AN ABSTRACT OF THE DISSERTATION OF

Timothy L. Deboodt for the degree Doctor of Philosophy in Rangeland Ecology and Management presented on May 8, 2008.

Title: Watershed Response to Western Juniper Control

Abstract approved by: ____
John C. Buckhouse

Western juniper (*Juniperus occidentalis)* encroachment has been associated with increased soil loss and reduced infiltration resulting in the loss of native herbaceous plant communities and the bird and animal species that rely on them. Hydrologically, however, change in water yield has been linked with the amount of annual precipitation a site received. Studies published in the 1970's and 1980's, suggest that a minimum 4500 mm (18 inches) of annual precipitation was necessary before an increase in water yield manifested itself following vegetation manipulation. In 1993, a paired watershed study was initiated in the Camp Creek drainage, a tributary of the Crooked River of central Oregon, to evaluate the impacts of cutting western juniper on the hydrologic function of those sites. The study involved a paired watershed approach using watersheds of approximately 110 hectares (270 acres) each to evaluate changes in a system's water budget following the reduction of western juniper. The 30 year average annual precipitation for the area is 3500 mm (13.75) and during the study period, annual precipitation ranged from 80 percent to 129 percent of average.

In 2005, following 12 years of pretreatment monitoring in the 2 watersheds (Mays and Jensen) all post-European aged juniper (juniper < 140 years of age) were cut from the treatment watershed (Mays). Analysis indicated that juniper reduction significantly

increased late season spring flow by 225 percent (alpha > .05), increased days of recorded ground water by an average of 41 days (alpha > .05) and increased the relative availability of late season soil moisture at soil depths of .76 m (27 inches) (alpha > 0.1).

Ephemeral channel flow did not show a predictable trend during 2 years of post treatment measurements.   Channel flow is dependent on spring snow melt and severe summer thunderstorm activity. When winter soils were greater than 0 degrees Celsius (32 degrees F), the source of channel flow in Mays was observed to be seepage from the channel banks. Channel flow in Jensen appeared to be a result of rock forcing subsurface flows to the surface.

Vegetative responses showed significant increases in perennial forb canopy cover (alpha > .01) and annual forb and annual grass basal cover (alpha > .05). Increases were also found in reduction of percent bare ground and increase in shrub cover, but were not significant. A statistically insignificant decrease in perennial grass cover was noted in the treated watershed however a large amount of reproductive culms were noted in the treated watershed in 2007 compared to the control watershed.

Hillslope erosion and channel morphology showed no predictable trend following treatment. Inherent differences in channel morphology between the two watershed prior to treatment existed. This difference may be a product of the two channels being at different evolutionary or successional stages relative to each other and thus indicating that channel recovery would be different for each watershed.

The Camp Creek project illustrated that for this system, managing vegetation for water yield may be obtainable at a much lower precipitation threshold than what was previously reported in the literature.

Watershed Response to Western Juniper Control

by

Timothy L. Deboodt

A DISSERTATION

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APPROVED:

Major Professor, representing Rangeland Ecology and Management

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Dean of the Graduate School

I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Timothy L. Deboodt, Author

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TABLE OF CONTENTS

Page

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF FIGURES

Figure Page

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF APPENDICES

WATERSHED RESPONSE TO WESTERN JUNIPER CONTROL

INTRODUCTION

PROJECT SUMMARY

According to U.S. Forest Service publication PNW-RB-249, *The Western Juniper Resource of Eastern Oregon*, western juniper's dominance on eastern Oregon rangelands has increased significantly since 1934 (Azuma et al. 2005). Azuma et al., (2005) estimated that land occupied by western juniper has increased from 1.5 million to 6.5 million acres since the 1930s. Implications of this increase include loss of native, herbaceous plant communities and the bird and animal species that rely on them, increased soil loss, and reduced water infiltration. Based on water use models for individual trees, the U.S. Forest Service estimated that mature western juniper tree densities, ranging from 9 to 35 trees per acre, are capable of utilizing all of the available soil moisture on a given site in a 13 inch precipitation zone (Gedney et al. 1999). Soil erosion rates from sites with higher than the natural range of variability for western juniper cover were an order of magnitude greater than similar sites that are within the natural range of cover (Buckhouse and Gaither 1982). Research has shown that junipers did increase soil loss rates due to the associated decline in herbaceous ground cover and elevated surface runoff (Buckhouse and Gaither 1982; Bates et al. 2005). The juniper canopy intercepts rain and snow, keeping it from reaching the ground thus making it unavailable for plant growth, stream flow, or groundwater recharge; and they consume large amounts of soil moisture. Previous monitoring of juniper control projects has focused on changes in vegetative composition and productivity (Bates et al. 2005). These studies have usually not monitored the hydrologic impacts of western juniper control.

This project was unique in that it involved a paired study approach to monitoring changes in a watershed's water budget following western juniper control. The value of a paired watershed study is that the impacts of the treatment can be compared to the untreated watershed. This study was unique in that it is the only long-term study of western juniper ecosystems of its kind in the Pacific Northwest. Because of the time and expense in monitoring treatment responses at the watershed level, such watershed comparison studies are rarely undertaken. Similar studies in different ecological and climatic zones have been conducted in Wyoming, Utah, Colorado and Arizona (Sturges 1994, McCarthy and Dobrowolski 1999, Bosch and Hewlett 1982) but no paired watershed studies have been implemented in western juniper ecosystems.

PROJECT DESCRIPTION

The Camp Creek Paired Watershed study was initiated in 1993 to study the effects of western juniper removal on sediment yield, water yield and vegetative conversion (Fisher 2004). Two watersheds, Mays and Jensen were identified in the Camp Creek drainage, a tributary of the Crooked River, Deschutes River Basin. Mays and Jensen were named for the original homesteaders in the area. The study area was created with the primary intent of calibrating and monitoring two watersheds for a period of time for the purpose of understanding the comparative relationships of vegetation, geomorphic and hydrologic parameters prior to treatment. Pretreatment monitoring and analysis occurred from 1994 through 2004 (Fisher 2004).

Project History:

This project was initiated as part of a 3 state effort funded by an Environmental Protection Agency (EPA) grant to look at arid land hydrologic issues in Oregon, Nevada, and California. In 1993, the Mays and Jensen watersheds were selected and monitoring of various attributes commenced. Each watershed was delineated on the upper bounds by its ridge-tops and the lower ends designated by the placement of a channel flume. Mays watershed is approximately 113 hectares and Jensen is approximately 106 hectares.

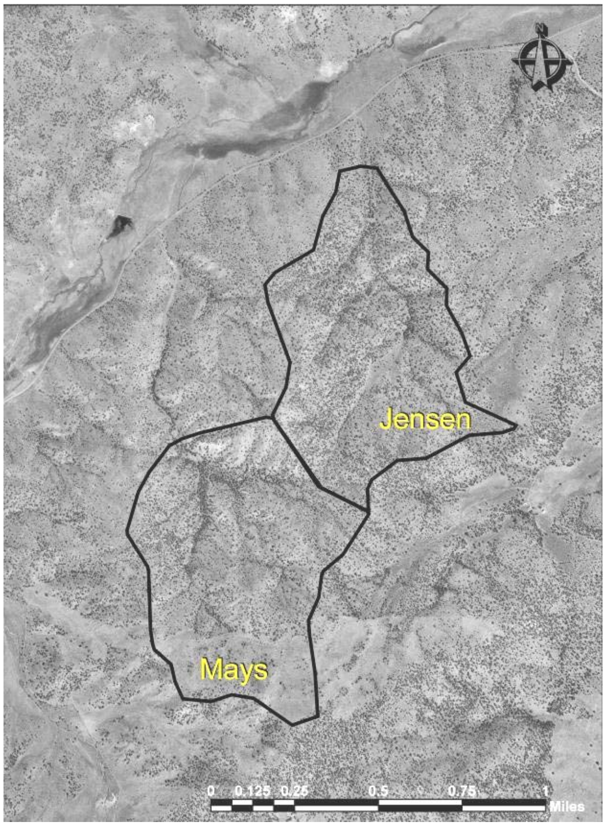

Figure 1. Aerial photograph of project area, 2004

The watersheds are located on the west branch of Camp Creek. Fourteen to twenty-five percent of each watershed was under private ownership and the remaining part study area is public land under the management of Prineville District, Bureau of Land Management (BLM) (Table 1).

Table 1. Federal versus Private Ownership of the Study Area

Mays	75% BLM	25% Private
Jensen	86% BLM	14% Private

The general orientation of both watersheds is to the north. Livestock grazing occurred in the project area and was administered by BLM under the guidance of the Brothers-La Pine Resource Management Plan (RMP)(Figure 2).

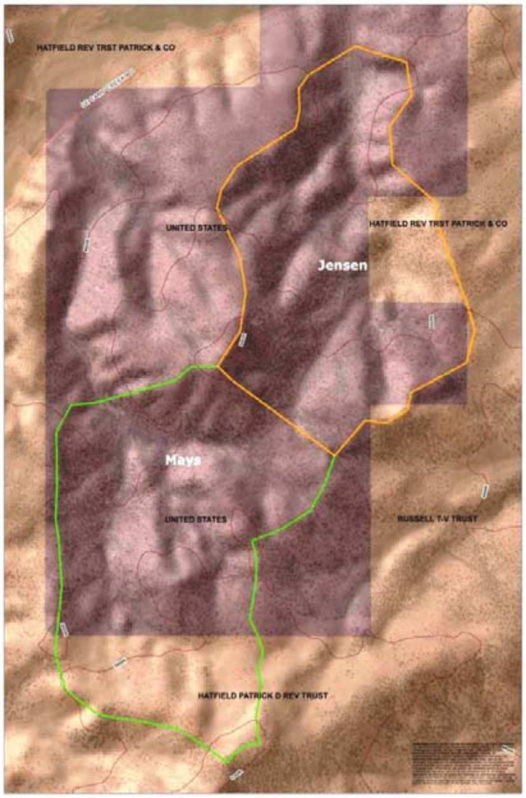

Figure 2. Ownership of Project Area

Pretreatment monitoring of the area occurred from 1993 to 2004. Monitoring parameters were vegetation composition, hillslope soil movement, and channel morphology and flow. Precipitation was collected onsite and weather data was compared with Barnes Station, a USGS weather station located approximately 10 miles east of the project area. Fisher (2004) analyzed the comparative similarities and differences between the two watersheds. These comparisons provided the basis for analyzing post-treatment effects. As a result of pre-treatment analysis, additional parameters were added to the data collection protocol; the monitoring of relative soil moisture, spring flow, and the sub-surface distance to ground water were added in 2003.

PROJECT SITE DESCRIPTION

Location

The project site is located approximately 65 miles southeast of Prineville, Oregon. Mays and Jensen watersheds are tributaries to the west branch Camp Creek, a tributary of the Crooked River, a sub-basin within the Deschutes River Basin. The study area is located within Section 32 and 33, T18S, R20E and Section 5, T19S, R20E Willamette meridian. The area is located at the southern end of the John Day Ecological Province (Anderson et al. 1998). The project site varied in elevation from 1370 meters to 1524 meters and the 30 year annual precipitation (1971 – 2000) at Barnes Station was 3500 mm. Sixty percent of the precipitation occured from October through March with only 25 percent falling during the growing season of April – June (Oregon Climate Service). Temperatures range from mean daily maximum of 30 degrees Celsius in August to mean minimum low of -7 degrees Celsius in February, with extremes recorded of 39 degrees Celsius and -34 degrees Celsius.

Soils

Fisher (2004) found there were no published soil surveys for the study area. Fisher worked with area BLM soil scientists to classify soils in the study area. Three (3) primary soil series, Westbutte, Madeline, and Simaton were defined. Several other soil series were noted but found to be in relatively minor amounts. Westbutte very stony loam and Madeline loam, the two primary soil types, were found to make up approximately 70 - 74 percent of the study area (Fisher 2004). Simaton gravelly silt accounted for the balance. The Westbutte series was derived from weathering lava rock and was found on predominately north facing slopes of 3 – 30 percent. The Madeline series has a rooting depth of 30 – 50 cm and a greater potential for runoff and erosion when compared to Westbutte. Simaton (gravelly silt loam) is a highly erosive soil. Fisher (2004) reported that Simaton series contained a higher degree of clay when compared to the other series. The soils in Jensen contained a higher percentage of Simaton soils series when compared to Mays. Madeline soil series was found to make up a large portion of the upper end of Jensen (Table 2). Mays watershed contained a high percentage of Westbutte soil series which was less prone to erosion.

Table 2. Soil series classification by percentage of total area in each watershed (Fisher, 2004, pg 42)

Soil Series	Jensen	Mays
Westbutte	26	50
Simaton	21	3
Madeline	48	20
Embal	0	1

In a review of hillslope erosion processes (soil movement), Fisher (2004) reported no significant difference between the two watersheds (*P*-value = 0.694). Fisher reported a weak to moderate relationship ($r^2 = 0.4174$) for the two watersheds. For every 1 cm of hillslope movement that took place within the gully systems in Jensen, there was approximately 0.5 cm of soil movement in the gully systems in Mays.

In 2006, NRCS conducted soil surveys in the area (Figure 3). Evaluation of the draft publication for the current soil classification data showed that Map Unit 246 occupies a significant part of both watersheds (56.7 % in Mays and 60.7 % in Jensen). Map units 272 and 248 were also found in both watersheds. Map units unique to only one watershed were: Jensen – 273, P500 and 430, Mays – 089 and 245 (Table 3 and Table 4).

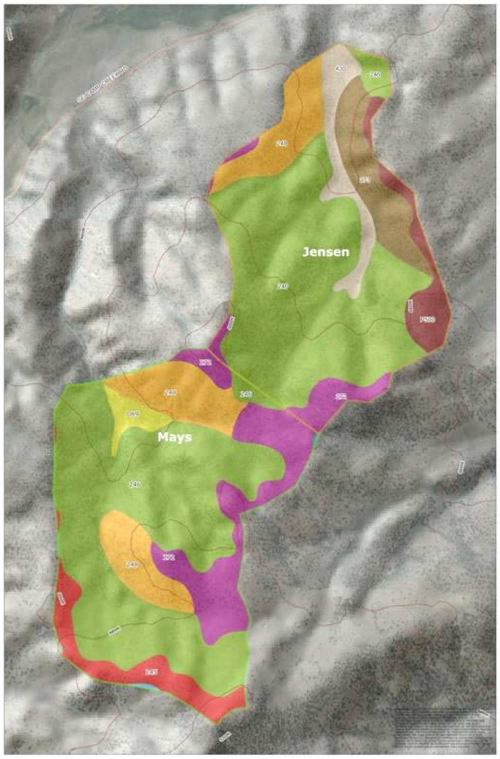

Figure 3**.** Soil information, NRCS, 2006 Soil Survey (draft document)

Table 3. Map Units for NRCS Soil Survey, 2007 (Draft)

Map Units – both watersheds

246	Anatone-Ateron-Polkbutte complex, 30 to 65 percent north slopes
272	Anatone-Bocker complex, 2 to 20 percent slopes
248	Anatone-Ateron complex, 30 to 65 percent slopes

Map Units – Jensen

273	Anatone-Bocker complex, 20 to 50 percent south slopes
430	Gerow silt loam, drained, 1 to 5 percent slopes
P500	Canest-Anatone complex, 0 to 10 percent slopes

Map Units – Mays

89	Luckycreek loam, 1 to 15 percent slopes
245	Anaton-Ateron-Polkbutte complex, 12 to 30 percent north slopes

Table 4. Soil Mapping Units by Percent of Area

Map Unit	Mays	Jensen
246	56.7	60.7
272	16.9	5.3
248	15.1	9.1
273	0.0	10.3
430	0.0	7.5
P500	0.0	6.9
89	2.6	0.0
245	8.4	0.0
Misc	0.3	0.2

Vegetation

Anderson et al. (1998) described the vegetative types associated with the John Day Ecological Province of which the study area was a part. The historic range of vegetation by cover would have been approximately 50 percent forest (pine, fir and mixed pine-fir forests) with approximately 40 percent being nonforested and primarily sagebrush-grassland. Western juniper would have occupied less than 10 percent of the province. Common shrubs that were found in the area included mountain big sagebrush (*Artemisia tridentata*, *spp vaseyana*), green and gray rabbitbrush (*Chrysothamnus viscidiflorus* and *C. nauseosus*), and bitterbrush (*Purshia tridentata*). Grasses included Idaho fescue (*Festuca idahoensis*), bluebunch wheatgrass (*Agropyron spicatum*), Sandberg bluegrass (*Poa secunda*), prairie junegrass (*Koelaria cristata*) and Indian ricegrass (*Oryzopsis hymenoides*). Forbs were numerous and highly dependent on winter moisture to express themselves (Appendix B).

Analysis of pretreatment vegetation in the study area showed no significant difference in vegetation composition when compared to aspect (Fisher 2004). Except for percent perennial grass cover, stratification by aspect did not indicate differences in percent cover of the various plant types between north and south slopes. Perennial grass cover was reported to be 16.4 percent on north slopes and only 8.1 percent on south slopes (significant *P*-value at alpha = 0.01)(Fisher 2004). The 3 variables most important in controlling erosion processes (percent perennial grass, bare soil and tree cover) were not significantly different between the two watersheds (Table 5). Fisher (2004) also reported that there were no significant differences in plant community changes between the two watersheds in regard to perennial grass, forb and tree cover from data collected in 1995 and 2003.

Table 5. Significant *P*-values from ANOVA for variables describing the differences in cover (%) between watersheds (Fisher, 2004, pg 43).

	Jensen	Mays	*P*-Value
Perennial grass	14.8	10.6	0.145
Bare soil	22.9	23.9	0.585
Litter	25.6	30.1	0.962
Live shrub	4.9	5.7	0.591
Dead shrub	5.5	2.1	0.053*
Tree	21.4	26.9	0.748
Forb	2.4	2.4	1.000

* shows significant differences at alpha = 0.05

Fisher (2004) reported tree density as high as 743 trees/ha and 680 trees/ha in Jensen and Mays respectively. Tree density was reported to be highest in valley bottoms and on toe slopes.

Geomorphologic characteristics

The topographical details of Mays and Jensen were similar. Slopes were similar between the two watersheds with Jensen's average slope equal to 25 percent and Mays' average slope equal to 24 percent (Fisher 2004). Table 6 shows the relationship of aspect between the two watersheds.

Table 6. Aspect distribution classified by percentage of total area Jensen and Mays watersheds (Fisher, 2004, pg. 64)

Aspect	Jensen	Mays
North	36	33
East	31	17
South	5	11
West	23	26

Mays had approximately 10 ha more of south facing slopes and Jensen had 13 more ha of east facing slopes (Fisher 2004). Both south and east facing slopes had similar characteristics, having dryer and harsher growing characteristics.

Orientation of the two watersheds was similar. Utilizing statistical slope orientation diagrams (SSO), Jensen's orientation is northerly and Mays was oriented north by northwest (Fisher 2004). These northerly orientations should lend the watersheds towards longer periods of frigid soils and maintenance of snow pack during spring melting periods than if their orientation were southerly (Fisher 2004). Frozen soils often limit infiltration of snow melt and increase risk of overland flow during spring snowmelt.

Channel profiles and Stream order

Channel profiles provided information about the watershed's ability to transport sediments out of the drainage area (Fisher 2004). Both watersheds exhibited similar drops in elevation per length of channel (115 m/km). Within Jensen, there were greater lengths of channel with less relief, lending support to the findings that within the lower portion of Jensen, channel deposition was greater than the lower portion of Mays.

Stream orders can be used to determine the complexity of a given watershed (Fisher 2004). Considering stream order frequency by watershed, since there are a higher number of overall channel segments in Mays, channel erosion potential should be higher than in Jensen (Table 7). Fisher (2004) reported that an increase in lower order stream channels resulted in a decrease in time that it took runoff to reach the lower elevation segments of the watershed.

Table 7. Frequency of stream order by watershed (Fisher 2004, pg.73).

Stream Order	Jensen	Mays
# 1	47	54
# 2	14	9
# 3	2	4
# 4	1	1

PROJECT OBJECTIVES

The purpose of this study was to quantify the impact – on a watershed scale – of juniper control on the availability of water (quantity and timing) for beneficial uses (water quality, fisheries, irrigation, recreation, etc.) as defined by Oregon State Statute. The study involved a paired watershed approach for evaluating changes in a system's water budget following western juniper control. Water budget was measured in terms of inputs (precipitation) and outputs (soil moisture, runoff, groundwater recharge and evapotranspiration). Watershed impacts included the water budget impacts plus changes in vegetation composition and cover, and erosion rates.

Monitoring water yield following juniper control had previously not been done in the western juniper vegetation type. The value of a paired watershed study was that the impacts of the treatment could be compared to the untreated watershed. The treatment was to control western juniper in one of the watersheds. Juniper control included the cutting of all post-European-aged junipers (juniper less than 140 years of age).

Study objectives were the following:

- Measure hydrologic changes following juniper removal on a watershed scale;
- Evaluate changes in timing, duration and quantity of water expressed in channel flow, spring output, ground water and soil moisture;
- Calculate changes in hill slope and channel morphology following juniper control;
- Quantify changes in plant community composition following juniper control.

In addition to changes in site condition, the wood products industry began to develop an interest and commercial market in western juniper. As part of the treatment activities, a harvest system was evaluated for costs of extracting juniper boles for use in log homes, dimensional wood, and fence post/fire wood. Analysis of harvest information provided land managers with information that can be used in determining opportunities for adding value and benefits to juniper control projects (Dodson and Deboodt 2007).

LITERATURE REVIEW

OVERVIEW OF VEGETATIVE MANIPULATION FOR WATER YIELD

The importance of managing landscapes for water and watershed function has been recognized for over 100 years. Water is an extremely important natural resource in the western United States (Shepperd et at. 1992). The Organic Act of 1897, as reported by Megahan, et al (2000, pg. 177) defined water as one the primary purposes for national forests: "No national forest shall be established, except to improve and protect the forest within the boundaries, or for the purpose of securing favorable conditions of water flows, and to furnish a continuous supply of timber for the use and necessities of citizens of the United States". Huff et al (2000) described the management of forest vegetation and its relationship to water yield as a long and lively issue. Research studies have focused on gauged watersheds representing a variety of geographic locations, forest types, topography and climate (Megahan et al. 2000; Hibbert 1979). For forested watersheds, manipulating vegetation to increase water yield has been the primary focus of these studies. Study results reported the effects of forests and forest disturbances on water yield, peak and flood flows, snow accumulation and melt, soil erosion and numerous water quality parameters including turbidity, nutrient loading and temperature (Megahan et al. 2000).

Watershed studies have also been conducted on rangelands. Ice and Stednick (2004) provided a summary of forest watershed research which has its roots in the Wagon Wheel Gap study, a 16 year study initiated in 1911. Wilcox (1994) summarized work done in the 1960's and 70's. Due to highly variable results in lower precipitation areas, rangeland research has shifted from measuring the effects of management treatments to measuring processes on a variety of management scales in order to identify predictable hydrologic responses (Roundy et al. 1999). Hibbert (1983) indicated that increasing water for onsite and offsite uses can be a viable objective for management of certain western rangelands. As with forested water yield projects, replacing vegetation that uses significant amounts of water with vegetation that uses less for the purpose of increasing soil water percolation to streams and ground water is highly desirable. Since wet winters are followed by dry summers in the Pacific Northwest, the effect of modifying the vegetative community for water yield is of significant concern (Keppeler 1998). Many residents in Oregon rely on springs and shallow wells for year-round water supply. Beneficial uses of increased water flow also include fish and other stream fauna as well as terrestrial species that depend on intermittent and perennial streams.

In central Oregon, United States Geological Survey (2000) concluded that ground water in the upper Deschutes River Basin is hydrologically connected to surface flows in the lower Deschutes River. Oregon Department of Water Resources (2002) has implemented the Upper Deschutes Ground Water Mitigation Plan, which requires a surface water mitigation plan before it will issue a water rights permit to pump from new ground water wells. The National Marine Fisheries Service, a department of the National Oceanic and Atmospheric Administration is currently working with Portland General Electric, Confederated Tribes of Warm Springs and the Oregon Department of Fish and Wildlife to re-introduce steelhead into the upper Deschutes River Basin above Pelton Dam. This project is part of the Relicensing of the Pelton Hydroelectric Project. Steelhead will be released into the Deschutes and Crooked Rivers in fall, 2007. Maintenance of appropriate stream flows will be essential for successful spawning and rearing activities in these watersheds. Hibbert (1979, pg. 2) stated “Public acceptance of water yield improvement practices will partly depend on how people view the need for more water (basically an economic issue) and on how they perceive the impacts of water improvement practices on the forest environment, including the less tangible resources such as wildlife and scenic beauty”.

Much debate has focused on the benefits of treating western rangeland for water yield (Baker 1984; Wilcox 1994). Hibbert (1983) summarized findings by stating that arid and semiarid rangelands are poor water producers because the potential evapotranspiration (PET) is greater than precipitation (P). Figure 4 provides the visual concept of how PET and P are related and in what type of plant communities, vegetation manipulation for water yield activities should be focused.

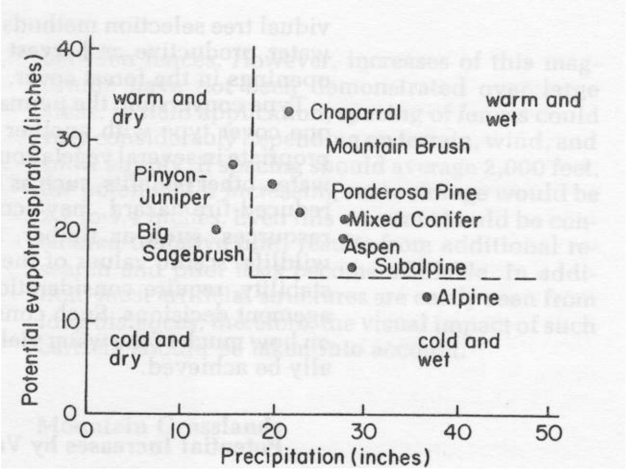

Figure 4. General relationship of vegetation to potential evapotranspiration (PET) and precipitation (P) in the Colorado River Basin. The ranges in PET and P are broader than indicated by the average values plotted for each vegetation type. The dashed lines represent approximate marginal conditions for improving water yield by manipulation of vegetation; the potential is greater in the direction of warm and wet climate. (Hibbert 1979 pg. 5)

Hibbert (1979) has set the minimum threshold for water yield response from vegetation manipulation at 4500 mm (18 inches) of precipitation. In cooler climates where precipitation is concentrated in winter months, the minimum threshold would be at 4000 mm (16 inches). Hibbert (1983) found that less than 1 percent of western rangelands could be managed for water yield. Little or no increase should be expected through the removal of low-density brush and pinyon-juniper woodlands.

Baker (1984) reporting on the long term watersheds project, Beaver Creek, Arizona, found that for 8 years following herbicide treatment to control pinyon-juniper (Utah juniper, *Juniperus osteosperma* (Torr.) Little) a statistically significant increase in streamflow was measured. Herbicide treatment involved spraying 114 ha of Utah juniper with a foliage applied application of 2.8 kg acid equivalent of picloram and 5.6 kg acid equivalent of 2,4-D [(2,4 – dichorophenoxy) acetic acid] as triisopropolamine salts in 94 liters of water per hectare, August, 1968 (Baker 1984). A streamflow increase of 157 percent during the post-herbicide period was measured. This was compared to 11 years of pretreatment data (1958-1968). Herbicide treatment killed 83 percent of the Utah junipers. Shrub live oak and pinyon pine were damaged but recovered after 2 to 3 years. Annual precipitation during the study period was 4630 mm with a high of 6910 mm and low of 2100 mm measured. Winter precipitation (October – April) accounted for 64 percent of the total. Soils were developed from volcanic parent material and were approximately 110 cm deep. The predominant soil type was Springerville Very Stony Clay with clay texture throughout. Within this soil, the clay type was montmorillonite, forming cracks as much as 5 cm wide and 1 m deep when dry.

Most of the water yield from the Beaver Creek experimental watersheds was winter flow. Stream discharge was recorded during the winter 15 of the 25 years. Overall, 21 of 25 years produced streamflow. The majority of flow occurred as snow melt runoff in March and April. Soil moisture studies reported (Johnsen 1980) as a part of this project that in the treated area, the soil below 30 cm did not reach the permanent wilting point (-15 bars of atmospheric pressure) for 7 years after treatment but that in the control area (untreated) soils dried to the permanent wilting point each spring.

Hibbert (1983) summarized two additional control methods conducted on the Beaver Creek experimental watersheds. On one watershed, Utah juniper was controlled by cabling and burning of the slash and in the second watershed, trees were felled by hand and slash was not burned. Streamflow was not significantly increased in these watersheds but more soil moisture was available for grass and forb production which increased on both treated watersheds.

Sturges (1994) reported on findings related to manipulating sagebrush for water yield. The 23 year study used herbicide to control sagebrush for water yield. A paired watershed approach was used, and both watersheds had perennial flow with water discharge being measured for 8 years before treatment and 14 years after treatment. Water yield increased for 11 years in the treated area and then returned to pretreatment levels. Two-thirds of the increase came from snowmelt discharge and the remaining increase was associated with groundwater discharge through the remainder of the year. The magnitude or date of the peak snowmelt discharge was not changed but the length of the snowmelt period increased 22 percent. Grass production doubled in the first 5 years and was 1.5 greater in the ninth and tenth years. Sagebrush density returned to pretreatment levels after 11 years. Soils had developed from sandstone and were part of the Mollisol and Aridisol order (Sturges 1994). Soils were loams in the A and B horizon, the B horizon extending more than 1 m deep. Precipitation averaged 5180 mm per year with 75 percent of the total falling as snow. Control of sagebrush did not affect snow deposition. Change of snow water content was not significant (51.7 cm before treatment and 54.9 after treatment). Increase in water yield was reported at 1.08 cm. Sturges concluded that sagebrush control practices for water yield would be expected where soil depth exceeds 0.9 m and precipitation is sufficient to fully recharge soil water. Long term control of sagebrush would be necessary for treatment effects to persist.

The pinyon-juniper ecosystem is the most extensive forest type in the Colorado River Basin (Hibbert 1979). This ecosystem type receives 3000 to 4500 mm (12 to 18 inches) of annual precipitation. Summer rains account for half or more of the annual precipitation in the lower basin; winter rain and snow provide the majority of precipitation in the upper basin. The potential for increasing water yield in this type of ecosystem is negligible although small increases of less than 12 mm may be possible on the wettest sites.

Swank (1969) in a study of the potential to increase water yield in the Ochoco Creek watershed (Prineville, Oregon) estimated that increased water yield varied from .03 acre-feet/acre per year with juniper control to .8 acre-feet/acre per year with lodgepole pine control. Ffolliott and Brooks (1988) noted that increases in annual water yields generally occurred on watersheds characterized by the removal of tree basal areas in excess of 100 ft^2 per acre.

USE OF THE PAIRED WATERSHED APPROACH

A paired watershed study involves at least two watersheds, control and treatment and two time periods – calibration and treatment. The purpose of the control watershed is to account for seasonal and year to year weather variations as the management activities remain the same. The treatment watershed has the changed management imposed on it at some time. During the calibration phase, no change of management occurs in either watershed. For a period of time, data are collected in both watersheds. In the treatment phase, one watershed receives the change in management while the other watershed remains with the original management. The strength of the study is in the amount of time that base-line data (pre-treatment) are collected. As noted earlier, studies in Arizona and Wyoming included 11 and 8 years respectively of pretreatment monitoring (Baker, 1984; Sturges, 1994).

EPA proposes that there are 3 questions to answer before shifting from the calibration phase to the treatment phase:

1) Is there significant relationship between the paired watersheds for all parameters of interest?
2) Has the calibration period continued for a sufficient length of time?
3) Are the residual errors about the regression smaller than the expected BMP effect?

The use of the paired watershed study approach is well documented in forest and hydrology (Hewlett et al. 1969; Bosch and Hewlett 1982; Wilcox 1994; Monteith et al. 2006). EPA (1993) published guidelines for establishing paired watershed studies. The first watershed experiment began in 1911 at Wagon Wheel Gap in Colorado. The paired watershed approach utilized a control and treatment watershed design to quantify the effects of deforestation on the volume and timing of streamflow, soil erosion, and sediment loading (Megahan and Hornbeck 2000).

The strength of the paired study approach is perhaps also its short coming. Alila et al (Web site accessed June, 2007) summarized the arguments against traditional paired watershed studies:

1) Lack of control from not-so-trivial but often extremely important differences between the physical characteristics of the control and treatment watersheds.
2) Lack of control from a spatially and temporally varying climate.
3) Short length of pre- and post-treatment record that cause statistical tests to be inconclusive.

Alila et al. (Web site accessed June, 2007) argued that the traditional method of measuring precipitation inputs and stream outputs fails to explain the internal catchment processes whether they be above or below ground. The “black box” approach makes transferring knowledge gained from a paired watershed study to other, ungauged nearby watersheds difficult. The authors of that paper suggested it is impossible to explain the extra variability in the relation between percent forest removal and the magnitude of the hydrologic impact if only precipitation/streamflow are measured. These authors also suggested that the use of modeling that incorporates detailed field work done throughout the watershed will provide a more enlightened look at the relationships of management activities and response. Modeling provides the opportunity to reduce calibration/treatment periods and allows the researcher to hold constant climate variables and vegetation changes associated with time.

HYDROLOGIC FUNCTION AND WESTERN JUNIPER

The hydrology of a given watershed is a function of the precipitation amount, intensity and seasonality, watershed geomorphic characteristics including topography and soil characteristics, and vegetation composition and complexity (Bowns 1999). Bedell and Borman (1997) credit Hugh Barrett (retired Rangeland Management Specialist, Oregon BLM) for describing and coining a phrase germane to the essence of watershed management as "the soil's ability to Capture, Store and Safely Release" precipitation which is delivered to a site. Watershed management extends beyond the concept of water management to include the importance of other resources and how they are interconnected. Those resources include plant, animal, soil and climate (expressed through precipitation, temperature, wind, solar radiation, etc.). Capture refers to the processes in which precipitation enters the soil profile. Storage focuses on the moisture within the soil profile. Safe release is the process of either soil moisture being used for plant growth or excess soil moisture moving through the soil profile, recharging ground water and expressing itself as either flow from springs or as contributing to streamflow through seepage from stream banks (Bedell and Borman 1997).

Vegetation plays a critical role in connecting precipitation with the soil profile. Vegetation serves as a buffer, reducing raindrop impact on the soil surface, adding to the soil surface roughness (litter and plant biomass) to slow overland flow and increase the amount of soil/water contact time, thus increasing opportunities for infiltration and by increasing soil water holding capacity through the addition of organic matter into the soil profile. Land managers, landowners and public land management agencies, through the application of management plans, impact vegetation's ability to buffer precipitation inputs and aid in the watershed's ability to capture, store and safely release water.

As discussed earlier, forest hydrologists have illustrated the benefit of forest tree reduction for the purposes of increasing water yield (Bosch and Hewlett 1982; Hibbert 1983; Wilcox 1994). While Baker (1984) illustrated benefits of removal of juniper in Arizona, there is general consensus that little water benefit will be realized in much of the intermountain west where annual precipitation varies from 2000 mm to 5000 mm (Hibbert 1979; Roundy and Vernon 1999). However, relatively small amounts of water yield can be critically important to sustain both livestock and wildlife during the late summer months. Based on various studies, Roundy and Vernon (1999) provided a conceptual water budget for these systems (Figure 5). Fitzgerald (1997) provided a water budget for forested systems before and after tree harvest (Figure 6).

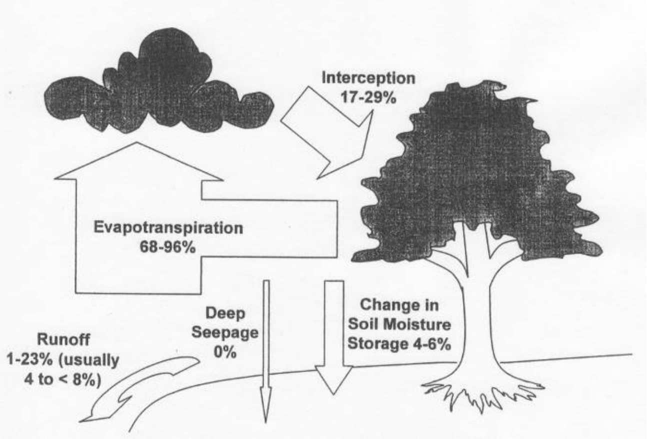

Figure 5. Hydrologic budget components of pinyon and juniper watersheds from estimates or complication of various studies (Roundy and Vernon 1999 pg. 173).

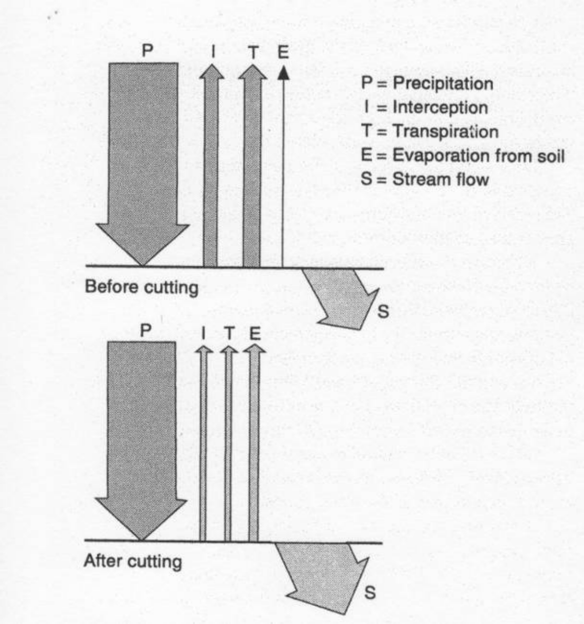

Figure 6. Relative sizes of components of the forest hydrologic cycles, before and after timber cutting (Fitzgerald 1997, pg. 59).

The impacts of expanding western juniper woodlands or juniper control treatments on hydrology and water balance are not well understood (Miller et al. 2005). Gedney et al (1999) found that landowners and land managers have reported small streams and springs drying up or have stopped flowing as juniper became established on their rangelands. It has been suggested that due to the interception of precipitation and transpiration by juniper, decreased flows are the result of reduced recharge of the shallow aquifers that feed the ephemeral streams and springs (Gedney et al. 1999; McCarthy III and Dobrowolski 1999; Larsen 1993). Roundy and Vernon (1999) suggested that although sites occupied by juniper tend to be areas of low precipitation and high evapotranspiration, there may be sites where a shallow impermeable layer may allow for seasonal saturation and sufficient interflow to feed local springs and streams. These and other similar, anecdotal stories provide the current basis for discussions regarding impact of western juniper on a site’s hydrologic function and the subsequent site response following juniper removal.

Western juniper has increased significantly in the last one hundred years in both the area and density that it now occupies. Azuma (2005) reported that western juniper has increased in eastern Oregon from 600,000 hectares to over 2.4 million hectares (1.5 million to over 6 million acres) since 1935. The increase in acreage is attributed to many factors but focus primarily on; 1) periods of higher precipitation and cooler temperatures in the late 1800’s that favored seed production, germination and survival of juvenile trees, 2) uncontrolled, excessive grazing by domestic livestock in the late 1800’s through the early 1900’s which removed grasses and favored shrub production (a primary host plant for juniper seedlings), and 3) reduction of fire as a result of grazing removing the fine fuels and humans increasing fire suppression efforts since the early 1900’s (Miller et al, 2005).

As illustrated in Figure 5, interception is the first barrier to precipitation entering a site. Canopy interception is the portion of gross precipitation that is retained by the canopy and eventually lost by evaporation. Larsen (1993) provided a summary of studies conducted on various juniper species and storm intensities throughout the intermountain west. He reported that interception rates varied from 4 to 70 percent with the average being 14 percent. Average annual precipitation lost to interception was estimated to be 17 percent across many studies.

Larsen (1993) also looked at the role of litter as an effective interceptor of precipitation. Beneath the junipers litter depths varied from 10 to 60 mm (canopy edge to near tree bole). Of the measured throughfall and stem flow of moisture measured coming from below the tree canopy, average water penetration into the litter layer was 10 to 31 mm (measured from canopy edge to near tree bole). Larsen suggested that interception of precipitation from the litter may be higher than losses from the tree itself. Larsen found that this condition created small islands (beneath individual trees) where precipitation inputs rarely reached mineral soil in the juniper woodland. The combination of tree interception plus litter (beneath the tree) interception would support the conclusion that effective or net precipitation is a reduction of 1:1 relationship of with canopy cover and gross precipitation. Eddleman et al. (1994) stated that small storms are likely to produce no stem flow and low throughfall which may be held in the litter. Net interception with subsequent evaporation or sublimation back into the atmosphere will be a high percentage of input for small storms.

Infiltration studies are limited (Eddleman et al. 1994). Infiltration rates in juniper ecosystems are comparable and not significantly different than sagebrush or grassland ecosystems. Mean infiltration values for these types of systems vary from 44 mm/hr to 66 mm/hr. Wood et al (1987) found a positive relationship between infiltration rates and grass production, litter, total ground cover and soil sand fraction near the soil surface and a negative relationship with soil moisture, bulk density and silt fraction near the soil surface. These results support the premises of Bedell and Borman (1997) that vegetation can play a significant role in controlling watershed function. Others also report the positive attributes of vegetation in affecting infiltration. Eddleman et al. (1994) found multiple studies which indicated that factors which shorten slope and increase detention storage (such as miniature terraces and plant density) as well as other organic or inorganic objects on the soil can cause infiltration rates to increase. Minimizing slope or organic debris dams hold water on the soil surface longer, thus increasing soil/water contact times and allowing for more water to move into the soil profile.

Opposite of infiltration is overland flow. Excessive overland flow would not be considered desirable within the concept of watershed function and the safe release of water. With overland flow, the concern is the potential to carry sediment and transport it off site. Sediment transported off site removes limited nutrients from the site and reduces site productivity (Eddleman et al. 1994). Buckhouse and Gaither (1982) illustrated the potential soil loss risk as it related to storm size and vegetative community type. Soil erosion rates from sites with higher than the natural range of variation for western juniper cover was a magnitude of order greater than similar sites that were still within their natural range of variation of cover.

Western junipers are evergreen and thus have the potential to utilize soil moisture throughout the year. Juniper maintains its ability to photosynthesize and transpire water whenever weather conditions are right and provides it a competitive advantage over grasses, forbs and some shrubs that must annually produce new leaves before photosynthesis can begin. Jeppesen (1977) found that if subsoils are not frozen, western juniper can use soil moisture throughout the year. Winter soil moisture use by juniper is from deep soil moisture, greater than 0.51 m (Jeppesen 1977). Soil temperatures at this depth remain relatively constant 1 to 4 degrees Celsius. This winter moisture use decreases herbaceous plant production during the spring and summer months. Miller (1990) reported that as long as the soil and air temperature was above freezing and soil moisture was available, western juniper was able to utilize soil moisture while other plant species were dormant.

METHODS

The Camp Creek Watershed Study was established in 1993 to quantify and understand how vegetative conversion (removal of western juniper) could affect hydrologic functions (Fisher 2004). Monitoring protocols were established in 1993 for the purpose of collecting baseline data for which the subsequent treatment phase of the study could be compared. Fisher (2004) provided the detailed explanation of those monitoring protocols. Protocols for reconnaissance, soil classification, vegetation, precipitation, hydrology, channel cross-sections, hillslope erosion processes and geomorphology are summarized here.

The calibration phase of this study provided the ecological and geomorphologic characteristics of the two watersheds. Protocols were developed to provide information about vegetation, soils, topography, geology, channel morphology streamflow, local climate and erosion processes (Fisher 2004).

RECONNAISSANCE

A general survey of the two watersheds provided initial information which was useful in developing initial sampling methods. Each watershed was stratified by slope, elevation and aspect. Geographical Information System (GIS) was used to provide assistance in interpretation of topographic maps and aerial photos. Boundaries of the watersheds were recorded with the assistance of Global Positioning Systems (GPS) along with the permanent locations of channel cross-sections, hillslope erosion plots and vegetative transects. Significant land features (streams, springs) and man made features such as roads were also mapped. Aerial photographs along with GIS interpretive assistance provided information useful in establishing vegetation plots and monitoring protocols. Ground truthing was used to validate and modify interpretations made from photos and GIS.

Aerial photography was used to provide information regarding the extent of western juniper (canopy cover). Topographical information was categorized into three subjects; aspect, slope and elevation. Aspect was classified into 5 units; north, south, east, west and level. Slope (rise over run) was classified into 6 units; 0-20 %, 21-40 %, 41 – 60%, 61-80 %, 80 – 100 % and 100 %+.

SOIL CLASSIFICATION

Original soil associations were described in conjunction with BLM soil scientist Larry Thomas (1995). At the initiation of the study, there was no soil survey information available. The original USDA, Crook County Soil Survey (1966) only incorporated soil information for the irrigated lands in the western one-third (Prineville area) of the county. The soils in the study area originally were mapped using ground reconnaissance and aerial photographs. Information was transferred into electronic data bases for analysis by GIS (Fisher 2004). In 2006, the soil survey team of the Natural Resources Conservation Service mapped the area and provided a draft report in 2007 (NRCS Crook County Soil Survey 2007 draft).

VEGETATION

Vegetation measurements were obtained utilizing the line-intercept method. Transects were permanently marked with angle iron and steel fence posts and GPS. Transects were stratified by slope and aspect (north, south, east and west). Transects (30 m) were established perpendicular to slope. Data from transects were collected 3 times prior to treatment (1995, 2003 and 2005) and once post treatment (2007). Basal cover was measured for perennial and annual grasses and foliar cover was measured for forbs, shrubs and trees. Bare ground was measured. Litter including moss, needles and woody material greater than 2 cm was recorded. Rock was measured if rock was equal to or greater than 13 cm at point of intercept. Species composition was estimated using ocular reconnaissance and western juniper frequency and stand density measurements were obtained using aerial photographs and GIS interpretation. In 2005, juniper densities in each watershed were measured through 160, 1/10 acre plots evenly blocked by aspect and cover (high and low). Within each block, 5 plots were measured for detailed tree information was collected including tree height, canopy width, diameter at breast height and designated as either sapling, juvenile, mature (pointed and rounded) or decadent.

PRECIPITATION

Precipitation was measured in each watershed utilizing a Belfort Instrument Company “Universal Rain Gauges”. Gauges to measure precipitation volume, storm intensity, and frequency were placed near each flume. Data were collected to an accuracy of 1 mm at 6-hr interval over 30-day periods. Precipitation data also were collected from USGS weather station “Barnes Station” through the Oregon Climate Service, Oregon State University.

HYDROLOGY

A 3.0 H-Flume was placed at the “bottom” or lower end of each study area for the purpose of recording flow leaving the study area. The actual location of each flume was controlled by channel morphology and site accessibility. A fabricated steel approach was attached upstream of each flume for the purpose of stabilizing flow. Data were collected utilizing a Druck© pressure transducer, placed in a stilling well which was connected to the flume. The purpose of the stilling well was to buffer the measuring device. Flow measurements were recorded utilizing Campbell Scientific CR10 data loggers. Flow measurements were set to collect temporary data every 10 seconds. After every 10 minute interval, minimum, maximum and average stage were sent to the data logger for storage. A factor of .05 inch or 1.27 mm stage height was established as the minimum number (not zero) to record as “flow”. This protocol limited the collection of “zero” data which can fill a database very quickly. Time of day, Julian date, and year were recorded along with 24 hour average, minimum and maximum stage measurement. Conversion from stage height to flow volume was calculated using conversion tables provided by the flume manufacturer.

CHANNEL CROSS-SECTIONS

To measure changes in channel morphology, 25 channel cross-sections were placed in the primary channels of each watershed upstream from the flume. After initially identifying the first cross-section through random selection, cross-sections were placed at 30 m intervals. Permanent stakes marked the location of each cross-section. A stationary steel tube (25mm^2) was used to measure the relative width and depth of the channel at 100 mm intervals. With the use of a carpenter's level to assure that the steel tube and steel angle iron were level and perpendicular to each other, measurement from ground to top of steel tube was recorded to nearest cm. At time of channel cross-section establishment, photos upstream and downstream were taken. Channel gradient between each cross-section was measured using a clinometer. Measurements were taken twice a year, after snow melt and spring channel flow had ceased, and then again after the summer thunderstorm period was over.

HILLSLOP EROSION PROCESSES

Sedimentation plots were used to measure annual or semi-annual active, sub-watershed level erosion processes. Sampling was established in sub-watersheds that had existing rills or small gullies and exhibited evidence of surface flow from the hillslope to the main channel at the time of the study's initiation. Twelve sub-watersheds were identified in each of the main watersheds. Three (3) sedimentation rods were placed in each sub-basin utilizing a systematic, randomized approach. Within the first 0 - 10 m of the sub-basin's intersection with the main channel, the first rod was randomly placed. The second and third rods were then placed at 20 m intervals. For this study, sedimentation was defined as the deposition or erosion of soil. Measurements were recorded for both the upslope and downslope side of the rod. Since 2000, measurements were taken after snow melt and channel flow had ceased and then again after the summer thunderstorm period was over. Prior to 2000, measurements were taken once a year. Some points were replaced due to loss of the stake (for unknown reasons) or stake was destroyed by someone or something bending it over.

GEOMORPHOMETRY

Website data were accessed for the purpose of obtaining Digital Elevation Models (DEM). The study area was located within the United States Geological Service (USGS) Logan Butte Quadrangle. The DEM for this quadrangle was obtained and imported into MicroDem© software. This software along with the DEM provided the opportunity to delineate watershed boundaries, measure stream channel lengths, and analyze geomorphologic characteristics.

ADDITIONAL MONITORING ADDED SINCE 2003

As the end of the pretreatment monitoring period was nearing, additional monitoring/data needs were identified. Additional monitoring activities would measure the additional ways that water conditions could change in the watersheds and would show if those conditions changed following juniper control. Initially limited by money for purchase and installation, additional grants obtained from the BLM and Oregon Watershed Enhancement Board (OWEB) provided the opportunity to expand the monitoring capabilities. Within each watershed, a spring had been identified but output was never measured. In 1995, a series of shallow wells were placed at the bottom of each watershed near the flume (5 wells per watershed). Well depth varied between 0.9 and 8.2

m. The collection of well data was sporadic and incomplete but free standing water in at least one of the deeper wells in each watershed was recorded sometime during the year.

Soil moisture had been shown to increase and remain available longer for plant growth following juniper removal (Hibbert 1983; Baker 1984). Jeppesen (1978) noted that if soil temperatures didn't freeze, western juniper was capable of utilizing soil moisture throughout the winter period. With the exception of precipitation, weather data was limited for the site. Winter snow accumulation had been shown to change with vegetation type changes (Sturges 1994). Temperature and wind were important factors in determining initiation of plant growth and evapotranspiration rates.

GROUND WATER WELLS

In the fall of 2003, USDA Forest Service personnel from the Ochoco National Forest provided the expertise and drilling equipment to install 6 ground water wells per watershed. A Simco© track portable drilling rig was equipped with a 5 inch auger drill bit. Wells were drilled to a maximum potential depth of 8.2 m (27 ft.). Well depth was less if bedrock was shallower or in the case of several holes in Mays, ash soils at about 6 m, collapsed the hole and filled in the bottom 0.5 - 0.9 m of the hole. Following the drilling of each hole, washed, crushed rock (20 – 25 mm (3/4 – 1 in)) was place on the bottom to a depth of approximately 50 mm. Each hole was cased with 50 mm (2 in.) perforated PVC pipe. Pipe was perforated with the use of a circular saw, cutting slits into the pipe every 0.15 m (6 in.). The pipe was rotated and slits cut on the opposite side of the pipe as well. After the pipe was installed, washed and crushed rock (20 – 25 mm) was placed on the outside of the pipe in the hole. The top of pipe was left above ground approximately 0.30 to 0.45 m (1 – 1.5 ft.). The top of the pipe was capped with a screw type cap to keep debris from falling into the pipe. Each pipe was marked with a 1.68 m (5.5 ft.) steel t-post.

Beginning Jan. 2004, water depth was measured from the top of the pipe utilizing a SoilTest© DR-760A water level indicator. This instrument was a portable, self-contained transistorized instrument for determining water levels in bore holes up to 300 ft. When the probe made contact with water, an electrical circuit was established and the ammeter indicator deflected from zero to full scale. The electrical cable was marked in 1.52 m (5 ft) sections and a tape measure was used to provide detailed measurements between marks (US Army Corp Eng., 1980).

To allow for remote monitoring, a LEVEL-WATCH© sensor was placed in each well on May, 2005. LEVEL-WATCH© sensors recorded the liquid level above the sensor and was measured indirectly by recording the hydrostatic head of pressure (Automata Service Manual, 2005). A vented tube was available for barometric pressure compensation. Recording level of each sensor was 0 – 10.54 m.

SPRING FLOW

Throughout the pre-treatment period, two springs (one in each watershed) were identified. Flow had never been recorded and in conversations with the person who is both the landowner and BLM permittee, the springs had been identified as “seasonal at best” (Hatfield, personal communication 2001). That is, each spring only flowed during spring snowmelt periods and provided no flows from mid-summer through the winter. In the fall of 2003, permission was received from the Prineville BLM District and the private land owner to improve the two springs and install spring boxes and pipe so that water could be collected and measured. A private contractor was hired to excavate and install the appropriate materials. Upon completion of the installation, a seed mixture of grass species was broadcast over the excavation sites to minimize erosion and weed infestation. In Mays, two 38 mm (1.5 in) PVC pipes were plumbed into the spring box. One pipe was placed approximately 0.15 m from the bottom of the spring box and the other pipe was placed 0.40 m from the bottom of the spring box. Jensen spring had one 38 mm (1.5 in.) PVC pipe plumbed at 0.15 m from the bottom of the spring box. Flow was periodically measured using a stop watch and 1.89 liter (2 qt.) pitcher. The amount of time required to fill the pitcher was recorded. Values were converted to liters per minute.

To allow for remote access of each spring, a VORTFLOW/FLOW COMP© sensor was installed at the end of each outflow pipe (Figure 7). The sensor was calibrated to read flows from 3 – 100 gpm. When flows dropped below 3 gpm, flow was not detectable by the sensor.

Figure 7. Spring flow monitoring site, Mays with VORTFLOW/FLOW COMP©

WEATHER STATIONS

With the exception of precipitation, the need for additional weather data was identified. Temperature, wind speed and snow accumulation were important variables in analyzing effects of the treatment. Two (2) weather stations were installed (one in each watershed) near the location of the flume in the fall of 2003. Monitoring sensors associated with each weather station were precipitation (tipping bucket), solar radiation, relative humidity, leaf wetness, temperature, snow accumulation and wind speed / wind direction. The following is a description of each of the sensors.

Sensor Name	**Model**	**Range/Units**
Leaf Wetness	LEAFWET	0-100 %
Wind Speed	200WS/WINDCOMP	0-100 mph
Wind Direction	200WS	0-360^o
Rain: Weight	1040-41	K/gm
Rain:	RW100	.01 inch
Air Temperature	AD592	Deg F
Relative Humidity	H50	0-100%
Solar Radiation	LI200SZ	0-2000W/Mˆ
Snow Depth Sensor	TS-15S	0.006768 inch

Sensors were supplied by Automata Inc., Nevada City, California. Installation was done by Wy-East RC&D technicians from The Dalles, Oregon. Sensors were mounted on a 50 mm diameter pole. The pole was 4.5 m tall and was built to pivot in the middle to allow access to sensors for maintenance and calibration. Solar panels were used to keep a 12 volt deep cycle battery charged and functioning (Figure 8). The Belfort Instruments Universal Range Gauges continued to be used and maintained as a redundant, back-up system (Fisher 2004).

Figure 8. Jensen weather station and flume

SOIL MOISTURE AND SOIL TEMPERATURE

In semi-arid watersheds, soil moisture may be the only measurable hydrologic response following vegetation conversion (Hibbert 1983; Wilcox 1994). Soil moisture and soil temperature monitoring were added to the monitoring protocol in May, 2005. Soil moisture sites were placed in two locations within each watershed. At each site, 3 soil moisture stations were located and at each station, 3 soil moisture probes were installed. Soil probes were installed at 0.2, 0.45 and 0.76 m of soil depth. At each station, a hole, 1m x 1.5m x 1.2m (width x length x depth) was dug utilizing a mini, track-excavator. Probe holes were then drilled into the wall of the large hole utilizing a 16 mm drill bit (5/8 inch) (Figure 9).

Figure 9. Installation of soil moisture probes

The hole was just slightly smaller that the diameter of the probe (3/4 inch) so that the soil to probe contact would be complete. This also assured that the soil around the probe was disturbed as little as possible. According to the manufacturer, disturbing the minimum amount of soil when installing the sensor reduces the stabilization time after installing the sensor (Automata Service Manual 2005). Sensors were installed in May, 2005 as recommended by the manufacturer.

The soil moisture probe used was an AQUA-TEL-TDR© probe. The AQUA-TEL-TDR© probe measured soil moisture reliably in all types of soils at all moisture levels (Automata Service Manual, 2005). Overall probe length was 0.7 m in length (sensor length is 0.48 m). The probe read the percent of available moisture by volume, independent of soil texture. The AQUA-TEL-TDR© probe measured the dielectric constant, which was directly related to water content in reasonable growing conditions (Automata Service Manual, 2005). Readings obtained from the probe represented the average dielectric constant, and were converted to percent moisture over the length of the 0.48 m active segment.

Sensors were calibrated in the factory utilizing a full emersion approach (Automata, 2005). Probes were placed in water to assure reading of 100 percent. In the field, probes were not calibrated. The data provided a picture of relative values, and are useful in illustrating how soils dry down and rewet. At each soil moisture site, 2 of the 3 probes placed at the 0.2 m depth included a temperature sensor (AQUA-TEL-TDR+T). The AQUA-TEL-TDR+T reported data in degrees F and soil moisture data from sensors AQUA-TEL-TDR and AQUA-TEL-TDR+T were reported in percent moisture (0-100 percent).

REMOTE ACCESS OF DATA

The Paired Watershed Project was located approximately 65 miles southeast of Prineville, Oregon. During the pre-treatment monitoring phase, it became evident that taking regularly timed data was critical in understanding the hydrological processes that were occurring at the site. Channel flow data were being recorded every 10 minutes but there would be times that the data logger would quit working and data would be “lost”. Traveling to the site daily or weekly was not possible so an effort was made to find a system that was compatible with the sensors installed. Remote access provided a means of accessing data and, if possible, provided a way to monitor the function of the equipment so that it could be determined, in real time, if sensors were working or not, which allowed for timely maintenance and repair.

Prior to choosing a system, several were reviewed and included cellular phone connections, radio, combination of radio and cellular phone and satellite radio. Due to the remoteness of the site and topography, there was no cellular signal near any of the monitoring sites. Radio access was limited and required licensing and locating sites for towers as well as getting through the permitting process. A combination of short distance radio (monitoring site to ridge top) and cellular phone was also evaluated. Vegetation (trees) limited signal quality and the cellular phone was limited to analog technology. Cellular phone companies in central Oregon at the time were abandoning analog technology in favor of digital. Working with Automata, Inc., satellite radios provided the solution. The only requirement of this system was an unobstructed view of the sky so that the radios could communicate with the orbiting satellites (Automata Service Manual, 2005). The satellite radio allowed access to all sensors daily, each on its own schedule. Satellite radios require no repeaters and each radio was separate and transmitted data through the satellite to a data server. Data were accessed through the internet web site: **http://ifpnet.com**.

Nine (9) stations were located throughout the study area (4 in Mays and 5 in Jensen) and served as focal points of all the sensors. Weather Stations were accessed hourly, hydro stations (including wells, spring flow and channel flow) were accessed 4 times per day (every 6 hours), soil moisture sites were accessed 4 times per day (every 6 hours) and Jensen spring flow was recorded every 12 hours (twice per day). Programming of each site allowed for increases or decreases of each station’s accessibility but the relative value of the data compared to the cost was used to set the schedule. Cost of operation was based on the number of times each sensor was accessed per day.

LOCATION OF MONITORING SITES

Figure 10 shows the location of the monitoring stations in which the data was collected through the satellite telemetry. The flume and well locations marked the lowest end of each of the watersheds.

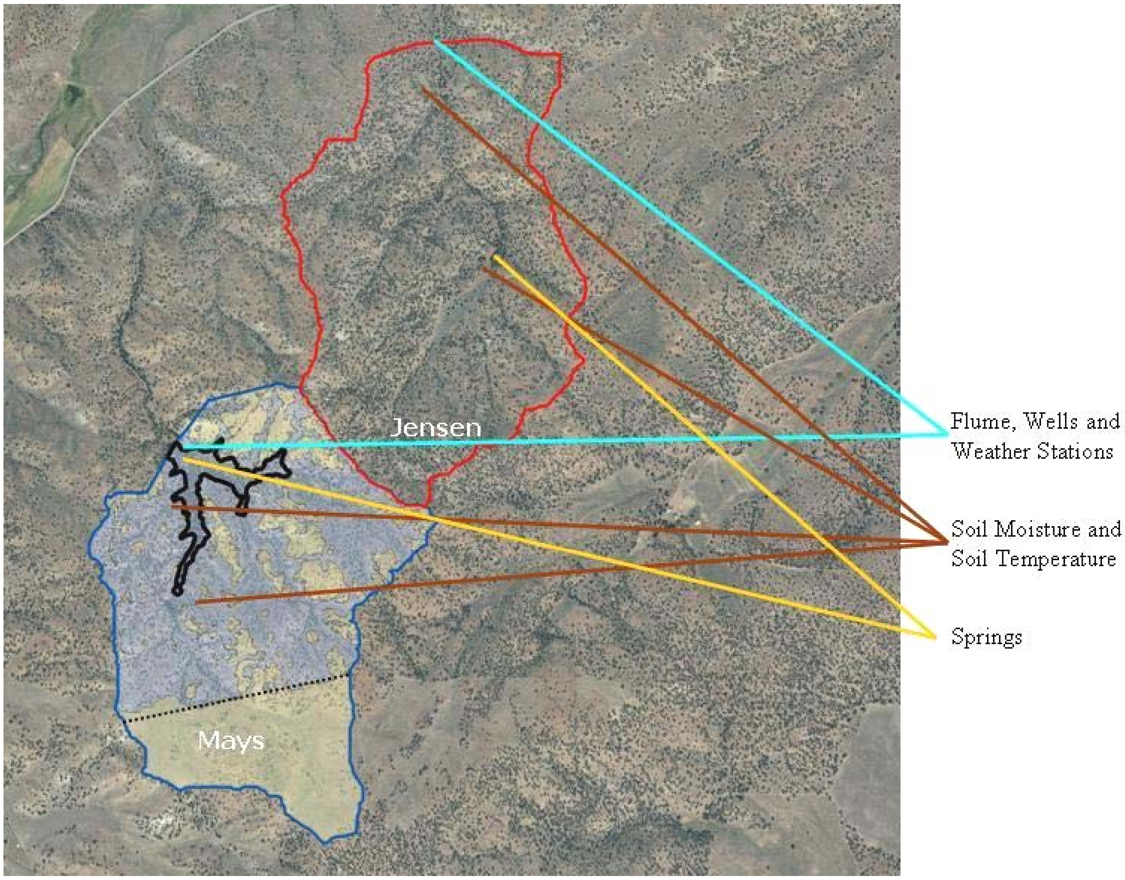

Figure 10. Location of monitoring stations

TREATMENT

In the fall of 2005, all post European aged juniper (trees less than 140 years old) were cut in Mays. Cutting instructions reflected the current understanding and practice associated with restoring pre-juniper dominant vegetative communities and watershed function. In addition to the cutting of all post European aged juniper, all old growth juniper was to remain on site. Old growth was defined as juniper with rounded tops, deeply folded bark, and moss and lichens growing on the limbs. Additionally, any juniper that was observed to be host to any wildlife was not cut.

The decision of which watershed to treat was made following extensive site visits and interviews with geologists, rangeland managers and researchers. Surface evidence of westerly sub-surface fracture orientation in the basalt parent material found in both drainages created conversation about treatment results showing up in Mays if Jensen watershed was treated. The geologic evidence and discussion resulted in Mays watershed being selected for treatment.

Figure 11 shows the areas cut in Mays. The area uncut in 2005 represented the land that is privately owned in this watershed. Treatment of this portion of Mays occurred in the late 1970's, prior to the initiation of this study. Jensen remains untreated, serving as the long term control for the study. The purpose of the control is to provide the statistical stability in which treatment effects can be differentiated.

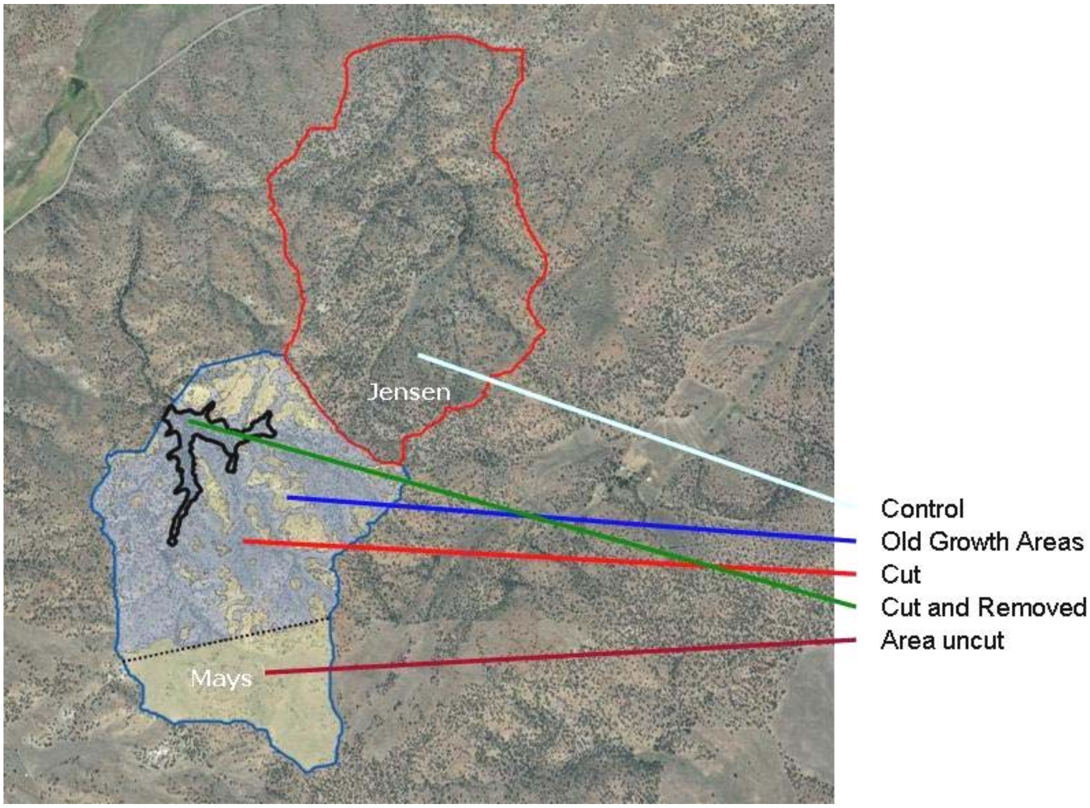

Figure 11. Types of treatment in Mays watershed in 2005

The cut and remove area represented approximately 11 acres of bottom land. Following the cutting of juniper in this area, it was determined that the volume of downed juniper presented an elevated fire risk. This elevated fire risk was determined to be extreme both to the potential loss of existing understory vegetation and scorching of the soil surface, and the potential loss of monitoring equipment placed on the site. A stroke-delimber was employed to delimb the juniper where it fell and deck the boles for removal from the site by a rubber-tired skidder with grapple. The bole wood was sorted off site into house logs and firewood. Material was sold to a local log home builder and firewood retailer, respectively.

RESULTS

WEATHER

Automated weather stations were installed in Mays and Jensen watersheds in November, 2004. Data collected included precipitation, temperature, relative humidity, wind speed and direction, solar radiation and leaf wetness.

Precipitation

Figure 12 shows the precipitation totals for Mays watershed for the 3 water years beginning October 1, 2003 and ending September 30, 2007. The figure also shows the precipitation patterns for Barnes Station, a USGS long term weather station for the same 3 water years plus the 30 year average. Mays and Jensen consistently received more moisture than the Barnes Station. Figures 13 shows the precipitation recorded in Jensen for the last 3 water years.

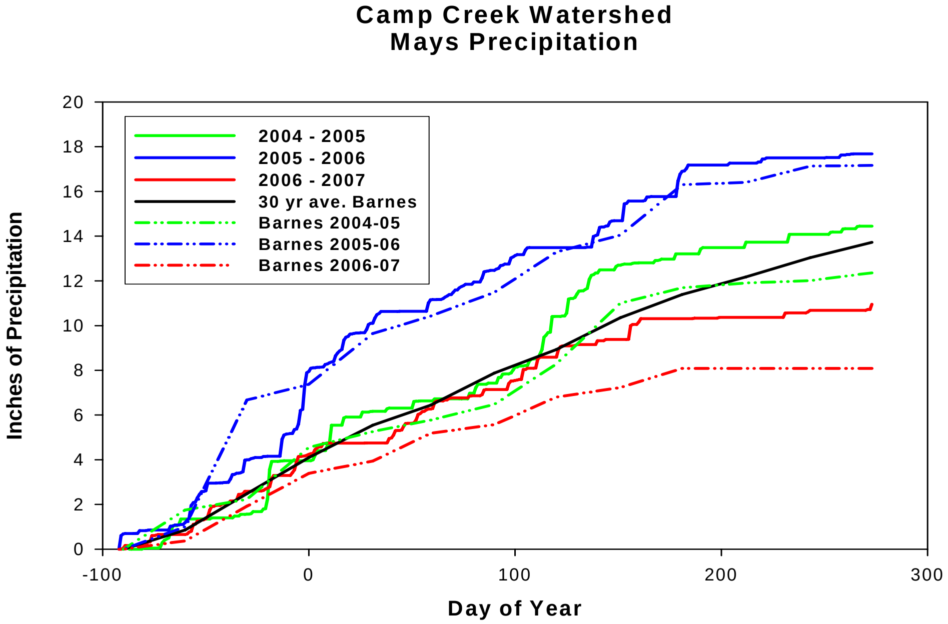

Figure 12. Camp Creek Watershed Mays precipitation compared to Barnes Station

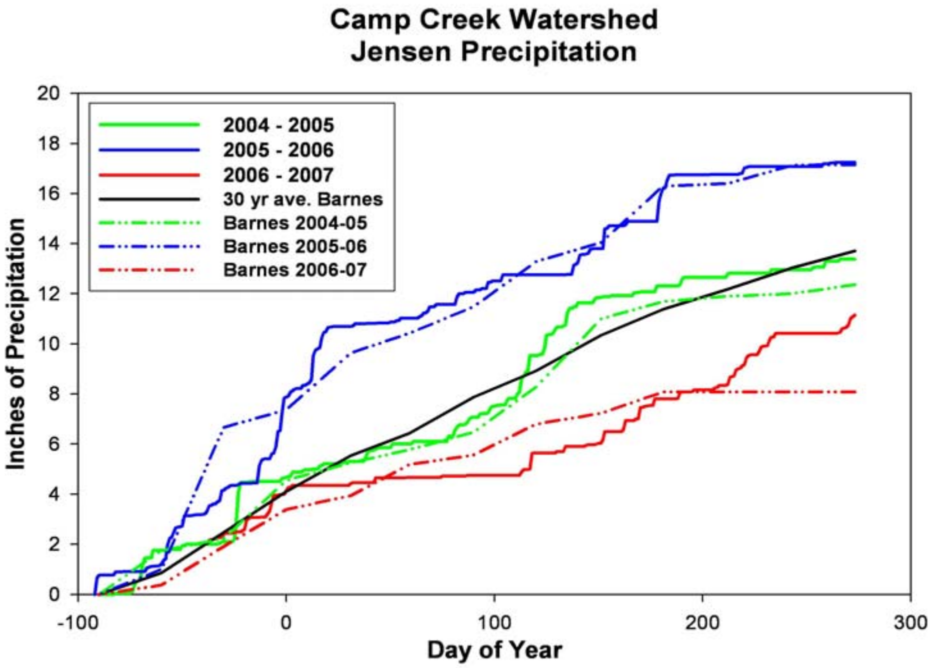

Figure 13. Camp Creek Watershed Jensen precipitation compared to Barnes Station

Table 8 shows the relationship of Mays and Barnes station for the three years. Water year precipitation (October – September), ranged from 59 percent of average for the Barnes Station in 2005-2006 (80 percent of Barnes 30-year average for Mays in the same year) to 125 percent and 129 percent for Barnes and Mays respectively the previous year (2004-2005). Since 1962, the lowest water year for Barnes was 1539 mm (6.06 inches) and the wettest year was 1983 with 6240 mm (24.57 inches).

Table 8. Annual water year precipitation for Mays and Barnes Station

Year	Station	Amount (mm)	% of 30 yr. Barnes Station average
2004-05	Barnes	3139	90
	Mays	3667	105
2005-06	Barnes	4359	125
	Mays	4491	129
2006-07	Barnes	2052	59
	Mays	2781	80

Air Temperature

Maximum temperatures ranged from 35 degrees C (95.48 degrees F) in Jensen (2005) to 40 degrees C (104.4 degrees F) in Mays (2007). Minimums ranged from -21 degrees C (-5.68 degrees F) in Jensen (2007) to -18 degrees C (-0.16 degrees F) in Mays (2005). Table 9 shows the minimum and maximum temperatures for the two watersheds (2005-2007).

Table 9. Minimum and maximum temperatures for Mays and Jensen Watersheds 2005-2007.

Year	Watershed	Minimum Temp(°C)	Maximum(°C)
2005	Jensen	-19	35
	Mays	-18	36
2006	Jensen	-19	36
	Mays	-21	36
2007	Jensen	-21	39
	Mays	-20	40

Wind

Wind speed was recorded up to 24 times per day (hourly). Recorded wind speed represented the speed of the wind at the time of data acquisition and did not represent wind speeds at any other time during a 24 hour period. Figures 14 and 15 show the maximum wind speeds recorded for each day. Numbers may not actually represent the "real" maximum if the actual maximum wind speed was not occurring at the time the data were recorded.

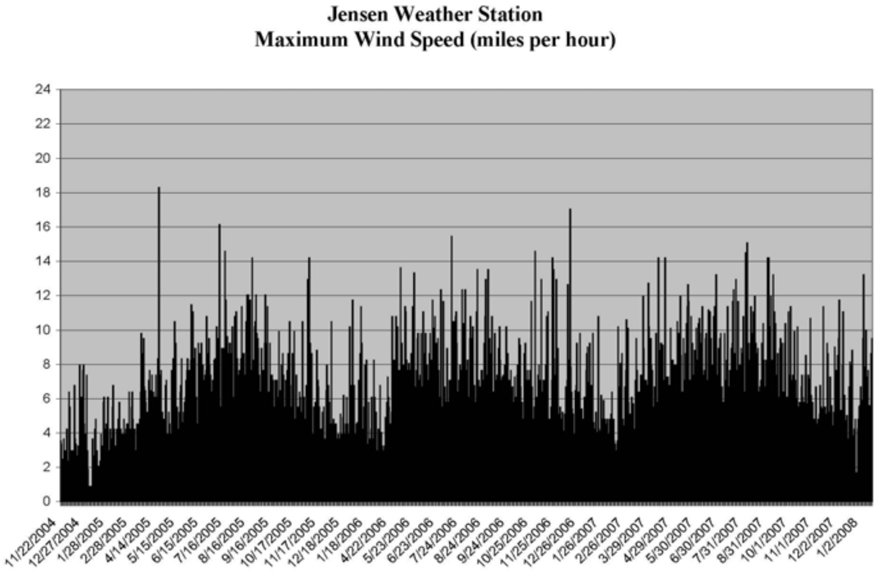

Figure 14. Jensen Weather Station, maximum wind speed (mph)

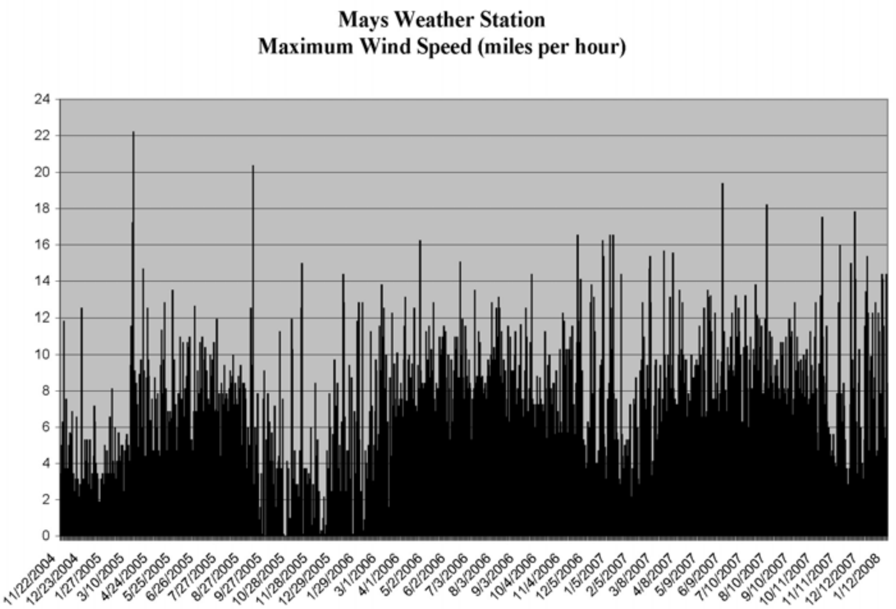

Figure 15. Mays Weather Station. Maximum wind speed (mph)

Relative Humidity

Percent relative humidity is a measure of the amount of water in the air compared with the amount of water the air can hold at the temperature it happens to be when recorded. Figures 16 and 17 illustrate the daily variation in minimum percent relative humidity. The lowest readings occurred during the summer months when temperatures and evaporation rates were the highest.

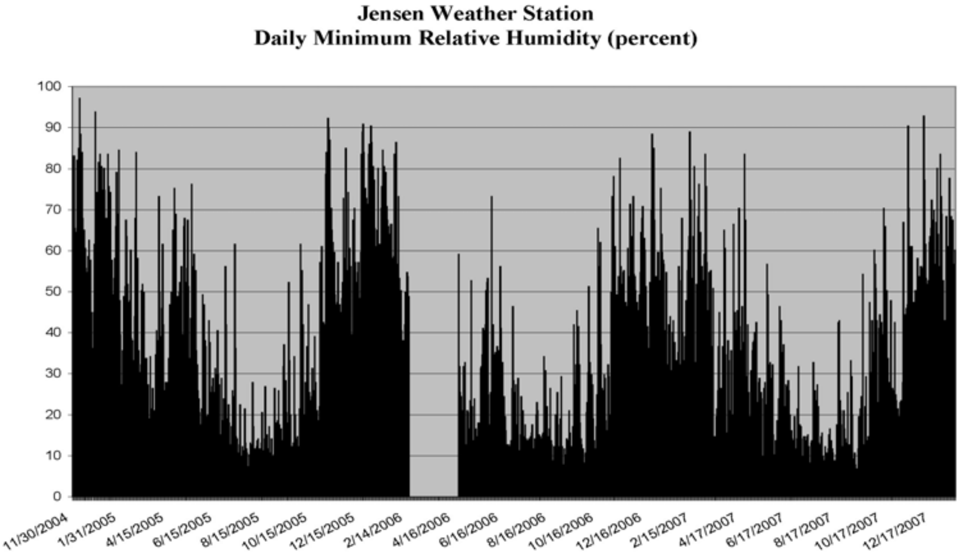

Figure 16. Jensen Weather Station, daily minimum Relative Humidity.

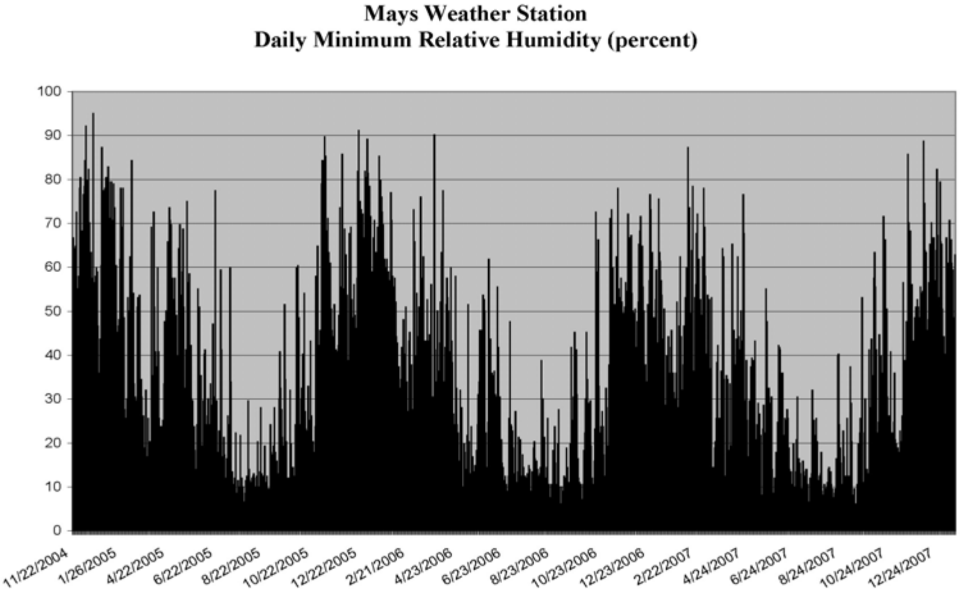

Figure 17. Mays Weather Station, daily minimum Relative Humidity.

VEGETATION

Vegetative cover data were collected from eight 30 meter transects within each watershed for the years 1995, 2003, 2005 and 2007. The first 3 years represented pre-treatment variation over time and 2007 data represented vegetative changes which occurred during the two growing seasons (2006 and 2007) post treatment of Mays. Data from two transects per aspect (north, south, east and west) were averaged and compared for treatment, year, aspect, and year by aspect effect. Basal cover was measured for the perennial and annual grasses. Canopy cover was recorded for perennial forbs, live and dead shrubs and trees. Analysis if variance (ANOVA) and single tailed t-tests were conducted.

Table 10. Comparison of the differences in means between Mays and Jensen Watersheds for Vegetative Cover before and after treatment.

Variable	treatment	Means	Difference	P-value one-tailed
Perennial grass	After	-3.6563	-0.628	0.4199
Perennial grass	Before	-3.0283		
Tree	After	-12.6288	-0.532	0.0004**
Tree	Before	3.6892		
Dead shrub	After	-2.1713	-0.059	0.4658
Dead shrub	Before	-2.1121		
Live shrub	After	0.3788	0.915	0.2851
Live shrub	Before	-0.5360		
Litter	After	0.6650	-1.455	0.4134
Litter	Before	2.1200		
Perennial forbs	After	2.2675	1.662	0.0126**
Perennial forbs	Before	0.6037		
Annual forbs	After	0.3163	0.279	0.0611*
Annual forbs	Before	0.0371		
Bare soil	After	-4.8963	-8.234	0.1456
Bare soil	Before	3.3379		
Annual grass	After	1.1963	1.656	0.0317**
Annual grass	Before	-0.4596		
Rock	After	0.1850	0.005	0.4934
Rock	Before	0.1800		

*significant at alpha = 0.1

** significant at alpha = 0.05

Table 10 shows the significance of treatment in the vegetative parameters. The removal of tree cover in Mays showed in the highly significant treatment effect on tree cover. Other vegetative responses that are shown include a treatment increase in perennial and annual forbs. No other parameter showed a treatment effect.

It was assumed that north and east aspects would be more favorable to understory growth than south and westerly facing slopes. To test this, north and east slope data were combined and averaged and south and westerly slope data were combined and averaged. Table 11 shows the interaction of aspect and treatment on the various vegetative parameters.

SOIL MOISTURE AND SOIL TEMPERATURE

Soil moisture probes were installed at 2 sites (upper and lower) of each watershed. Probes were located at soil depths (profiles) of .2m (top), .45m (middle) and .76m (bottom). This provided for a total of 6 probes per profile depth in each watershed (a total of 24 soil moisture probes per watershed). Probe readings were recorded 4 times per day and data were transmitted via satellite radio phone and logged on computer hard drives. Probes were laboratory calibrated but were not field calibrated. Numbers may not reflect actual soil moisture but provided a relative value for which trends in soil drying and wetting could be observed.

Analysis of data involved looking at the differences between each of the watersheds within a year and the differences between each of the treatment years. Combinations of the pretreatment (2005-06) and post-treatment years (2006-07) for each profile location and watershed were also analyzed.

Table 11. Comparison of before and after treatment means of the vegetative cover values for Mays and Jensen watersheds for the NE and SW aspects.

Aspect	Variable	treatment	Mean	Difference	P-value one-tailed
NE	Perennial grass	After	0.9900	0.581	0.3360
NE	Perennial grass	Before	0.4086		
NE	Tree	After	-7.2175	-2.857	0.2619
NE	Tree	Before	-4.3606		
NE	Dead shrub	After	-2.4850	-0.810	0.2686
NE	Dead shrub	Before	-1.6753		
NE	Live shrub	After	3.4500	3.658	0.1039*
NE	Live shrub	Before	-0.2083		
NE	Litter	After	-7.4350	1.027	0.4679
NE	Litter	Before	-8.4622		
NE	Perennial forbs	After	2.3525	1.806	0.0475**
NE	Perennial forbs	Before	0.5469		
NE	Annual forbs	After	0.1525	0.164	0.3510
NE	Annual forbs	Before	-0.0117		
NE	Bare soil	After	-2.2150	-6.149	0.3466
NE	Bare soil	Before	3.9342		
NE	Annual grass	After	0.0000	0.0	
NE	Annual grass	Before	0.0000		
NE	Rock	After	-0.3575	-0.242	0.3122
NE	Rock	Before	-0.1158		
SW	Perennial grass	After	-8.3025	-1.837	0.3519
SW	Perennial grass	Before	-6.4653		
SW	Tree	After	-18.0400	-29.77	0.0109**
SW	Tree	Before	11.7389		
SW	Dead shrub	After	-1.8575	0.685	0.2739
SW	Dead shrub	Before	-2.5489		
SW	Live shrub	After	-2.6925	-1.829	0.2255
SW	Live shrub	Before	-0.8636		
SW	Litter	After	8.7650	-3.937	0.3308
SW	Litter	Before	12.7022		
SW	Perennial forbs	After	2.1825	1.522	0.1027*
SW	Perennial forbs	Before	0.6606		
SW	Annual forbs	After	0.4800	0.394	0.0091**
SW	Annual forbs	Before	0.0858		
SW	Bare soil	After	-7.5775	-10.319	0.2001
SW	Bare soil	Before	2.7417		
SW	Annual grass	After	2.3925	3.312	0.0889*
SW	Annual grass	Before	-0.9192		
SW	Rock	After	0.7275	0.252	0.3328
SW	Rock	Before	0.4758		

*significant at alpha = 0.1
** significant at alpha = 0.05

Average daily moisture was then calculated by adding all the readings for each day together and dividing by the number of readings. Figures 18 through 23 show the lowest reading of each probe for the 3 years. Probes 1 through 3 were located at the monitoring site at the lower end of each of the watersheds and probes 4 through 6 were located at the upper site of each watershed. Probe locations can be found in Appendix F.

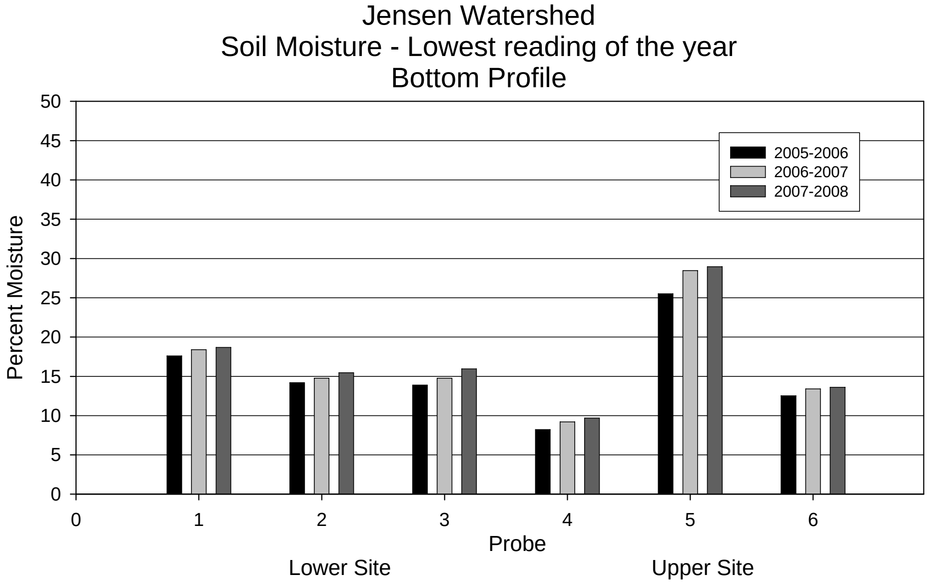

Figure 18. Jensen Watershed Soil Moisture, end of season probe readings for bottom profile.

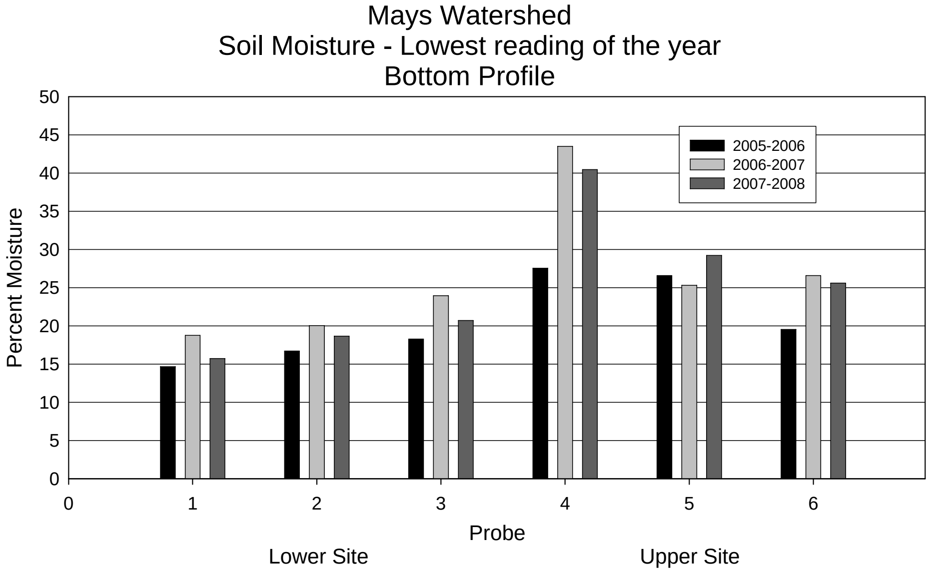

Figure 19. Mays Watershed Soil Moisture, end of season probe readings for bottom profile.

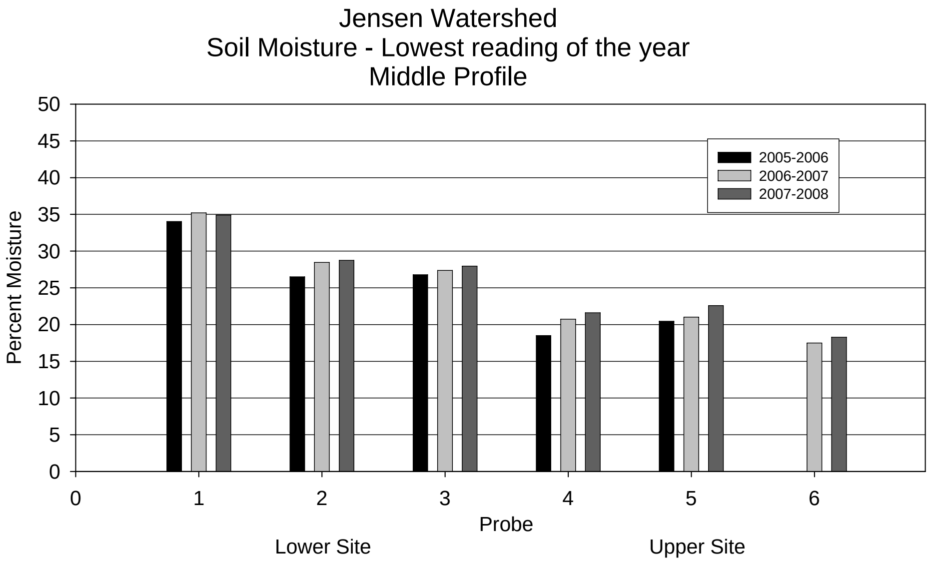

Figure 20. Jensen Watershed Soil Moisture, end of season probe readings for middle profile.

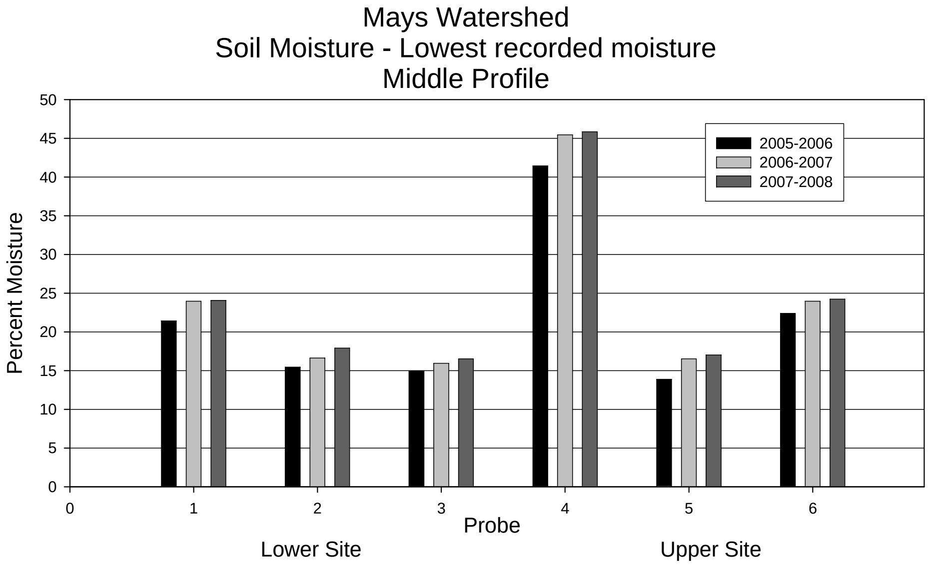

Figure 21. Mays Watershed Soil Moisture, end of season probe readings for middle profile.

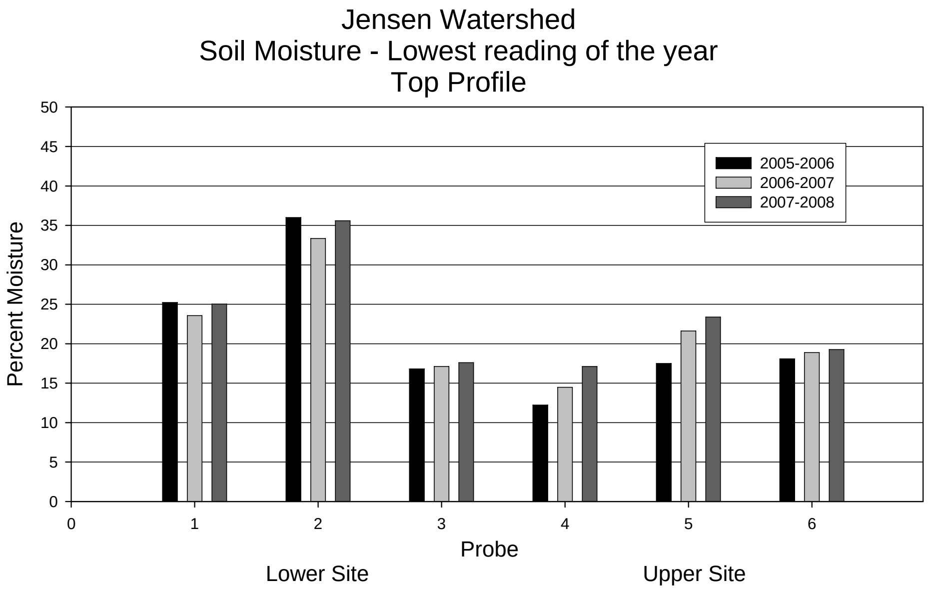

Figure 22. Jensen Watershed Soil Moisture, end of season probe readings for top profile.

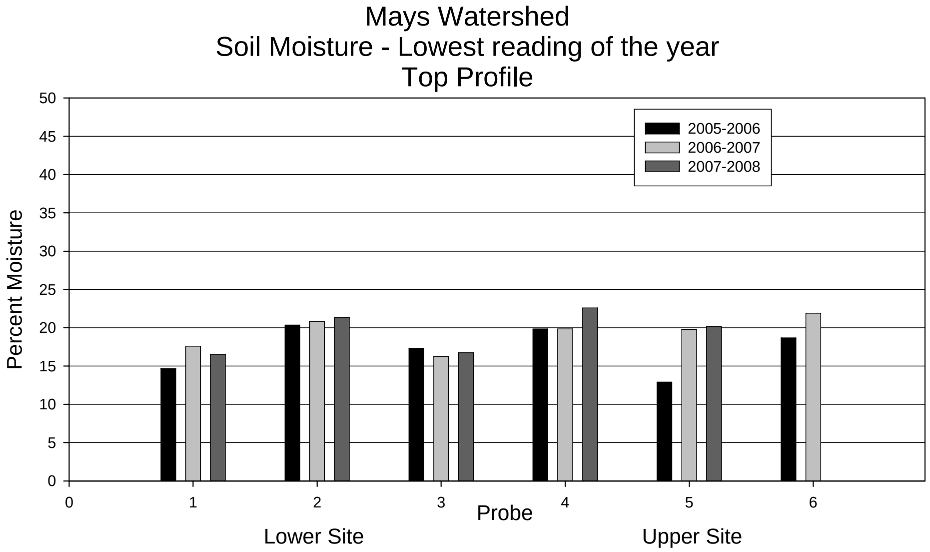

Figure 23. Mays Watershed Soil Moisture, end of season probe readings for top profile.

Figures 24 through 26 show the average soil moisture readings for each of the probe locations by watershed. A review of these figures showed that there were recorded differences in the averages of soil moisture at the end of the season. The end of season soil moisture was defined as the point at which the decline of soil moisture stopped and soil moisture storage began. This period usually occurred in fall or early winter with some probes measuring their lowest reading as late as February of the water year. The bottom profile (Figure 24) shows that the recorded soil moisture for Mays was slightly higher in 2005 when compared to Jensen but the differences in 2006 and 2007 became much larger. For the top and middle profiles (Figures 25 and 26), Jensen recorded a slightly higher reading (but not significant) than Mays.

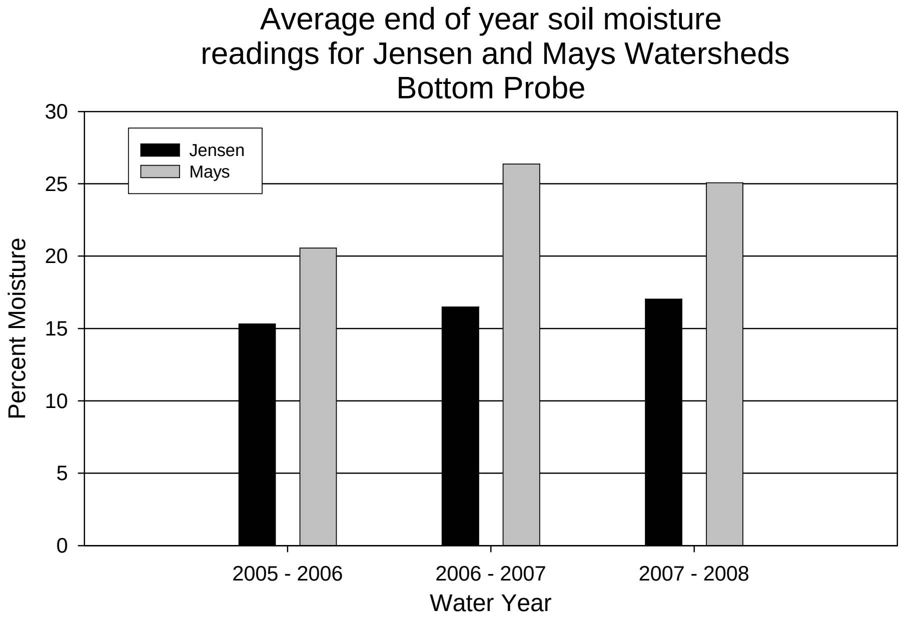

Figure 24. Average end of season soil moisture reading for Jensen and Mays watersheds, bottom profile.

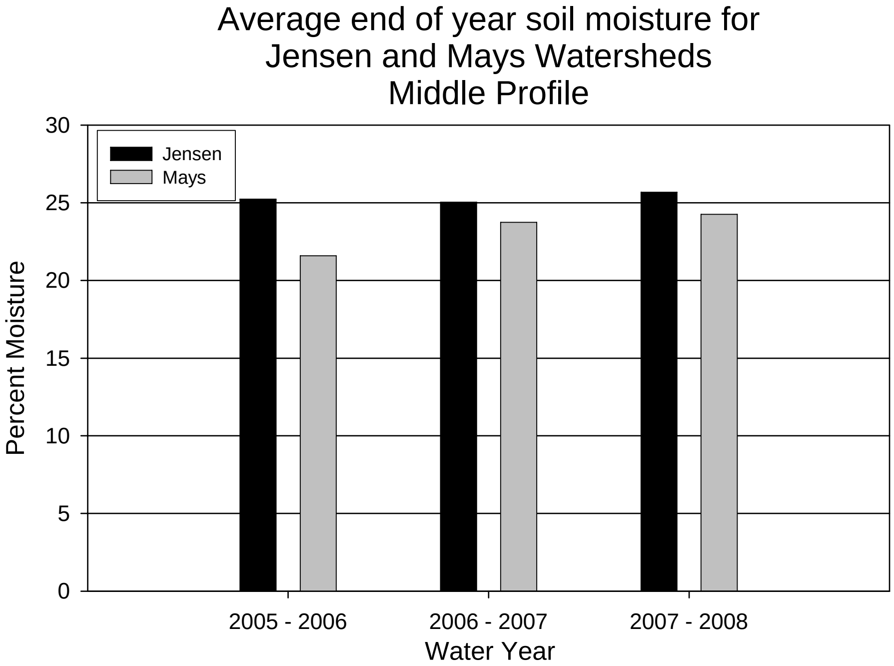

Figure 25. Average end of season soil moisture reading for Jensen and Mays watersheds, middle profile.

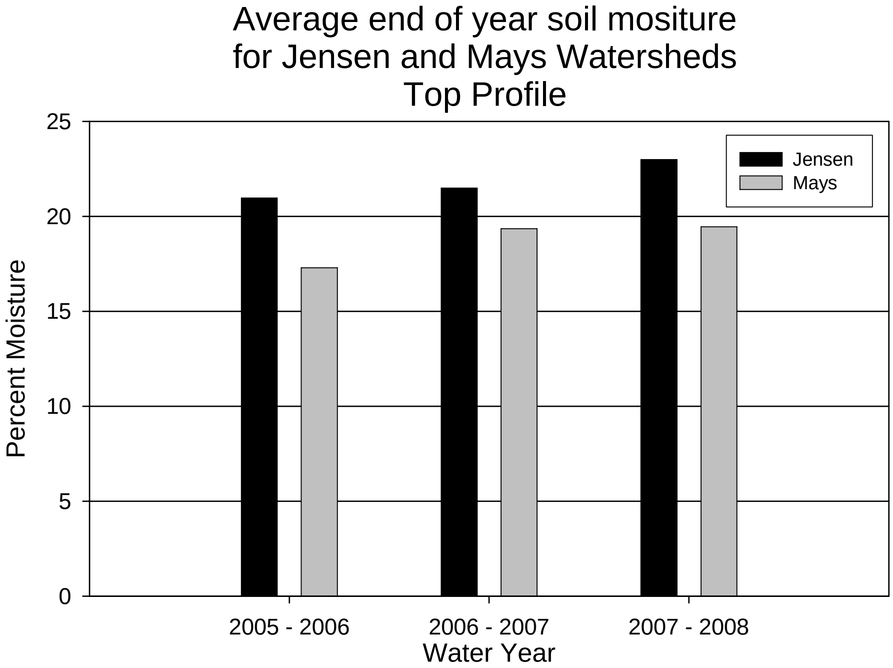

Figure 26. Average end of season soil moisture reading for Jensen and Mays watersheds, top profile.

T-test analysis indicated that there was no significant difference in soil moisture at any soil depth in 2005 (the pretreatment year) between the two watersheds. Table 12 provides the average soil moisture readings for each of the 3 years.

Table 12. Mean soil moisture readings for the end of the year by probe location for both Mays and Jensen watersheds.

	Jensen			Mays		
	2005-06	2006-07	2007-08	2005-06	2006-07	2007-08
Bottom	15.31	16.49	17.04	20.56	26.36	25.07
Middle	25.24	25.04	25.68	21.59	23.74	24.26
Top	20.97	21.49	22.99	17.29	19.35	19.45

Throughout the analysis of soil moisture data, the Satterthwait method (SAS protocols) was used for combining the variances from data of the two watersheds. Significant difference at the Alpha=.1 level did exist for the bottom profile in both 2006 and 2007 (the post-treatment years) between the two watersheds (Table 13).

Table 13. A comparison of the probe depth mean differences between Mays and Jensen for each year.

Year	Profile location	Diff. of Mean	P-value
2005	Bottom	5.29	.1349
	Middle	- 3.65	.5071
	Top	- 3.68	.3378
2006	Bottom	9.87	.0540*
	Middle	- 1.3	.1957
	Top	- 2.14	.4696
2007	Bottom	8.03	.1066*
	Middle	- 1.42	.7892
	Top	- 3.54	.3144

* = significant at the alpha = .1

A t-test analysis comparing each of the treatment years against 2005 showed that the relationship between watersheds and the treatment was strongest in 2006 (precipitation was 125 – 129 percent of normal) (Table 14). A mean increase in the difference was greatest for the bottom profile (significant at alpha = .1). All other probe locations showed a slight increase in the difference indicating that end of season soil moisture had increased more in Mays than in Jensen for each of the post treatment years but that difference was not significant.

Table 14. A comparison of the mean differences between each of the treatment years and the pre-treatment year.

Year	Profile Location	Diff. of Means	P-value
2006 vs. 2005	Bottom	4.58	.0783*
2007 vs. 2005	Bottom	2.74	.1637
2006 vs. 2005	Middle	2.35	.1957
2007 vs. 2005	Middle	2.23	.2283
2006 vs. 2005	Top	1.54	.3421
2007 vs. 2005	Top	0.42	.8085

* significant at Alpha = .1

T-test analysis comparing the average of 2006 and 2007 against 2005 again shows That the average for treatment years was significant at the alpha = .1 level for the bottom profile. The other profiles showed slight increases in overall moisture but were not significant (Table 15).

Table 15. A comparison of the average of the mean differences for the two post-treatment years with the pre-treatment year.

Year	Profile Location		Diff. of Means		P-value
		Jensen	Mays	Diff.	
2006-07 vs. 2005	Bottom	1.45	5.15	3.7	.1002*
2006-07 vs. 2005	Middle	0.12	2.44	2.29	.1796
2006-07 vs. 2005	Top	1.27	2.14	0.87	.6132

significant at Alpha = .1

The time of year in which the lowest reading was acquired was examined. The purpose of this was to see if there were differences in when the lowest reading occurred and if there was any relationship to the treatment. Table 16 illustrates day of year when the lowest reading occurred. Day of year was calculated from September 1 of each year. September 1 was used so that no negative numbers existed. Table 17 shows the average number of days for each profile location by year for each of the watersheds. Changes in difference in number of days when soil moisture began to accumulate could be affected by vegetation (tree intercept) and/or the site's ability to encourage infiltration.

T-test showed a significant difference within each year between the watersheds for some profiles within each of the years (Table 18). When the difference in means was negative, that showed that Mays took fewer days (from September 1) to begin to store soil moisture. In the treatment year (fall 2005), the bottom profile was significant and corresponded to cutting of the trees. In 2006 and 2007, the top (alpha = .01) and middle (alpha = .05) profiles were significant. In 2007, the bottom profile also was again significant (alpha = .01) indicating that with tree removal the site’s ability to begin storing soil moisture was improved with treatment.

In a comparison of treatment years with the pre-treatment readings, the top profile was the only profile to show significant difference. T-test showed significant difference (alpha = .01) for the top profile when comparing the first treatment year 2006 and 2005 but no significant difference for the second treatment year 2007 and 2005 (Table 19). This reflected the dry year of 2007 (80 percent of average) with 2005 which was near the long term precipitation average for Barnes Station.

A t-test looking at the average of the two post treatment years compared to the pretreatment year is found in Table 20. Significance was only found in the changes in the top profile (alpha = .01). A reduction in the number of days for the middle profile was also found but was not significant. There was no difference in the bottom profile when comparing Mays to Jensen.

Table 16. Number of days from Sept 1 in which lowest soil moisture reading was recorded.

			2005-06		2006-07		2007-08	
Watershed	Probe	Site	Date	Days	Date	Days	Date	Days
Mays	Top	Lower	11/7/2005	68	10/31/2006	61	10/6/2007	36
			11/8/2005	69	11/1/2006	62	10/22/2007	52
			9/24/2005	24	11/1/2006	62	10/6/2007	36
		Upper	11/17/2005	78	12/15/2006	106	11/15/2007	76
			12/19/2005	110	1/15/2007	137	9/29/2007	29
			11/10/2005	71	12/4/2006	95	*************	
	Middle	Lower	11/29/2005	90	11/19/2006	80	11/15/2007	76
			12/13/2005	104	2/3/2007	156	12/18/2007	109
			11/5/2005	66	11/18/2006	79	11/8/2007	69
		Upper	11/29/2005	90	11/2/2006	63	12/18/2007	109
			11/6/2005	67	11/18/2006	79	11/17/2007	78
			12/13/2005	104	1/18/2007	140	12/17/2007	108
	Bottom	Lower	11/26/2005	87	2/19/2007	172	12/9/2007	100
			12/19/2005	110	1/9/2007	131	12/10/2007	101
			12/11/2005	102	11/10/2006	71	12/4/2007	95
		Upper	12/3/2005	94	12/16/2006	107	12/20/2007	111
			11/4/2005	65	11/1/2006	62	12/14/2007	105
			11/21/2005	82	2/2/2007	155	12/18/2007	109
Jensen	Top	Lower	11/10/2005	71	2/2/2007	155	11/15/2007	76
			11/6/2005	67	2/2/2007	155	10/18/2007	48
			11/9/2005	70	2/2/2007	155	11/4/2007	65
		Upper	11/3/2005	64	2/2/2007	155	11/15/2007	76
			11/10/2005	71	2/3/2007	156	11/15/2007	76
			11/4/2005	65	2/2/2007	155	11/4/2007	65
	Middle	Lower	12/14/2005	105	1/30/2007	152	12/24/2007	115
			12/22/2005	113	2/2/2007	155	12/25/2007	116
			1/22/2006	144	2/3/2007	156	12/28/2007	119
		Upper	11/11/2005	72	12/9/2006	100	11/30/2007	91
			11/11/2005	72	2/3/2007	156	12/24/2007	115
			************		2/2/2007	155	12/23/2007	114
	Bottom	Lower	12/20/2005	111	2/1/2007	154	12/26/2007	116
			12/19/2005	110	2/1/2007	154	12/19/2007	110
			12/3/2005	94	2/2/2007	155	12/21/2007	112
		Upper	12/30/2005	121	1/23/2007	145	12/23/2007	114
			12/16/2005	107	12/24/2006	115	12/18/2007	109
			12/17/2005	108	2/3/2007	156	12/21/2007	112

******* = no probe reading during this time period

Table 17. The average number of days (from September 1) until soil moisture began to accumulate at the various probe depths for each of the watersheds.

Watershed	Profile	2005-06	2006-07	2007-08
Mays	Top	70	87	46
	Middle	87	100	92
	Bottom	90	116	104
Jensen	Top	68	155	78
	Middle	101	146	112
	Bottom	109	147	112

Table 18. A comparison of the average number of days between Mays and Jensen watersheds when soil moisture began to accumulate for each year.

Year	Profile Location	Watershed			P-value
		Mays	Jensen	Diff.	
2005-06	Bottom	90	109	- 19	.0311**
	Middle	87	101	- 14	.3462
	Top	70	68	2	.8631
2006-07	Bottom	116	147	- 31	.1491
	Middle	100	146	- 46	.0293**
	Top	87	155	- 68	.0003***
2007-08	Bottom	104	112	- 8	.0086***
	Middle	92	112	- 20	.0456**
	Top	46	68	- 22	.0398**

** significant at Alpha = .05
*** significant at Alpha = .01

Table 19. A comparison of the difference in the average number of days before soil moisture accumulation began by profile depth for each of the treatment years and the pre-treatment year between Mays and Jensen.

Year	Profile Location	Watershed			P-value
		Mays	Jensen	Diff.	
2006 vs. 2005	Bottom	26	38	- 12	.5688
	Middle	13	45	- 32	.1114
	Top	17	87	- 70	.0001***
2007 vs. 2005	Bottom	14	3	11	.2735
	Middle	5	11	- 6	.6433
	Top	- 24	10	-34	.8085

*** significant at Alpha = .01

Table 20. A comparison of the difference of the average number of days before soil moisture accumulation began for the combination of post-treatment years with the pre-treatment year.

Year	Profile Location	Watershed			P-value
		Mays	Jensen	Diff.	
2006-07 vs 2005	Bottom	20	20	0	.9403
	Middle	9	28	- 19	.1796
	Top	- 12	48	-60	.0006***

*** significant at Alpha = .01

GROUND WATER

Depth to water was recorded since January, 2003. In June, 2005, data collection also included automated recordings which were collected 4 times per day. Analysis was done on days of recorded water. Figure 27 illustrates the annual variation in the 4 years of data collecting for both watersheds. Table 21 shows the average days pre and post treatment for the two watersheds and the differences.

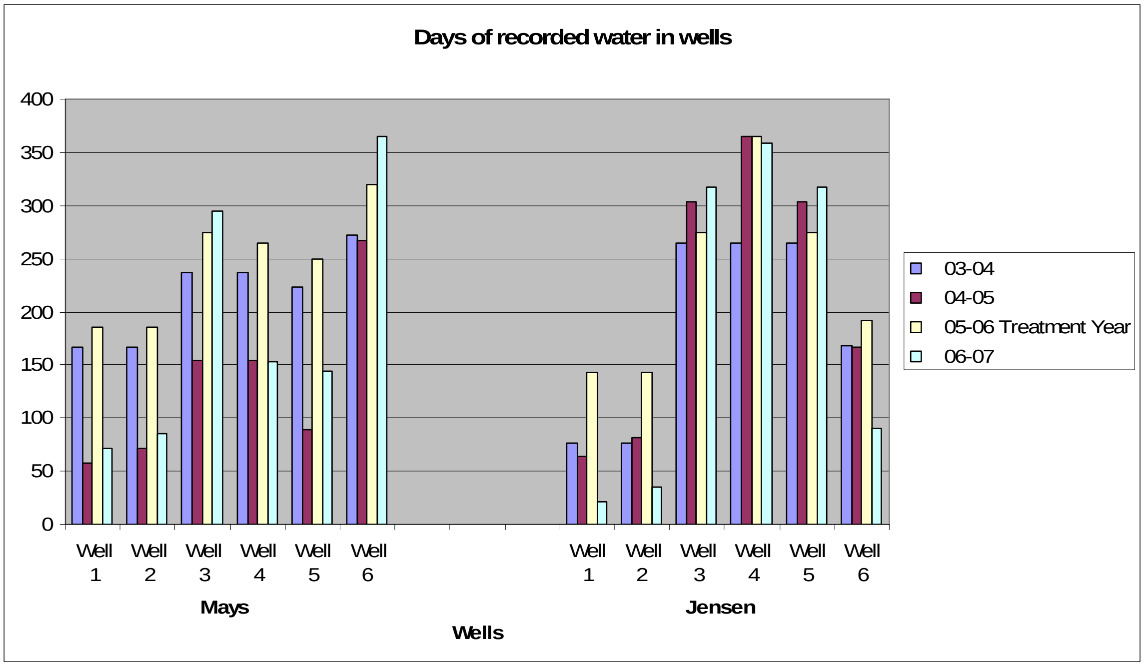

Figure 27. Days of recorded water in wells for the water years 2003-04 through 2006-07.

Table 21. Comparison of average number of days water was recorded in each well. Pre and post treatment years consist of 2 years each.

Watershed	Well	Pretreatment	Posttreatment	Difference
Mays	1	112.5	128.5	16
	2	119.5	135	15.5
	3	195.5	285	89.5
	4	195.5	209	13.5
	5	156	197	41
	6	269.5	342.5	73
Jensen	1	70	82	12
	2	78.5	89	10.5
	3	283.5	296	12.5
	4	314.5	361.5	47
	5	283.5	296	12.5
	6	167.5	141	-26.5

Figure 28 illustrates the average of each of the 2-year periods of pre and post treatment. The difference between the two years is shown as well.

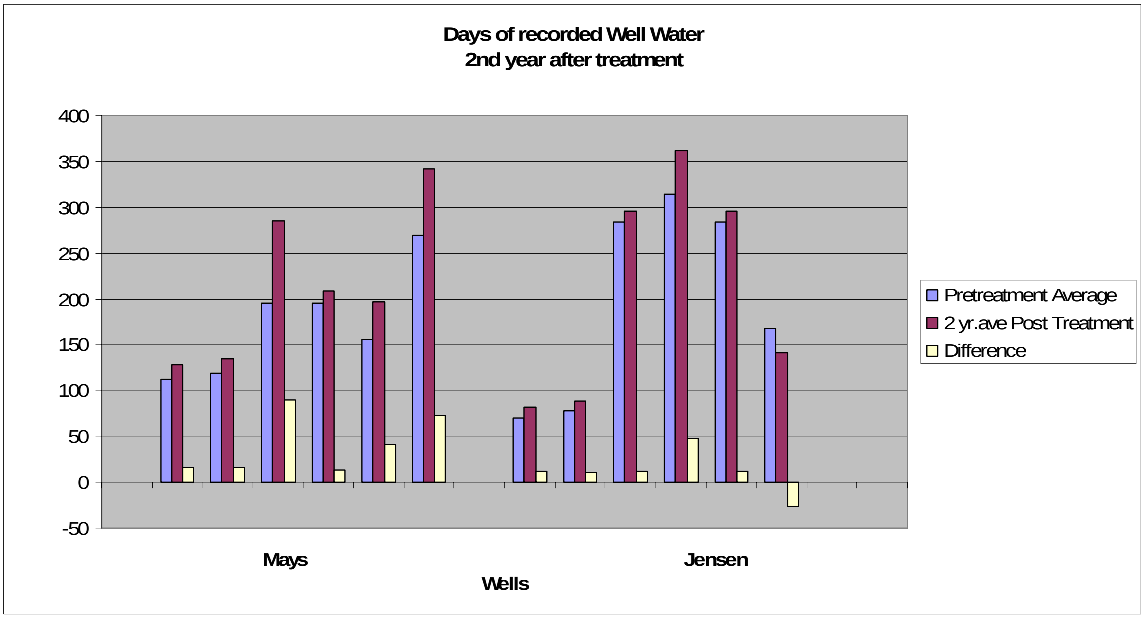

Figure 28. Days of recorded well water pre and post treatment and the associated difference.

A two-sample t-test was applied to test for treatment differences. Results of that test are in Table 22. A significant difference in the change of number of days water was present in Mays following treatment was at the alpha > .05.

Table 22. Test for treatment differences in days of recorded water.

Watershed	Average Difference	Standard Error	t value	P-value one-tailed
Jensen	11.33	11.63	-1.83	0.049**
Mays	41.42	11.63		

** significant at alpha = 0.05

Figures 29 and 30 illustrate the changes in curve shape and depths that water was recorded over time. The curve shape for Jensen (control) was similar for all years. The height of curve (closeness of water to the surface) was a reflection of the precipitation received during that water year. The curve shape for Mays changed between the pretreatment years and the post treatment. The pretreatment curve for Mays was best described as spiked, with the peak of the curve occurring quickly and then dropping off. The post treatment curves were flatter, with the peaks not being as sharp. Since the treatment, well 6 in Mays did not go dry. Well 4 in Jensen recorded water in years 2004, 2005 and 2006 but went dry in late September, 2007.

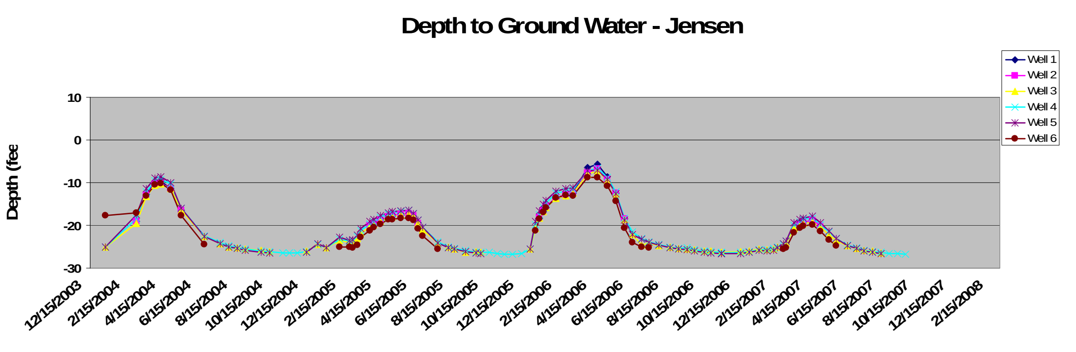

Figure 29. Depth to ground water, Jensen wells 2003 – 2007.

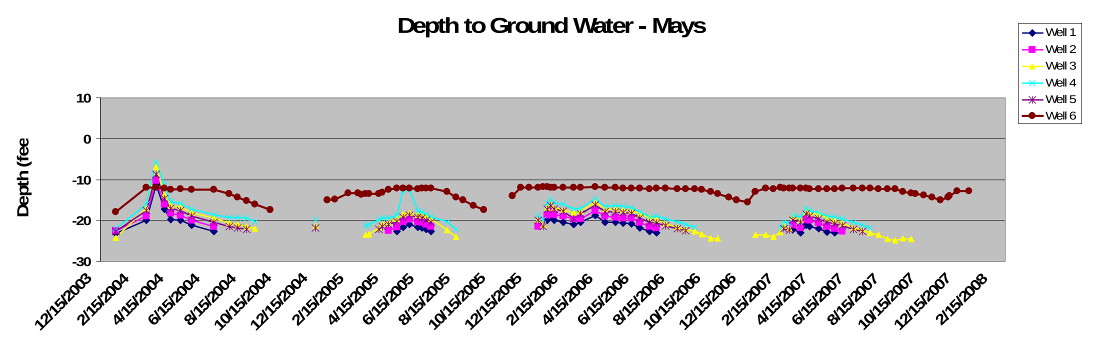

Figure 30. Depth to ground water, Mays wells 2003 – 2007.

SPRING FLOW

Flows from two spring boxes, one in Mays and one in Jensen were measured approximately every two weeks since September, 2004. Measurements were automated in May, 2005 and thereafter were recorded 4 times per day. Manual measurements were taken throughout the entire period for calibration and verification purposes. Data loggers were not able to accurately measure flows below 3 gpm.

Figure 31 illustrates the differences in output between the two springs and the differences between years. Spring flow was dependent on timing/type and amount of precipitation. Base flow (that flow which is least likely to be influenced by a recent precipitation event or snow melt period) was the late season flow, the period between July and November.

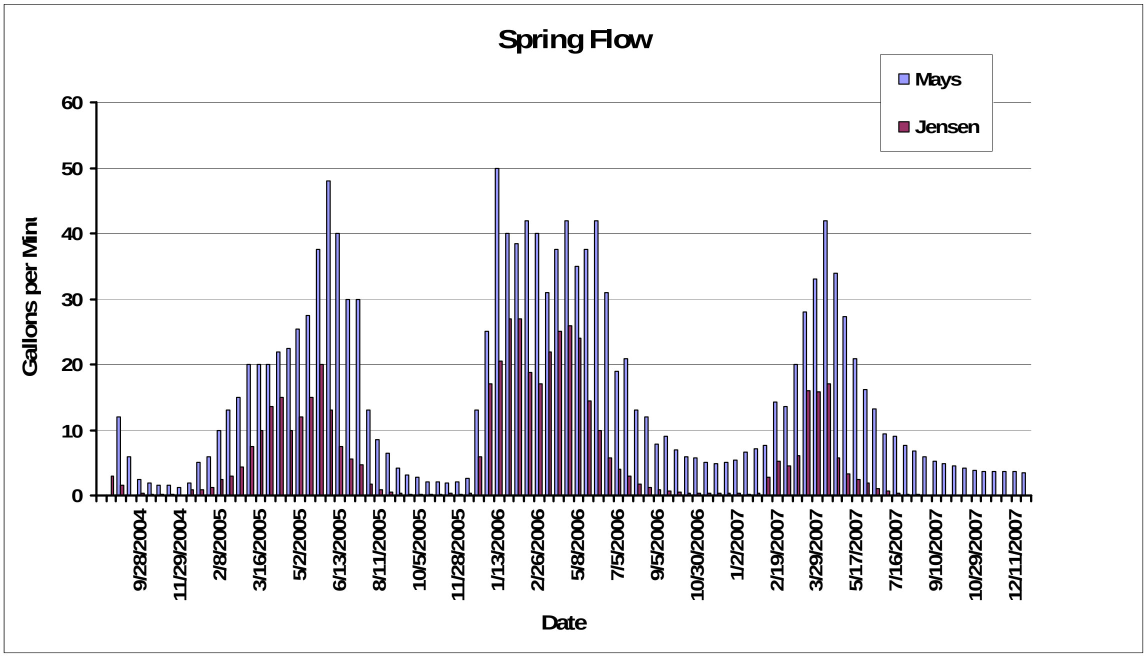

Figure 31. Mays and Jensen spring flow, 2004 – 2007.

Figure 32 shows the base flows for the 2 years prior to treatment and the 2 years post treatment.

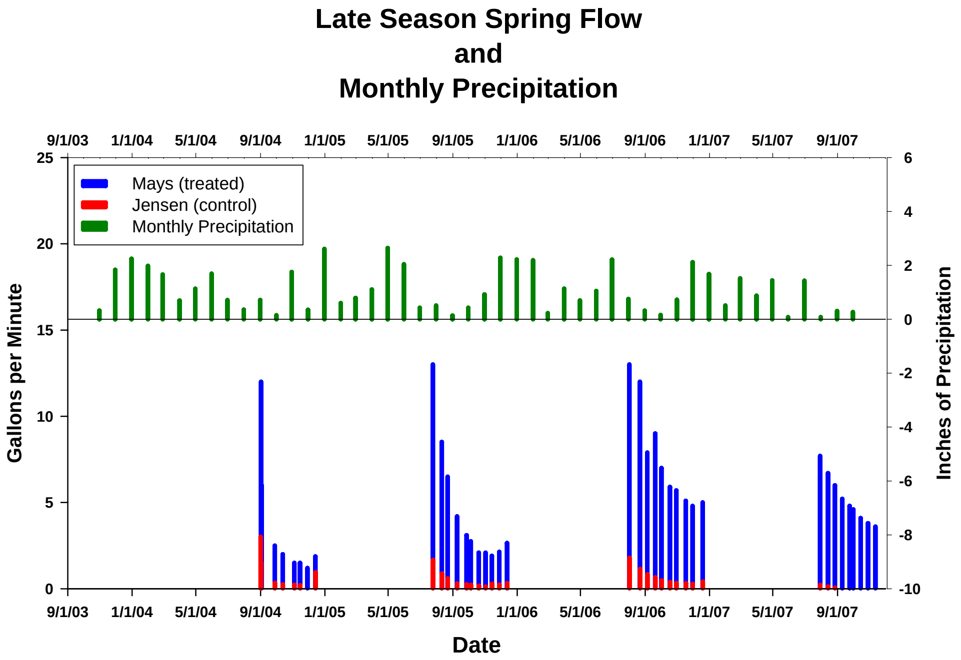

Figure 32. Late season flows for Mays and Jensen springs.

Table 23 shows the t-test results for comparisons of late season flow (lowest flow recorded) between the two watersheds and the pre and post treatment years. The one tailed P-value is significant at alpha = .05.

Table 23. T-test for spring flow data, lowest flow recorded (gpm)

Treatment	Year	Watershed		Difference	Mean	Variance
		Mays	Jensen			
Pre	2004	1.87	0.20	1.67		
Pre	2005	1.90	0.13	1.77	1.720	0.00500
Post	2006	4.80	0.23	4.57		
Post	2007	3.6	0.00	3.60	4.085	0.47045
		Difference			2.365	
		Standard error			0.4876	
		t-test			4.8506	
		One tailed P-value			0.020 **	

**significant at Alpha = 0.05

CHANNEL FLOW

The channel flows of Mays and Jensen were ephemeral in nature, only existing during periods of snow melt or summer thunderstorm activity. In an attempt to look at channel flow as influenced by the treatment, total flow volumes and days of flow were looked at for the entire year and seasonally looking at spring flows (Figure 33). Spring flows were singled out because they were most likely to occur. For the years of data collection in which complete years were recorded (10 out of 13 years) Mays had 6 years of springtime flow data and Jensen had 7 years. Spring flow was defined as any flow occurring from January 1 to June 30 of each year. In all but 1 year (1996) days of channel flow in Mays exceeded Jensen.

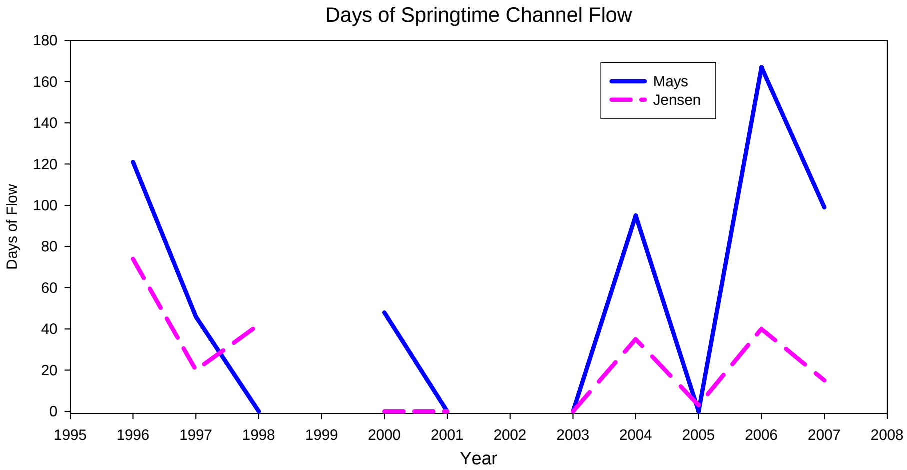

Figure 33. Number of days of channel flow from January to June.

Figure 34 shows the springtime flow in cfs (cubic feet per second). Unlike the days of flow, Mays exceeded flow in Jensen in all years except 3. One of those years it did not exceed Jensen was in 2007, the 2nd year of post treatment.

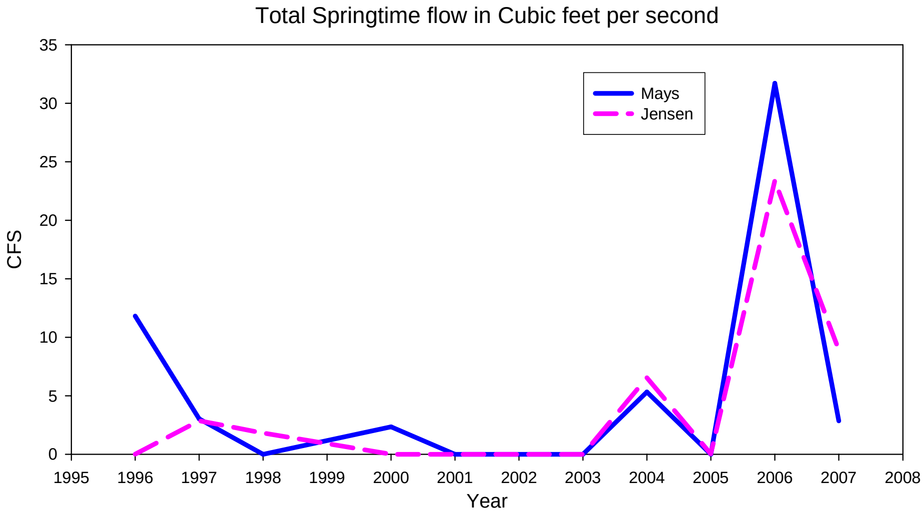

Figure 34. Springtime channel flow by year (January through June) in cfs.

Figure 35 shows days of annual channel flow. This figure represents the total number of days that flow was recorded. As with the springtime channel flow, Mays flow days were always greater than Jensen except for one.

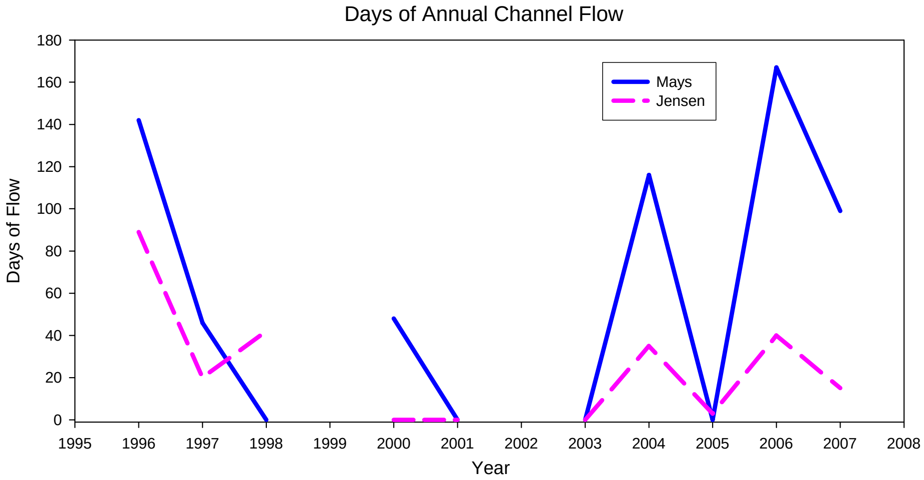

Figure 35. Number of days of annual channel flow.

Figure 36 illustrates the highly variable annual channel flow associated with the two watersheds. In 1997, total flow of the 2 watersheds was almost identical (5.99 cfs for Mays and 5.65 cfs for Mays). In 2004, springtime flow for Jensen was greater than Mays

(12.95 cfs vs. 10.54 cfs), but total annual flow flipped with Mays ending up with greater annual flow (13.15 cfs vs. 12.95). While springtime flow, 3 years of Jensen flow exceeded Mays, in annual flow, only 2007 did Jensen's total flow exceed Mays.

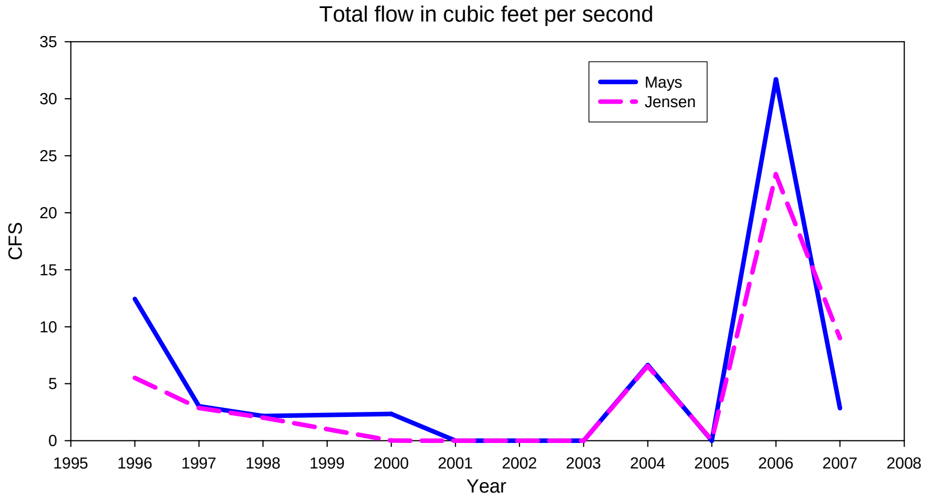

Figure 36. Total annual flow in cubic feet per second

DISCUSSION

WEATHER

The water balance equation is made of inputs (rain and snow) and outputs. Outputs are interception and evaporation, soil infiltration (for plant growth and ground water recharge) and overland flow. Weather in its many forms (precipitation, temperature, wind and relative humidity) plays an important role in the function of semi-arid watersheds. Weather interacts with vegetation and the soil surface. Precipitation interacts by way of storm intensity, total amount per event, frequency of event, and type of precipitation. Temperature affects the type of precipitation, the condition of the soil surface (frozen, dry) and influences plant utilization via transpiration. Wind affects potential soil surface and plant water utilization by increasing evaporation as wind speed increases. Wind may also affect deposition of precipitation, particularly in the winter when blowing snow may be swept from one site and deposited on another. Relative humidity is important in controlling the rate of transpiration by creating a moisture deficit in the atmosphere surrounding the plant. As the deficit gets larger, transpiration increases until the plant can no longer move adequate amounts of water at which point the plant will close its stomata if possible. If the plant cannot control its water use this way, the plant will desiccate.

Precipitation

The annual precipitation for the watersheds is 3500 mm or 13.75 inches (Barnes Station, 30 year average). Within the watersheds, precipitation for the last 3 water years has varied from 80 to 129 percent of the average. Timing of precipitation is critical to plant growth and ground water recharge. Sixty to Sixty-five percent of the total is delivered from October 1 to May 1 in the form of snow or rain.

Typically the site will receive fall rains, wetting the soil surface. Precipitation amounts from October 1 to December 1 ranged from 381 to 1016 mm during the study period. During the winter months, precipitation generally comes in the form of snow. Snow depths were variable during the study time. During the study, there were winters of relatively no snow pack (bare ground observed most of the winter) to winters with snow pack depths of 3048 mm (12 inches) to 4064 mm (16 inches). During the winters of 2005-2006 and 2007–2008, soil temperatures in both watersheds stayed above 0 degrees Celsius (32 degrees Fahrenheit). Snow pack during these two winters lasted into mid-March, with peak depths of 4000 mm plus. During the winter of 2006–2007, snow depth was relatively nonexistent and February soil temperatures approached -5 degrees Celsius (22 degrees Fahrenheit). It was during this period in February, 2007 that the watersheds experienced a rain on frozen ground event that resulted in significant overland and channel flow in both watersheds.

Summer thunderstorms can contribute significant amounts of precipitation to the total annual precipitation amount but are more localized and sporadic in nature. It is not uncommon to see that a storm came through and impacted part of a watershed but missed another part of the same watershed. Sometimes a storm would completely miss one of the watersheds. On June 29, 2006, a summer thunderstorm occurred on both watersheds. Precipitation amounts recorded equaled 177 and 203 mm (152 and 177 mm in the first hour) respectively in Mays and Jensen. Flow (10.2 cm on the staff gauge) was recorded in Jensen’s flume, the untreated control, but not in Mays, the treated watershed. An inspection of each of the watershed’s channels revealed that large amounts of overland flow had deposited sediment in Jensen (burying three-fourths of cross-section number 4 and filling the flume) while the channel in Mays showed no signs of overland flow and sediment movement (even though this was only 6 days after finishing the skidding operation in Mays, which removed the bole wood from 4.45 hectares [11 acres] surrounding the channel).

As a result of these observations and measurements, it was apparent that precipitation as well as organic ground cover played a vital role in how these watersheds functioned. Storm intensity and type of precipitation are some of the critical factors in determining how a watershed will respond to precipitation inputs. Snow cover is critical in controlling winter time soil temperature, the degree in which the soil is frozen and as a result, whether that soil will accept infiltration or result in overland flow.

Air Temperature

Air temperature affected the type of precipitation delivered to the study area. Cold temperatures will usually result in precipitation coming in the form of snow and with warmer temperatures, coming in the form of rain. Without snow cover, cold winter temperatures drive soil temperatures well below freezing. Frozen soils act like a lid on the soil surface and prevent water infiltration.

Air temperature also affects plant growth. As winter turns to spring and then to summer, warmer air temperatures promote photosynthesis and plant growth. Plant growth utilizes soil moisture. Vegetation serves as a thermal blanket, dampening the heating of the soil surface by intercepting short wave radiation.

Table 9 (pg. 47) illustrates the maximum and minimum temperatures recorded in the two watersheds. There was less than 1 degree Celsius (2 -3 degrees F) difference in either the winter lows or the summer highs.

Wind

Wind can increase a plant's water use by drying the surface of the leaf tissue, creating a moisture imbalance, which results in an increase in water demand by the plant. No measurable differences in recorded wind speed were observed as a result of the treatment. In each watershed, the wind speed indicator was located on top of a 4.5 m pole. At this height, the indicator was generally above the associated plant community and most importantly, the height of the tree canopy. Following tree removal, one might suppose that wind speeds closer to the soil surface would increase. However, this component was not measured.

There was some concern that the removal of the trees would affect snow deposition as a result of drifting. In looking for evidence of drifting snow within the juniper stand or in the treated area, little evidence of drifted snow was observed. During the winter of 2007-08, some small drifts were observed in the cut areas of Mays. Drifts were found on the northwest slopes (winds predominately out of the southwest) behind sagebrush. However, the drifts were small and were most easily observed only as the sun was setting and shadows were cast. Drifted snow did not appear to be a significant factor in winter snow deposition in these watersheds.

Relative Humidity

Relative humidity is a relationship between the amount of moisture held in the air and the amount of moisture the air can hold at a given temperature. It is a relationship that is largely connected to air temperature and thus is a landscape controlled feature, one not easily affected by local (watershed) conditions. A review of the data showed no indication that relative humidity was affected by the presence or absence of western juniper in the watersheds.

VEGETATION

Initial changes in vegetation showed some statistical significance as a result of the treatment. Significant changes attributed to the treatment included a decrease in tree cover, and an increase in perennial and annual forbs cover as well as annual grass cover. Vegetative changes that seem important but were not statistically significant were a decrease in percent bare soil and a slight increase in live shrub cover. Perennial grass cover showed a slight decrease. These changes do not seem surprising. The understory was present in the treated watershed before the removal of the trees. Perennial grass cover was measured as basal cover so these plants were already on site. There was no evidence or expectation of new grass plants during the first two years following the cutting of the junipers. Understory plants may have been suppressed and the increase in perennial forb and shrub cover would support this concept. Perennial grass cover measured an insignificant 0.05 percent reduction in cover from pretreatment levels. This is well within the limits of observer error.

What was evident but not shown in the data was the large amount of reproduction culms associated with the perennial grasses. Observer notes indicated that in Mays watershed, for bluebunch wheatgrass, Junegrass, bottlebrush squirrel tail there were 10's of reproductive culms per plant. Idaho fescue had generally less than 10 per plant. In Jensen, reproductive culms were limited, with the major perennial grass species all having less than 10 culms per plant.

Greenness of the plants was also observed during 2007 with the majority of grass plants (greater than 70 percent) in Mays still having green leaves in the plant bunch at the time of observation (July 25, 2007) while those same species of grass plants in Jensen were generally dormant and not showing any green (less than 20 percent of the plants). This observation was made in a year when annual precipitation was less than 80 percent of the long term average for the site.

Changes in plant community were also examined based on aspect (Table 11, pg. 52). It was thought that generally, north and east slopes would be less hostile to plant growth while south and west slopes are more hostile due to orientation to the sun and the associated warming of the site and available soil moisture. A review of the analysis showed that on north and east slopes, only perennial forb cover increase was significant. Non-significant changes associated with aspect included an increase in perennial grass cover, increase in live shrub cover and an increase in bare ground.

Significant changes on combined south and west slopes included an increase in annual grass and perennial/annual forb cover. Other vegetative parameters showed only non-significant changes.

Vegetative changes are anticipated to be much greater in the years to come. Following the large amount of seed produced in 2007, it is anticipated that within Mays watershed, bare ground will continue to decrease and forb and grass cover will increase as new plants are produced and existing plants continue to be released. Shrub cover will increase in the coming years primarily from release but new plants may increase as seed production increases as well.

SOIL MOISTURE AND SOIL TEMPERATURE

A review of the soil moisture data provided an opportunity to see how precipitation moved into the system and was utilized. The data provided an illustration of relative soil moisture over time and showed how the soil wets and dries, season to season, year to year. What was most interesting was the evidence (Figure 24, pg. 56) that by removing the deep rooted juniper, deep soil moisture was no longer being utilized for the entire length of the growing season and therefore the treated watershed ended the season with more soil moisture than where it had the year before. While it is too early to know if this is a long term trend, it is one that showed itself not only in the above average precipitation year of 2006 (129 percent of average) but also in the dry year of 2007 (80 percent of average).

In a functioning watershed, the first thing that happens is the capture of the water droplet where it falls. Vegetation (plants and litter) serves to break up the speed of the droplet before it strikes the soil. As quickly as possible, that water droplet should infiltrate into the soil profile. Much like a sponge, soils that have some moisture in them are more likely to absorb additional moisture quicker than dry soils. Dry soils can be hydrophobic and almost always repel water at first. Soil organic matter increases a soil's ability to store water. Growing plants increase soil organic matter through root production followed by root die off and decomposition. Increased soil moisture can increase plant root productivity if it is available during the growing season. The removal of the juniper reduced water utilization during periods when the other components of the plant community were not growing. The removal of juniper allowed soil moisture to build during the winter and early spring period providing the opportunity for improved herbaceous plant productivity and potential ground water recharge.

A review of Figures 18 through 23 (pgs. 53-55) showed how end of season soil moisture amounts compare at the various probe depths. For Jensen (control), the average readings for both sites showed that for the 3 years, end of season soil moisture was relatively constant for both the bottom probes and those at the middle profile. The top profile probes showed a slight but insignificant increase in end of season soil moisture level in 2007. For Mays, all soil profiles (bottom, middle and top) showed increases in end of season soil moisture levels as a result of the treatment. The bottom probes, averaged across both sites in Mays watershed, were the only probe location where the observed change was significant as a result of the treatment (alpha = .1).

Soil temperatures were influenced by conditions near the soil surface (Figures 37 and 38). In the winter, the presence or absence of a snow pack controls whether or not subsurface soil temperatures drop below 0 degrees Celsius (32 degrees Fahrenheit). During the winters of 2005-06 and 2007-08, near surface soil temperatures did not drop below 0 degrees Celsius.

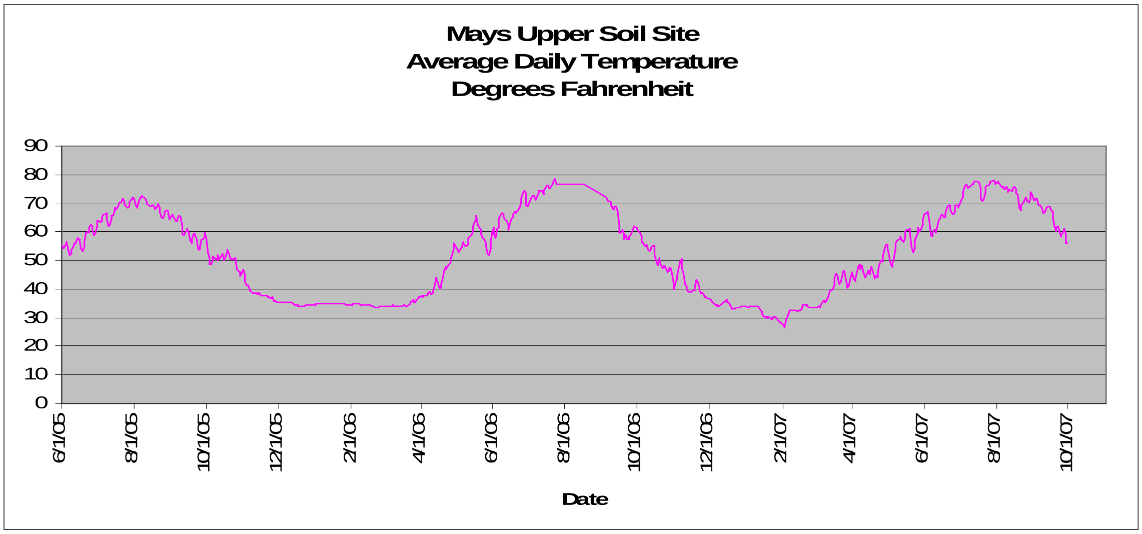

Figure 37. Average daily soil temperature, Mays upper monitoring site.

While ambient air temperatures dropped to near -17 degrees Celsius (0 degrees Fahrenheit), the snow pack served as an insulator, moderating soil temperatures. In contrast, during the winter of 2006-07, soil temperatures approached -5 degrees Celsius (22 degrees Fahrenheit) for an extended period of days. Frozen soil prevents snow melt

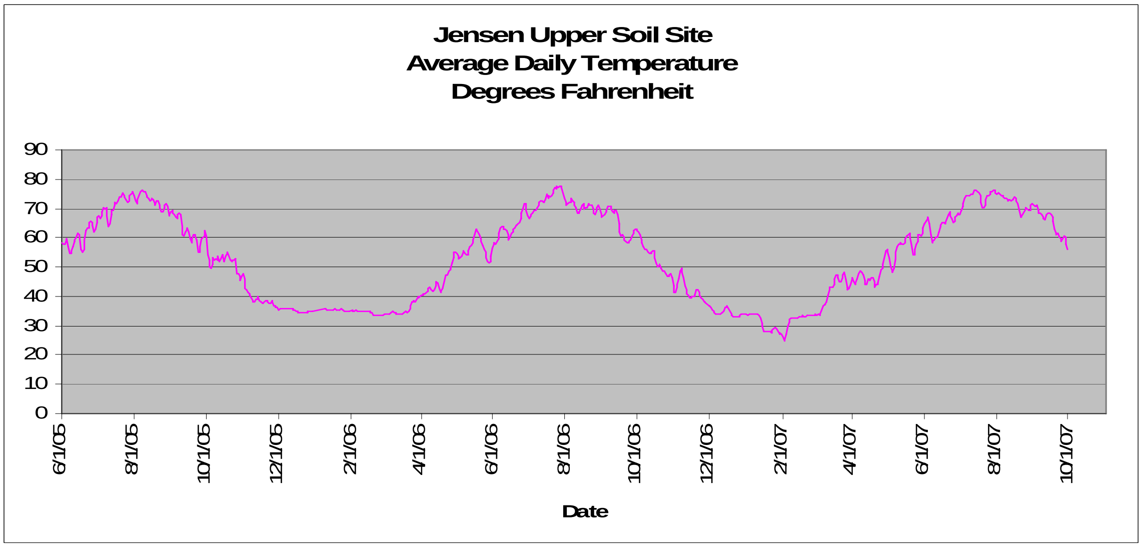

Figure 38. Average daily soil temperature. Jensen upper monitoring site.

and early spring rains from entering the soil profile. On frozen soil, as rains occur and snow melts, overland flow is observed. During the winters with adequate snow pack, and therefore unfrozen soils, overland flow was not observed and channel flow was originating from bank seepage.

During the summer months, there did appear to be a slight elevation in soil temperatures in Mays watershed following treatment. Soil temperatures during the summer months for both watersheds were similar the year prior to treatment (2005). Following the cutting of the trees, there appeared to be slight increase in summer time soil temperatures in Mays in both 2006 and 2007 (.5 – 1.5 degrees Celsius, 2 – 3 degrees F). The removal of the tree canopy and the corresponding shade allowed the direct sunlight greater access to the soil surface, causing it to warm. One might suppose that this temperature increase would result in a shorter growing season (removal of soil moisture through transpiration and soil water evaporation) but this did not appear to be the case. A review of the data indicated that soil moisture was available longer in Mays following treatment than before treatment. In reviewing other site parameters (soil moisture, plant cover and observed greenness throughout the summer) it did not appear that these observed temperature changes were negative.

GROUND WATER

In a healthy watershed, the storage and safe release of water is important since water is a limited resource. From a management perspective, it becomes important to make that water available for all beneficial uses over an extended period of time.

Beneficial uses include plant growth (on site), water in the stream for fisheries and other aquatic species and irrigation/recreational uses farther down the watershed. Just like a hydrograph for a stream system, a hydrograph for ground water shows how water moves through the system subsurface, accumulating ground water as the snow melts and spring rains come, reaching a peak in late spring and early summer, then diminishing throughout the summer, disappearing by mid to late summer. For a watershed that is not functioning properly, a hydrograph may show a spike in flow following a storm event or spring snow melt, indicating that the site was not able to absorb what is delivered during the time it was delivered and it immediately shows up in the channel. For a watershed that is functioning properly, contact time between the soil and the precipitation is increased on the uplands, increasing the opportunity for infiltration. Water that cannot infiltrate and moves down slope to the channel as overland flow potentially becomes flood waters. These flood waters are moved onto the floodplain, slowing it down and again increasing the opportunity to have that water move into the soil profile through infiltration. The hydrograph in this case would show a flow that had its peak flow dampened and its length of flow (expressed in days) extended.

Monitoring the ground water in Mays and Jensen provided a look beneath the soil surface and into the “channel” we cannot see. Figures 29 and 30 (pg. 67) illustrate the hydrographs for ground water in these two watersheds. The hydrograph for Jensen (Figure 29) exhibited a curve that has been relatively consistent for the 4 years since the wells were placed. While height and width of the curve was somewhat controlled by the amount and timing of precipitation for each year, the shape was a reflection of how the “system” was working in Jensen, which included the condition of the vegetation.

For Mays (Figure 30) we saw the effect of the treatment. During the first two years (prior to treatment) the hydrograph showed that most of the wells had a short, spiked curve that reflected spring run off and a system where water moved through the watershed very quickly. Following treatment, the next two years showed a significant dampening of the curve (no longer spiked) and a flattened, extended flow of water subsurface. For well 6, even more significant, was that since treatment two years ago this well has not gone dry, whereas, before treatment it was always dry by late summer.

It is important to point out that precipitation for both years prior to treatment and after treatment have been very similar (Figures 12 and 13, pgs. 45-46). Prior to treatment, we had a relatively wet year (110 percent) and a relatively normal year (95 percent), and in the post treatment years, we have had a relatively wet year (125 percent) and a relatively dry year (80 percent). The reason for pointing this out is that there is a tendency to think that treatment effect was just because it was a “wet year”. Because the analysis used the average of pre-treatment years and post-treatment years, the extremes have been dampened.

Figure 27 (pg. 65) shows the number of days water was recorded in the wells for each year. The pre-treatment normal year was 2004-05 and the post-treatment dry year was 2006-07. A review of Figure 23 (pg. 55) indicated that five of the six wells in Mays showed increases in the post-treatment days of recorded water and the sixth well was equal to its pretreatment level. Within Jensen, two wells showed slight increases in days of recorded water but four of the wells showed a clear reduction in number of days of recorded water. A comparison of the wet years (2003-04 and 2005-06) showed that for both Mays and Jensen, a slight to large increase was measured in all wells. Therefore, water availability was significant in the dry years as a result of the treatment. During the wet years, precipitation may overcome watershed condition and therefore a “shortage” may not be as evident.

SPRING FLOW

A review of the spring flow data provided an insight similar to that of the well data. Springs are a surface expression of ground water. As water moves subsurface down slope, if it encounters an impervious obstruction, deflection from that obstruction may force it to the surface. If this happens, a spring is formed. Anecdotal information about juniper control includes the observation that following juniper removal, flow from known springs increased and sometimes new springs were identified in treated areas where they were not documented to be before.

If springs are a product of ground water, and in a functioning watershed increased infiltration results in increased stored soil water, than increased spring flow would be an indicator that site is functioning better. Figure 31 (pg. 68) shows the actual measurements of each of the springs located in Mays and Jensen. The general shapes of the curves (the peaks and flow lengths) are a reflection of the amount of precipitation received each year. For treatment effects, what is of concern is the change in the differences between the two.

For the purpose of minimizing the inputs of precipitation on spring output, an analysis of late season spring flow was conducted. Late season flow was selected because it is the flow period least likely to be influenced by a recent precipitation event while illustrating any changes associated with increased infiltration of precipitation. Late season spring flows are comparable to the “base flow” of a stream or river.

A change in the differences in the two springs output was measured. Figure 31 (pg. 68) illustrates the differences in output between the two springs both prior to and after treatment. Analysis of this time period showed that a significant increase in the difference in output has occurred since treatment, almost 225 percent increase in the difference (alpha>.05). Conversely, during the dry year of 2007 (80 percent of average), late season flow in Jensen ceased for the first time since monitoring began.

Developing a spring for livestock water or other purposes can be costly. The cost of developing the springs in this study was $4000.00 each. Landowners and land managers want to be sure their investment in a water development is a sound one and in the case of a spring, that soundness is measured in flow and that flow’s ability to meet the needs of the intended use (i.e., gallons of water per minute to meet the needs of a given number of livestock for a given period of time). Without vegetative treatment, both of these springs provided minimal late season flows. Given the annual precipitation of 3500 mm (13.75 inches), output from either spring (Mays or Jensen) may not have been enough for the investment to develop. In fact, the landowner was hesitant to provide his approval for the spring developments because the flow, as he knew it, was seasonal and had only the potential of creating livestock behavior problems.

This study showed that the increase in output for the Mays spring following treatment justified the investment in developing it. Even when annual precipitation was 80 percent (2800 mm or 11 inches) of the long term average, flow was greater in late season following treatment when compared to pretreatment flows (approximately 225 percent – 1.8 gallons per minute to 4.2 gallons per minute). Mays spring now provides off-site water in late August for 240 cow-calf pairs.

CHANNEL FLOW

Channel flow in the two watersheds is ephemeral. These channels only have flow during periods of snow melt and extreme summer thunderstorm activity. Ephemeral channels tend to be more influent in relation to the ground water, contributing to ground water rather than ground water contributing to channel flow.

Comparisons of ephemeral channel flows or days of flow did not show a relationship to the treatment. A comparison of Figures 34 and 36 (pgs. 71-72) illustrated that in most years, recorded channel flow occurred during the spring and early summer months. In 1996 and 2004 total annual days of flow (Figure 36) were greater than days of springtime channel flow, a result of late summer thunderstorms and early fall rain (Figure 34). In all years but one, Mays flowed longer than Jensen. Only in 1998 did Jensen flow longer when compared to Mays. In 2007, while length of flow was greater in Mays, Jensen’s flow as measured in accumulated cubic meters per second (cms.) was greater than Mays’ flow.

Of special note in the observation of these systems was the winter of 2006, following the cutting of juniper in Mays. The snow pack, which began its accumulation in December, 2005 was static at approximately 40 cm (16 inches). December and early January rain events saturated the snow pack. While no water content measurements were taken, field notes indicate that the snow was saturated and frozen on top. Field notes also indicated that the snow pack was solid enough for researchers to be able to walk on top of the snow without breaking through. As mentioned earlier, soil temperatures during this period did not drop below 0 degrees Celsius (32 degrees F) for either watershed. Channel flow in Mays began on January 7, 2006. Flow was recorded through mid-June, 2006. In contrast, flow in Jensen did not begin until April 1, 2006 and ceased to flow by early May. During this period, all observations for both watersheds indicated that flow was generated exclusively from bank seepage and that no evidence of overland flow was observed for either watershed.

In contrast, during the winter of 2007, very little snow pack was accumulated. Bare ground was observed in both watersheds (50 – 70 percent of the landscape) with snow accumulation areas measuring less than 15 cm (6 inches). Soil temperatures in early February were approximately -5 degrees Celsius (22 degrees F). An early February storm produced a rain on snow event. Flow was recorded in both watersheds and evidence was observed which indicated the majority of channel flow originated as overland flow. Sediment movement was observed on the hill slopes and in the channels. Sediment deposits had to be removed from both flumes. These two different observations help to illustrate the high variability within these systems and the difficulty in connecting channel flow data to treatment effects, especially during the first two years following treatment.

FUTURE RESEARCH THOUGHTS

Over the course of a long term study, there is always the occasional thought, what should we have done differently if we knew then, what we know now. Fisher (2004) pointed to the need to keep it simple. Collection, organization and analysis has been overwhelming when dealing with 4 to 14 years of eight different sets of data.

When this study was first established, I believe that no one thought it would last this long. Now, the commitment has been made to continue monitoring for the foreseeable future. In addition, other similar sites are being explored throughout eastern Oregon to further our understanding of semi-arid land function and in particular, the hydrologic impacts of western juniper control on our landscapes. It is my hope that these thoughts will provide some guidance for the initiation of those efforts.

Long term studies require the commitment of time, resources and personal investment. Time and resources may be the easiest to schedule and plan for, personal investment ebbs and flows as times change. First and foremost, when initiating this type of study, maintaining relationships and communication with those directly involved and as time permits, with those who will become involved as time goes forward. In the 12 years that transpired before treatment was imposed in Mays, leadership roles in the BLM changed, leadership in ranching operations changed and leadership in the research roles changed. Maintaining the focus of the study, its importance in developing our understanding of watershed function while staying relevant to the current needs and anticipate future questions and opportunities was always a challenge. Regularly scheduled field visits, emails and written reports are useful in keeping everyone engaged and the project moving forward.

The adoption of technology has made the job of data collection and storage manageable. During the early years of the study, periods of time (as large as months) would go by and due to technical problems, events (ex. channel flow) would be missed. With the installation of the satellite communication technology, sensors could now be checked weekly with the simple ease of logging onto the internet and going to the website to see that data were being collected. Sensors not working could be identified and repairs scheduled with the supporting agencies. Even with this new found capability, the necessity for regular field visits was never eliminated.

Satellite communication technology provided the ease of data acquisition in an area where other types of communication would have been difficult (cell phone or radio). Acquisition of data via satellite communication was never a problem. That link in the flow of data (satellites being available) was always there.

Understanding data needs and adjusting the timing of collection is important. Weather data were collected 24 times a day in each watershed. Other sensors collected data 4 times a day. For many of the parameters (i.e., soil moisture, soil temperature and spring flow, ground water wells) once a day collection would have provided enough data to see the changes that occurred with time.

With the satellite technology, I would explore the use of newer sensors (analog in nature) that would provide data collection and storage during the periods between satellite acquisition. The precipitation sensor is an example of a sensor that provides this type of flexibility and detail in real time system monitoring. Precipitation data included rain events between periods of data acquisition but all other weather parameters reflected what was happening in the watersheds and the very moment the satellite acquired the station. The sensor sensitivity was acceptable, however, we probably missed periods of high wind gusts, by a degree or two missed the daily high and low temperatures, and channel flow measured by the system. For channel flow, we had redundant systems and the Campbell Scientific data logger installed at the initiation of the study provided more frequent measurements (every 10 minutes).

As new ideas are generated and funding opportunities come along, one should not be afraid to add monitoring to the system. The paired watershed project started with precipitation and channel flow being monitored on a daily basis. Our understanding of paired-watershed studies conducted primarily in forested systems provided this early framework. As time progressed and observations were made, the question was asked, “if we didn’t see changes in channel flow, how would change in watershed function have been noted”? Through observed seasonal springflow and seepage in both watersheds, a review of studies which focused on changes in erosion rates and vegetation, and the review of early ground water findings, it was determined that additional monitoring was needed in order to understand changes in soil moisture, ground water availability and springflow discharge. While it would have been desirable to have the same length of time on these parameters prior to treatment as was available for channel flow, channel morphology and hillslope erosion, the information we did have was useful in noting change.

The value of this study will come as additional studies are initiated and replication in the study is conducted. In order for the results of this study to have meaning across the 6 million acres now occupied by western juniper, additional studies will be needed in different landscapes and different soil types in different regions of eastern Oregon. It is my hope that those studies will take advantage of the lessons learned during the last 14 years of the Camp Creek Paired Watershed Study, keep what has worked, and develop new strategies for furthering our understanding of western juniper’s impact on the hydrologic function of the landscapes it now occupies.

CONCLUSIONS

Anecdotal observations of watershed restoration activities across the west suggest that ground water responds quickly to improved watershed conditions; vegetative response follows shortly after leading to a reduction in erosion. These responses have been observed to occur within a matter of months or at least within a very few years. Channel morphological changes have been the last to occur and it has been surmised to take years, even decades, depending on site capabilities and extent of the channel degradation at the time of the restoration activity. The Camp Creek Paired Watershed Study was initiated to provide long term, statistical data collected systematically in order to test the hypothesis created by these long term observations and experiences, that being:

> Does the removal of western juniper change the hydrologic function of a watershed?

The hydrology of a given watershed is a function of the precipitation amount, intensity and seasonality, watershed geomorphic characteristics including topography and soil characteristics, and vegetation composition and complexity (Bowns 1999). The essence of watershed management has been described as the “soil’s ability to Capture, Store and Safely Release” precipitation where it falls. Watershed management as a concept reaches beyond just water management and incorporates the importance of all the resources and how they are interconnected. Those resources include plant, animal, soil and climate as expressed through precipitation, temperature, wind, solar radiation, etc.

Capture refers to the processes in which precipitation enters the soil profile. Soil surface roughness provided by plants, litter, rock and micro-terrain encourage the process of infiltration. Storage of that moisture relies on the soil profile to hold moisture for plant growth or allow it to move through the profile in to the ground water. Safe release is the process of soil moisture being used for plant growth or excess soil moisture moving through the soil profile, recharging ground water and expressing itself as either flow from springs or as contributing to streamflow through seepage from stream banks (Bedell and Borman 1997).

Land managers have the opportunity to affect watershed function through the management of vegetation. Land managers, landowners and public land management agencies through the application of management plans, impact vegetation’s ability to buffer precipitation inputs and aid in the watersheds ability to capture, store and safely release water.

SOIL MOISTURE

Juniper removal had a positive effect on the end of season (lowest recorded reading of the year) soil moisture readings. In Mays, end of season soil moisture readings increased at all profile depths (.2, .45 and .76 m). A significant difference was found in the increased end of season moisture reading for the deepest profile for Mays since treatment when compared to the pretreatment year. Changes in Jensen soil moisture over the study period were not significant.

GROUND WATER

Juniper removal had a positive effect on the number of days that water was recorded in the wells located in the treatment watershed (Mays). In Mays watershed, well 6 has not gone dry since the junipers were cut. The two years prior to treatment, all wells in Mays were dry by late summer. In 2007, all wells in Jensen went dry by late September. Prior to this, well 4 in Jensen had never gone dry since depth to ground water measurements began in January, 2004. Since treatment, the average increase in number of days water is recorded in each well of Mays is 41.4 days while in Jensen, the average number of days water was recorded since treatment increased 11.3 days.

SPRING FLOW

Juniper removal had a positive effect on the amount of spring flow in Mays. Since treatment in 2005, flow in late season has increased 225 percent. Late season flow is critical because it is during this period of time (late July through early November) that precipitation is limited and flow is at its minimum. The increase in spring flow was statistically significant even in a year in which the study area received only 80 percent of its long term average annual rainfall (2006-07). During this dry year, the spring in the control watershed (Jensen) went dry for the first time since flow monitoring began in 2004.

CHANNEL FLOW

Channel flow in the two watersheds was ephemeral. These channels were influent with flow often going subsurface along the channel length and most often, contributing to groundwater as opposed to groundwater contributing to channel flow. Flow in these channels remained unpredictable and associated with snow melt and severe summer thunderstorm activity. Channel flow, its presence or absence, responded very quickly to its surrounding environment. If soils are dry or frozen, precipitation results in flashy flows. If soils were moist and covered in snow, flow data from Mays indicated that early season (spring time) flow was constant and its source was from bank seepage.

VEGETATION

At the end of the two year post treatment monitoring period, significant changes in vegetative cover attributed to the treatment were increased canopy cover for perennial forbs, annual forbs and an increased basal cover for annual grasses. Decreases in bare soil and increases in shrub cover were measured but were not statistically significant. Perennial grasses showed a slight decrease in basal cover which could be attributed to observer error. Field observations in 2007 noted a large number of reproductive culms per plant for all perennial grass species in the treated watershed while observations in the control watershed noted very few reproductive culms per perennial grass plant. In 2008, field observations and monitoring should begin to show an increase in plant density as a result of increased seed production. Greenness of the grass plants was also noted. Greenness (amount of green leaves within the plant) was greater in Mays when compared to Jensen. Most of the plants in Jensen had gone dormant by late July, whereas, grass plants in Mays appeared to still be photosynthesizing. Precipitation in the study area during this monitoring period was 80 percent of the long term average.

HILLSLOPE EROSION

Hillslope erosion did not show any statistical changes as a result of treatment. Precipitation events that would have caused significant soil erosion were absent during the post treatment monitoring. As noted earlier, however, there was a rain on frozen ground event the winter of 2007 but due to the frozen ground, minimal (not measurable) hillslope soil movement was observed with that event. Summer thunderstorms in the summer of 2006 generated observable soil movement in Jensen (control watershed) but the impact of this storm was localized in only a part of that watershed and statistically was not significant.

In Mays, hillslope erosion resulting in deposition of sediments into the channel had been dampened due to the woody debris placed near the channel as a result of the extraction activity which removed the juniper bole wood from the site. Woody debris was observed to be acting as a filter, slowing any overland flow that occurred, thus allowing the sediments to fall out before the flow entered the channel.

CHANNEL MORPHOLOGY

Channel morphology (the shape of the channel) was unique to each of the two watersheds at the time the study was initiated. The channel in Jensen can be described as being generally shallow, with less steep sides and a wider channel bottom. The channel in Jensen could be characterized as U-shaped with the channel bottom controlled by rock. The channel depth is rarely more than 3 feet deep. This channel also appeared to be influenced more by side-hill erosion processes as demonstrated by channel cross-sections being completely silted in due to side-hill sediment movement. The channel in Mays can be characterized as being deeper and V-shaped with multiple head cuts found along its length. This channel bottom was not controlled by rock.

The channel morphology data showed no statistical differences associated with the treatment. Over the course of the monitoring period, channel data from Mays tended to depict periodic but extreme soil movement events with intermixed periods of little to no soil movement. Alternatively, the channel data from Jensen showed more consistent soil movement with fewer extremes. This variation may be a product of the two channels being at different evolutionary or successional stages relative to each other and thus indicating that channel recovery would be different for each watershed.

By acknowledging these inherent differences within each watershed, we may expect potentially different channel forming processes. Long term monitoring questions yet to be answered include how ephemeral channel processes work following vegetation treatments, and how recovery periods associated with vegetative treatments may differ based on channel morphology, associated vegetative conditions and hydrologic processes.

Hibbert (1983) summarized that arid and semiarid rangelands are poor water producers because potential evapotranspiration is greater than precipitation. Hibbert (1979) set a minimum threshold of 4500 mm (18 inches) of precipitation (4000 mm or 16 inches in cooler climates) as the point at which increases in water yield from perennial stream systems could be measured as a result of vegetation manipulation. This study provides evidence that these generalizations may be too conservative. The Camp Creek Paired Watershed study has illustrated that in an ephemeral system, removing juniper for the purpose of increasing water yield may be obtainable at a much lower precipitation threshold. Seasonality of precipitation, with the majority of the annual precipitation falling during the dormant season (October – April) may have been an important variable in the measured water yield response occurring at the lower precipitation amount. As a result of juniper removal, water yield increases were found in the amount of late season, deep soil moisture, the amount of late season spring flow and number of days of available near surface, ground water.

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APPENDICES

APPENDIX A.

NRCS Soil Classifications for Mays and Jensen Watersheds, Draft 2008.

Map Unit Description (OR)

Crook County Area, Oregon

DRAFT - SUBJECT TO

089 - Luckycreek loam, 1 to 15 percent slopes

Mean annual precipitation: 12 to 16 inches
Mean annual temperature: 39 to 46 degrees F
Frost-free period: 40 to 70 days
Farmland class: Prime farmland if irrigated

Luckycreek and similar soils

Extent: about 85 percent of the unit
Landform(s): alluvial benches
fan terraces
small drainageways
stream terraces
Slope gradient: 1 to 12 percent
Parent material: fine-loamy alluvium from volcanic rock with ash in the surface.
Restrictive feature(s): none
Seasonal high water table: greater than 60 inches
Flooding frequency: frequent
Ponding frequency: none

Soil loss tolerance (T factor): 5
Wind erodibility group (WEG): 5
Wind erodibility index (WEI): 56
Land capability subclass, non- 4e
Land capability subclass, irrigated:
Drainage class: well drained
Hydric soil class: no
Hydrologic C

Representative soil profile:

			Texture	*Permeability*	*Available Water Capacity*	*pH*	*Kw*	*Kf*
A1	--	0 to 2 in	ashy loam	moderately rapid	0.3 to 0.4 in	6.6 to 7.3	.15	.20
A2	--	2 to 8 in	ashy loam	moderately rapid	0.6 to 1.2 in	6.6 to 7.3	.20	.28
2Bt1	--	8 to 23 in	clay loam	moderately slow	1.5 to 3.1 in	6.6 to 7.3	.24	.32
2Bt2	--	23 to 38 in	gravelly clay loam	moderately slow	1.5 to 3.2 in	6.6 to 7.3	.20	.32
2Bk1	--	38 to 52 in	clay loam	moderately slow	1.4 to 2.9 in	7.4 to 7.8	.28	.37
2Bk2	--	52 to 60 in	very gravelly clay loam	moderately slow	0.8 to 1.7 in	7.9 to 8.4	.10	.37

Ecological Site / Plant Association: SR MOUNTAIN SWALE 12-16 PZ (R010XC017OR)

245 - Anatone-Ateron-Polkbutte complex, 12 to 30 percent north slopes

Mean annual precipitation: 12 to 16 inches
Mean annual temperature: 39 to 46 degrees F
Frost-free period: 40 to 70 days
Farmland class: Not prime farmland

Anatone and similar soils

Extent: about 40 percent of the unit
Landform(s): hillslopes
mesas
mountain slopes
ridges
Slope gradient: 12 to 30 percent
Parent material: colluvium and residuum derived from volcanic rock.
Restrictive feature(s): lithic bedrock at 10 to 20 inches
Seasonal high water table: greater than 60 inches
Flooding frequency: none
Ponding frequency: none

Soil loss tolerance (T factor): 1
Wind erodibility group (WEG): 8
Wind erodibility index (WEI): 0
Land capability subclass, non- 7s
Land capability subclass, irrigated:
Drainage class: well drained
Hydric soil class: no
Hydrologic D

Representative soil profile:

		Texture	*Permeability*	*Available Water Capacity*	*pH*	*Kw*	*Kf*
A --	0 to 3 in	extremely cobbly ashy loam	moderately rapid	0.1 to 0.2 in	6.6 to 7.3	.02	.28
BA --	3 to 7 in	very gravelly loam	moderate	0.2 to 0.5 in	6.6 to 7.3	.10	.37
Bw1 --	7 to 11 in	very cobbly clay loam	moderate	0.3 to 0.6 in	6.6 to 7.3	.05	.28
Bw2 --	11 to 15 in	extremely cobbly clay loam	moderate	0.2 to 0.3 in	6.6 to 7.3	.02	.28
R --	15 to 19 in	unweathered bedrock	----				

Ecological Site / Plant Association: JD MOUNTAIN CLAYPAN 12-16 PZ (R010XB080OR)

Ateron and similar soils

Extent: about 35 percent of the unit
Landform(s): south-facing mountain slopes
tops and south-facing hillslopes
Slope gradient: 12 to 30 percent
Parent material: residuum/colluvium from volcanic rock.
Restrictive feature(s): lithic bedrock at 12 to 20 inches
Seasonal high water table: greater than 60 inches
Flooding frequency: none
Ponding frequency: none

Soil loss tolerance (T factor): 1
Wind erodibility group (WEG): 8
Wind erodibility index (WEI): 0
Land capability subclass, non- 7s
Land capability subclass, irrigated:
Drainage class: well drained
Hydric soil class: no
Hydrologic D

Map Unit Description (OR)

Crook County Area, Oregon

DRAFT - SUBJECT TO

Representative soil profile:	*Texture*	*Permeability*	*Available Water Capacity*	*pH*	*Kw*	*Kf*
A -- 0 to 5 in	extremely stony ashy loam	moderate	0.3 to 0.4 in	6.6 to 7.3	.05	.32
Bt1 -- 5 to 12 in	very cobbly clay loam	moderately slow	0.5 to 0.9 in	6.6 to 7.3	.05	.28
Bt2 -- 12 to 18 in	extremely stony clay	slow	0.3 to 0.9 in	6.6 to 7.3	.02	.24
R -- 18 to 28 in	unweathered bedrock	----				

Ecological Site / Plant Association: SR MOUNTAIN SHALLOW NORTH 12-16 PZ (R010XC075OR)

Polkbutte, north and similar soils

Extent: about 15 percent of the unit
Landform(s): north-facing hillslopes
north-facing mountain slopes
Slope gradient: 12 to 30 percent
Parent material: volcanic ash over volcanic rock
Restrictive feature(s): lithic bedrock at 40 to 60 inches
Seasonal high water table: greater than 60 inches
Flooding frequency: none
Ponding frequency: none

Soil loss tolerance (T factor): 5
Wind erodibility group (WEG): 7
Wind erodibility index (WEI): 180
Land capability subclass, non- 6e
Land capability subclass, irrigated:
Drainage class: well drained
Hydric soil class: no
Hydrologic A

Representative soil profile:	*Texture*	*Permeability*	*Available Water Capacity*	*pH*	*Kw*	*Kf*
A -- 0 to 3 in	ashy loamy sand	rapid	0.2 to 0.3 in	6.6 to 7.3	.10	.17
C -- 3 to 42 in	cobbly ashy loamy sand	rapid	1.9 to 6.2 in	6.6 to 7.3	.10	.15
R -- 42 to 52 in	unweathered bedrock	----				

Ecological Site / Plant Association: JD ASHY DEEP NORTH 12-16 PZ (R010XB088OR)

246 - Anatone-Ateron-Polkbutte complex, 30 to 65 percent north slopes

Mean annual precipitation: 12 to 16 inches
Mean annual temperature: 39 to 46 degrees F
Frost-free period: 40 to 70 days
Farmland class: Not prime farmland

Anatone, north and similar soils

Extent: about 45 percent of the unit
Landform(s): north-facing hillslopes
north-facing mountain slopes
ridges
Slope gradient: 30 to 65 percent
Parent material: colluvium and residuum derived from volcanic rock.
Restrictive feature(s): lithic bedrock at 10 to 20 inches
Seasonal high water table: greater than 60 inches
Flooding frequency: none
Ponding frequency: none

Soil loss tolerance (T factor): 1
Wind erodibility group (WEG): 8
Wind erodibility index (WEI): 0
Land capability subclass, non- 7s
Land capability subclass, irrigated:
Drainage class: well drained
Hydric soil class: no
Hydrologic D

Representative soil profile:

		Texture	*Permeability*	*Available Water Capacity*	*pH*	*Kw*	*Kf*
A --	0 to 3 in	extremely cobbly ashy loam	moderately rapid	0.1 to 0.2 in	6.6 to 7.3	.02	.28
BA --	3 to 7 in	very gravelly loam	moderate	0.2 to 0.5 in	6.6 to 7.3	.10	.37
Bw1 --	7 to 11 in	very cobbly clay loam	moderate	0.3 to 0.6 in	6.6 to 7.3	.05	.28
Bw2 --	11 to 15 in	extremely cobbly clay loam	moderate	0.2 to 0.3 in	6.6 to 7.3	.02	.28
R --	15 to 19 in	unweathered bedrock	----				

Ecological Site / Plant Association: JD MOUNTAIN CLAYPAN 12-16 PZ (R010XB080OR)

Ateron, north and similar soils

Extent: about 35 percent of the unit
Landform(s): north-facing hillslopes
north-facing mountain slopes
north-facing ridges
Slope gradient: 30 to 65 percent
Parent material: residuum/colluvium from volcanic rock.
Restrictive feature(s): lithic bedrock at 12 to 20 inches
Seasonal high water table: greater than 60 inches
Flooding frequency: none
Ponding frequency: none

Soil loss tolerance (T factor): 1
Wind erodibility group (WEG): 8
Wind erodibility index (WEI): 0
Land capability subclass, non- 7s
Land capability subclass, irrigated:
Drainage class: well drained
Hydric soil class: no
Hydrologic D

Map Unit Description (OR)

Crook County Area, Oregon

DRAFT - SUBJECT TO

Representative soil profile:		*Texture*	*Permeability*	*Available Water Capacity*	*pH*	*Kw*	*Kf*
A --	0 to 5 in	extremely stony ashy loam	moderate	0.3 to 0.4 in	6.6 to 7.3	.05	.32
Bt1 --	5 to 12 in	very cobbly clay loam	moderately slow	0.5 to 0.9 in	6.6 to 7.3	.05	.28
Bt2 --	12 to 18 in	extremely stony clay	slow	0.3 to 0.9 in	6.6 to 7.3	.02	.24
R --	18 to 28 in	unweathered bedrock	----				

Ecological Site / Plant Association: SR MOUNTAIN SHALLOW NORTH 12-16 PZ (R010XC075OR)

Polkbutte, north and similar soils

Extent: about 15 percent of the unit

Landform(s): north-facing hillslopes
north-facing mountain slopes

Slope gradient: 30 to 65 percent

Parent material: volcanic ash over volcanic rock

Restrictive feature(s): lithic bedrock at 40 to 60 inches

Seasonal high water table: greater than 60 inches

Flooding frequency: none

Ponding frequency: none

Soil loss tolerance (T factor): 5

Wind erodibility group (WEG): 7

Wind erodibility index (WEI): 180

Land capability subclass, non- 6e

Land capability subclass, irrigated:

Drainage class: well drained

Hydric soil class: no

Hydrologic A

Representative soil profile:		*Texture*	*Permeability*	*Available Water Capacity*	*pH*	*Kw*	*Kf*
A --	0 to 3 in	ashy loamy sand	rapid	0.2 to 0.3 in	6.6 to 7.3	.10	.17
C --	3 to 42 in	cobbly ashy loamy sand	rapid	1.9 to 6.2 in	6.6 to 7.3	.10	.15
R --	42 to 52 in	unweathered bedrock	----				

Ecological Site / Plant Association: JD ASHY DEEP NORTH 12-16 PZ (R010XB088OR)

Map Unit Description (OR)

Crook County Area, Oregon

DRAFT - SUBJECT TO

247 - Anatone-Ateron complex, 12 to 30 percent south slopes

Mean annual precipitation: 12 to 16 inches
Mean annual temperature: 39 to 46 degrees F
Frost-free period: 40 to 70 days
Farmland class: Not prime farmland

Anatone, south and similar soils

Extent: about 45 percent of the unit
Landform(s): hillslopes
mesas
mountain slopes
ridges
Slope gradient: 12 to 30 percent
Parent material: colluvium and residuum derived from volcanic rock.
Restrictive feature(s): lithic bedrock at 10 to 20 inches
Seasonal high water table: greater than 60 inches
Flooding frequency: none
Ponding frequency: none

Soil loss tolerance (T factor): 1
Wind erodibility group (WEG): 8
Wind erodibility index (WEI): 0
Land capability subclass, non- 7s
Land capability subclass, irrigated:
Drainage class: well drained
Hydric soil class: no
Hydrologic D

Representative soil profile:

		Texture	*Permeability*	*Available Water Capacity*	*pH*	*Kw*	*Kf*
A --	0 to 3 in	extremely cobbly ashy loam	moderately rapid	0.1 to 0.2 in	6.6 to 7.3	.02	.28
BA --	3 to 7 in	very gravelly loam	moderate	0.2 to 0.5 in	6.6 to 7.3	.10	.37
Bw1 --	7 to 11 in	very cobbly clay loam	moderate	0.3 to 0.6 in	6.6 to 7.3	.05	.28
Bw2 --	11 to 15 in	extremely cobbly clay loam	moderate	0.2 to 0.3 in	6.6 to 7.3	.02	.28
R --	15 to 19 in	unweathered bedrock	----				

Ecological Site / Plant Association: JD MOUNTAIN CLAYPAN 12-16 PZ (R010XB080OR)

Ateron, south and similar soils

Extent: about 35 percent of the unit
Landform(s): south-facing mountain slopes
tops and south-facing hillslopes
Slope gradient: 12 to 30 percent
Parent material: residuum/colluvium from volcanic rock.
Restrictive feature(s): lithic bedrock at 12 to 20 inches
Seasonal high water table: greater than 60 inches
Flooding frequency: none
Ponding frequency: none

Soil loss tolerance (T factor): 1
Wind erodibility group (WEG): 8
Wind erodibility index (WEI): 0
Land capability subclass, non- 7s
Land capability subclass, irrigated:
Drainage class: well drained
Hydric soil class: no
Hydrologic D

Map Unit Description (OR)

Crook County Area, Oregon

DRAFT - SUBJECT TO

Representative soil profile:		*Texture*	*Permeability*	*Available Water Capacity*	*pH*	*Kw*	*Kf*
A --	0 to 5 in	extremely stony ashy loam	moderate	0.3 to 0.4 in	6.6 to 7.3	.05	.32
Bt1 --	5 to 12 in	very cobbly clay loam	moderately slow	0.5 to 0.9 in	6.6 to 7.3	.05	.28
Bt2 --	12 to 18 in	extremely stony clay	slow	0.3 to 0.9 in	6.6 to 7.3	.02	.24
R --	18 to 28 in	unweathered bedrock	----				

Ecological Site / Plant Association: SR MOUNTAIN SHALLOW SOUTH 12-16 PZ (R010XC054OR)

Map Unit Description (OR)

Crook County Area, Oregon

DRAFT - SUBJECT TO

248 - Anatone-Ateron complex, 30 to 65 percent south slopes

Mean annual precipitation: 12 to 16 inches
Mean annual temperature: 39 to 46 degrees F

Frost-free period: 40 to 70 days
Farmland class: Not prime farmland

Anatone, south and similar soils

Extent: about 45 percent of the unit
Landform(s): ridges
south-facing hillslopes
south-facing mountain slopes
Slope gradient: 30 to 65 percent
Parent material: colluvium and residuum derived from volcanic rock.
Restrictive feature(s): lithic bedrock at 10 to 20 inches
Seasonal high water table: greater than 60 inches
Flooding frequency: none
Ponding frequency: none

Soil loss tolerance (T factor): 1
Wind erodibility group (WEG): 8
Wind erodibility index (WEI): 0
Land capability subclass, non- 7s
Land capability subclass, irrigated:
Drainage class: well drained
Hydric soil class: no
Hydrologic D

Representative soil profile:		*Texture*	*Permeability*	*Available Water Capacity*	*pH*	*Kw*	*Kf*
A --	0 to 3 in	extremely cobbly ashy loam	moderately rapid	0.1 to 0.2 in	6.6 to 7.3	.02	.28
BA --	3 to 7 in	very gravelly loam	moderate	0.2 to 0.5 in	6.6 to 7.3	.10	.37
Bw1 --	7 to 11 in	very cobbly clay loam	moderate	0.3 to 0.6 in	6.6 to 7.3	.05	.28
Bw2 --	11 to 15 in	extremely cobbly clay loam	moderate	0.2 to 0.3 in	6.6 to 7.3	.02	.28
R --	15 to 19 in	unweathered bedrock	----				

Ecological Site / Plant Association: JD MOUNTAIN CLAYPAN 12-16 PZ (R010XB080OR)

Ateron, south and similar soils

Extent: about 40 percent of the unit
Landform(s): south-facing hillslopes
south-facing mountain slopes
Slope gradient: 30 to 65 percent
Parent material: residuum/colluvium from volcanic rock.
Restrictive feature(s): lithic bedrock at 12 to 20 inches
Seasonal high water table: greater than 60 inches
Flooding frequency: none
Ponding frequency: none

Soil loss tolerance (T factor): 1
Wind erodibility group (WEG): 8
Wind erodibility index (WEI): 0
Land capability subclass, non- 7s
Land capability subclass, irrigated:
Drainage class: well drained
Hydric soil class: no
Hydrologic D

Map Unit Description (OR)

Crook County Area, Oregon

DRAFT - SUBJECT TO

Representative soil profile:				*Texture*	*Permeability*	*Available Water Capacity*	*pH*	*Kw*	*Kf*
A	--	0	to 5 in	extremely stony ashy loam	moderate	0.3 to 0.4 in	6.6 to 7.3	.05	.32
Bt1	--	5	to 12 in	very cobbly clay loam	moderately slow	0.5 to 0.9 in	6.6 to 7.3	.05	.28
Bt2	--	12	to 18 in	extremely stony clay	slow	0.3 to 0.9 in	6.6 to 7.3	.02	.24
R	--	18	to 28 in	unweathered bedrock	----				

Ecological Site / Plant Association: SR MOUNTAIN SHALLOW SOUTH 12-16 PZ (R010XC054OR)

Survey Area Version: 0
Survey Area Version Date: 04/18/2007

Map Unit Description (OR)

Crook County Area, Oregon

DRAFT - SUBJECT TO

272 - Anatone-Bocker complex, 2 to 20 percent slopes

Mean annual precipitation: 12 to 16 inches
Mean annual temperature: 39 to 46 degrees F
Frost-free period: 40 to 70 days
Farmland class: Not prime farmland

Anatone and similar soils

Extent: about 45 percent of the unit
Landform(s): hillslopes
mesas
mountain slopes
ridges
Slope gradient: 2 to 20 percent
Parent material: colluvium and residuum derived from volcanic rock.
Restrictive feature(s): lithic bedrock at 10 to 20 inches
Seasonal high water table: greater than 60 inches
Flooding frequency: none
Ponding frequency: none

Soil loss tolerance (T factor): 1
Wind erodibility group (WEG): 8
Wind erodibility index (WEI): 0
Land capability subclass, non- 7s
Land capability subclass, irrigated:
Drainage class: well drained
Hydric soil class: no
Hydrologic D

Representative soil profile:

				Texture	*Permeability*	*Available Water Capacity*	*pH*	*Kw*	*Kf*
A	--	0 to	3 in	extremely cobbly ashy loam	moderately rapid	0.1 to 0.2 in	6.6 to 7.3	.02	.28
BA	--	3 to	7 in	very gravelly loam	moderate	0.2 to 0.5 in	6.6 to 7.3	.10	.37
Bw1	--	7 to	11 in	very cobbly clay loam	moderate	0.3 to 0.6 in	6.6 to 7.3	.05	.28
Bw2	--	11 to	15 in	extremely cobbly clay loam	moderate	0.2 to 0.3 in	6.6 to 7.3	.02	.28
R	--	15 to	19 in	unweathered bedrock	----				

Ecological Site / Plant Association: JD MOUNTAIN CLAYPAN 12-16 PZ (R010XB080OR)

Bocker and similar soils

Extent: about 40 percent of the unit
Landform(s): hillslopes
mesas
mountain slopes
ridges
Slope gradient: 2 to 20 percent
Parent material: colluvium/residuum from volcanic rock
Restrictive feature(s): lithic bedrock at 4 to 10 inches
Seasonal high water table: greater than 60 inches
Flooding frequency: none
Ponding frequency: none

Soil loss tolerance (T factor): 1
Wind erodibility group (WEG): 8
Wind erodibility index (WEI): 0
Land capability subclass, non- 7s
Land capability subclass, irrigated:
Drainage class: well drained
Hydric soil class: no
Hydrologic D

Map Unit Description (OR)

Crook County Area, Oregon

DRAFT - SUBJECT TO

Representative soil profile:		*Texture*	*Permeability*	*Available Water Capacity*	*pH*	*Kw*	*Kf*
A --	0 to 3 in	very gravelly loam	moderate	0.2 to 0.4 in	6.6 to 7.3	.05	.28
BA --	3 to 7 in	very gravelly loam	moderate	0.2 to 0.5 in	6.6 to 7.3	.10	.32
Bw --	7 to 10 in	very gravelly loam	moderate	0.1 to 0.4 in	6.6 to 7.3	.10	.28
R --	10 to 14 in	unweathered bedrock	----				

Ecological Site / Plant Association: JD VERY SHALLOW 12-16 PZ (R010XB032OR)

Map Unit Description (OR)

Crook County Area, Oregon

DRAFT - SUBJECT TO

273 - Anatone-Bocker complex, 20 to 50 percent south slopes

Mean annual precipitation: 12 to 16 inches
Mean annual temperature: 39 to 46 degrees F
Frost-free period: 40 to 70 days
Farmland class: Not prime farmland

Anatone, south and similar soils

Extent: about 50 percent of the unit
Landform(s): hillslopes
mesas
mountain slopes
ridges
Slope gradient: 20 to 50 percent
Parent material: colluvium and residuum derived from volcanic rock.
Restrictive feature(s): lithic bedrock at 10 to 20 inches
Seasonal high water table: greater than 60 inches
Flooding frequency: none
Ponding frequency: none

Soil loss tolerance (T factor): 1
Wind erodibility group (WEG): 8
Wind erodibility index (WEI): 0
Land capability subclass, non- 7s
Land capability subclass, irrigated:
Drainage class: well drained
Hydric soil class: no
Hydrologic D

Representative soil profile:

	Texture	*Permeability*	*Available Water Capacity*	*pH*	*Kw*	*Kf*
A -- 0 to 3 in	extremely cobbly ashy loam	moderately rapid	0.1 to 0.2 in	6.6 to 7.3	.02	.28
BA -- 3 to 7 in	very gravelly loam	moderate	0.2 to 0.5 in	6.6 to 7.3	.10	.37
Bw1 -- 7 to 11 in	very cobbly clay loam	moderate	0.3 to 0.6 in	6.6 to 7.3	.05	.28
Bw2 -- 11 to 15 in	extremely cobbly clay loam	moderate	0.2 to 0.3 in	6.6 to 7.3	.02	.28
R -- 15 to 19 in	unweathered bedrock	----				

Ecological Site / Plant Association: JD MOUNTAIN CLAYPAN 12-16 PZ (R010XB080OR)

Bocker, south and similar soils

Extent: about 40 percent of the unit
Landform(s): hillslopes
mesas
mountain slopes
ridges
Slope gradient: 20 to 50 percent
Parent material: colluvium/residuum from volcanic rock
Restrictive feature(s): lithic bedrock at 4 to 10 inches
Seasonal high water table: greater than 60 inches
Flooding frequency: none
Ponding frequency: none

Soil loss tolerance (T factor): 1
Wind erodibility group (WEG): 8
Wind erodibility index (WEI): 0
Land capability subclass, non- 7s
Land capability subclass, irrigated:
Drainage class: well drained
Hydric soil class: no
Hydrologic D

Map Unit Description (OR)

Crook County Area, Oregon

DRAFT - SUBJECT TO

Representative soil profile:		*Texture*	*Permeability*	*Available Water Capacity*	*pH*	*Kw*	*Kf*
A --	0 to 3 in	very gravelly loam	moderate	0.2 to 0.4 in	6.6 to 7.3	.05	.28
BA --	3 to 7 in	very gravelly loam	moderate	0.2 to 0.5 in	6.6 to 7.3	.10	.32
Bw --	7 to 10 in	very gravelly loam	moderate	0.1 to 0.4 in	6.6 to 7.3	.10	.28
R --	10 to 14 in	unweathered bedrock	----				

Ecological Site / Plant Association: JD VERY SHALLOW 12-16 PZ (R010XB032OR)

Survey Area Version: 0
Survey Area Version Date: 04/18/2007

Map Unit Description (OR)

Crook County Area, Oregon

DRAFT - SUBJECT TO

391 - Ateron-Anatone-Erakatak complex, 0 to 50 percent slopes

Mean annual precipitation: 12 to 16 inches
Mean annual temperature: 39 to 46 degrees F
Frost-free period: 40 to 70 days
Farmland class: Not prime farmland

Ateron and similar soils

Extent: about 35 percent of the unit
Landform(s): hillslopes
mountain slopes
Slope gradient: 1 to 12 percent
Parent material: residuum/colluvium from volcanic rock.
Restrictive feature(s): lithic bedrock at 12 to 20 inches
Seasonal high water table: greater than 60 inches
Flooding frequency: none
Ponding frequency: none

Soil loss tolerance (T factor): 1
Wind erodibility group (WEG): 8
Wind erodibility index (WEI): 0
Land capability subclass, non- 7s
Land capability subclass, irrigated:
Drainage class: well drained
Hydric soil class: no
Hydrologic D

Representative soil profile:

		Texture	*Permeability*	*Available Water Capacity*	*pH*	*Kw*	*Kf*
A --	0 to 5 in	extremely stony ashy loam	moderate	0.3 to 0.4 in	6.6 to 7.3	.05	.32
Bt1 --	5 to 12 in	very cobbly clay loam	moderately slow	0.5 to 0.9 in	6.6 to 7.3	.05	.28
Bt2 --	12 to 18 in	extremely stony clay	slow	0.3 to 0.9 in	6.6 to 7.3	.02	.24
R --	18 to 28 in	unweathered bedrock	----				

Ecological Site / Plant Association: SR MOUNTAIN VERY SHALLOW 12-16 PZ (R010XC039OR)

Anatone and similar soils

Extent: about 25 percent of the unit
Landform(s): hillslopes
mountain slopes
ridges
Slope gradient: 1 to 12 percent
Parent material: colluvium and residuum derived from volcanic rock.
Restrictive feature(s): lithic bedrock at 10 to 20 inches
Seasonal high water table: greater than 60 inches
Flooding frequency: none
Ponding frequency: none

Soil loss tolerance (T factor): 1
Wind erodibility group (WEG): 8
Wind erodibility index (WEI): 0
Land capability subclass, non- 7s
Land capability subclass, irrigated:
Drainage class: well drained
Hydric soil class: no
Hydrologic D

Representative soil profile:

	Texture	Permeability	Available Water Capacity	pH	Kw	Kf
A -- 0 to 3 in	extremely cobbly ashy loam	moderately rapid	0.1 to 0.2 in	6.6 to 7.3	.02	.28
BA -- 3 to 7 in	very gravelly loam	moderate	0.2 to 0.5 in	6.6 to 7.3	.10	.37
Bw1 -- 7 to 11 in	very cobbly clay loam	moderate	0.3 to 0.6 in	6.6 to 7.3	.05	.28
Bw2 -- 11 to 15 in	extremely cobbly clay loam	moderate	0.2 to 0.3 in	6.6 to 7.3	.02	.28
R -- 15 to 19 in	unweathered bedrock	----				

Ecological Site / Plant Association: JD MOUNTAIN CLAYPAN 12-16 PZ (R010XB080OR)

Erakatak and similar soils

Extent: about 25 percent of the unit
Landform(s): hillslopes
mountain slopes
Slope gradient: 1 to 12 percent
Parent material: colluvium/residuum from volcanic rock with a ash surface mantle
Restrictive feature(s): lithic bedrock at 20 to 40 inches
Seasonal high water table: greater than 60 inches
Flooding frequency: none
Ponding frequency: none

Soil loss tolerance (T factor): 2
Wind erodibility group (WEG): 4
Wind erodibility index (WEI): 86
Land capability subclass, non- 4e
Land capability subclass, irrigated:
Drainage class: well drained
Hydric soil class: no
Hydrologic C

Representative soil profile:

	Texture	Permeability	Available Water Capacity	pH	Kw	Kf
A -- 0 to 3 in	very gravelly ashy loam	moderate	0.2 to 0.4 in	6.6 to 7.3	.05	.28
2Bt1 -- 3 to 8 in	very gravelly ashy clay loam	moderately slow	0.3 to 0.7 in	6.6 to 7.3	.05	.32
2Bt2 -- 8 to 16 in	very cobbly clay	slow	0.4 to 0.8 in	6.6 to 7.3	.05	.24
2Bt3 -- 16 to 26 in	very cobbly clay	slow	0.5 to 1.0 in	6.6 to 7.3	.05	.20
2Bt4 -- 26 to 28 in	extremely cobbly silty clay	slow	0.1 to 0.2 in	7.4 to 7.8	.02	.20
R -- 28 to 32 in	unweathered bedrock	----				

Ecological Site / Plant Association: JD MOUNTAIN CLAYPAN 12-16 PZ (R010XB080OR)

Map Unit Description (OR)

Crook County Area, Oregon

DRAFT - SUBJECT TO

430 - Gerow silt loam, drained, 1 to 5 percent slopes

Mean annual precipitation: 16 to 22 inches
Mean annual temperature: 39 to 45 degrees F
Frost-free period: 30 to 70 days
Farmland class:

Gerow, Drianed and similar soils

Extent: about 85 percent of the unit
Landform(s): incised stream terraces
Slope gradient: 1 to 5 percent
Parent material: alluvium from volcanic rock with volcanic ash throughout.

Restrictive feature(s): none

Seasonal high water table: approximately 52 inches

Flooding frequency: rare

Ponding frequency: none

Soil loss tolerance (T factor): 5
Wind erodibility group (WEG): 5
Wind erodibility index (WEI): 56
Land capability subclass, non- 6c

Land capability subclass, irrigated:

Drainage class: somewhat poorly drained

Hydric soil class: yes

Hydrologic C

Representative soil profile:		*Texture*	*Permeability*	*Available Water Capacity*	*pH*	*Kw*	*Kf*
A --	0 to 6 in	ashy silt loam	moderate	1.2 to 1.4 in	5.6 to 6.0	.24	.24
2AB --	6 to 10 in	ashy silty clay loam	moderately slow	0.8 to 0.9 in	5.6 to 6.0	.32	.32
2Bwb1 --	10 to 15 in	ashy silty clay loam	moderately slow	1.1 to 1.2 in	5.6 to 7.8	.32	.32
2Bwb2 --	15 to 25 in	ashy silty clay loam	moderately slow	2.1 to 2.4 in	5.6 to 7.8	.32	.32
2Bwb3 --	25 to 36 in	silty clay	moderately slow	1.5 to 2.2 in	6.1 to 8.4	.20	.20
2Bwb4 --	36 to 60 in	silty clay loam	moderately slow	3.4 to 5.0 in	6.1 to 8.4	.32	.32

Ecological Site / Plant Association: MOUNTAIN MEADOW (R010XY002OR)

Survey Area Version: 0
Survey Area Version Date: 04/18/2007

Map Unit Description (OR)

Crook County Area, Oregon

DRAFT - SUBJECT TO

P500 - Canest-Anatone complex, 0 to 10 percent slopes

Mean annual precipitation: 12 to 24 inches
Mean annual temperature: 39 to 46 degrees F

Frost-free period: 30 to 90 days
Farmland class: Not prime farmland

Canest and similar soils

Extent: about 70 percent of the unit
Landform(s): lava plains
plateaus
Slope gradient: 0 to 10 percent
Parent material: residuum weathered from basalt
Restrictive feature(s): lithic bedrock at 5 to 10 inches
Seasonal high water table: greater than 60 inches
Flooding frequency: none
Ponding frequency: none

Soil loss tolerance (T factor): 1
Wind erodibility group (WEG): 6
Wind erodibility index (WEI): 48
Land capability subclass, non- 7s
Land capability subclass, irrigated:
Drainage class: well drained
Hydric soil class: no
Hydrologic C

Representative soil profile:		*Texture*	*Permeability*	*Available Water Capacity*	*pH*	*Kw*	*Kf*
A --	0 to 5 in	very cobbly clay loam	moderately slow	0.4 to 0.7 in	6.6 to 7.3	.10	.32
Bt --	5 to 9 in	very cobbly clay	slow	0.2 to 0.4 in	6.6 to 7.3	.10	.28
2R --	9 to 14 in	unweathered bedrock	----				

Ecological Site / Plant Association: JD VERY SHALLOW 12-16 PZ (R010XB032OR)
stiff sagebrush/Sandberg bluegrass (SD9111)

Anatone and similar soils

Extent: about 15 percent of the unit
Landform(s): hillslopes
summits of mountain slopes
Slope gradient: 0 to 10 percent
Parent material: colluvium and residuum derived from basalt or rhyolite.
Restrictive feature(s): lithic bedrock at 10 to 20 inches
Seasonal high water table: greater than 60 inches
Flooding frequency: none
Ponding frequency: none

Soil loss tolerance (T factor): 1
Wind erodibility group (WEG): 8
Wind erodibility index (WEI): 0
Land capability subclass, non- 7s
Land capability subclass, irrigated:
Drainage class: well drained
Hydric soil class: no
Hydrologic D

Map Unit Description (OR)

Crook County Area, Oregon

DRAFT - SUBJECT TO

Representative soil profile:	*Texture*	*Permeability*	*Available Water Capacity*	*pH*	*Kw*	*Kf*
A -- 0 to 3 in	extremely cobbly ashy loam	moderately rapid	0.1 to 0.2 in	6.6 to 7.3	.02	.28
BA -- 3 to 7 in	very gravelly loam	moderate	0.2 to 0.5 in	6.6 to 7.3	.10	.37
Bw1 -- 7 to 11 in	very cobbly clay loam	moderate	0.3 to 0.6 in	6.6 to 7.3	.05	.28
Bw2 -- 11 to 15 in	extremely cobbly clay loam	moderate	0.2 to 0.3 in	6.6 to 7.3	.02	.28
R -- 15 to 19 in	unweathered bedrock	----				

Ecological Site / Plant Association: JD MOUNTAIN CLAYPAN 12-16 PZ (R010XB080OR)

APPENDIX B. Partial Watershed Plant Species List (Fisher 2004)

Perennial Grasses

Agropyron spicatum	bearded bluebunch wheatgrass
Elymus glaucus var. glaucus	blue wildrye
Festuca idahoensis	Idaho fescue
Koeleria cristata	prairie junegrass
Oryzopsis humenoides	Indian ricegrass
Poa ampla	big bluegrass
Poa sandbergii	sandberg bluegrass
Olypogon monspeliensis	rabbitfoot grass
Sitanion hystrix	bottlebrush squirreltail
Stipa comata	needle-and-thread
Stipa occidentalis	western needlegrass (Columbiana)

Sedge-Rush

Carex geyeri	elk sedge

Annual Grasses

Bromus tectorum	cheatgrass brome

Perennial Forbs

Achillea millefolium	common yarrow
Antennaria stenophylla	pussy toes
Arenaria frankinii	sandwort
Balzamorhiza sagittata	arrowleaf balsamroot
Calacohortus macrocarpus	sagebrush mariposa
Chaenactis douglasii	Douglas c. / false yarrow
Erigeron linearis	lineleaf fleabane (yellow)
Gilia aggregate, var. aggregata	skyrocket scarlet gilia
Geum trifolium	prairie star
Lithopermum ruderale	stoneseed
Lupinus spp.	lupine
Penstemon eriantherus	fuzzy tongue
Phacelia hastate	silverleaf phacelia
Salvia dorrii	greyball sage
Senecio integerrimus	western groundsel

Biennial Forbs

Tragopogan dubius	yellow salsify

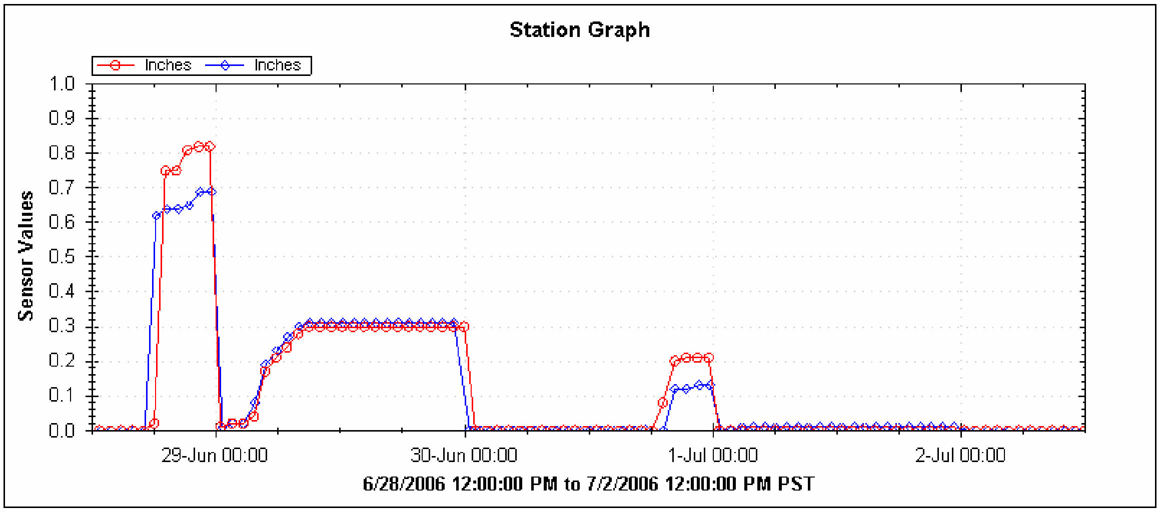
Annual Forbs

Collinsia grandoflora	pagoda plant
Collomia grandiflora	bigflower gilia
Cordylanthus ramosus	bushy birdbeak
Erysimum occidentale	pale wallflower
Lygodesmia juncea	rush skeletonweed
Mimulus breweri	crimson monkeyflower

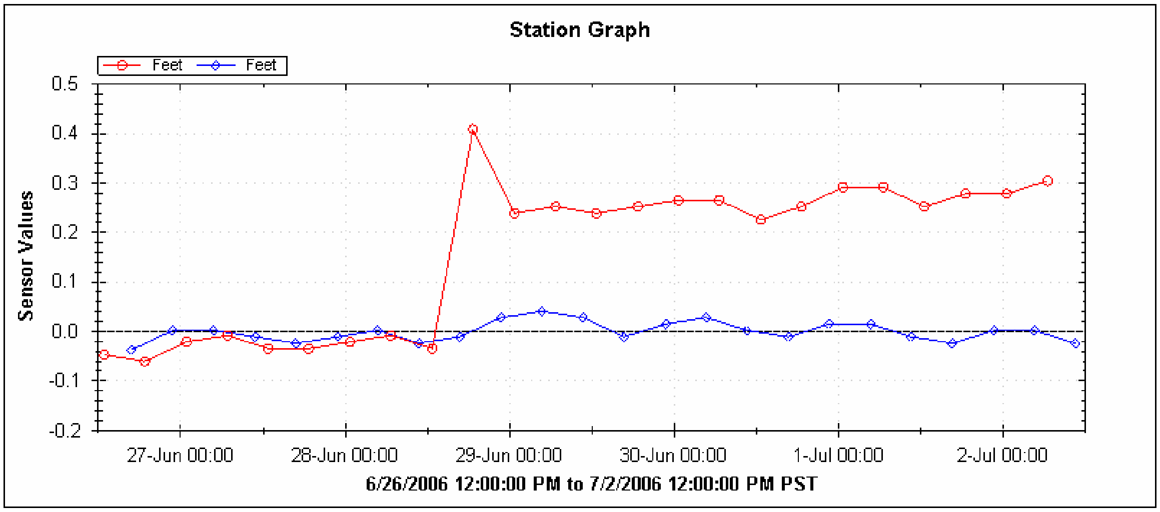
Shrubs and Trees

Amelanchier alnifolia	pacific serviceberry
Artemisia ludoviciana	prairie sage
Artemisia tridentata var. tridentata	basin big sagebrush
Artemisia tridentata var. wyomingensis	Wyoming big sagebrush
Artemisia tridentata var. vaseyana	mountain big sagebrush
Atriplex spinosa	
Cercocarpus ledifolius	curl-leaf mountain mahogany
Chrysothamnus nauseosus	gray rabbitbrush
Chrysothamnum viscidiflorus	green rabbitbrush
Holodiscus dumosus	little oceanspray
Juniperous occidentalis	western juniper
Pinus ponderosa	ponderosa pine
Purshia tridentata	bitterbrush
Ribes cereum	wax current
Sambucus racemosa	elderberry
Symphorycarpos albus	snowberry
Tetradymia canescens	gray spineless horsebrush

APPENDIX C: Story of June 28 – 29, 2006 thunderstorm in Mays and Jensen.



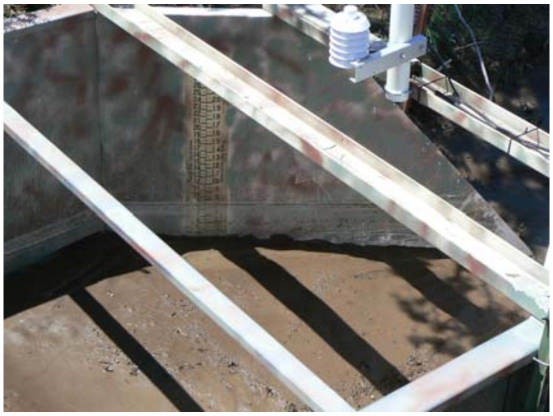
On June 28th, 2006, a late-evening thunderstorm occurred over the paired watershed study area. In one hour, precipitation in Jensen (red) weather station measured 190 mm (.75 inches) and Mays weather station (blue) recorded 165mm (.65 inches) of rain. At the end of the storm (15 hours), total precipitation received measured 289 mm (1.2 inches) in Jensen and 279 mm (1.1 inches) in Mays.



Within 1 hour of the start of the storm, sensors in Jensen flume (red) recorded flow of .4 ft on the staff gauge. Flow in Mays (blue) was not detected. The continuous flow in Jensen after the initiation of the storm reflects sediment deposits in the flume and not actual flow. Flow lasted less than 6 hours.

Jensen flume 4 days after summer thunderstorm, notice sediment deposits in the floor of the flume.

Staff gauge in Jensen flume showed that actual flow may have been as high as 22.86 cm (9 inches). The bottom of the photo shows the height of mud in the flume.



The sensor posed over the throat of the flume is an ultrasonic sensor, measuring the changes in distance between the sensor and bottom of flume. Sediment deposits are evident on the flume floor and measure 10 cm (4 inches).

Mays flume 4 days after the same storm. Floor of flume has dusting of sediment but floor is already dry.

Staff gauge in Mays flume showed that rain drop splatter scattered mud on the walls of the flume but no flow line is visible.

The ultrasonic sensor in Mays recorded no changes in depth of flow. Sediments on the flow of the flume are less than 31 mm (1/8 inch) deep.

Channel deposits in Jensen. This deposit was laid across channel cross-section number 4. The stake on the far side of the channel was buried with deposits to the top of the stake. Channel cross section here is 338 cm (133 inches).

Near Jensen cross-section number 22, overland flow was evident. Overland flow moved sediment and organic material into the channel.

Channel deposits were numerous in Jensen following the storm. These deposits were place near Jensen spring.

The channels of Mays showed no evidence of large flows or sediment deposits. This photo shows vegetation and a small amount of channel flow just above Mays' flume. Flow disappears before crossing through the fence.

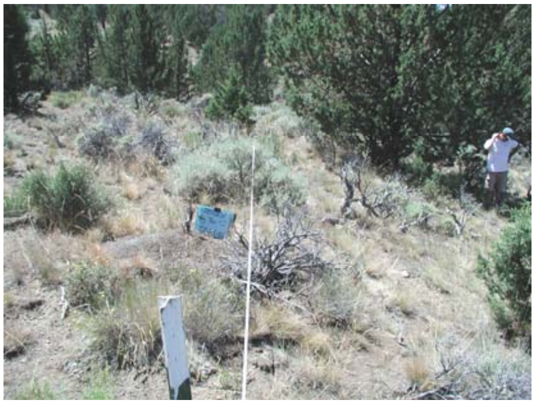
This road was used as a skid trail. Just days before the storm, road condition was soft, with several inches of loose soil on top.

One of two channels monitored in Mays. Road used for skidding is on the right. Evidence of channel flow was minimal.

APPENDIX D: Vegetative monitoring changes from 2005 and 2007

Jensen vegetation transect #1, 7/25/05

Jensen vegetation transect #1, 7/24/07



Jensen vegetation transect #2, 7/25/05

Jensen vegetation transect #2, 7/24/07

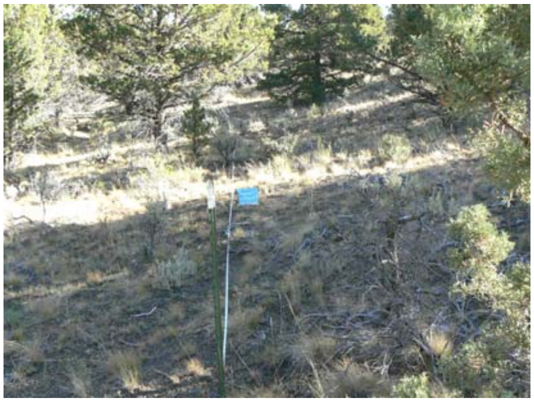
Jensen vegetation transect #3, 7/25/05

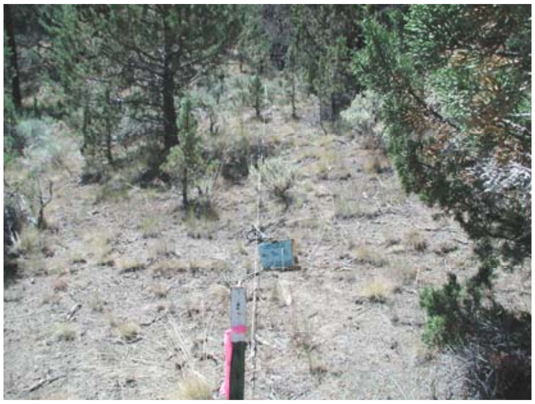
Jensen vegetation transect #3, 7/24/07


Jensen vegetation transect #4, 7/25/05


Jensen vegetation transect #4, 7/24/07


Jensen vegetation transect #5, 7/25/05


Jensen vegetation transect #6, 7/24/07


Jensen vegetation transect #6, 7/25/05


Jensen vegetation transect #6, 7/24/07

Jensen vegetative transect #7, 7/25/05

Jensen vegetative transect #7, 7/24/07

Jensen vegetative transect #8, 7/25/05

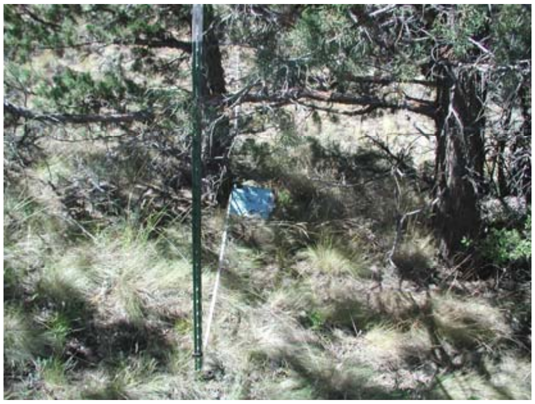
Jensen vegetative transect #8, 7/24/07

Mays vegetative transect #1, 7/26/05

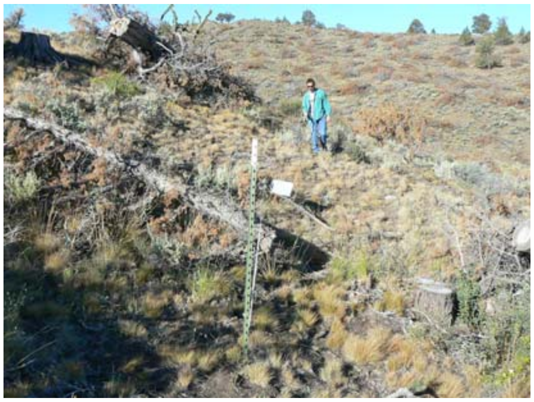
Mays vegetative transect #1, 7/26/07

Mays vegetative transect #2, 7/26/05

Mays vegetative transect #2, 7/26/07



Mays vegetative transect #3, 7/26/05



Mays vegetative transect #3, 7/26/07

Mays vegetative transect #4, 7/26/05

Mays vegetative transect #4, 7/26/07

Mays vegetative transect #5, 7/26/05

Mays vegetative transect #5, 7/26/07

Mays vegetative transect #6, 7/26/05

Mays vegetative transect #6, 7/26/07

Mays vegetative transect #7, 7/26/05

Mays vegetative transect #7, 7/26/07

Mays vegetative transect #8, 7/26/05

Mays vegetative transect #8, 7/26/07

APPENDIX E. Vegetative responses, pictures from 7/25/07 – 7/28/07

Overview of Jensen Watershed

General view of the understory condition in Jensen. Grasses are mature and mostly dormant. Slope is generally easterly. There is very little “greenness” left.

Jensen watershed, another view of understory, north slope.

Jensen watershed, a south slope, very few reproductive culms are evident.


Mays watershed overview, pre treatment (July, 2005)


Mays watershed overview, post treatment (July, 2007).

Mays watershed, south slope highlighting the flush of cheatgrass.

Mays watershed - Reproductive culms on Junegrass and Big blue.

Mays Watershed - Plant release and reproduction of basin wildrye.

Mays watershed – Reproductive culms on bluebunch wheatgrass and Indian ricegrass. Also visible is the reproductive release of mountain big sagebrush.

Mays watershed - Increase in perennial forb cover was noted. *Crepis* in bloom.

Mays watershed – Lupine spp. in bloom in late July.

Appendix F. Soil moisture probe locations.

Watershed	Probe Location	Site	Probe Number
Mays	Top	Lower	11303
			11323
			11342
		Upper	11403
			11411
			11442
	Middle	Lower	11304
			11324
			11343
		Upper	11404
			11424
			11443
	Bottom	Lower	11322
			11341
			11344
		Upper	11422
			11423
			11444
Jensen	Top	Lower	11703
			11722
			11741
		Upper	11803
			11822
			11842
	Middle	Lower	11704
			11724
			11743
		Upper	11804
			11823
			11843
	Bottom	Lower	11723
			11742
			11744
		Upper	11824
			11841
			11844