry season water yield in burned watersheds in southern California," Environmental Research Letters, 10(1) DOI 10.1088/1748-9326/10/1/014003.

Meisen, P. and Phares, N. (2011). "Impacts of climate change on California's water supply," Global Energy Network Institute. 47 p.

Nelson, B. (2012). "Southern California's new wave of local water supplies," http://switchboard.nrdc.org/blogs/bnelson.

Pitt, M.D., Burgey, R.H., and Heady, H.F. (1978). "Influences of brush conversion and weather patterns on runoff from a northern California watershed," Journal of Range Management, 31(1), pp. 23-27.

Ratzlaff, J.R. (1994). "Mean annual precipitation, runoff, and runoff ratio for Kansas, 1971-1990," Transactions of the Kansas Academy of Science, 97, pp 94-101.

Rice, R.M., Corbett, E.S., and Bailey, R.G. (1969). "Soil slips related to vegetation, topography, and soil in southern California," Water Resources Research, 5(3), pp. 647-659.

Rice, R.M., Crouse, R.P., and Corbett, E.S. (1965). "Emergency measures to control erosion after a fire on the San Dimas Experimental Forest," U.S. Department of Agriculture, Miscellaneous Publication 970, pp 123-130.

Rich, L.R. and Gottfried, G.F. (1976). "Water yields resulting from treatments on the Workman Creek experimental watersheds in central Arizona," Water Resources Research, 12(6), pp. 1053-1060.

Riggan, P.J., Lockwood, R.N., and Lopez, E.N. (1985). "Deposition and processing of airborne nitrogen pollutants in Mediterranean-type ecosystems in southern California," Environmental Science and Technology, 19(9), pp. 781-789.

Wohlgemuth, P.M. (2006). "Hillslope erosion and small watershed sediment yield following a wildfire on the San Dimas Experimental Forest, southern California," Proceedings of the 8th Federal Interagency Sedimentation Conference, Reno, NV, Interagency Advisory Committee on Water Data, Subcommittee on Sedimentation, Washington, D.C.