LONG-TERM FOREST WATERSHED STUDIES IN THE SOUTHWEST: RECYCLED FOR WILDFIRE AND PRESCRIBED FIRE

Daniel G. Neary[1], Gerald J. Gottfried[2], Peter F. Ffolliott[3], and Boris Poff[4]

A hydrologic research network was established in Arizona in the 1950s and 1960s called the Arizona Watershed Program (Baker et al. 1999). It consisted of a number of public agencies and private groups interested in obtaining more water for future economic growth while maintaining the State's watersheds in good condition. As part of the Program, paired watershed studies were established at Workman Creek, Three-Bar, Whitespar, Mingus Mountain, Battle Flat, Beaver Creek, Castle Creek, Willow Creek, Thomas Creek, Seven Springs, and Stermer Ridge. Initially, most of the research emphasis was on water yield and silvicultural manipulations to increase streamflow for large water supply reservoirs. In the early 1980s the active data collection on 43 watersheds was shut down, but most of the gauging structures remained in-place. By the mid-1990s, wildfire area and severity increased an order of magnitude, and prescribed fire was reintroduced into Southwest forests to reduce fuel loads that were contributing to the increases in wildfire (DeBano et al. 1998). Concerns were raised about the effects of fire on water yield and water quality since little information was available on fire effects (Neary et al. 2005). Starting in 2000, a series of wildfires progressively burned over some of the Arizona Watershed Program watersheds. That year, the Coon Creek Fire burned over the Workman Creek four watersheds in the Sierra Ancha Experimental Forest on the Tonto National Forest (Gottfried and Neary 2001, 2002, 2003; Neary and Gottfried 2002). In 2002, the very large, landscape-scale Rodeo-Chediski Fire burned the Stermer Ridge watersheds on the Apache-Sitgreaves National Forest. The even larger Wallow Fire of 2011, also on the Apache-Sitgreaves National Forest, burned all or parts of Willow Creek, Castle Creek, Thomas Creek, and Seven Springs watersheds.

These and other watersheds were then re-activated in a second cycle of watershed science aimed at developing information on watershed response to wildfires (Neary et al. 2005, Poff et al. 2012). In addition, large scale restoration initiatives underway or planned for the ponderosa pine forests of the Mogollon Rim and White Mountains incorporate prescribed fire or prescribed natural fires as part of landscape fuel management strategies (Fule et al. 2001, Brown et al. 2004.

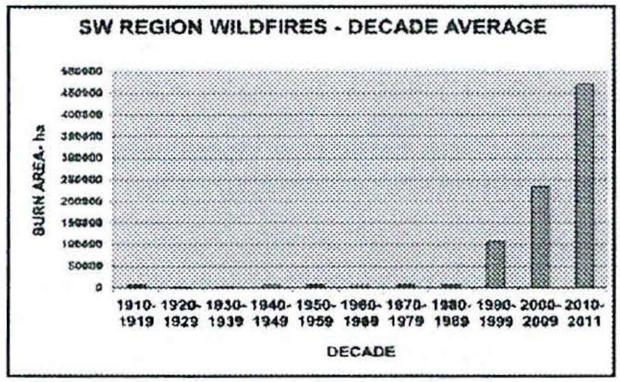

Figure 1. Decade average wildfire area in the Southwest from 1910 to 2011 (Source: Southwest Coordination Center 2012).

MEGA FIRES

The Southwest USA and other parts of the West moved into an era of "Mega Fires" not experienced since the beginning of the 20th Century (Williams and Hamilton 2005). These fires are considered landscape fires that exceed 30,000 ha in size and present great difficult in controlling. Prior to the decade starting in 1990, the area of wildfires in the Southwest averaged <7,500 ha/year (Figure 1). Fire reached an ecological "tipping point" in 1990 because of increasing fuel loads and wide-spread drought. The decadal average wildfire area increased in the last decade to 107,244 ha. It more than doubled in the first decade of the 21st Century to 234,723 ha, and, based on the first two years of the second decade (2010 and 2011) doubled again to 468,8076 ha. These fires, besides being larger in area, frequently have areas of high severity that exceed 10% of the burned area. The environmental consequences are increased soil erosion, watershed

1. USDA Forest Service, Rocky Mountain Research Station, Flagstaff, Arizona
2. USDA Forest Service, Rocky Mountain Research Station, Phoenix, Arizona
3. School of Natural Resources, University of Arizona, Tucson, Arizona
4. USDI Bureau of Land Management, Las Vegas, Nevada

Table 1: Summary of watersheds current instrumented with proposed treatments

Watershed	Area – ha	Proposed Treatment
9	454	Thin 22%, Burn 33%
11	76	Burn 100%
12	184	Burn 100%
13	368	Control
14	546	Thin 55%, Burn 100%

Other gauged Beaver Creek watersheds include 19, 20 and 85 - 87. These watersheds create new treatment opportunities (or they are just waiting for the next wildfire.)

Table 2: Summary of watersheds currently instrumented without proposed treatments

Watershed	Area – ha	Operated since
19	4884	Since 1962
20	6662	Since 1962
85	62	1970/71; Since 2003
86	40	1970/71; Since 2003
87	22	1970/71; Since 2003

function degradation, floods, and negative impacts on municipal water supplies (Neary et al. 2012).

ARIZONA WATERSHED PROGRAM

Background

In the mid-1950s, some of the local ranchers and State and Federal natural resource managers noticed that were a lot more trees around than at the turn of the 20th Century (Baker et al. 1999). The region had also just come out of a multi-year drought that had been preceded by a rather long wet period in the 1940s. Hence, questions were being raised about a possible connection between the amount of trees on the landscape and the amount of water available for livestock and people. This was early recognition of the growing forest fuels problem that was not recognized for the threat that it is until the 1990s (Graham et al. 2004). The ranchers and managers realized that there was very little scientific information on water use and production in Arizona's forests. There was strong consensus that this situation needed to change by establishing a research program to understand use of water by vegetation, the potential to increase water yield by manipulating vegetation, and the effects of the Southwest climate on water supplies. This was the beginning of the Arizona Watershed Program. State officials and Federal agencies (USDA Forest Service, USDI Geological Survey, which already had a strong research presence in Arizona) came up with numerous experimental watershed study approaches to investigate how the landscape could be manipulated in order to harvest more water of Arizona. In Arizona and the Southwestern US forest watersheds supply majority of the public water supply (70-90%). Forested watersheds have consistent flow, high quality water and are mostly on public land (USFS). The majority of this water comes in the form of snowmelt as is the case in most of the western USA.

Paired Watersheds of the Arizona Watershed Program

Sierra Ancha (1932-1983; 2000 - present): This is the oldest experimental watershed study in Arizona and was established on the Sierra Ancha Experimental Forest within the Tonto National Forest. There were three sets of gaged watersheds: Parker Creek, Natural Drainages and Workman Creek (Gottfried et al. 1999a). Parker Creek has a USDI Geological Survey gaging site. The Workman Creek watersheds sizes range from 100 to 211 ha and were the main sites for studying the effects of vegetation management. The vegetation types range from chaparral to mixed conifer. The treatment methods differed depending on vegetation type. A wildfire occurred in the Workman Creek watersheds in 2000. Short term increases in water yield were produced.

Beaver Creek (1955 – Present): The most extensive set of experimental watersheds created in Arizona is the Beavercreek Experimental Watershed, consisting of 20 paired watersheds and several additional sub-watersheds, of which several are still in operation today (Baker et al. 1999). Watershed sizes range from 22 – 6662 ha. Within these past research activities focused on several silvicultural and natural forest management options. Three levels of overstory removal (33-100%) were used and three levels of strip-cuts (31-68%) within the Beaver Creek basin. Water yield increases were statistically significant, 15-45%, but lasted less than 3-7 years. These were mostly one-time treatments and none of the treatments involved prescribed fire (Baker, 1986).

Stermer Ridge (1976-1980; 2002-2010): Auxiliary watersheds (30 ha in size) for the Beaver Creek study were established in sandstone terrain at Stermer Ridge on the Apache-Sitgreaves National Forest. Since the Beaver Creek watersheds were all on basalt-derived soils, Stermer Ridge was added to compare and contrast the effects of geology and soil on vegetation treatments. These watersheds were later burned over by the Rodeo-Chediski Fire of 2002, providing an opportunity to contrast the impacts of high severity fire with low severity fire on runoff, soil erosion, vegetation, and fauna (Neary and Gottfried 2002, Ffolliott and Neary 2003).

Rattle Fire Watersheds (1972-1975): These watersheds (4-18 ha) were established specifically to look at the ecosystem effects of the 290 ha Rattle Fire (Campbell et al. 1977). The watersheds are on the Coconino National Forest and in close proximity to the Beaver Creek watersheds. The Rattle Fire study was operated as an auxiliary study to Beaver Creek and at the time was the only wildfire-related study in the Arizona Watershed Program. It provided an opportunity to study the ecosystem effects of high severity fire and moderate severity fire compared to an unburned watershed. Some other watersheds had wildfires (Three Bar), but the Rattle Fire ones were the only catchments used for specific fire effects studies during the Arizona Watershed Program's existence rather than fire as a vegetation control treatment. There was a 3.5-fold increase in average annual storm flow discharge from the severely burned Rattle Fire watershed. In the moderately burned watershed, there was a 2.3-times increase in average annual storm flow discharge. In comparison to the moderately burned watershed, the average runoff efficiency on the severely burned watershed was 357 percent greater when precipitation input was rain and 51 percent less in snowmelt periods. Observed differences were largely due to the lower tree density, a greater reduction in litter cover and more extensive formation of hydrophobic soils (Campbell et al. 1977).

Three Bar (1956 - 1982): Three Bar consists of five watersheds (A – F) that range from 10 to 39 ha in size (Hibbert and Scholl 1974, DeBano et al. 1999a). The vegetation is chaparral. High-density chaparral to grassland conversions using herbicides were evaluated for an increase in water yield. The evaluation showed only short-term increase in water yield. While hydrologic evaluations on the watersheds ceased in 1982, wildlife studies and monitoring are still being conducted.

Whitespar (1958 – 1982): The two watersheds involved within the Whitespar study are watersheds A and B, at 121 and 101 ha respectively (DeBano et al. 1999b). The vegetation consists of chaparral and treatment consisted of high density chaparral conversion (15%). The hydrology results were an increase in amount and duration of streamflow. The research conducted at Whitespar was carried out to supplement the work conducted at the Three Bar watersheds.

Mingus Mountain (1960 – 1982): The Mingus Mountain watersheds are in the Prescott National Forest and consist of three catchments: Watershed A (39 ha) was treated with a prescribed burn, watershed B (27 ha) was treated chemically, and watershed C (18 ha) was the control (DeBano et al. 1999b). The vegetation is chaparral and different methods of low density chaparral conversions were used. After treatment a short-term increase in water yield occurred. The magnitude of response was similar to that measured on the low precipitation watersheds on the Sierra Ancha Experimental Forest.

Battle Flat (1975-1986): Battle Flat has two watersheds, Battle Flat Creek at 889 ha and Tuscumbia Creek at 650 ha (DeBano et al. 1999b). The vegetation consists of chaparral and was scheduled to be treated with herbicides to study their environmental fate in chaparral ecosystems. The project was postponed indefinitely due to political and legal constraints surrounding the widespread use of herbicides and then finally cancelled . However, some research was conducted and the results supplemented findings from previous research on chaparral watersheds

Castle Creek (1962 – 1982): Castle Creek is in the

Apache-Sitgreaves National Forest has two watersheds, East Fork at 470 ha and West Fork at 365 ha (Gottfried et al. 1999b). The vegetation is predominantly ponderosa pine with some oak. The treatment was thinning and resulted in short term increase in water yield. Further studies included snow effects, sediment yield and treatment effects on wildlife (squirrels).

Thomas Creek (1962 – 1991; 2011 - Present): Thomas Creek, also in the Apache-Sitgreaves National Forest, has two watersheds: North Fork at 189 ha, which is considered the control, and South Fork at 227 ha which was thinned (Gottfried et al. 1999b). The vegetation consists of mixed conifer forest. The treatment includes 63 small patch clearcut and group selection openings, averaging 0.5 – 1 ha, over 13% of the South Fork watershed. The overall stand density was reduced by 34%. Eight years of post-treatment evaluation showed increasing water yields and stand growth while incurring adequate regeneration. It has also benefited many wildlife species as well as livestock.

Willow Creek (1962-1980; 2011 – Present): The Willow Creek study was another paired watershed investigation of the hydrologic effects of overstory removal and timber selection (Gottfried et al. 1999b). It consisted of two watersheds (East Fork – 198 ha and West Fork – 117 ha) in mixed conifer forest at high altitude (2,680 – 2,835 m). The vegetation treatment was similar to that applied to the West Fork of Castle Creek. It was designed to bring the basal area level to optimum stocking primarily by removing mature, over-mature, defective, damaged, and high risk trees.

Seven Springs (1964 – 1980): Seven Springs is another watershed study in the Apache-Sitgreaves National Forest (Gottfried et al. 1999b). It consists of two watersheds: East Fork at 303 ha and West Fork at 195 ha. Seven Springs is considered high elevation grassland and was treated by thinning. There is potential for increased water yield if snow could be held where it falls. It may be possible to establish tree windbreaks in the grassland by altering the microclimate during establishment, and introducing mycorrhizae with the planted seedlings. This conclusion is supported by good survival in a 2-year planting trial.

WILDFIRE BURNED WATERSHEDS

Starting in 2000, a series of wild fires has burned over a number of the Arizona Water Program watersheds. The 9,600 ha Coon Creek Fire struck the Workman Creek watersheds on the Sierra Ancha Experimental Forest in 2000 (Gottfried and Neary 2001, 2002; Neary and Gottfried 2002). Two years later (2002), parts of the 183,000 ha Rodeo-Chediski Fire burned over the Stermer Ridge watersheds (Ffolliott and Neary 2003, Garcia et al. 2005, Stropki et al. 2006). In 2011, the larger Wallow Fire (217,741 ha) on the Apache-Sitgeaves National Forest burned through Castle Creek, Seven Springs, Thomas Creek, and Willow Creek. Three Bar was burned during the Edge Complex Fire in 2005. That leaves only four of the original Arizona Watershed Program study sites (Battle Flat, Beaver Creek, Mingus Mountain, and Whitespar) that have not been impacted by wildfire since 2000. The Gladiator Fire in 2012 burned close to the Battle Flat watersheds, which are primed for a wildfire and lacking only an ignition source.

PLANNED PRESCRIBED FIRE ON WATERSHEDS – BEAVER CREEK

New treatments proposed watersheds 9, 11,12, and 14 are listed in Table 1: Watershed 9, thin 22% and burn 33%; Watershed 11, burn 100%; Watershed 12 burn 100%; Watershed 13 remains the control and Watershed 14, thin 55% and burn 100%.

SUMMARY AND CONCLUSIONS

Watersheds gauged during the Arizona Watershed Program (1950s to 1980s) or before 1950 have provided a valuable resource for evaluating the landscape effects of wildfires. Fire never played much of a role as a silvicultural treatment in the early watershed research. Some fire research was conducted on the Battle Flat watersheds (Campbell et al. 1977) and at Sierra Ancha (Hendricks and Johnson 1944). However the rapid increase in burned areas starting in the 1990s, raised a lot of concern about impacts on watershed function, erosion, and flooding and inspired a lot of new research. A number of legacy watersheds are available for new research on prescribed fires and will certainly be valuable for the new Four Forests Restoration Initiative.

REFERENCES

Baker, M.B. Jr., (Comp.), History of Watershed Research in the Central Arizona Highlands, USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-29, 63 pp.

Baker, M.B. Jr.; Ffolliott, P.F. 1999. Chapter 5: Interdisciplinary land use along the Mogollon Rim. Pp. 27-34. In: Baker, M.B. Jr., (Comp.), History of Watershed Research in the Central Arizona Highlands, USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-

GTR-29, 63 pp.

Brown, T.T.; Agee, J.K.; Franklin, J.F. 2004. Forest restoration and fire: Principles in the context of place. Conservation Biology 18: 903-912.

Campbell, R. E., Baker Jr., M.B., Ffolliott, P.F., Larson, F.R., Avery, C.C. (1977) Wildfire effects on a ponderosa pine ecosystem. USDA Forest Service Research Paper RM-191. Fort Collins CO: Rocky Mountain Forest and Range Experiment Station.

Ffolliott, P.F.; Neary, D.G. 2003. Impacts of a historical wildfire on hydrologic processes: A case study in Arizona. Proceedings of the American Water Resources Association International Congress on Watershed Management for Water Supply Systems, New York, NY, June 29 – July 2, 2003. CD-ROM.

DeBano, L.F.; Baker, M.B. Jr.; Gottfried, G.J. 1999a. Chapter 3: Providing water and forage in the Salt-Verde River Basin. Pp. 13-18. In: Baker, M.B. Jr., (Comp.), History of Watershed Research in the Central Arizona Highlands, USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-29, 63 pp.

DeBano, L.F.; Baker, M.B. Jr.; Overby, S.T. 1999. Chapter 4: Managing chaparral in Yavapai County. Pp. 19-25. In: Baker, M.B. Jr., (Comp.), History of Watershed Research in the Central Arizona Highlands, USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-29, 63 pp.

Ffolliott, P.F.; Neary, D.G. 2003. Impacts of a historical wildfire on hydrologic processes: A case study in Arizona. Proceedings of the American Water Resources Association International Congress on Watershed Management for Water Supply Systems, New York, NY, June 29 – July 2, 2003. CD-ROM.

Fule, P.F.; McHugh, C.; Heinlein, T.A.; Covington, W.W. 2001. Potential fire behavior is reduced following forest restoration treatments. Pp. 28-35 In: USDA Forest Service Proceedings RMRS-P-22.

Garcia, P.; Ffolliott, P.F.; Neary, D.G. 2005. Soil erosion following the Rodeo-Chediski wildfire: an initial assessment. Hydrology and Water Resources in Arizona and the Southwest 34:51-56. Gottfried, G.J.; Neary, D.G. 2001. History of the Workman Creek watersheds, Sierra Ancha Experimental Forest, Arizona. In: Proceedings of the 2000 National Convention, Society of American Foresters, November 16-20, Washington, D.C. Pp. 454-458.

Gottfried, G.J.; Neary, D.G. 2002. Hydrology of the Upper Parker Creek Watershed, Sierra Ancha Mountains, Arizona. Water Resources in Arizona and the Southwest 32:5-18.

Gottfried, G.J.; Neary, D.G. 2003. Preliminary assessment of sediment measurements at weir basins following the Coon Creek Fire in central Arizona. Hydrology and Water Resources in Arizona and the Southwest 33: 103-111.

Gottfried, G.J.; DeBano, L.F.; Baker, M.B. Jr. 1999a. Chapter 2: Beginning of water studies in the Central Arizona Highlands. Pp. 7-11. In: Baker, M.B. Jr., (Comp.), History of Watershed Research in the Central Arizona Highlands, USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-29, 63 pp.

Gottfried, G.J.; DeBano, L.F.; Ffolliott, P.F. 1999b. Chapter 6: Creating a basis for watershed management in high elevation forests. Pp. 35-41. In: Baker, M.B. Jr., (Comp.), History of Watershed Research in the Central Arizona Highlands, USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-29, 63 pp.

Graham, R.; McCaffrey, S.; Jain, T. (2004). Science basis for changing forest structure to modify wildfire behavior and severity. USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-120, 43 pp.

Hendricks, B.A.; Johnson, J.M. 1944. Effects of fire on steep mountain slopes in central Arizona. Journal of Forestry 42:568-571.

Hibbert, A.R.; Scholl, D.G. 1974. Chaparral conversion potential in Arizona Part I: Water yield response and effects on other resources. USDA Forest Service Research Paper RM-126. Fort Collins CO: Rocky Mountain Forest and Range Experiment Station.36 p.

Neary, D.G.; Gottfried, G.J. 2002. Fires and floods: post-fire watershed responses. Pp. 203 and Pp. 1-9 in CD version of complete papers. In: Viegas, D.X. (ed.) Forest Fire Research and Wildland Fire Safety, Proceedings of the 4th International Forest Fire Research Conference, Luso, Portugal, 18-22 November 2002. Mill Press, Rotterdam.

Neary, D.G.; Koestner, K.A.; Youberg, A.; Koestner, P.E.

2012. Post-fire rill and gully formation, Schultz Fire 2010, Arizona, USA. Geoderma 191: 97-104.

Poff, B.; Neary, D.G.; Henderson, V.; Tecle, A. 2012. The hidden treasures of long-term paired watershed monitoring in the forests of Arizona. Pp. 42-48. In: Webb, A.A.; Bonell, M.; Bren, L.; Lane, P.N.J.; McGuire, D.; Neary, D.G.; Nettles, J.; Scott, D.F.; Stednick, J.D.; Wang, Y. (eds.).International Association of Hydrological Sciences Book, Proceedings of the Workshop "Revisiting Experimental Catchment Studies in Forest Hydrology", 2011 International Union of Geodesy and Geophysics XXV General Assembly, Melbourne, Australia, July 6-8, 2011.

Southwest Coordination Center. 2012. USDA Forest Service, Fire and Aviation Management, Albuquerque, New Mexico. Accessed 12-12-12. http://gacc.nifc.gov/swcc/predictive/intelligence/ytd_historical/historical/historical_fires_and_acres.htm

Stropki, C.L.; Ffolliott, P.F.; DeBano, L.F.; Neary, D.G. 2006. Water repellent soils on the Stermer Ridge watersheds following the Rodeo-Chediski wildfire: A preliminary assessment. Hydrology and Water Resources in Arizona and the Southwest 34:47-50