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The Effects of a Prescribed Burn on Streambed Sediments, Macroinvertebrate Assemblages, and Water Quality in the Valle Toledo, Valles Caldera National Preserve, New Mexico

by

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Committee Approval

The Master of Water Resources Professional Project Report of Jeanine K. McGann is approved by the committee:

Clifford N. Dahm 11/6/06

Chair Date

6 Nov 06

11/6/2006

Abstract

Lotic ecosystems of the southwestern U.S. can be severely affected by wildfires causing alterations in water chemistry, sedimentation from runoff events, and changes in macroinvertebrate community structure. In these same systems, the use of prescribed burns as forest and/or grassland management tools also may cause changes. The severity of these changes in comparison to wildfires is of primary importance to the effectiveness of these management tools, as any degradation of aquatic habitats is of serious concern in a semi-arid region.

This study evaluates the effects of a recent prescribed burn in the Valle Toledo section of the Valles Caldera National Preserve, November 2005. Factors affecting the outcome of the burn, including a marked lack of winter precipitation, are discussed and data are presented on changes in water chemistry, sedimentation, and macroinvertebrate assemblages, or the lack thereof, from pre-burn to post-burn and post-snowmelt conditions.

Results of the study show no major overall degradation of the aquatic habitats in this area, although some localized changes did occur. Elevation of stream nitrate/nitrite concentrations were observed in the burn stream immediately post-burn, which did not decline until late spring. Carbon/nitrogen analysis of stream sediments revealed a localized effect of C:N ratio increase at snowmelt at two of the burn sampling sites. Macroinvertebrate assemblages were mostly unaltered immediately after the burn, though some decline in taxa richness and Jaccard's similarity within the burn stream were observed at snowmelt. Continued monitoring will be needed to determine if these effects are mitigated and how quickly.

Acknowledgements

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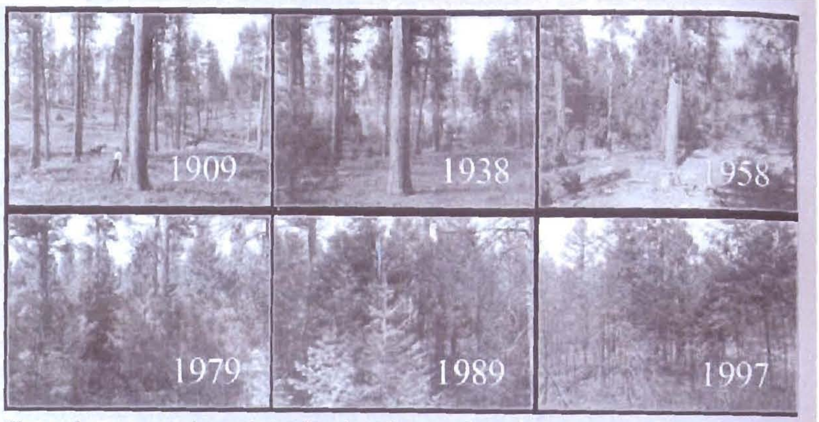
CHAPTER 1 – 'Fighting fire with fire': Wildfires and prescribed burns

Introduction

The purpose of this project was to determine the effects of a prescribed burn on the streambed sediments, water quality, and macroinvertebrate assemblages in several streams in the Valle Toledo section of the Valles Caldera National Preserve (VCNP), located in the northern Jemez Mountains, Sandoval County, New Mexico. Prescribed burns are often used as a management tool, along with forest thinning, in the western and southwestern United States to reduce the amount of ground cover, and hence, fuel, available in an ecosystem in the event of a catastrophic wildfire event. Wildfires have long been an integral part of many forest and scrub or grassland ecosystems, often removing old, dead organic matter and debris and paving the way for new growth. However, a century of fire suppression and unsustainable logging practices has left many forested areas with a dangerous accumulation of thick underbrush, which ignites quickly and burns more intensely than traditional sparsely-populated conifer stands (Ekwurzel, 2004). Figure 1 shows a typical temporal underbrush accumulation pattern in a western forest.



Western forests accumulate underbrush and smaller trees during fire suppression. Photo courtesy of the U.S. Forest Service Fire Effects Laboartory.

Figure 1: Temporal accumulation of underbrush in western forests (Ekwurzel, 2004).

When a wildfire ignites in this dense underbrush, the resulting crown fire quickly can spread and devastate millions of acres, endangering habitats, human populations and property, and watershed quality. In order to mitigate these effects, prescribed burns have become an increasingly popular forest management option in these areas over the last few decades. But there are concerns involved with this practice as well. Prescribed burns can sometimes get out of control, as in the case of the Cerro Grande fire, which burned 43,000 acres of forest in the Pajarito Plateau watershed near Los Alamos, New Mexico in May 2000 (Bitner et al., 2001). There are also questions about the effects of prescribed fire on riparian areas and aquatic habitats. Wildfires can have pronounced effects on aquatic systems within the burned watershed…do these effects translate to prescribed burns as well?

Most aquatic research on this subject has focused on wildfires (e.g., Inbar et al., 1998; Legleiter et al., 2003; Mihuc & Minshall, 1995; Minshall, 2003; Prieto-Fernandez et al., 2004; Rinne, 1996) with the effects of prescribed burns presumed to be similar. However, several new studies by Bêche et al., (2005), Elliott and Vose (2005), and Stephens et al., (2004) have suggested that the effects of prescribed burns are actually much less pronounced than that of wildfires and, under controlled conditions, can be carried out safely, even in close proximity to riparian zones and aquatic habitats. The stream study detailed in this paper is part of a larger effort by the Valles Caldera Trust to quantify the effects of prescribed burns on ecosystems in the Valle Toledo and determine whether this practice is a viable tool for land management within the VCNP.

The next section will detail the major effects of wildfire on sediment, stream chemistry, and benthic macroinvertebrates in watersheds in the southwestern U.S. and set the stage for comparisons with prescribed burns.

Effects of wildfire on watersheds in the southwestern U.S.

Sediment

Newly burned areas are often the sites of erosion and increased runoff, which can alter the chemistry of the surrounding watershed. These effects are particularly pronounced in streams in the southwestern U.S. (Gallaher et al., 2002). Over the past 10 years, a surge of drought in this region has helped to increase the number of wildfires occurring each year and raised concerns about the effects of these fires on watersheds, as the supply of water is limited in this region and any major disturbance in water quality can have serious consequences. In New Mexico, the current drought began in 2000 when the Palmer Drought Severity Index approached -4 (extreme drought) for many parts of the state (Sammis, 2003). Although the unusually wet monsoon season of 2006 brought the index up to mid-range (+/- 1.99) or moist conditions (> +2.0) in New Mexico the longer term drought may not yet be over (NOAA, 2006). Of additional concern is the fact that the effects of fires may grow more pronounced with time if climatic conditions, such as global warming, help to produce fires of greater intensity and frequency in the coming years (Philibert et al., 2003) and drought continues unabated.

The southwestern U.S. is in general an arid to semiarid region; specifically, precipitation in the north central mountains of New Mexico is approximately 38 cm (15 inches) per year (Veenhuis & Bowman, 2002). Greater than half of this amount falls during the summer monsoon season, which usually lasts from July-September and is characterized by short, heavy thunderstorms that often result in annual peak flows for the affected stream systems (Veenhuis & Bowman, 2002). As the monsoon season also occurs during peak wildfire season, the ash and debris resulting from fires has the potential to be transported in large quantities and over great distances from the original burn site (Earl & Blinn, 2003). In a post-fire study on the Colorado Front Range, Moody and Martin (2001) found that hillslope erosion rates increased 200-fold immediately after the burn and took about 3 years to recover. Additionally, they noted a legacy effect in which greater than half of this eroded sediment may be retained in the watershed for more than 300 years, altering the baseline for future disturbances (Moody & Martin, 2001).

In addition to increasing erosion and sedimentation by removing vegetation, fire also can render soils hydrophobic under certain conditions, which increases the amount of runoff that will accrue during precipitation events (Shakesby et al., 2003). This effect can be especially pronounced in the southwestern U.S., where steep canyons funnel large volumes of storm water during the monsoons even without the added effects of post-fire erosion and/or hydrophobicity. The conjunction of factors leading to increases in sedimentation in burned stream systems has the potential to alter cation and anion uptake by vegetation and increase mineral weathering (Gallaher et al., 2002).

The accumulation of fine sediments in pools has been observed in burn areas, especially after storm events (Zelt, 2000). These newly-deposited sediments often have higher concentrations of carbon due to charcoal and ash mobilization following a fire (Bitner et al., 2001; Laird & Campbell, 2000; Meyer et al., 1995; Philpot et al., 2003). When organic carbon from ash and debris is concentrated in these pools, it may begin to breakdown and cause both a dissolved oxygen decline and increased nutrient availability, which can have complex ecological consequences for the stream system (Philpot et al., 2003).

Not only does this increase have an effect on carbon cycling in a stream, but the effects can translate into the nitrogen cycle as well, since the biogeochemical links between C and N cycles are cardinally important to the ecosystem (Dodds et al., 2003). For example, Strauss and Lamberti (2000) found that a sudden influx of organic carbon can reduce nitrification rates and alter primary production. The total organic carbon to total nitrogen (C:N) ratio is an important indicator of whether this type of process is occurring in stream sediments (Dodds et al., 2003; Strauss & Lamberti, 2000).

Stream chemistry

The actual aqueous chemical changes in water following a fire can vary widely depending on the interactions of variables such as fire severity and duration, stream size, geomorphology, soil and vegetation type/amount, and the timing and magnitude of subsequent precipitation events (Earl & Blinn, 2003). However, the levels of many similar dissolved chemicals were found to increase in burned streams following fires in

Mortar Creek, Idaho (Minshall et al., 2001a), the Gila River drainage in southwest New Mexico (Earl & Blinn, 2003), and the streams affected by the Cerro Grande fire in northern New Mexico (Bitner et al., 2001), so some generalizations can be made. Inorganic ions such as dissolved calcium, magnesium, nitrogen, phosphorus, and potassium have been noted to increase, along with pH and alkalinity, as the rapid introduction of minerals induces geochemical changes (Gallaher et al., 2002). Table 1 shows some of the major inorganic ions and the likely impacts of fire on their concentration in a watershed.

Carbon concentration also may increase in water after a burn, along with metals such as manganese, copper, zinc, and iron (Bitner et al., 2001; Gallaher et al., 2002). Other changes that can be noted in burned watersheds include a decrease in dissolved oxygen (Earl & Blinn, 2003).

Inorganics	Burn Effects	Source	Number of Studies
Calcium	Increases	Ash, surface soil	5
Magnesium	Increases	Ash	4
Nitrogen	Increases	Vegetation, ash	6
Potassium	Increases	Vegetation, ash	8
Sodium	Slight increase or same	Surface soil	5
Phosphorus	Increases	Vegetation, ash	6
Sulfur	Inconclusive	Vegetation, ash	2

Table 1: Inorganic ion concentrations in stream waters: pre-burn and post-burn (data from Bitner, Gallaher, & Mullen, 2001).

All of these chemical changes are subject to varying time constraints. Earl and Blinn (2003) noted that most of the concentrations of the major ions they studied returned to normal after 4 months in the Gila River drainage. However, 3 to 5 years elapsed before base-flow water quality returned to pre-fire levels after the 1977 La Mesa fire in the Jemez Mountains (Gallaher et al., 2002). Peak concentrations of ions after the Cerro Grande fire occurred around June 28, 2000, as a result of a large precipitation event in the area (Gallaher et al., 2002).

Benthic macroinvertebrates

Benthic macroinvertebrate species have long been used as bioindicators of water quality in aquatic systems. Different taxa or assemblages of taxa have different responses to disturbances in the environment ranging from point and non-point source pollution to wildfire, flooding, and drought. On a basic level, the presence or absence of certain orders of macroinvertebrates can provide clues to the cause/effect relationship of ecological disturbance and recovery in catchments. Figure 2 shows some common macroinvertebrate taxa in the western U.S.

Figure 2: Some common macroinvertebrate taxa (l to r): Chironomid (order Diptera), mayfly larvae (*Baetis bicaudatus* – order Ephemeroptera), caddisfly larvae (*Rhycophila acropedes* – order Trichoptera).

Wildfire has specific effects on catchments that can significantly alter the assemblages of these and other macroinvertebrate taxa. Minshall (2003) divides these effects into direct and indirect effects of fire – the direct effects being associated with the intense thermal effects generally experienced by smaller (1st and 2nd order) streams, as well as deposits of ash, charcoal, and released nutrients and exposure to smoke or fire retardants. Indirect effects reflect changes to the overall catchment and can include increases in sedimentation caused by erosion and subsequent precipitation, turbidity, and channel incision and scouring (Minshall et al., 2001b; Minshall, 2003). In addition, the opening of the forest canopy to additional sunlight can provide a means for increased photosynthesis and primary production, especially when the availability of nitrogen and phosphorus is increased through deposition or runoff events (Minshall et al., 2001b; Spencer et al., 2003).

However, the same mitigating factors that affect stream chemistry and sedimentation also can have an effect on fire impact on the macroinvertebrate community. Fire temperature, area burned, and burn severity all directly affect the watershed; while stream size, aspect, and gradient, along with the intensity and timing of precipitation and runoff events, landscape topography, and other disturbances such as drought all contribute to either reducing or enhancing the disturbing effects of fire (Earl & Blinn, 2003; Minshall et al., 2001b; Spencer et al., 2003).

For example, Minshall et al.'s (2001b) study of the long term effects of fire on benthic macroinvertebrate communities in a watershed in central Idaho revealed that an intense, localized precipitation event in the summer following the 1979 Mortar Creek fire caused a much more pronounced reduction in both periphyton and benthic species in the affected streams than in other streams that were not affected by flash floods, even those that had been part of the same burn event during the past year.

Another study by Spencer et al. (2003) on the 1988 Red Bench Fire in northwestern Montana also revealed the mitigating effects of the catchment itself on post-fire disturbance. Areas of this floodplain catchment were not steeply graded and were subject to lighter than average precipitation following the fire, allowing for more minimal physical disturbance of benthic habitats in stream beds, as well as intense algal blooms that served as food sources.

The presence of these types of mitigating effects has caused some difficulties in generalizing between studies in different watersheds, however, the more these effects are studied the more researchers will be aware of how these dynamics come into play and will be able to recognize and account for discrepancies.

One general pattern that has emerged across several studies is the decrease in macroinvertebrate taxa richness following wildfires (Mihuc & Minshall, 1995; Minshall et al., 2001b; Minshall & Richards, 1992; Roby & Azuma, 1995; Rinne, 1996). Figure 3 shows a sample of the total taxa richness, density, and biomass of macroinvertebrates over a 10-year period in the Minshall et al. (2001b) Mortar Creek fire watershed study.

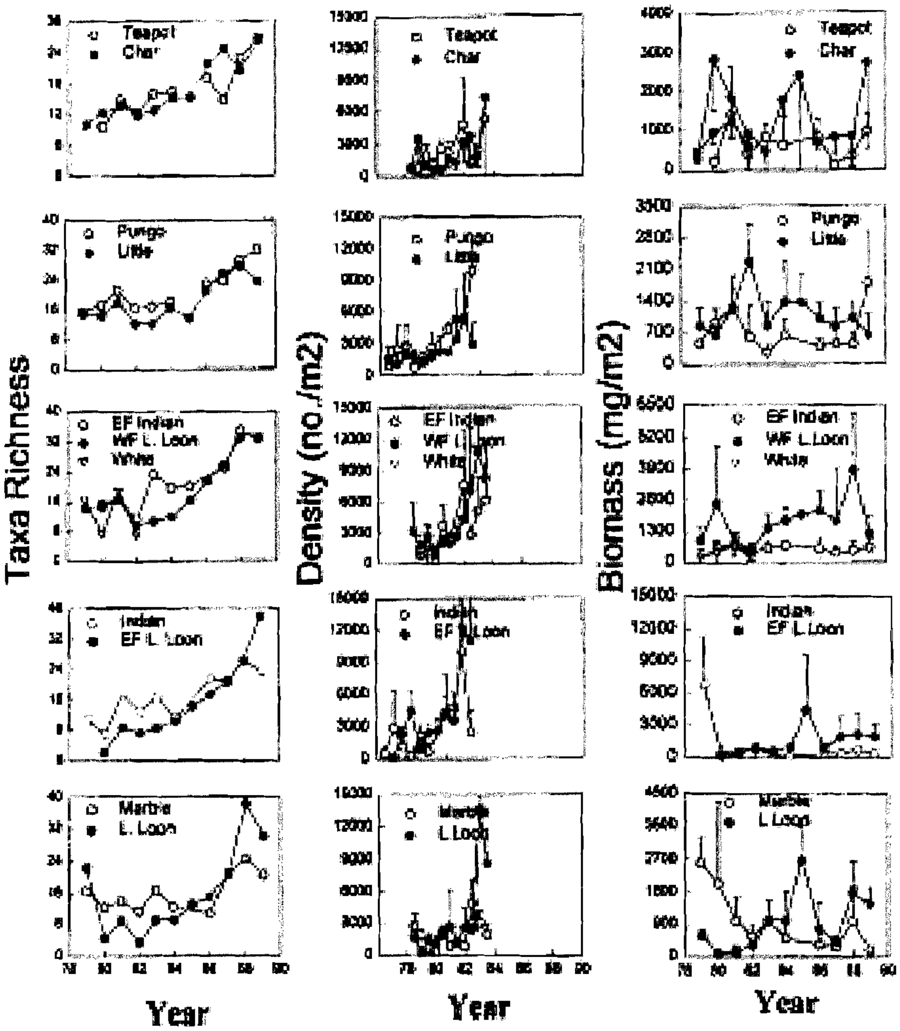


Figure 3: Taxa richness, density, and biomass of benthic macroinvertebrates in streams after the Mortar Creek fire (Minshall et al., 2001b).

Although there are variations in taxa richness among different pairs of burned and unburned (reference) streams the taxa richness in general in the unburned streams is higher, at least in the first half of the study. Some longer term studies such as this one suggest that the effects of the fires tends to dissipate with time, and species richness usually returns to post-fire levels after several years (Minshall et al., 2001b; Roby & Azuma, 1995). The density and biomass of macroinvertebrates taxa is trickier about which to generalize. Overall macroinvertebrate density and biomass often will decrease after a particularly intense fire in a smaller order stream (Roby & Azuma, 1995).

However, density and biomass may actually increase following a fire in other systems due to the rapid establishment of disturbance-tolerant species that can feed on new crops of periphyton growing in the wake of an opened canopy and an influx of nutrients (Earl & Blinn, 2003; Minshall et al., 2001a; Minshall et al., 2001b; Spencer et al., 2003).

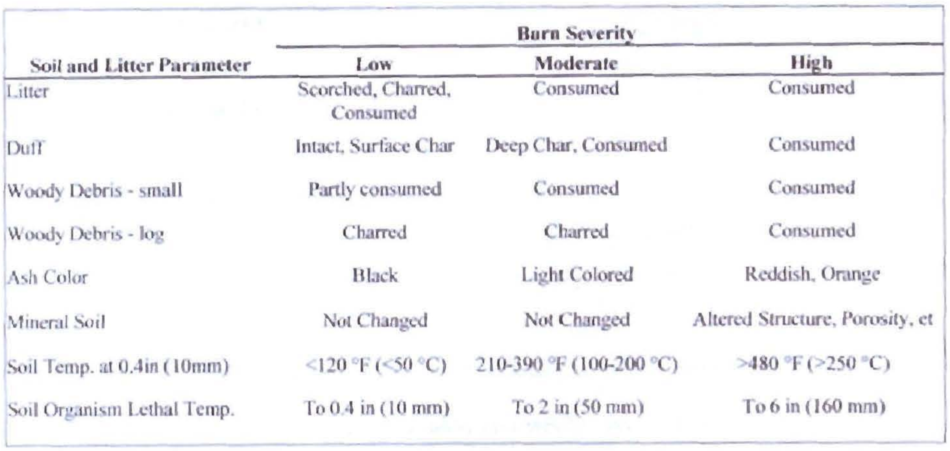
Effects of prescribed burns

In contrast to wildfires, prescribed burns tend to be less intense and burn over a smaller area. To avoid excess runoff and sedimentation following the fire, they often are scheduled to take place at a time of year when heavy monsoonal rains are not expected. In the southwestern U.S., that usually means fall or spring. In the initial search for a prescribed burn area to examine for this study, this author found the majority of prescribed burns in the region scheduled for the fall rather than spring. Depending on the elevation and locale of the prescribed burn, spring conditions can often be too moist on the ground due to runoff from snowmelt or too windy due to local weather patterns.

Weather conditions are always somewhat unpredictable, however, and high winds and heavy precipitation can occur at any time of the year. While it is not possible to control for every single scenario, a well-planned prescribed burn can be a very useful management tool and can help restore balance to ecosystems, especially grasslands that need periodic fires in order to regenerate and renew themselves (VCNP, 2005).

The intense thermal effects that Minshall (2003) noted as direct effects of wildfires are usually not a factor for prescribed burns. Rather, it is the prescribed fire's effect on the surrounding landscape and riparian area that affects aquatic ecosystems.

How this type of treatment will affect aquatic ecosystems is a function of several factors including fire severity, topography and slope, post-fire precipitation volume and intensity, and stream geomorphology, all of which contribute to determining how much of the burned litter and soils are transported into the stream (Bêche et al., 2005; Elliott & Vose, 2005). The nature and composition of this burned material then becomes important to stream chemistry and sedimentation. Figure 4 shows the common attributes of several levels of burn severity on litter and soils.



	Burn Severity		
Soil and Litter Parameter	Low	Moderate	High
Litter	Scorched, Charred, Consumed	Consumed	Consumed
Duff	Intact, Surface Char	Deep Char, Consumed	Consumed
Woody Debris - small	Partly consumed	Consumed	Consumed
Woody Debris - log	Charred	Charred	Consumed
Ash Color	Black	Light Colored	Reddish, Orange
Mineral Soil	Not Changed	Not Changed	Altered Structure, Porosity, et
Soil Temp. at 0.4in (10mm)	<120 °F (<50 °C)	210-390 °F (100-200 °C)	>480 °F (>250 °C)
Soil Organism Lethal Temp.	To 0.4 in (10 mm)	To 2 in (50 mm)	To 6 in (160 mm)

Figure 4: Burn severity classification based on post-fire appearances of litter, soil, and soil temperature profiles (Montaño Allred, 2005, p. 10).

A study conducted on one moderate-intensity, fall-ignited fire in the Lake Tahoe Basin, California (Stephens et al., 2004) found an increase in ammonium in soil after the prescribed fire, which translated to a small increase in stream water nitrate post-burn. Other ions showing an increase were Ca, Mg, and sulfate, although these effects were mitigated within 3 months of the burn (Stephens et al., 2004). The researchers found no increase in phosphorus despite an earlier model suggesting that P enrichment would occur. This result was attributed to either changes in soil chemistry resulting in phosphate adsorbtion or the precipitation of apatite caused by higher pH levels (Stephens et al., 2004).

A low-intensity, spring-ignited fire conducted in the Southern Appalachian Mountains resulted in no significant differences in concentrations of Ca, Mg, K, sulfate, phosphate, nitrate or pH in either soil solution or stream water (Elliott & Vose, 2005). In the case of nitrate, the study attributed this lack of response partially to the timing of the burn, citing a study by Clinton et al. (2003) in which spring-ignited prescribed burns showed no nitrate response while those burned in the fall demonstrated a detectable change in this parameter. The effect of nitrate immobilization and uptake by vegetation in the spring was thought to be the cause of this difference (Elliott & Vose).

A study by Bêche et al. (2005) also examined post-burn stream water chemistry, along with stream sediment, macroinvertebrate populations and periphyton biomass, in a stream in the Sierra Nevada Mountains of California. This low- to moderate-severity burn resulted in little change in sedimentation or macroinvertebrate communities, with short-term effects on water chemistry and periphyton observed. Short-term increases in Ca, Mg, sulfate, total P, and ammonium were detected, while periphyton biomass suffered a post-fire decrease but rebounded within the year (Bêche et al., 2005).

Both this study and that of Elliott and Vose (2005) noted that a pattern of below average precipitation following the prescribed burns in each locale may have had something to do with the lack of effects from the burn. All three of these studies were conducted in areas of gentle slope, where erosion and sedimentation were less likely to be a big post-fire concern, especially in the absence of heavy precipitation (Bêche et al., 2005; Elliott & Vose, 2005; Stephens et al., 2004). Also, they all had in common a low- to moderate fire intensity and severity and were not widespread over tens of thousands of acres, as often is the case with wildfires.

The next section will examine some of the landform features and hydrologic factors that might affect the results of a prescribed burn in the Valles Caldera study area.

CHAPTER 2 – Study area

The Valles Caldera

Topography

The 89,000 acre Valles Caldera National Preserve is located in the northern Jemez Mountains, Sandoval County, New Mexico, on the Southern Rocky Mountain and Colorado Plateau. The bowl-shaped landform contains a variety of ecosystems ranging from its signature open grasslands (the Spanish *valles*) to mixed conifer forest and sub-alpine ecotones (deBuys, 2003). The base level elevation is around 2450 m (8000 feet) with the highest point, the summit of Redondo Peak, reaching 3413 m (11,200 feet) (Johnson, 2006). The grassy *valles* are punctuated by a semi-circle of mountains and the entire area is ringed by the higher peaks of the Pajarito Plateau. Figure 5 shows a 3-dimensional topographic map of the Valles Caldera.

Figure 5: 3-dimensional topographic map of the Valles Caldera created by mosaic of 15' Quad Digital Elevation Models (DEMs) from http://rgis.unm.edu.

Geology

This present day landform is a product of a series of volcanic events that began about 1.22 million years ago with a massive eruption of an older volcanic field in the location of the current caldera (deBuys, 2003). A huge protuberance of magma erupted in an enormous cloud of steam and ash which deposited what is now known as the Bandelier Tuff in hundred-meter thick layers (Treiman, 2003). Following this event, the ring fracture collapsed in upon itself creating a new caldera with a diameter of approximately 13 to 14 miles that is now known as the Valles Caldera (deBuys, 2003). The word *caldera* is Spanish for "kettle" or "cauldron" and the Valles Caldera is well-known in geologic literature as a near-perfect example of this type of landform (deBuys, 2003; Hamilton, 2003). The resurgence of bulging magma underlying old volcanic rocks left from previous eruptions creates domes, such as the one currently uplifting Redondo Peak. This process also creates deposits of gas and steam, which are actively present in the area today (Hamilton, 2003). Figure 6 shows an explanation of the geological formation of this landform.

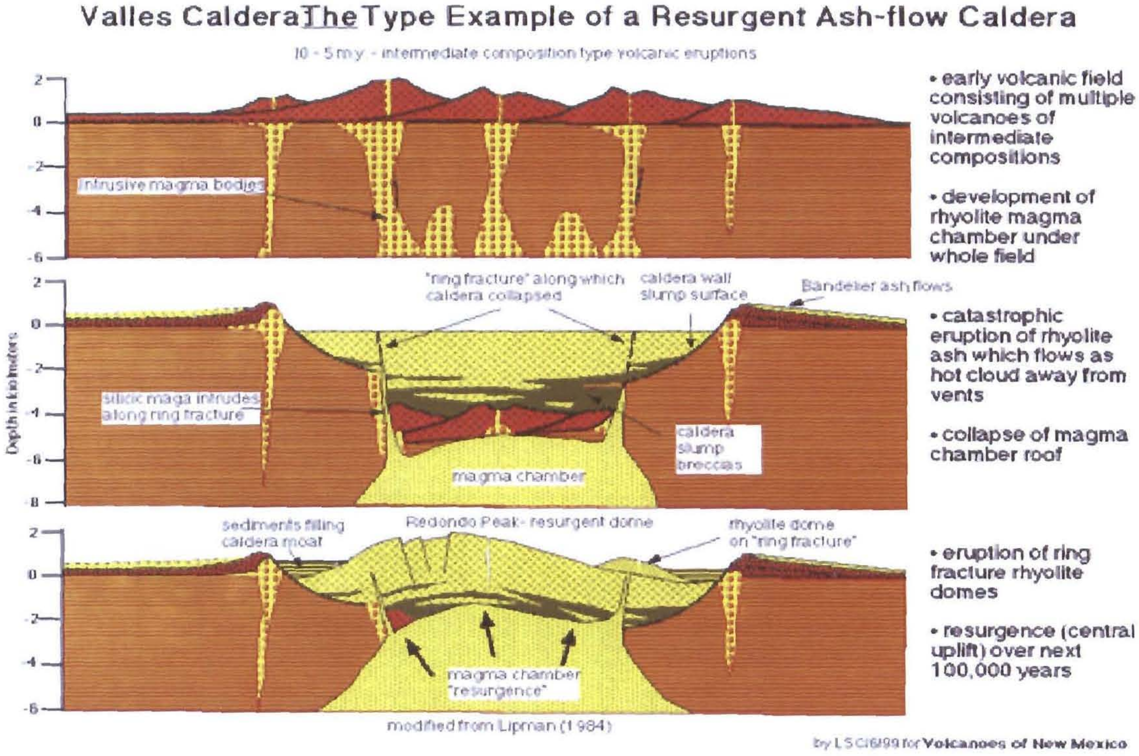


Figure 6: Diagram of a resurgent ash-flow caldera (http://www.nmmnh-abq.mus.nm.us/nmmnh/volcano/jemez_data.html).

The current geologic structure of the Valles Caldera is composed of the tuff, or pyroclastic ash-flow deposits, from these large-scale eruptions, overlain with younger pumice beds and rhyolite flows that formed obsidian in areas of rapid cooling (Martin, 2003). The tuff on which the caldera sits is known as the Tshirege Member of the Bandelier Tuff, a deposit which had flowed over the older Otowi Member from the ancient caldera (Kelley, 2004). The Precambrian rocks underneath both these layers are now buried at depths of up to 4570 m in some areas (Martin, 2003).

A deep canyon draining the southwest portion of the caldera was carved by the draining of a large lake that filled the caldera during a period of accelerated volcanic resurgence about 500,000 million years ago. The accumulation of fine lakebed sediments in the *valles* may help account for the rich establishment of grass species in these areas (Martin, 2003).

Soils

Due to its unique geological history, several distinct soil types are located in the region of the Valles Caldera. Grassland areas such as the Valle Toledo are characterized by fine-particle lacustrine deposits from the ancient lake and alluvial deposits from valley streams. The montane areas are generally underlain by volcanic soils associated with the Bandelier tuff and Redondo dome. Some areas where landslides have historically occurred show more of a coarse-fragment colluvium (Gardner et al., 2006). Soil orders found in this region include entisols, inceptisols, alfisols, mollisols, and aridisols (National Park Service, 2005). See Figure 7 for a soil map of the Valles Caldera.

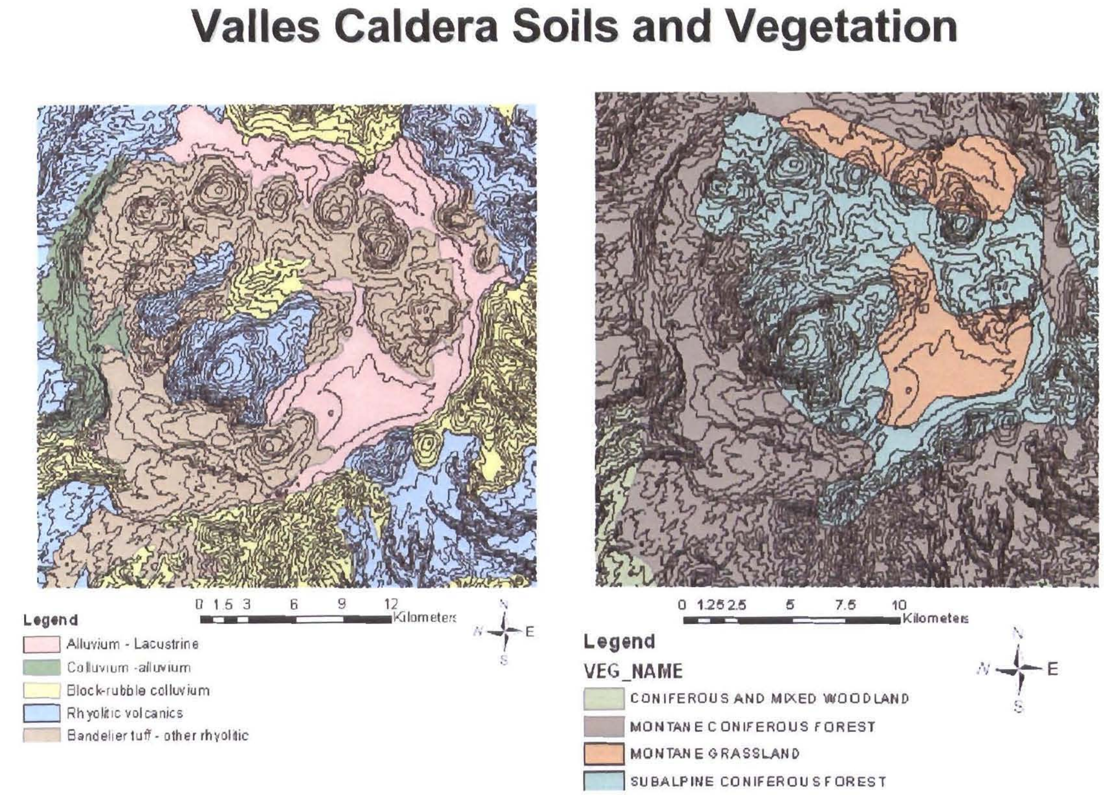


Figure 7: Soil and vegetation maps of the Valles Caldera. (Soil data from Gardner et al., 2006 and http://rgis.unm.edu. Vegetation data from http://rgis.unm.edu).

Climate

The Valles Caldera has the type of temperate, seasonal climate characteristic of higher-elevation mountain regions in the semiarid southwestern U.S. Precipitation measures between 15-19 inches per year in the lower elevations, with increasing amounts of rain and snowfall in the upper montane areas (Gallaher et al., 2004; Veenhuis & Bowman, 2002). Summers can be hot, with temperatures reaching above 30°C, although daytime temperatures average around 25°C and nights are usually 6-12 degrees cooler. Winter temperatures range from occasional nights of -15°C or less to highs between 0-10°C. Most precipitation is concentrated during the summer monsoon period from July to September (Veenhuis & Bowman, 2002), though considerable snowpack also can form during the winter in wet years. Typically, the spring and fall are the drier seasons, though spring ground conditions can be moist due to snowmelt.

Hydrology

The Valles Caldera sits at the top of the watershed for the larger Jemez Mountain region and contributes hydrologically to four major tributaries of the Jemez River, which eventually joins the Rio Grande (Parmenter, 2005). Locally, the mountains that rim the bowl-shaped caldera form a natural watershed boundary which contains a variety of intermittent and perennial streams, approximately 43 km in all (deBuys, 2003) (see Figure 8). The unique geology of the caldera contributes to a wealth of geothermal activity in the area, including some surface hot springs. Various springs and seeps can be found throughout the caldera, which compose a significant hydrological contribution to some of its small creeks and streams (de Buys, 2003; Martin, 2003).

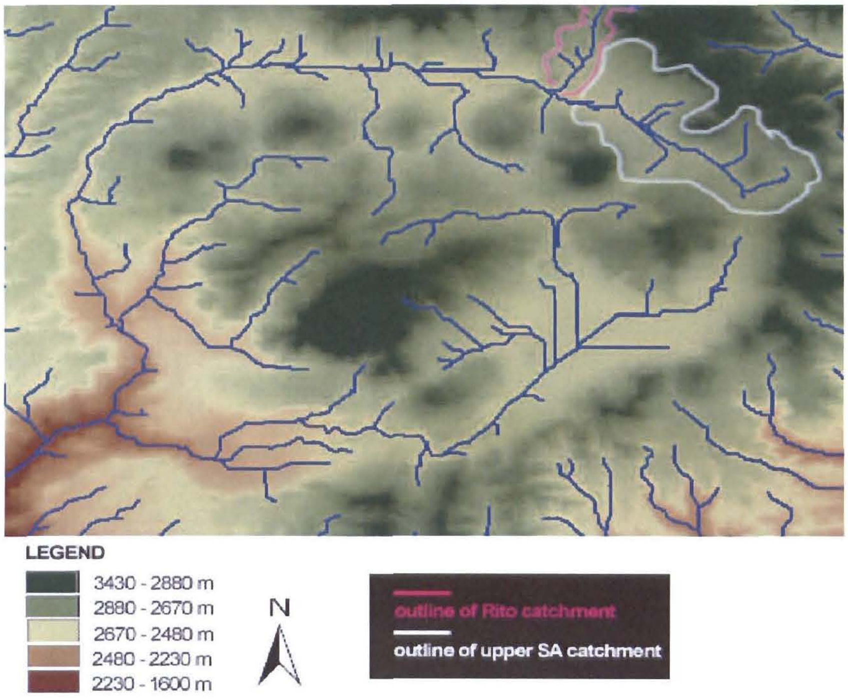


Figure 8: Stream systems of the Valles Caldera (DEMs from http://rgis.unm.edu).

Biota

The preserve supports a diverse array of flora and fauna. Over 550 plant species have been identified within the VCNP with maybe another hundred more likely present (deBuys, 2003). Grasses, forbs, rushes, and sedges dominate the *valles*, while the montane forests support a large population of aspens along with mixed conifers like Ponderosa pine, Douglas fir, and blue spruce. Figure 7 shows the general distribution of VCNP vegetation. Some additional wetland species are also in evidence, as well as rarities like a boggy fen containing peat deposits (deBuys, 2003). See Table 2 for a more detailed survey of common vegetation in the Valles Caldera.

Trees and shrubs	Grasses and forbs	Grasses and forbs (cont.)
Pseudotsuga menziesii (Douglas fir)	*Bromus anomalus* (Nodding bromegrass)	*Stipa comata* (Needle and thread)
Pinus ponderosa (Ponderosa pine)	*Sitanion jubatum* (Big squirreltail)	*Agropyron smithii* (Western wheatgrass)
Pinus flexilis (Limber pine)	*Koeleria cristata* (Prairie junegrass)	*Sitanion hystrix* (Bottlebrush squirreltail)
Abies concolor (White fir)	*Thalictrum fendleri* (Fendler meadowrue)	*Bromus carinatus* (Mountain brome)
Populus tremula tremuloides (Quaking aspen)	*Achillea millefolium lanulosa* (Western yarrow)	*Poa pratensis* (Kentucky bluegrass)
Juniperus communis (Common juniper)	*Thermopsis rhombifolia montana* (Mountain thermopsis)	*Danthonia parryi* (Parry's oatgrass)
Juniperus monosperma (One-seed juniper)	*Fragaria vesca americana* (Wild strawberry)	*Arenaria fendleri* (Fendler's sandwort)
Quercus gambeii (Gambel oak)	*Festuca arizonica* (Arizona fescue)	*Potentilla hippiana* (Woolly cinquefoil)
Abies lasiocarpa arizonica (Corkbark fir)	*Muhlenbergia montana* (Mountain muhly)	*Arctostaphylos uva-ursi* (Kinnikinnick)
Picea pungens (Blue spruce)	*Potenilla anserina* (Silverweed cinquefoil)	*Bromus japonicus* (Japanese brome)

Table 2: Common vegetation of the Valles Caldera (from http://rgis.unm.edu and Parmenter et al., 2005a).

With regard to Animalia, the Valles Caldera supports a thriving elk population, along with other large mammals such as mountain lion, coyote, black bear, and bobcat. Gunnison's prairie dog and a species of pika also inhabit the area, along with over 100 species of birds (deBuys, 2003). Other fauna include several native and non-native fish species and amphibians like the rare and elusive Jemez Mountain salamander. See Table 3 for more VCNP species (list is not comprehensive).

Mammals	Birds	Amphibians	Fish
Rocky Mountain elk	Wilson's snipe	Jemez Mountain salamander	Brown trout
Mule deer	Cooper's hawk	Chorus frog	Rainbow trout
Bobcat	Osprey	Tiger salamander	Cutthroat trout (native species may be reintroduced)
Mountain lion	Northern goshawk		
Coyote	Savannah sparrow		
Meadow jumping mouse	Stellar's jay		
Black bear	Eastern meadowlark		
Pika	Black-headed grosbeak		
Gunnison's prairie dog	Ruby-crowned/Golden-crowned kinglets		
	Bald eagle/Golden eagle		
	Mexican spotted owl		
	Peregrine falcon		

Table 3: Selected biota inhabiting the Valles Caldera (from deBuys, 2003).

History/Land use

This rich and diverse land also has a long history of human habitation and use. The Valles Caldera has been at least seasonally inhabited by various human populations since approximately 5500 BC (Martin, 2003). After centuries of traditional hunting, gathering, and ceremonial use by Native Americans, the arrival of the Spanish in the 1500s heralded the beginning of grazing in the Valles by domesticated livestock. The area was included as part of a land grant from newly-independent Mexico to Luís María

Cabeza de Baca in 1821, beginning the official history of the caldera that would be known as Baca Location No. 1 for the next 200 years (deBuys, 2003).

During that time, ownership of the Valles Caldera changed hands frequently. After an initial sale of the property in 1899 from a group of 46 owners (largely composed of the heirs Luís María Cabeza de Baca), the Valles Caldera was owned/leased and managed by a shifting mélange of ranching companies (Valles Land Company), timber outfits (Redondo Development Company, New Mexico Timber), the Forest and National Park services, and several private owners (Frank Bond, James Patrick Dunigan) (deBuys, 2003; Martin, 2003). Along the way, the Valles Caldera was used for cattle and sheep grazing, logging, hunting, some limited sulfur mining, and drilling for possible oil, gas, and geothermal leases. In 2000, the Valles Caldera Preservation Act (P.L. 106-248) created what is today known as the Valles Caldera National Preserve (de Buys, 2003; Martin, 2003).

The Preserve is still managed as a working ranch, with an active livestock grazing program (Parmenter, 2006). While not completely open to the public, public recreational uses such as trout fishing, elk hunting, and hiking are available on a limited basis. Due to its striking natural beauty, the VCNP has been the setting for Hollywood films; but it is also the site of research and studies by scientists from many New Mexico institutions as well as the Valles Caldera Trust itself, the governing board that manages and oversees operations on the Preserve (deBuys, 2003; Martin, 2003). Figure 9 shows current land use patterns on the VCNP.

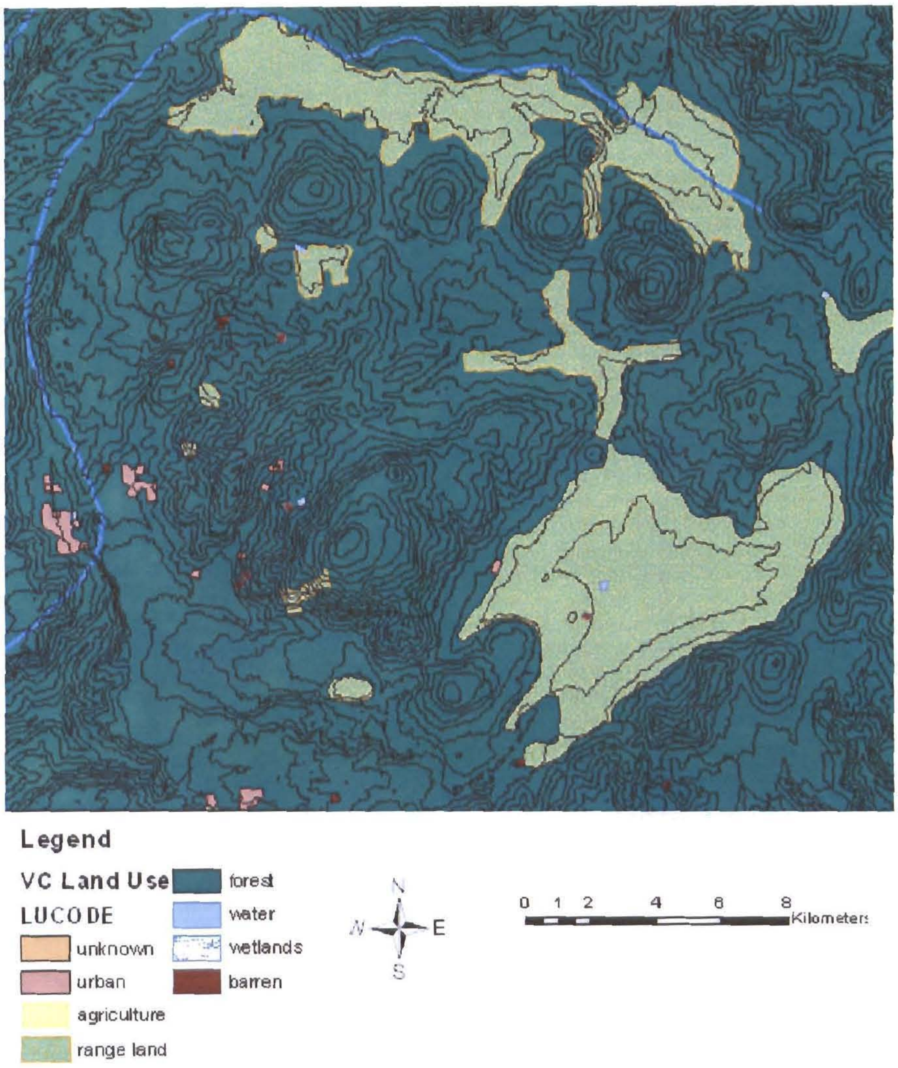


Figure 9: Valles Caldera current land use (from data accessed at http://edcftp.cr.usgs.gov/pub/data/LULC/250K/).

Despite this long history of use, the ecosystems of the Valles Caldera have either escaped extreme degradation or managed to rebound after some abuses (see Figure 10 for a pictorial illustration). The timber industry, in particular, denuded over 16,000 ha on the Valles before logging operations were shut down in 1972 (Martin, 2003). The 1,600 km of dirt roads that were graded prior to this still cause some problems with erosion and sedimentation, although the trees themselves have long since returned (Martin, 2003).

There has been degradation of aquatic habitats in some reaches, largely due to grazing by cattle, sheep, and a large population of elk, however, most riparian areas of the caldera are in generally good condition (deBuys, 2003).

Figure 10: (Left) View to the southeast taken by Vernon Bailey (of the U.S. Bureau of Biological Survey) in August 1906 along Valle San Antonio. (Right) The September 1997 retake (from http://www.fort.usgs.gov/resources/spotlight/place/place_exhistory.asp).

However, the historical use of the Valles Caldera as ranch and rangeland also has contributed to the suppression of the natural fire regime in the area (VCNP, 2005). This suppression has allowed excess litter to accumulate both in the grasslands and in the forested portions of the Preserve. This excess litter has the potential to increase the severity and intensity of a naturally occurring fire event in the area by providing an abundant source of fuel (VCNP, 2005).

The VCNP would take years to recover from a large-scale catastrophic fire event. The Preserve's importance as a natural resource, as a research study site, and as a regulated area for hunting, fishing, and grazing requires that the probability of such an event be diminished as much as possible. The potential impacts of a prescribed burn would first need to be assessed before a decision could be made on the viability of this tool for forest/grassland management. For this reason, among others, a prescribed fire event took place on 1800 acres of the Valle Toledo area in early November 2005 (VCNP, 2005). The conjunction of two streams running through this area, San Antonio Creek and the Rito de los Indios, provided an excellent study site for examining the effects of this burn on stream water quality, aquatic macroinvertebrate communities, and the streambed sediments which make up a large part of their habitat. Figure 11 shows the general location of the Valle Toledo within the VCNP.

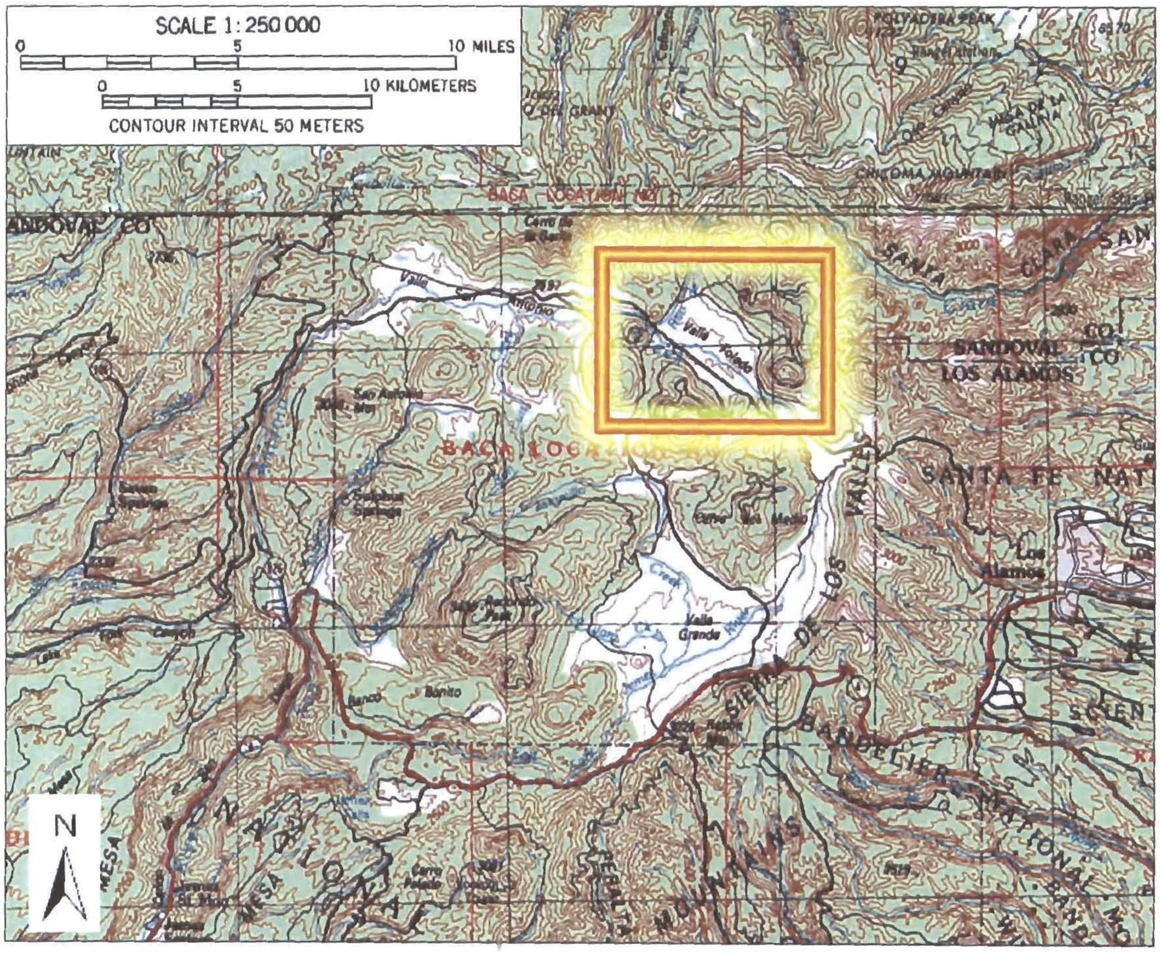


Figure 11: Contour map of the Valles Caldera National Preserve and surrounding area with Valle Toledo section highlighted (http://www.skimountaineer.com/ROF/NorAm/Valles/VallesCalderaMap.jpg).

The Valle Toledo

Valle general characteristics

The Valle Toledo is located in the northeastern region of the Valles Caldera and is a broad, flat, grassy plain ringed by steeper elevation mountains and mixed deciduous and coniferous forest. The grassland is characterized by species including Parry's oatgrass (*Danthonia parryi*), Arizona fescue (*Festuca arizonica*), Junegrass (*Koeleria cristata*), Fendler's sandwort (*Arenaria fendleri*), and Woolly cinquefoil (*Potentilla hippiana*) (Parmenter et al., 2005a). Figure 12 shows a view of the Valle Toledo standing southeast of San Antonio Creek and looking northwest.

Figure 12: Valle Toledo near Upper San Antonio Creek, Oct. 13, 2005 (photo by G. Shore).

The mountains surrounding the Valle Toledo were logged extensively in the mid-20th century according to Martin (2003):

> Between 1963 and 1971 New Mexico Timber graded over 1,000 miles of road. Their first cable-logging operations were on the north sides of the ring fracture domes of both caldera-forming eruptions. The hills surrounding the Valle Toledo were hit hardest: Cerros del Abrigos, Cerros de los Posos, Cerro Toledo, and Cerro del Medio were covered with a spaghetti-network of interlocking roads. (p. 93)

Today these areas are reforested, but the roads remain and can contribute to erosion in some steeply graded areas. The Valle Toledo also is currently the site of elk/cattle grazing as well, which is managed by the Valles Caldera Trust (Parmenter, 2006).

Study stream characteristics

The upper portion of San Antonio Creek meanders across the lower portion of the *valle* from east to west and is fed by intermittent streams and springs in the mountains to the east, near Los Alamos. Once it reaches the Valle Toledo, the stream is fairly low gradient and velocity, and relatively small until about a third of the way along its course where a constant flow of water from an open artesian well doubles its size. This portion of the San Antonio flows through the remainder of the Valle Toledo before joining the Rito de los Indios in the other side of a ridge that marks the extent of the *valle* to create a larger stream, the lower San Antonio. The Rito de los Indios flows out of a steeper and more heavily forested watershed to the north, though the study reach itself is more open.

The upper San Antonio (USA) and the Rito de los Indios (RTO) are both first order streams, while the lower San Antonio (LSA) is second order. The RTO is the smallest of the three, with an average wetted width of 0.5 m. The LSA's wetted width averages 1.4 m while the USA averages 1.6 m. The RTO is also the shallowest system, with average depth of 16 cm, while the USA (23 cm) and the LSA (25 cm) are deeper. The RTO and LSA are the most consistent with these average widths and depths, while the USA is more variable along the sampling length, with wide, shallow pools connected by narrower rills. Figure 13 shows the stream flow measurements taken on each stream on the sampling dates.

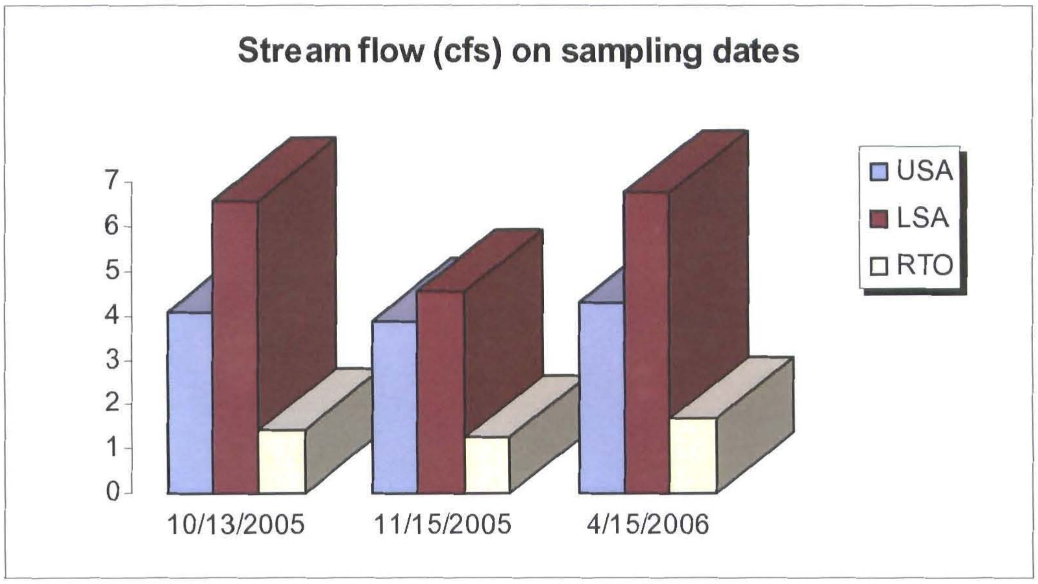


Figure 13: Stream flow at Upper San Antonio, Lower San Antonio, and Rito de los Indios on 3 sampling dates.

A temporal analysis of the dissolved oxygen (DO) and temperature values in the San Antonio and Rito suggests that more primary production takes place in the San Antonio than the Rito, which appears to be more physiochemically controlled. This analysis follows the single-station diurnal DO change method outlined as a viable indicator of in-stream metabolism by Mulholland et al. (2005), and not the upstream-downstream change method used by Marzolf et al. (1994; 1998), among others, as there is only one Sonde DO sensor on each of the two streams.

Mulholland et al. (2001) noted that streams with high photosynthetically active radiation (PAR) and less canopy cover, such as the San Antonio, often have relatively high rates of GPP that peak in the afternoon. Streams with greater canopy cover and lower PAR, such as the Rito, which meets these characteristics immediately upstream of the study reach, have intermediate to low rates of GPP.

Figure 14 shows dissolved oxygen highs plotted against time of day for the two streams and reveals that highs in the San Antonio often occur in the afternoon rather than the early morning, as is the case in the Rito. This pattern can be evidence of primary production in the San Antonio, since photosynthesis has had several hours to raise DO levels by midday/afternoon. In contrast, DO highs in the Rito often occur in the early morning, when stream water is at its coldest and photosynthesis has yet to contribute substantively to DO concentration.

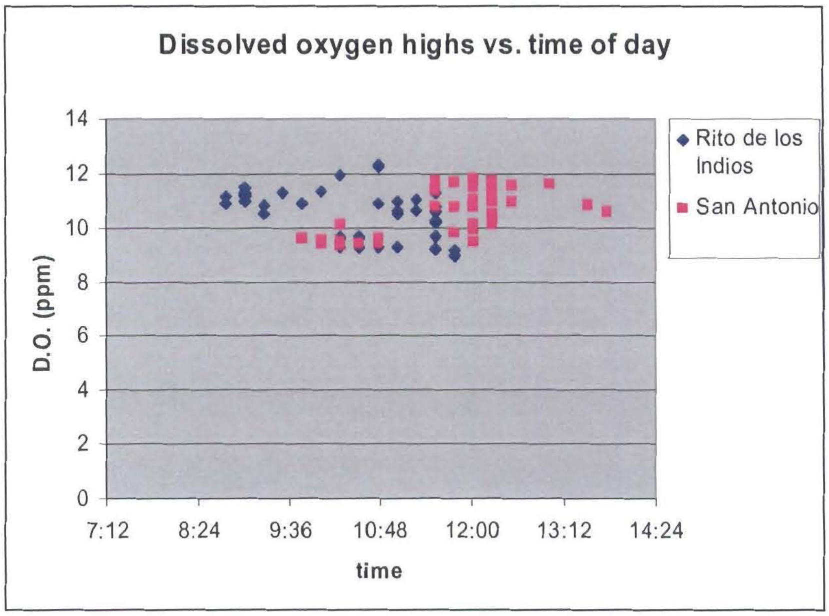


Figure 14: Dissolved oxygen highs vs. time of day

The diurnal dissolved oxygen differential (ΔO) in the San Antonio declined from an average of 3.79 (mg/l) in mid-October to an average of 2.78 (mg/l) in the first half of November, while the Rito experienced the opposite effect (Figure 15). This is likely due to the decline of primary production in the San Antonio with the onset of colder temperatures. The Rito, being more physiochemically controlled, showed a low DO differential during the warmer months, but began to vary more widely when colder temperatures began (colder water generally can hold more dissolved oxygen than warmer water). This carried through into the spring, when larger temperature differences in the Rito resulted in larger DO differences through the end of April (Figure 16).

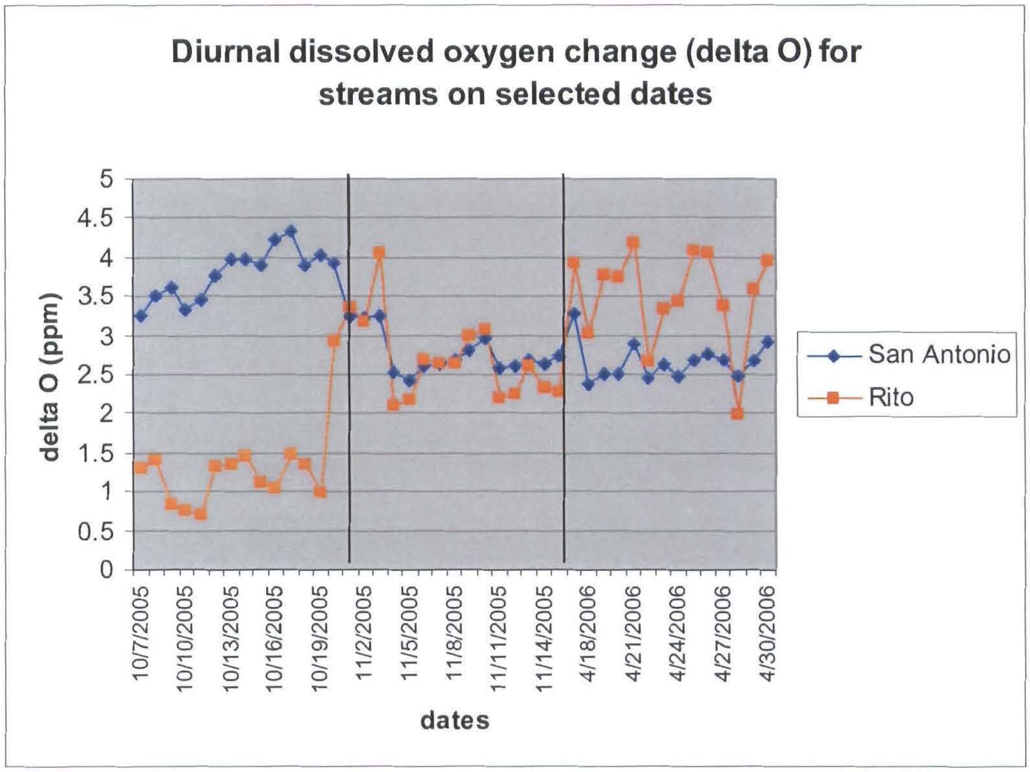


Figure 15: ΔO values for 3 sampling periods (October, November, and April) in the San Antonio and Rito

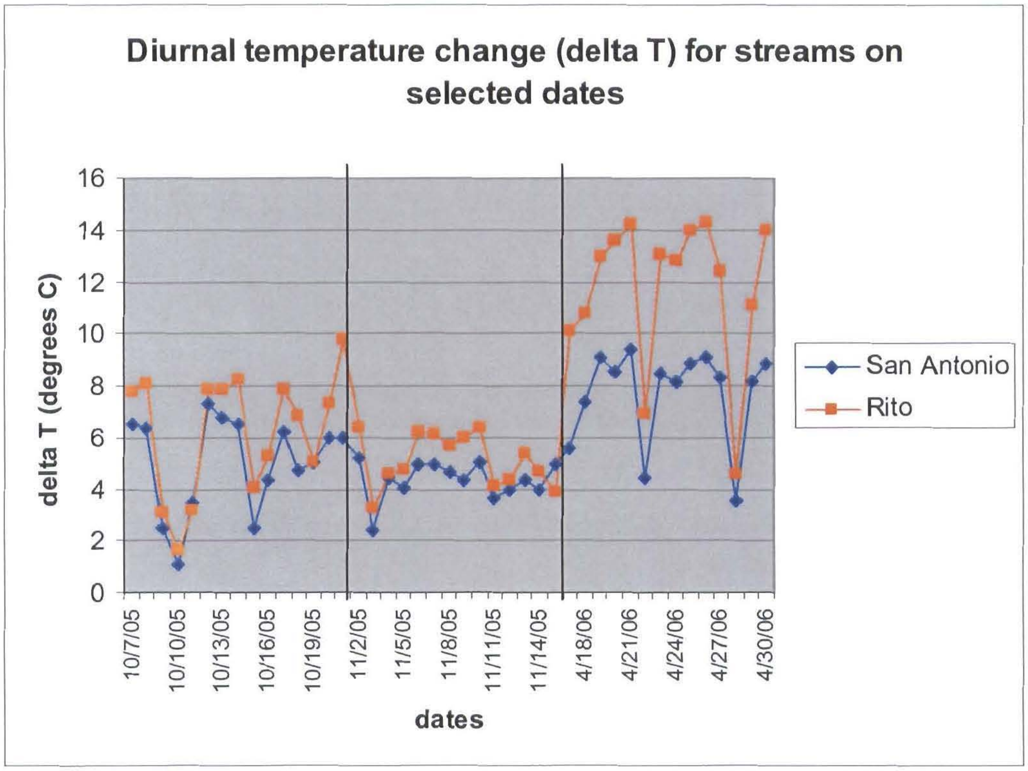


Figure 16: ΔT values for 3 sampling periods (October, November, and April) in the San Antonio and Rito

An analysis of dissolved oxygen percent saturation in the two streams also bears out these conclusions, as saturation in the San Antonio experienced a larger fluctuation in daily saturation values during October, which decreased as primary production tapered off in November (Figure 17). The Rito showed almost no fluctuation during October and increased somewhat during November. This pattern held into April when the Rito was still experiencing large temperature fluctuations (possibly due to snowmelt runoff). The San Antonio had not yet returned to the higher saturation fluctuations experienced in October, indicating that primary production may not yet have ramped up for the spring.

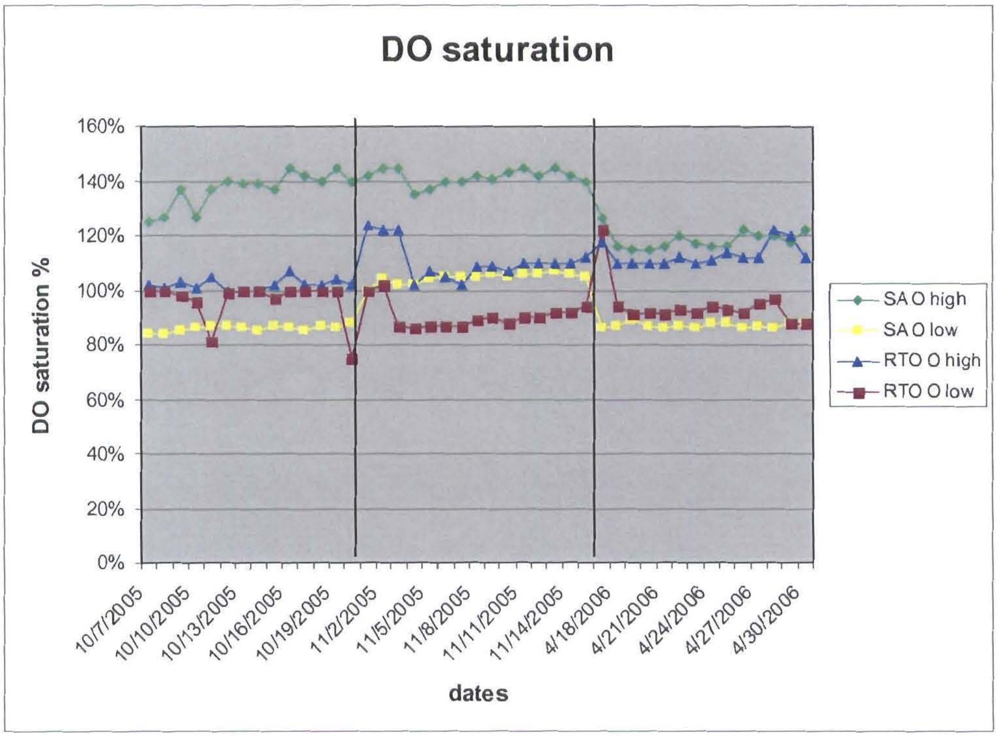


Figure 17: Dissolved oxygen percent saturation highs and lows for San Antonio and Rito on 3 sampling dates (from nomogram in Wetzel & Likens (1979), p. 78 – see Appendix A).

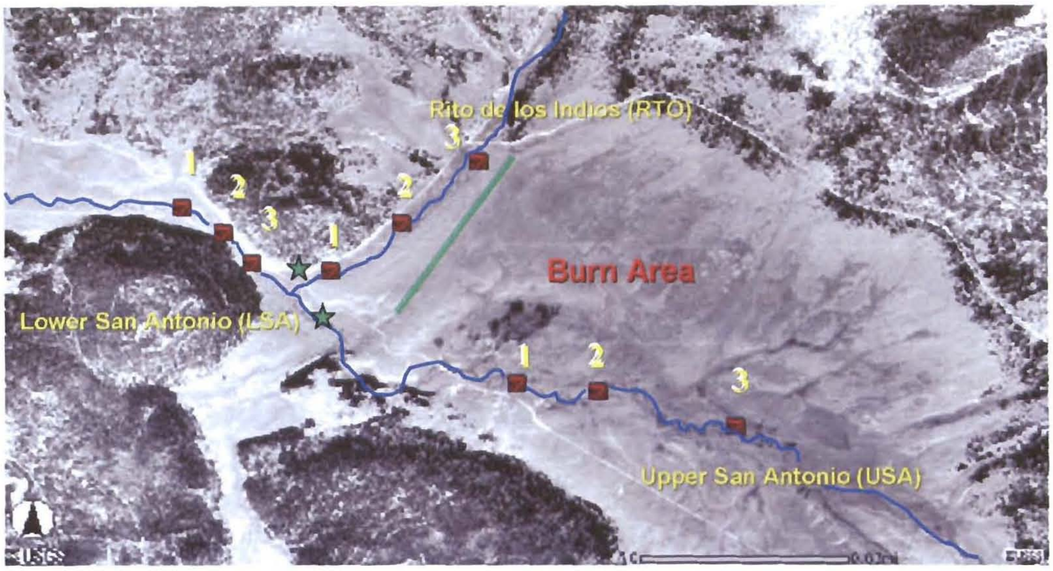
The high DO saturation values in the San Antonio, and their large fluctuations, indicate that this is a highly productive system (OzEstuaries, 2005). Cloern et al.'s (1999) study of water quality patterns in the San Francisco Bay used DO saturation as an indicator of primary production, noting that an area with saturation persistently lower than 100% had lower production than an area where the DO reached 127% saturation, and that an area in the Central Bay where DO reached 140% or greater had occurrences of very high primary production. DO saturation in the San Antonio routinely reached 140% and, during October, fluctuated daily to this high from lows in the mid-80s.

CHAPTER 3 – Study design

This study is part of a much larger undertaking initiated by the Valles Caldera National Preserve entitled "Ecosystem Responses to Prescribed Fire and Elk/Cattle Grazing in an Upland Watershed of the Middle Rio Grande Basin: Valles Caldera National Preserve, New Mexico" (Parmenter et al., 2005a). This specific study is designed to sample benthic sediments and macroinvertebrate assemblages in the benthos before and after the prescribed burn and after spring snowmelt. The field sampling portion of this research was carried out under the guidance of Dr. Gerald Jacobi, one of the principal investigators on this project, who is monitoring the effects of the burn on in-stream macroinvertebrate assemblages. Additional water quality data from Sonde sensors deployed as part of the larger study and other pertinent information were provided by Dr. Robert Parmenter, Chief Scientist, VCNP.

This study used a BACI (Before-After-Control-Impact) design which focused on three stream sections in the Valle Toledo area of the Valles Caldera. The first section is located on Upper San Antonio Creek (USA) above the confluence with the Rito de los Indios and another is located on Lower San Antonio Creek (LSA) below the confluence. The third and final section is located on the Rito de los Indios above the confluence with San Antonio Creek (RTO). The Rito de los Indios served as the control stream since its surrounding riparian area was not burned. The Upper San Antonio Creek is situated directly in the burn area, and thus should show the largest effects, if any, from the burn, while the lower portion of San Antonio Creek represented a conjunction of effects from both the burn and non-burn streams. Three sampling sites were located on each of the three sections and three samples were collected at each site, for a total of 27 samples per each sampling round. See Figure 18 for an overall layout of the study sites and Table 4 for general study site parameters.

General design for Valle Toledo burn study



Section of a digital orthophoto quadrangle (DOQ) from http://statgraph.cr.usgs.gov
(NAD 83 – scale factor 0.0001 dd/pixel)

Figure 18: General layout of Valle Toledo burn study with sampling sites (red squares) and Sonde sensors (green stars) marked.

Location	Altitude (m)	Latitude	Longitude
USA 1	2,633.35	35°57'29.25930" N	106°28'49.45752" W
USA 2	2,624.62	35°57'24.35954" N	106°28'27.14423" W
USA 3	2,642.80	35°57'14.16323" N	106°27'51.19482" W
LSA 1	2,616.32	35°58'04.09379" N	106°29'44.85411" W
LSA 2	2,615.95	35°57'59.72385" N	106°29'37.98403" W
LSA 3	2,619.87	35°57'51.08984" N	106°29'32.59665" W
RTO 1	2,624.96	35°57'52.47192" N	106°29'19.46264" W
RTO 2	2,633.18	35°58'00.74280" N	106°29'04.90469" W
RTO 3	2,636.74	35°58'15.48461" N	106°28'51.47301" W

Table 4: Valles Caldera Preserve 2005 aquatic invertebrate sampling sites GPS data (Montgomery, 2005).

The prescribed burn took place November 1-2, 2005. Sampling was done 2 weeks before the burn (October 13, 2005) and 2 weeks after (November 15, 2005). One final round of sampling was completed 6 months later, at the time of spring snowmelt (April 14, 2006). Field notes from all sampling dates can be found in Appendix B.

The burn was conducted by fire teams from the US Forest Service and Bandelier National Monument under the auspices of the Valles Caldera Trust (Parmenter et al., 2005a). Ignition commenced on the morning of November 1, 2005, using drip torches for blackline hand ignition with additional air ignition by helicopter. Air ignition consisted of projectiles (ping pong balls) filled with potassium permangate and injected with ethylene glycol (Dr. Robert Parmenter, personal communication, Aug. 17, 2006). Figure 19 shows a general overview of the burn area before, during, and after ignition.

Figure 19: Valle Toledo (l to r): Before, during, and after prescribed burn, autumn 2005 (photos by G. Shore and from Parmenter et al., 2005b.

Flame heights in the grassland area near the USA study sites ranged from 0.3 m to 3 m high and spread at an average rate of 10 m in 25 seconds. Part of the forest in the hills above the Valle Toledo was burned as well, but flame heights there only ranged between 0.1 and 0.3 m, and had much lower (averaging 10 m in 4.5 minutes) spread rates. According to Parmenter et al. (2005a), "Approximately 70% of the surface area of the designated fire acreage was burned; as expected, areas that did not burn either had insufficient fuel loads or (in the case of some riparian areas) were too moist and replete with green vegetation" (unpaged excerpt). Figure 20 shows a pre- and post-fire close-up of a burned grassland plot.

Figure 20: Pre-burn and post-burn grassland plot (Parmenter et al., 2005a).

CHAPTER 4 – Study methods

Stream sediments

Sediment samples were collected using an open-bottomed plastic sediment sampler with a height of 51 cm and a diameter of 21 cm. Five cups of sediment (approximately 1.75 liters) were removed from the benthos and placed into each sample bag. The bags of wet sediment were sealed and placed in a cooler for transport. In the lab, sediment samples were wet sieved using a set of .25-.5-1-2-4-8-16 mm sieves. Macroinvertebrates contained in the sediment samples were removed during this process. All samples were processed within 36 hours of removal from the field and were refrigerated until processed to preserve benthic organisms.

Fractioned samples were then dried following Beschta's protocols in Chapter 5 of Hauer and Lamberti (1996). Dried samples consisted of .25-.5, .5-1, 1-2, 2-4, 4-8, 8-16, and >16 mm fractions, which were then weighed and particle size distribution determined. A sample amount of the four smallest fraction sizes (.25-.5, .5-1, 1-2, 2-4) from each of the 9 main site locations was ground using a mortar and pestle and analyzed for carbon and nitrogen content using a Carlo Erba C/N analyzer. Portions of all fraction sizes 16 mm and less for each of the 27 samples were combusted in a 550°C muffle furnace, pre- and post ash weights were recorded, and mass percent loss was determined for each.

Benthic macroinvertebrates

The macroinvertebrate species were preserved in 85% ethyl alcohol solution, examined, and identified to the level of family using information from Merritt and

Cummins (1996), Ward et al. (2002), and Voshell (2002), with additional information provided by Schrader (2002). Macroinvertebrates were counted by order and sorted into family. Relative percentages by order were quantified; however, a more qualitative analysis may have to suffice on a more detailed taxonomic level. Jaccard's index of similarity ($W/[a_1 + a_2 - W]$ where W is number of shared taxa and a_1 and a_2 are total taxa in samples 1 and 2) was used for taxonomic comparisons between streams and among sampling dates (http://www.usc.edu/dept/LAS/biosci/Caron_lab/MO/docs/ARISA_explanation.pdf).

Stream chemistry

In addition, measurements of dissolved oxygen and carbon dioxide (ppm) were made at site #1 in each stream section using LaMott water quality field test kits. Stream discharge was also approximated at each of these locations using the flotation device method outlined by Gore in Chapter 3 of Hauer and Lamberti (1996).

Sonde data sensors installed on the San Antonio and Indios creeks (see Figure 18 for locations) provided measurements of temperature, conductivity, dissolved oxygen, pH, and turbidity at 15-minute intervals beginning June 1, 2005, and terminating November 16, 2005. Sonde sensors were removed for the winter and reinstalled on April 17, 2006. Readings of all variables recommenced at this time.

Nutrient and ion water quality data measurements of total phosphorus, TKN, ammonia, nitrate and nitrite, fluoride, sodium, hardness (Ca $_{\&}$ Mg), calcium, magnesium, alkalinity (CO_3 & HCO_3), carbonate, potassium, chloride, ion balance, sulfate, color, conductivity, pH, TDS, TSS, and bicarbonate were taken twice per month from May until December 2005 and then monthly from February 2006 to the present. Water samples were taken immediately upstream from the Sonde sensors on both the Rito de los Indios and San Antonio Creek by Dr. Parmenter following NMED methods. Nutrient samples were preserved in sulfuric acid and both nutrient and ion samples were sent to the state labs on the University of New Mexico's main campus and processed within 24 hours of collection.

Additional data

Precipitation and temperature readings were obtained from the NOAA station at Valle Grande and accessed at: http://www.ncdc.noaa.gov/crn/report?report=som&siteids=05B47A&por_start_month=03&por_start_day=20&por_start_year=2006&por_tref=LST&format=web&go=Generate+Report.

Photographic documentation of the each of the 9 sampling sites before and after the burn, as well as at the time of the spring sampling, was established with other digital imagery of the burn provided by Dr. Parmenter.

Mapping

ArcGIS tools were used for display and analysis of some of the study data using a digital orthophoto quadrangle (DOQ) of the Valle Toledo obtained at http://statgraph.cr.usgs.gov (NAD 1983), which was registered using a world file created with the latitudes and longitudes of the four corners of the photo (Kerski, 2004). The world file is a simple text file consisting of 6 lines, one number on each line. The numbers are presented in a fixed order and represent the information shown in Table 5.

Line #		Explanation	My numbers
LINE1	=	how much of a map unit (in this case, degrees) is represented by moving one pixel eastward from any spot (positive number).	.000058
LINE2	=	how much the image should be skewed from the sides (negative number, but usually zero)	0.0
LINE3	=	how much the image should be skewed from top and bottom (positive number, but usually zero)	0.0
LINE4	=	how much of a map unit (in this case, degrees) is represented by moving one pixel southward from any spot (negative number)	-.000064
LINE5	=	X coordinate (in this case, decimal degrees longitude) of the top left (northwest) corner of the image	-106.5058
LINE6	=	Y coordinate (in this case, decimal degrees latitude) of the top left (northwest) corner of the image	35.9778

Table 5: Explanation of the GIS world file (from Kerski, 2004).

After the 9 study sites were plotted on the DOQ, an Excel database could then be imported and any pertinent data displayed visually. This was especially useful for analysis and display of macroinvertebrate assemblages.

Statistical methods

An ANOVA (analysis of variance) model for the stream sediment C:N data was performed to determine if the C:N ratio varied significantly among the sites and if the overall C:N ratio values for each sampling iteration showed a significant temporal (pre-burn, post-burn, and post-snowmelt) variation. The t-test was used on stream water chemistry data to determine any pre- to post-burn significant change in ions between the control and experimental streams.

CHAPTER 5 – Results and discussion

Sediments

Particle size distribution

Sediment particle size distribution at the three sample sites followed consistent patterns for each of the three sites across all sampling dates with a generally higher concentration of finer particle sediments (.25 mm and less) in the Upper San Antonio vs. both the Rito de los Indios and Lower San Antonio. This would be expected, as the USA is slightly wider and shallower than the LSA with a lower stream flow. The LSA is a second order stream with higher discharge that can transport larger (up to 16 mm and greater) particles. The RTO, while significantly narrower than either of the other two streams, is fast-flowing for its size and more consistent in flow velocity along the sample length, resulting in a more even distribution of particle sizes (see Figures 21, 22, and 23). See Appendix C for a full graphical breakdown of sediment cumulative percent weights.

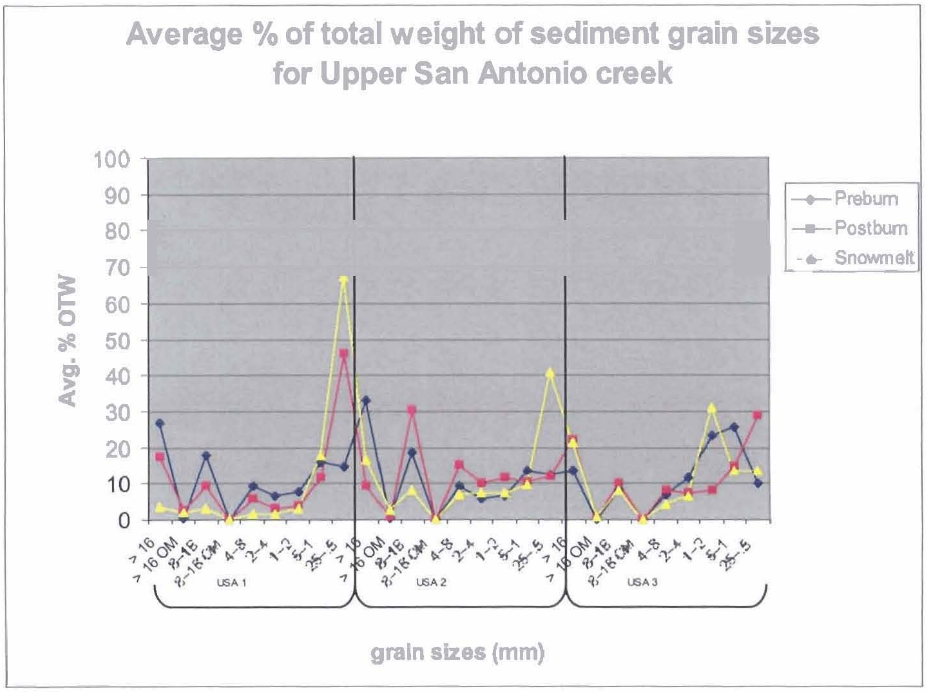


Figure 21: Average % of total weight of sediment grain sizes for Upper SA creek sites.

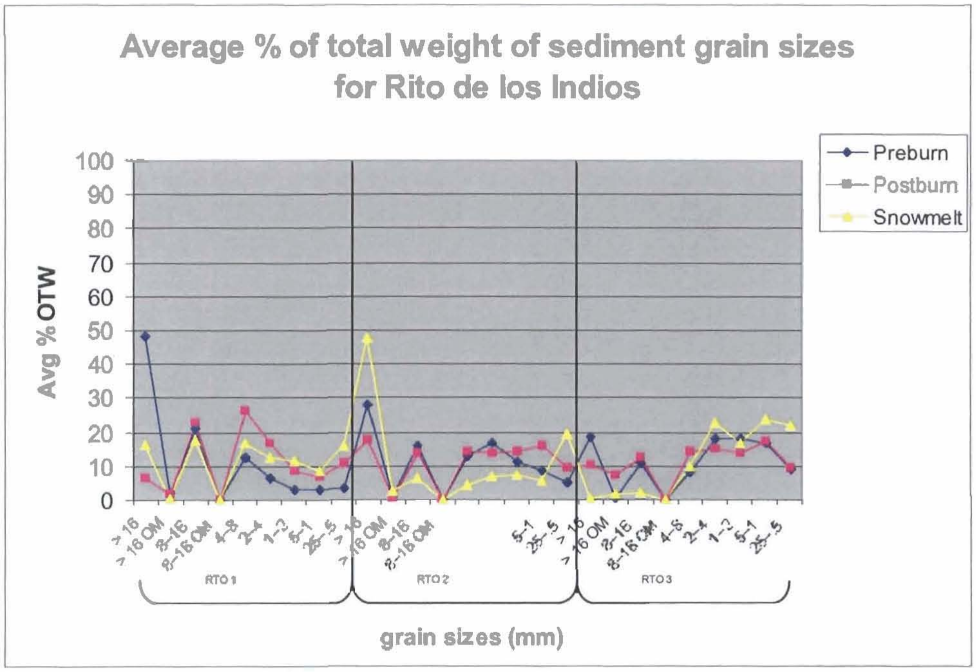


Figure 22: Average % of total weight of sediment grain sizes for Rito de los Indios sites.

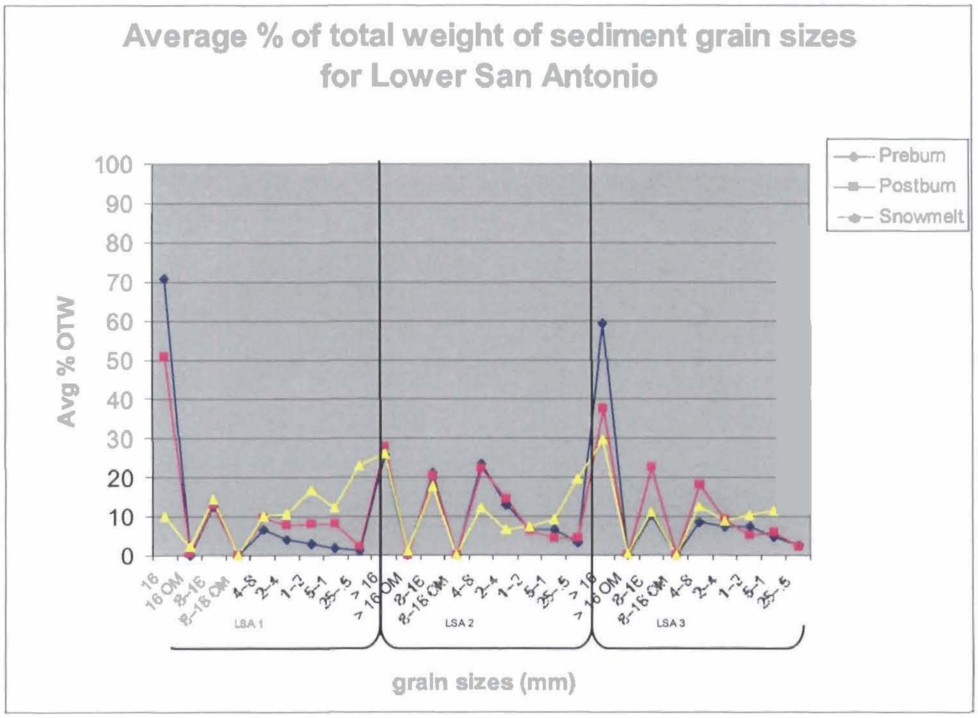


Figure 23: Average % of total weight of sediment grain sizes for Lower SA creek sites.

Neither the Rito nor the LSA (barring a few exceptions) showed much difference in particle distribution between pre-burn, post-burn, and snowmelt. There is a clearer pattern of finer sediment accumulation in the USA. This occurred mainly at the time of snowmelt, and most notably at sites 1 & 2. Whether this is a direct result of the fire, however, is debatable. Although precipitation was very low during the winter (see Figure 24), there was still evidence of runoff during the spring sampling. Figure 25 shows the USA 2 site at snowmelt, where a number of small rivulets were observed running into the stream from the surrounding grassland. These undoubtedly contributed to the accumulation of fine particles in the USA, but this may be a normal annual occurrence and cannot be definitively attributed to the effects of the burn.

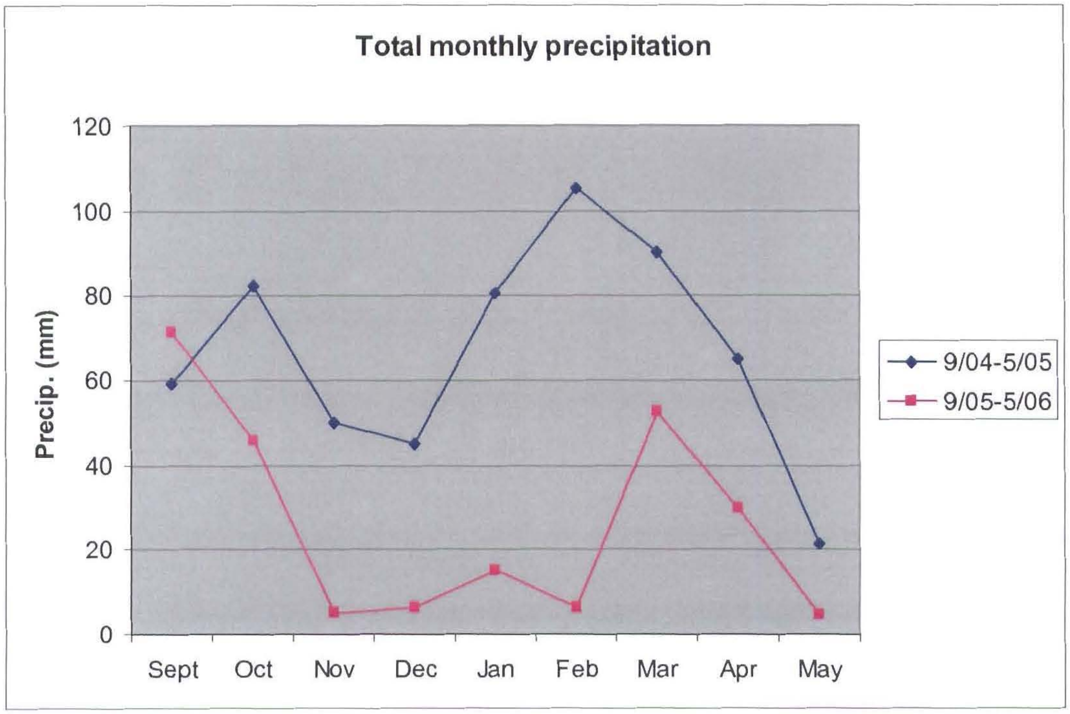


Figure 24: Total monthly precipitation in the Valles Caldera: Sept. 2004-May 2005 vs. Sept. 2005-May 2006.

Figure 25: Site USA 2 on April 14, 2006 (photo by J. McGann).

C:N analysis

The C:N ratio of stream sediments is a better indicator of whether ash and debris from the burn were deposited in the Valle Toledo stream system. Battle and Golladay (2002) suggested that the way a fire affects soils plays a large role in its effects on aquatic systems. Fires have been shown to increase C:N ratios of the top layer of soil organic matter in some studies (Ojima et al., 1994; Monleon et al., 1997; Rhoades et al., 2004), which, if mobilized into a stream by precipitation or snowmelt runoff, has the potential to affect sediment C:N ratios. The Ojima et al. (1994) study is particularly pertinent in that it was conducted in a grassland ecosystem. *Festuca arizonica*, a bunchgrass found throughout the Valle Toledo, is known to have a high C:N ratio (USDA, 2006; VCNP, 2002), which may be reserved in the ash composition post-burn. Brye et al. (2002) found C:N ratios of around 45 in post-burn ash in a tallgrass prairie ecosystem.

The C:N results in this study were confirmed by combustion of samples and subsequent analysis of mass percent loss (see Appendix D). Analysis of variance (ANOVA) tests conducted on C:N data from this study showed a significant difference across all sites occurring at the time of snowmelt (ANOVA, *p* = < 0.001). Initial pre-burn variance and post-burn variance were not significant (ANOVA, *p* = > 0.05). The USA and RTO both had higher C:N values at snowmelt, although this was distributed more evenly in the RTO control system. USA 2 had the highest C:N ratios at snowmelt for that system, with USA 1 also significantly elevated and USA 3 showing the only decline (Figure 26). The LSA was the most stable system across all times.

The largest individual site variance occurred at USA 2 across all 4 grain sizes with the highest ratios occurring at snowmelt (ANOVA, *p* = < 0.001). It is likely that the C:N ratio increase at USA 2 during snowmelt shows some effects of ash deposition. Very little precipitation occurred during the winter months so little mobilization of ash had

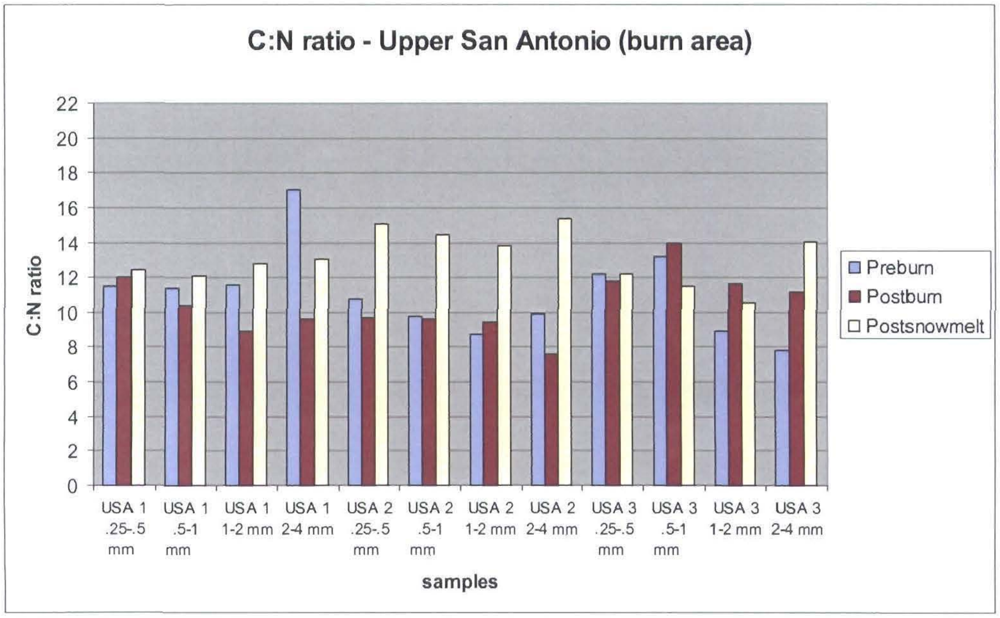


Figure 26: C:N ratios for 4 smallest grain sizes – Upper San Antonio.

a chance to occur until snowmelt (see Figure 24). Even with the lack of winter precipitation, some snowmelt did occur in April. A visual analysis of the sampling sites indicated a larger amount of runoff and erosion from the surrounding riparian area at USA 2, which would convey previously immobilized ash to this site (see Figure 27 & 28). USA 1 also showed higher C:N ratios at snowmelt, though not as high as USA 2. A visual analysis of USA 1 shows burn materials very close to the riparian zone, so that any incumbent precipitation could mobilize small quantities into the stream system at this point (see Figure 29).

Figure 27: Rivulet feeding site USA 2 on April 14, 2006 (photo by J. McGann).

Figure 28: Long shot of numerous areas of runoff at USA 2, April 14, 2006 (photo by J. McGann).

Figure 29: Burned area near stream at USA 1, Nov. 15, 2005 (photo by J. McGann).

The riparian zone around USA 3 was the least completely burned of all the USA sites with a wider margin between burned areas and the stream (Figure 30). USA 3 is also located close to the source of the artesian well water (see Figures 31 & 32) that supplements the USA, which may have contributed to diluting any ash and debris and pushing them further downstream to USA 1 & 2.

Figure 30: Riparian zone near site USA 3, Nov. 15, 2005 (photo by J. McGann).

Figure 31: The artesian well near site USA 3, October 13, 2005 (photo by J. McGann).

Figure 32: Confluence of artesian well water and San Antonio creek near USA 3 (photo by J. McGann).

The consistently higher C:N values in the Rito control system (see Figure 33) may be attributable to a visually observed greater snowpack and runoff in the upper RTO watershed (above the sample sites), which resulted in mobilization of organic matter in this system. Starry et al. (2005) noted that alterations in the availability of organic matter may seasonally dictate the C:N ratio, with colder temperatures and large pulses of OM contributing to higher quantities of C relative to N. In the Appalachian mountain headwater system observed in that study, streambed particulate C:N ratios were much lower in summer than other seasons, while autumn showed the largest concentrations of both particulate C and N.

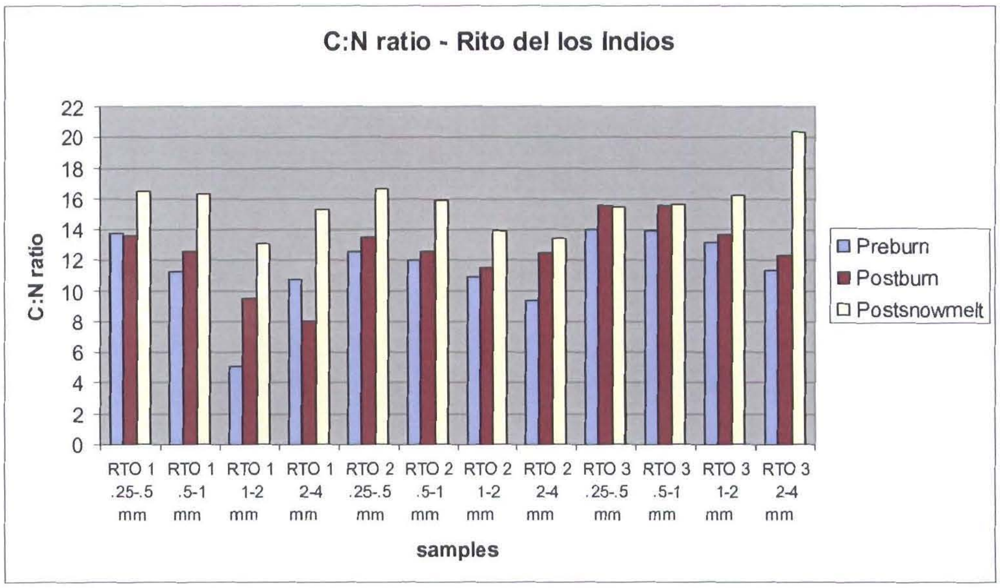


Figure 33: C:N ratio for 4 smallest grain sizes – Rito de los Indios

In contrast, the sub-alpine watershed of the Rito de los Indios is largely dominated by conifers and the relatively small increase in C:N observed in the Rito during autumn might be a result of less leaf and litterfall during that season. At snowmelt, however, OM would be mobilized downstream from the upper forested watershed contributing to a higher pulse of particulate C relative to N (see Figure 34). OM in the form of conifer needles has a C:N ratio between 60-110 or even higher (McGroddy et al., 2004; Washington State University, 2006). There is no forested watershed in immediate proximity to the Upper San Antonio and allochthonous inputs would be limited to the surrounding grasslands on a much more limited gradient.

Figure 34: (Left) The upper watershed of the Rito de los Indios, April 14, 2005; (Right) Site 1 on the Rito, October 13, 2005 (photo by J. McGann).

The Lower San Antonio did not show as much of an effect, either after the burn or at snowmelt (Figure 35). This site had the least significant C:N ratio variance (ANOVA, $p = >0.05$) and can be inferred to have been largely unaffected by the burn or by snowmelt itself. Any contributions of OM from the Upper Rito watershed appear to have not been mobilized as far as the confluence with the LSA. Alternatively, if they were mobilized, they were quickly absorbed by the second order system (Figure 36). Again, the extreme winter drought in the area suggests that this may not be a normal occurrence, and (during wet years) the LSA might be expected to show a more significant change in C:N ratio at snowmelt.

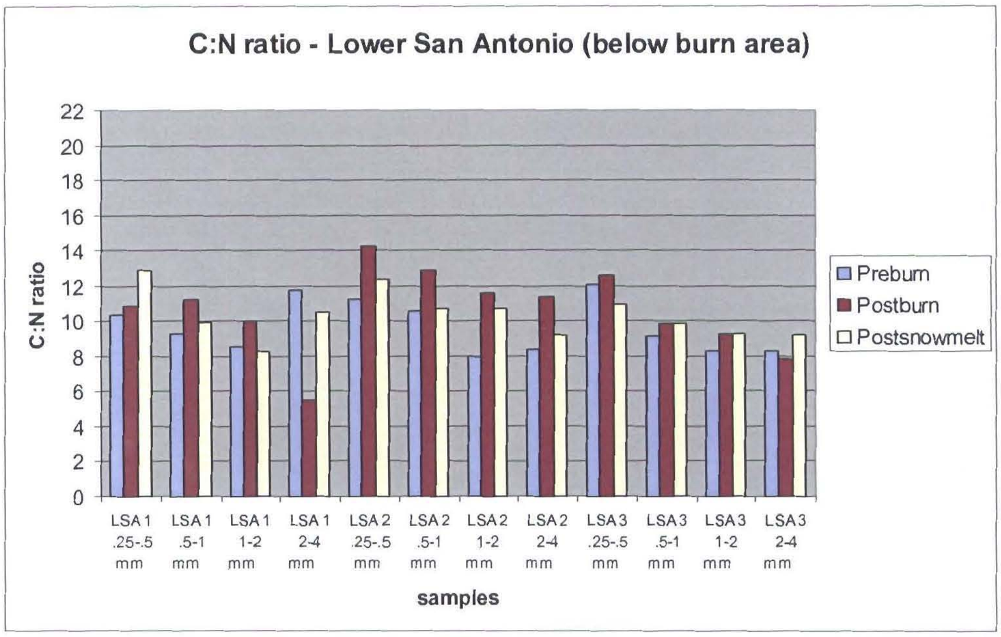


Figure 35: C:N ratio for 4 smallest grain sizes – Lower San Antonio.

Figure 36: Lower San Antonio creek, Oct. 14, 2005 (photo by J. McGann).

Stream chemistry

There were no detectable changes in dissolved oxygen, pH, conductivity, or turbidity in San Antonio Creek following the burn. Other ions that generally show elevation after wildfire, such as Ca, Mg, and Na, also showed little post-burn or post-snowmelt increases. Both K and P did increase in the San Antonio after the burn, but as these increases are concurrent with similar increases in the same ions in the Rito, evidence that the burn was the primary cause is inconclusive (see Figures 37 & 38). T-tests performed on this data indicate no significance in either P ($t = -0.64$, $p > 0.05$) or K ($t = -0.91$, $p > 0.05$).

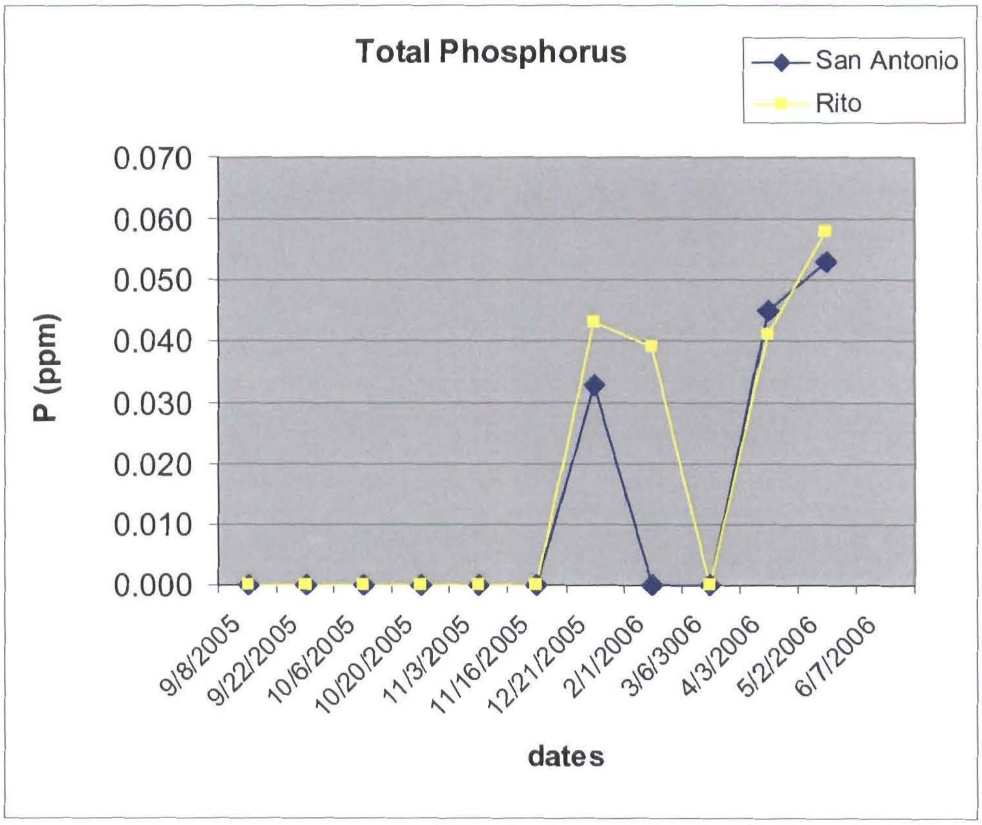


Figure 37: Total phosphorus (ppm) in the San Antonio and Rito, Sept. 2005 to June 2006.

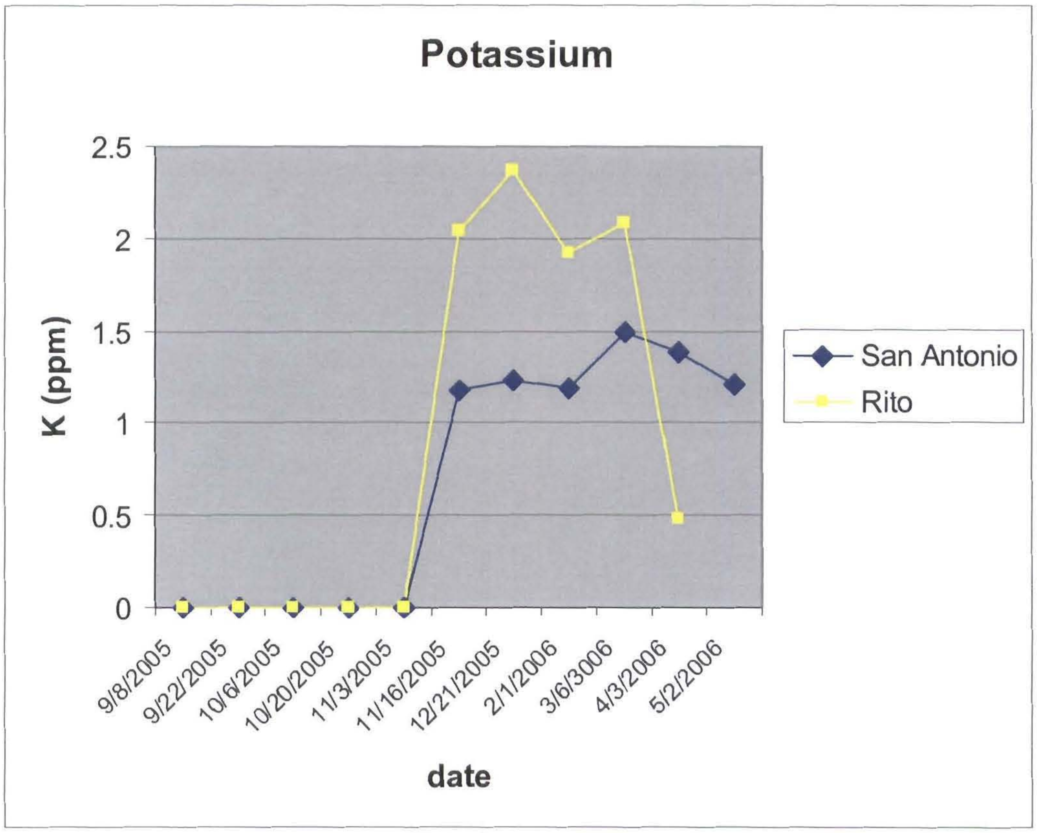


Figure 38: Total potassium (ppm) in the San Antonio and Rito, Sept. 2005 to May 2006.

The one water quality parameter that showed a significant ($t = 1.79, p < 0.05$) post-burn difference between the San Antonio and the Rito is the nitrate plus nitrite (NO_3-NO_2) level (Figure 39). NO_3-NO_2 concentrations in the San Antonio increased immediately after the burn and remained elevated until June 2006. Concentrations in the Rito also increased during the late fall, but not until mid-December, and only stayed elevated until early April 2006. There may be some seasonality to elevated NO_3-NO_2 levels in these streams in general, but the larger and more prolonged increase in the San Antonio indicates at least some effects from the burn.

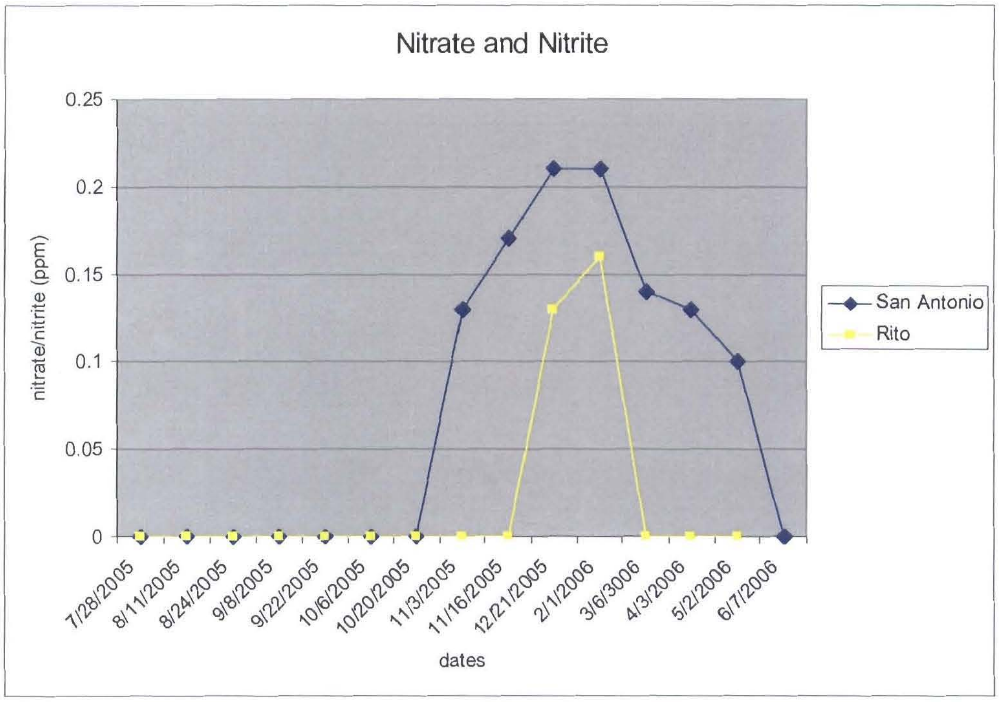


Figure 39: Nitrate and nitrite (ppm) in the San Antonio and Rito, July 2005 to June 2006.

Studies such as Coats et al. (1976) show a strong seasonal signal in NO_3-NO_2 output in stream water in western coniferous forests, with the largest outputs occurring at the time of snowmelt and during winter rain events. This is consistent with the outputs found in the Rito de los Indios, as the highest NO_3-NO_2 outputs in this system occurred in March, when there was large increase in precipitation and some small snowmelt. By mid-April, however, this signal was gone with the remainder of the snow. The San Antonio would be expected to show a similar pattern, since winter precipitation was the same as the Rito, but the extended NO_3-NO_2 output here points to burn effects being dominant.

An informal perusal of water quality data from some other streams in the Valles Caldera also bears out these conclusions. Though not part of the formal study, water quality data from Redondo Creek and the East Fork of the Jemez during the same time period show nearly identical patterns of K elevation in the winter months as well as higher levels of P year-round. None of these other streams showed any elevation in NO_3-NO_2 beyond the baseline level of <0.1 at any time (see Appendix E for VCNP water quality data). A comparison with the Rio Calaveras, a stream similar to San Antonio Creek in size and geomorphology that is located in a similar ecosystem near the Valles Caldera, shows NO_3-NO_2 values of about 0.14 mg/L (ppm), which is similar to the winter values in the Rito, but still less than the San Antonio (Baker et al., 2000; Vallett et al., 1996).

Benthic macroinvertebrates

An analysis of benthic macroinvertebrate taxa present in the sediments suggested some overall trends that may indicate possible effects from the fire in the Upper San Antonio, especially at sites 1 and 2, and most prominent at the post-snowmelt sampling. Figures 40, 41, and 42 show the relative density of select macroinvertebrate taxa present per total (1.75 liter) sediment sample for each sample site at pre-burn, post-burn, and post-snowmelt. For a comprehensive list of all taxa present and a full numerical breakdown of taxa per site see Appendix F.

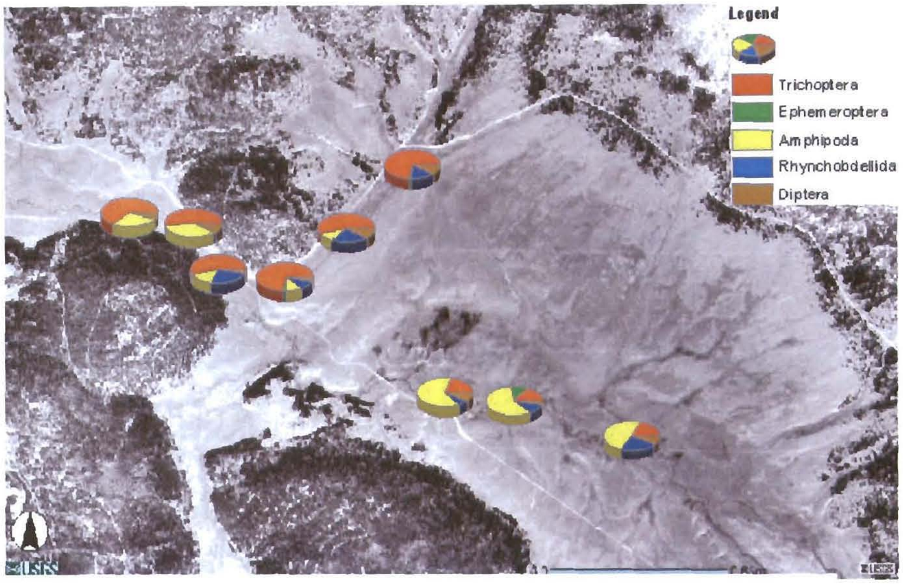


Figure 40: Pre-burn relative density of select macroinvertebrate taxa.

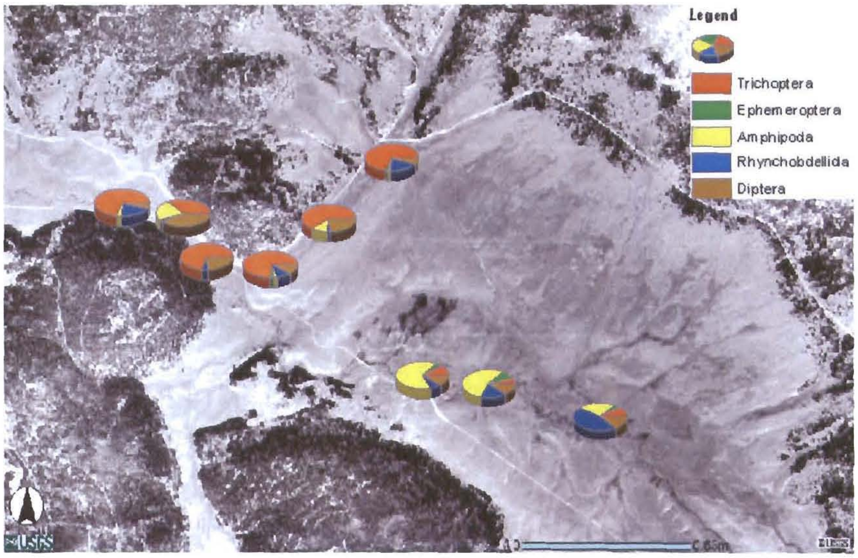


Figure 41: Post-burn relative density of select macroinvertebrate taxa.

Relative densities remained similar for pre- and post-burn sampling, with trichopteran species dominant in the majority of RTO and LSA sites, and amphipods dominating the USA sites. There was an increase in dipterans in the LSA and USA post-burn, which can indicate degradation in water quality. However, with no other indicators of water quality degradation present except for the influx of nitrate, the prescribed burn cannot be said to be the absolute cause of this change.

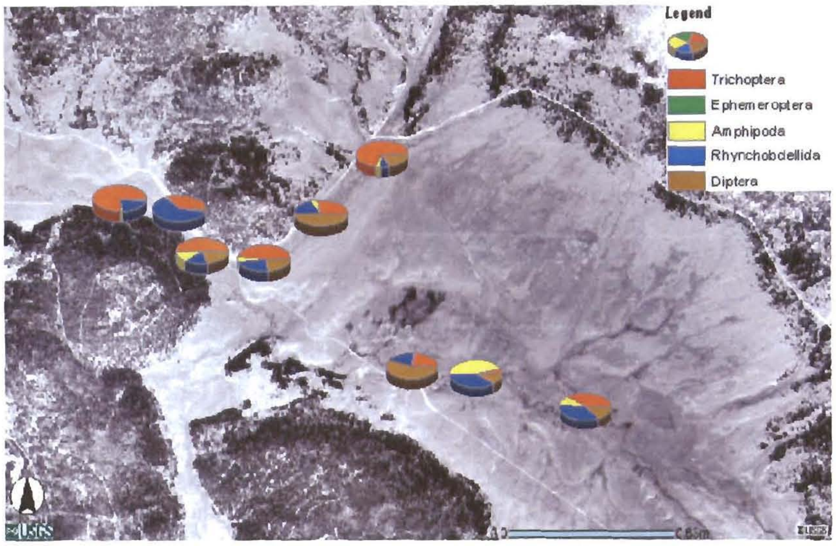


Figure 42: Post-snowmelt relative density of select macroinvertebrate taxa.

The largest changes occurred in relative density, with a large reduction in amphipods at most USA and LSA sites and an increase in dipteran and leech (rhynchobdellida) species, during post-snowmelt sampling. However, dipterans also increased in the RTO at this time, while trichopterans declined. At least some of these changes may have been due more to breeding cycles and hydrologic changes than effects of fire. For example, at LSA 2 the high density of leeches and high of number of leeches with egg sacs (which had not been observed at any time before) indicated breeding. At RTO 2 the larger percentage of dipterans during snowmelt may be due to overbank flow from runoff creating ideal conditions for chironomid larvae versus the previously dominant trichopteran larvae (see Figure 43).

Figure 43: Site RTO 2 at snowmelt, April 14, 2006 (photo by J. McGann).

The cause of the overall reduction in amphipods in the USA at snowmelt remains unclear. This may be due to sedimentation and ash and debris mobilization, especially at USA 1, but the lack of data on the "normal" effects of snowmelt and the lack of a good comparison population in the control stream makes conclusions difficult to draw.

However, an analysis of mean taxa richness showed a continuing decline in richness in the USA between each sampling (Figure 44). Jaccard's similarity index (Figure 45) between the USA and RTO declined from a pre-burn level of 0.6 to 0.35 for both post-burn and post-snowmelt sampling, which is a better indication that some fire effects may have occurred, especially in light of the fact that Jaccard's index between the LSA and RTO showed no such decline.

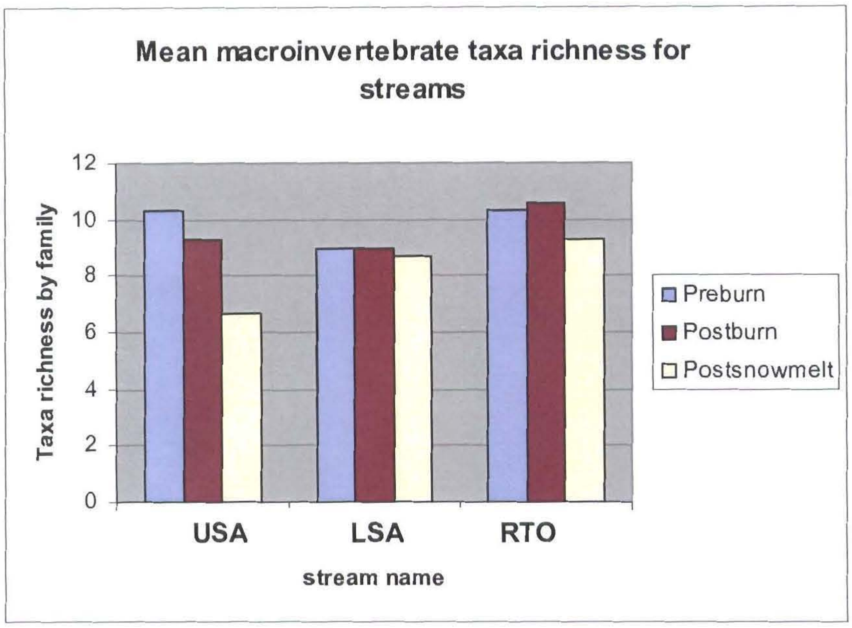


Figure 44: Mean macroinvertebrate taxa richness for sample streams – pre-burn, post-burn, and post-snowmelt.

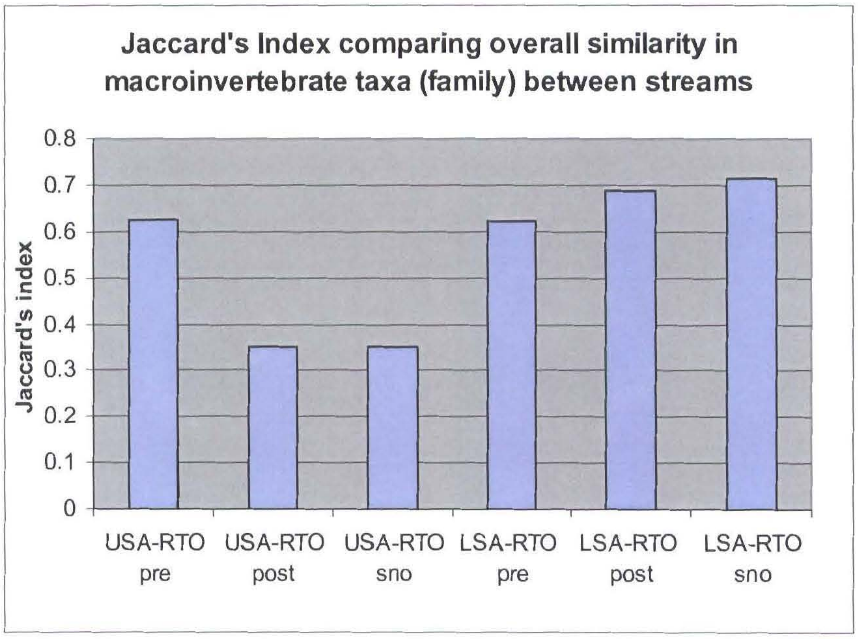


Figure 45: Jaccard's index comparing overall similarity in macroinvertebrate taxa (family) between control and experimental streams – pre-burn, post-burn, and snowmelt.

Almost all the sampling sites (USA 3 being the exception) showed a within stream decline in Jaccard's similarity between pre-burn and snowmelt, possibly indicating a seasonal variation in taxa groupings that would have little to do with any effects of burn disturbance (Figure 46). The severe winter drought of 2005-2006 also may have had an effect on macroinvertebrate assemblages, but this is difficult to quantify with the available data. The literature suggests (e.g., Bêche et al., 2005; Elliott & Vose, 2005) that post-fire drought may actually have a mitigating effect on prescribed burns. It is possible that this is the phenomenon being observed here. Further data on macroinvertebrate taxa at various times of the year would be needed to make a definitive statement.

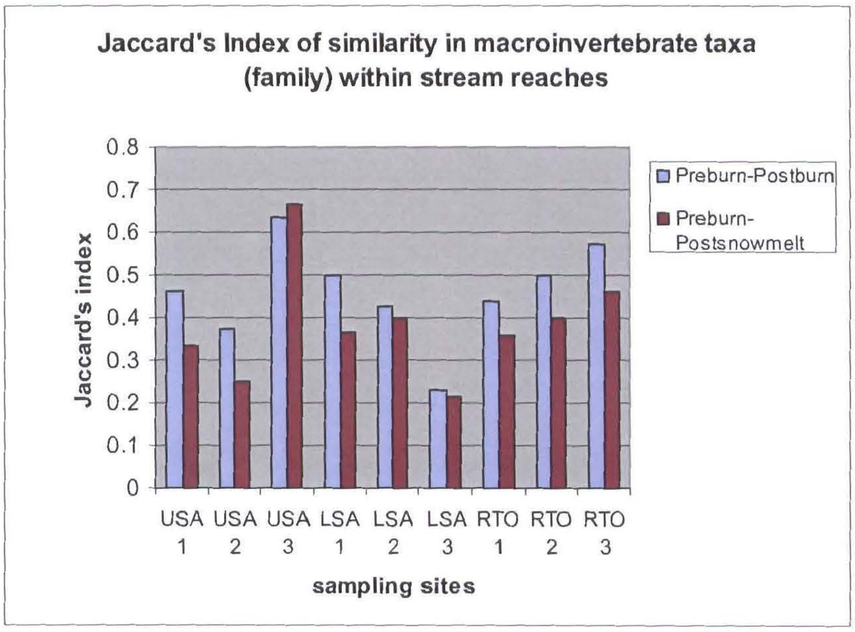


Figure 46: Jaccard's index of similarity in macroinvertebrate taxa (family) within stream reaches.

Overall density of macroinvertebrate taxa, represented by the number of individuals per liter, increased for all sites between pre-burn and post-burn sampling and decreased at the post-snowmelt sampling in all but the RTO (see Figure 47). The LSA had the highest overall density at all sampling times, while the RTO had the lowest, except for the post-snowmelt sampling. The large reduction in amphipods in the USA, which were the dominant species until their numbers fell sharply at snowmelt, was the major contributor to this observed change. T-tests showed significant differences in density between the LSA and the RTO at the pre-burn ($t = 5.30$, $p < 0.05$) and post-burn ($t = 3.26$, $p < 0.05$) samplings, but this vanished in the post-snowmelt sampling ($t = 0.87$, $p > 0.05$). All other comparisons (USA-RTO) and (USA-LSA) showed no significant differences in overall macroinvertebrate density at any of the sampling times.

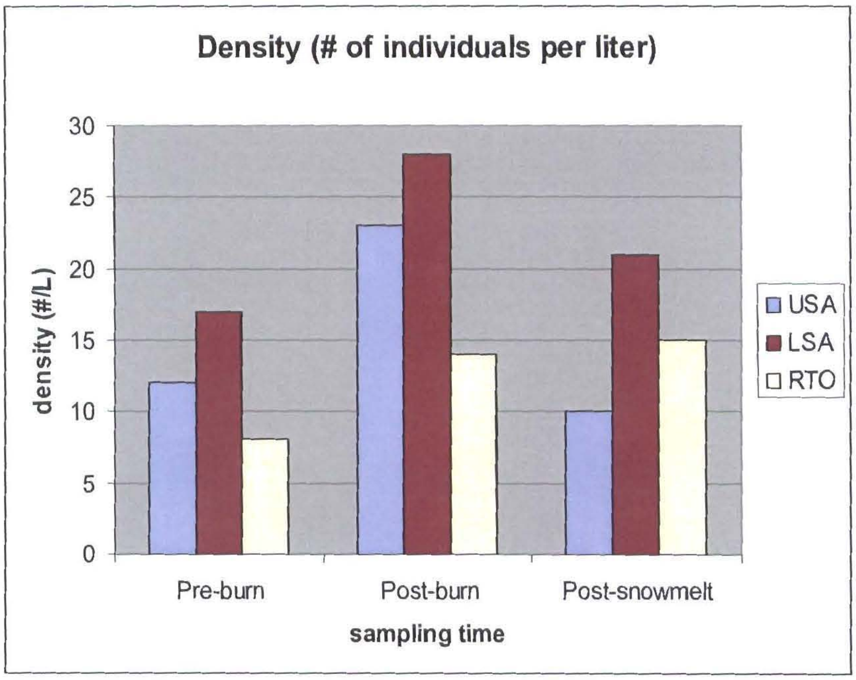


Figure 47: Overall density (number of individuals per liter of sediment) in the USA, LSA, and RTO on each of three sampling dates.

Between samplings at each site, both the USA and the LSA showed significant differences in density between the pre-burn and post-burn (USA $t = -4.19$, $p < 0.05$) (LSA $t = -2.84$, $p < 0.05$) samplings, but not between pre-burn and post-snowmelt (USA $t = -0.63$, $p > 0.05$) (LSA $t = -0.91$, $p > 0.05$). The RTO did not show significant conditions at snowmelt providing the only deviation. The dominance of Amphipoda in the USA in the fall sampling, but not the spring, can also be attributed to a difference in habitat and perhaps life cycle rather than burn effects.

Limitations

Some limitations relative to this study include the differences in several stream parameters between the control and burn streams. The differences in the Rito vs. the upper San Antonio watersheds and morphology made some comparisons difficult, especially with regard to interseasonal variations in C:N ratio and composition of macroinvertebrate taxa assemblages. These sites were predefined by the larger VCNP burn study, however, to measure any effects on the lower San Antonio below the confluence as well. For the most part, these goals were met by scrupulously accounting for these discrepancies.

Another limitation that should be mentioned with regard to macroinvertebrate assemblages is that some individuals were missed during the sieving and removal process. This became apparent once the samples were dried. However, the individuals missed were always part of the most abundant taxa in the sample (i.e., amphipods and smaller trichopterans). Using the relative density method, these taxa were still represented as the most abundant by a dominant margin. The loss of amphipods in the spring sampling was not tied to this limitation, as there were no undiscovered individuals in the samples after drying in this iteration.

CHAPTER 6 – Conclusions and recommendations

The November 2005 prescribed burn in the Valle Toledo section of the Valles Caldera appears to have had some localized effects on both macroinvertebrates and stream sediments on the USA, which was located directly within the burn area. Taxa richness declined in USA macroinvertebrate populations and some elevation of fine sediment transport and C:N ratio was observed. These effects were most pronounced after snowmelt in April 2006. The lack of precipitation immediately after the burn and severe drought of winter 2005-2006 likely contributed to this outcome by delaying full mobilization of ash until spring 2006. The large increase in stream water nitrate/nitrite concentration in the San Antonio in early November 2005, and continued elevation throughout the winter, is also another likely effect of the burn.

However, the effects on sedimentation and macroinvertebrate assemblages did not appear to translate downstream to the area of the LSA past its confluence with the Rito de los Indios. The LSA did not experience a significant increase in C:N ratio at any time following the burn nor were its macroinvertebrate assemblages much altered.

Higher C:N values across all sites in the control stream at snowmelt make it difficult to use as a comparison to the San Antonio and suggest other mechanisms may be at work in elevation of C:N values in the control stream watershed. The Rito's differences in primary production, size, and geomorphology from the San Antonio keep it from being a perfect control system.

Also, the lack of data on all these parameters from previous years (and precipitation regimes) makes it difficult to determine how many of the observed changes are directly related to fire and how many are normal seasonal fluctuations. The addition of the drought factor further complicates this comparison.

However, the elevated C:N ratio in sediments at USA 1 & 2, where the closest burn proximity to the stream (USA 1) and highest snowmelt runoff from the surrounding burned fields (USA 2) was directly observed, suggests that at least some of these localized effects can be traced to the burn. The fact that there was no elevated ratio at USA 3, where the riparian zone remained relatively unburned and artesian well water may have served as a flushing mechanism, corroborates these findings. Additional sampling will be needed to determine if these localized effects are mitigated, and how quickly.

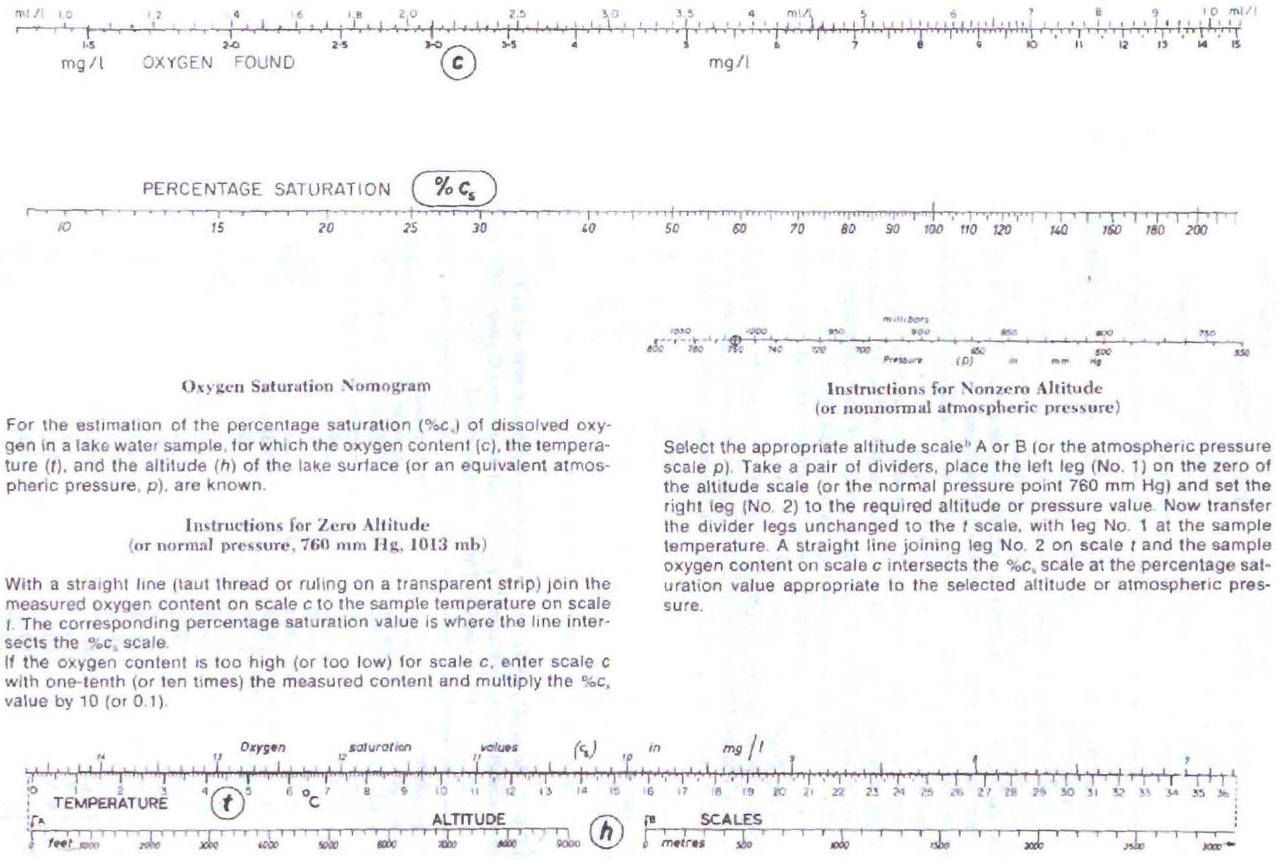
As of now, it seems that low-severity and intensity prescribed burning is a viable management tool for VCNP, even in some proximity to riparian zones and aquatic habitats. While the best practice would be to keep these burns away from streams whenever possible, they don't seem to have any severely damaging effects to these ecosystems. However, it is unknown how much of a mitigating effect the winter drought may have had on the burn. Management tools such as this must always be evaluated closely within the context of the specific environments in which they are being used. Every watershed has its own distinct features that must be taken into account for a comprehensive analysis to occur.

changes in density at either time. If the fire had any effect at all on overall macroinvertebrate densities, it was quickly mitigated.

T-tests conducted on specific orders, including Trichoptera, Amphipoda, Diptera, and Rhynchobdellida only turned up a significant difference for dipterans in the USA between pre-burn and post-burn sampling ($t = -5.54$, $p < 0.05$) and amphipods in the USA between pre-burn and post-snowmelt sampling ($t = 2.46$, $p = 0.05$).

Between sites, significant differences in Trichopteran densities were maintained between the USA and LSA across all three sampling times (PRE $t = -3.05$, $p < 0.05$; POST $t = -3.45$, $p < 0.05$; SNOW $t = -3.27$, $p < 0.05$), while the USA and RTO also differed significantly in density of this order at every time except the April sampling (PRE $t = -5.98$, $p < 0.05$; POST $t = -4.33$, $p < 0.05$; SNOW $t = -1.26$, $p > 0.05$). Amphipoda densities were significantly different between the USA and RTO both pre-burn and post-burn, but not at snowmelt (PRE $t = 3.59$, $p < 0.05$; POST $t = 2.73$, $p = 0.05$; SNOW $t = 1.02$, $p > 0.05$). Diptera and Rhynchobdellida showed no significant differences across the sites at any of the sampling times.

These results indicate that there are significant differences in habitat in the two systems that have little to do with the effects of fire. The wide, slow-moving pools in the USA are not suited to Trichopteran species, while the faster, more streamlined system of the LSA below the confluence supports large numbers of this order. Trichopterans are also well-supported in the RTO system through much of the year, with the murkier



Oxygen Saturation Nomogram

For the estimation of the percentage saturation (%c_s) of dissolved oxygen in a lake water sample, for which the oxygen content (c), the temperature (t), and the altitude (h) of the lake surface (or an equivalent atmospheric pressure, p), are known.

Instructions for Zero Altitude
(or normal pressure, 760 mm Hg, 1013 mb)

With a straight line (taut thread or ruling on a transparent strip) join the measured oxygen content on scale c to the sample temperature on scale t. The corresponding percentage saturation value is where the line intersects the %c_s scale.
If the oxygen content is too high (or too low) for scale c, enter scale c with one-tenth (or ten times) the measured content and multiply the %c_s value by 10 (or 0.1).

Instructions for Nonzero Altitude
(or nonnormal atmospheric pressure)

Select the appropriate altitude scale[b] A or B (or the atmospheric pressure scale p). Take a pair of dividers, place the left leg (No. 1) on the zero of the altitude scale (or the normal pressure point 760 mm Hg) and set the right leg (No. 2) to the required altitude or pressure value. Now transfer the divider legs unchanged to the t scale, with leg No. 1 at the sample temperature. A straight line joining leg No. 2 on scale t and the sample oxygen content on scale c intersects the %c_s scale at the percentage saturation value appropriate to the selected altitude or atmospheric pressure.

[a] From Mortimer, C. H.: Addendum to Mitteilung Internationale Vereinigung für Limnologie, 6: 120 pp., 1956 (revised 1975).

[b] Based on the simplifying assumptions of Schmassmann, H.: Schweiz. Zeitschrift für Hydrologie, 11:430, 1949, discussed in Mortimer, 1956.

Figure 6-1 Oxygen saturation nomogram (From Wetzel, 1975).

Appendix B – Field notes

October 13, 2005

Upper San Antonio, Site 1 – 1:00 pm

Water temperature: 12°C

Air temperature: 15°C

Lamott field test kit results

Dissolved oxygen: 8.6 ppm

Carbon dioxide: 3.5 ppm

Lower San Antonio, Site 1 – 12:00 pm

Water temperature: 11°C

Air temperature: 14°C

Lamott field test kit results

Dissolved oxygen: 10.0 ppm

Carbon dioxide: 0.0 ppm

Rito de los Indios, Site 1 – 3:35 pm

Water temperature: 10°C

Air temperature: 14°C

Lamott field test kit results

Dissolved oxygen: 7.6 ppm

Carbon dioxide: 3.2 ppm

November 15, 2005

Upper San Antonio, Site 1 – 11:00 am

Water temperature: 4°C

Air temperature: 9°C

Lamott field test kit results

Dissolved oxygen: 9.2 ppm

Carbon dioxide: 4.7 ppm

Lower San Antonio, Site 1 – 12:30 pm

Water temperature: 7°C

Air temperature: 9.5°C

Lamott field test kit results

Dissolved oxygen: 9.6 ppm

Carbon dioxide: 0.0 ppm

Rito de los Indios, Site 1 – 11:15 am

Water temperature: 1.5°C

Air temperature: 7°C

Lamott field test kit results

Dissolved oxygen: 10.0 ppm

Carbon dioxide: 3.2 ppm

April 14, 2006

Upper San Antonio, Site 1 – 11:07 am

Water temperature: 10°C

Air temperature: 20°C

Lamott field test kit results

Dissolved oxygen: 9.2 ppm

Carbon dioxide: 6.0 ppm

Lower San Antonio, Site 1 – 3:30 pm

Water temperature: 15°C

Air temperature: 19°C

Lamott field test kit results

Dissolved oxygen: 8.2 ppm

Carbon dioxide: 0.0 ppm

Rito de los Indios, Site 1 – 12:00 pm

Water temperature: 7.5°C

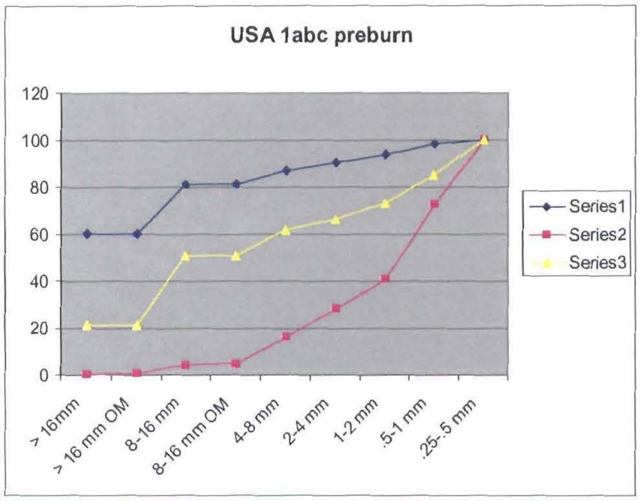
Air temperature: 18°C

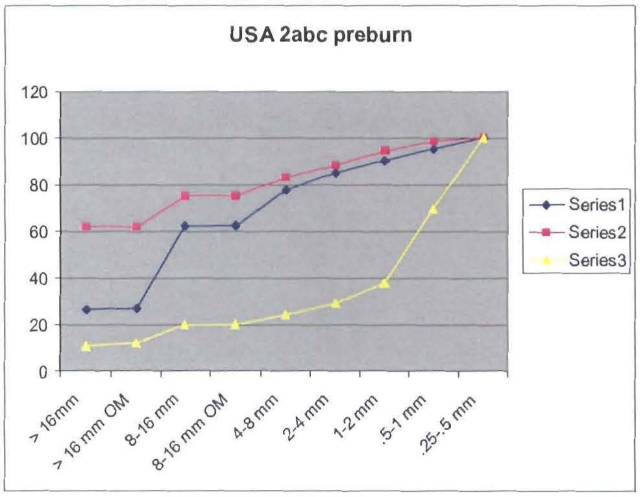
Lamott field test kit results

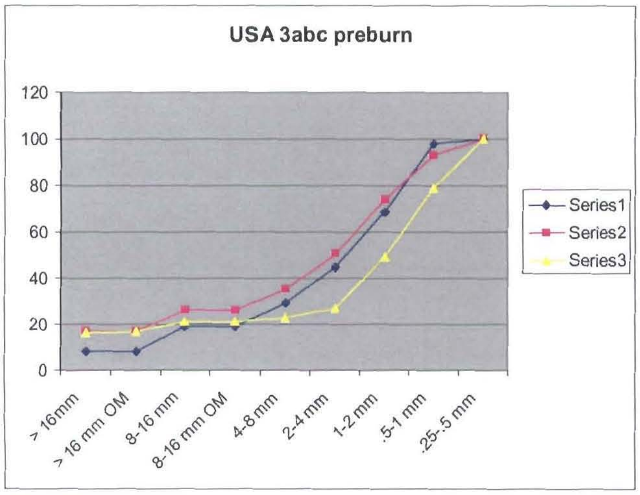
Dissolved oxygen: 9.1 ppm

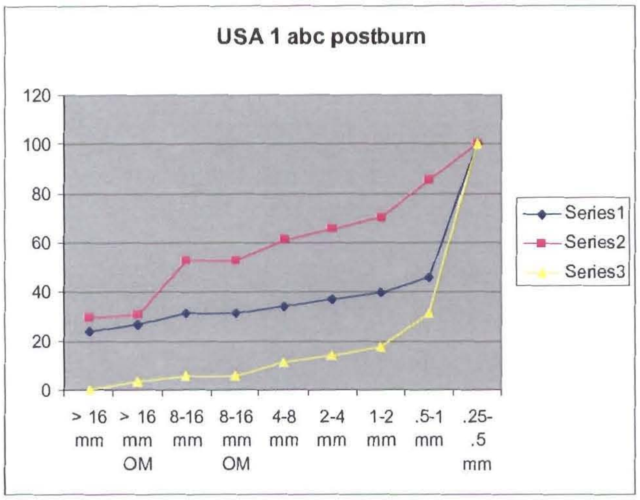
Carbon dioxide: 4.0 ppm

Appendix C – Cumulative percent weight graphs for all samples








USA 1 abc postburn
120
100
80
60
40
20
0
> 16 mm
> 16 mm OM
8-16 mm
8-16 mm OM
4-8 mm
2-4 mm
1-2 mm
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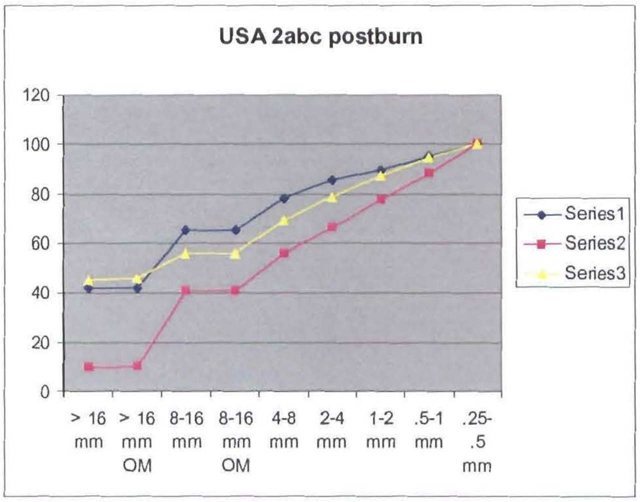
.25-.5 mm
Series1
Series2
Series3


USA 2abc postburn
120
100
80
60
40
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0
> 16 mm
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8-16 mm
8-16 mm OM
4-8 mm
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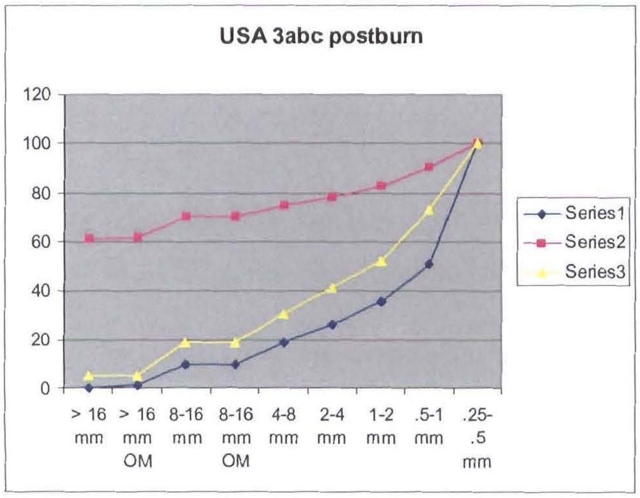
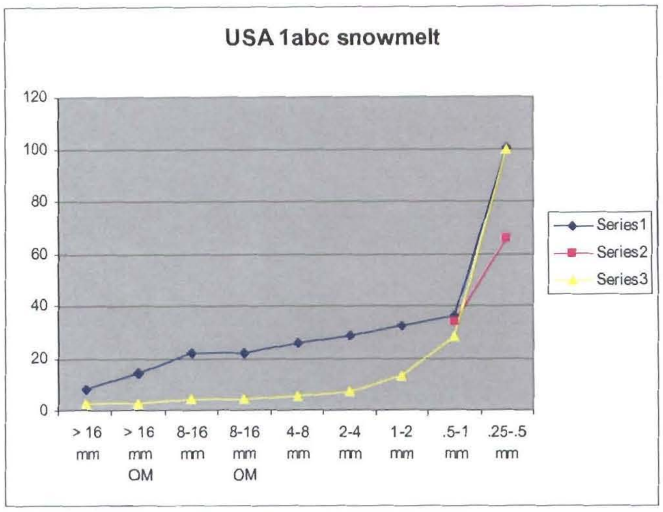
1-2 mm
.5-1 mm
.25-.5 mm
Series1
Series2
Series3


USA 3abc postburn
120
100
80
60
40
20
0
> 16 mm
> 16 mm OM
8-16 mm
8-16 mm OM
4-8 mm
2-4 mm
1-2 mm
.5-1 mm
.25-.5 mm
Series1
Series2
Series3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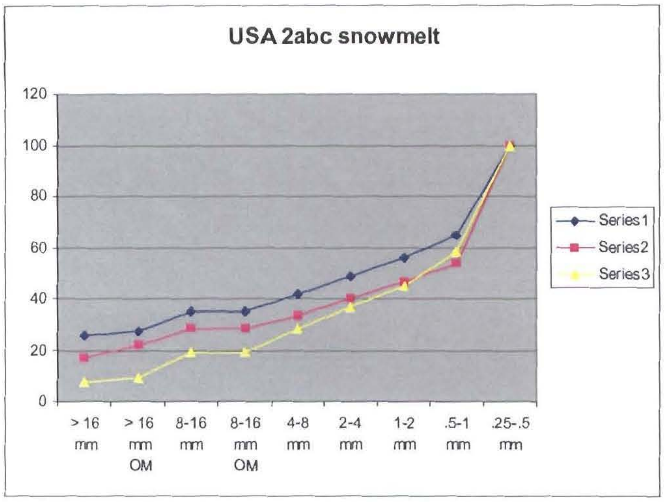
120
100
80
60
40
20
0
> 16 mm
> 16 mm OM
8-16 mm
8-16 mm OM
4-8 mm
2-4 mm
1-2 mm
.5-1 mm
.25-.5 mm
Series1
Series2
Series3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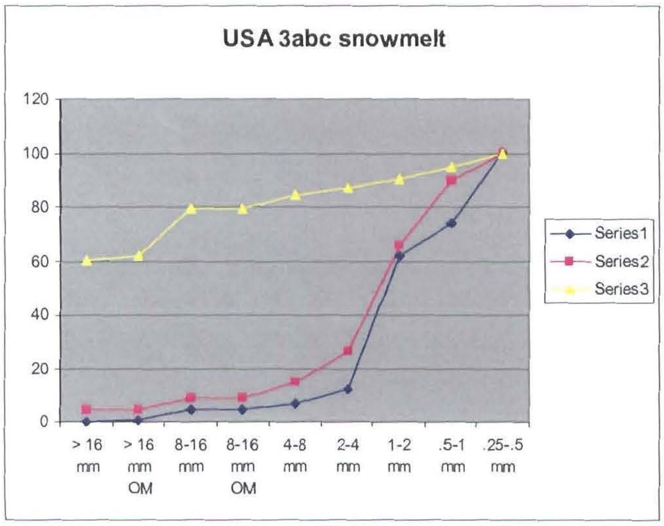
100
80
60
40
20
0
> 16 mm
> 16 mm OM
8-16 mm
8-16 mm OM
4-8 mm
2-4 mm
1-2 mm
.5-1 mm
.25-.5 mm
Series1
Series2
Series3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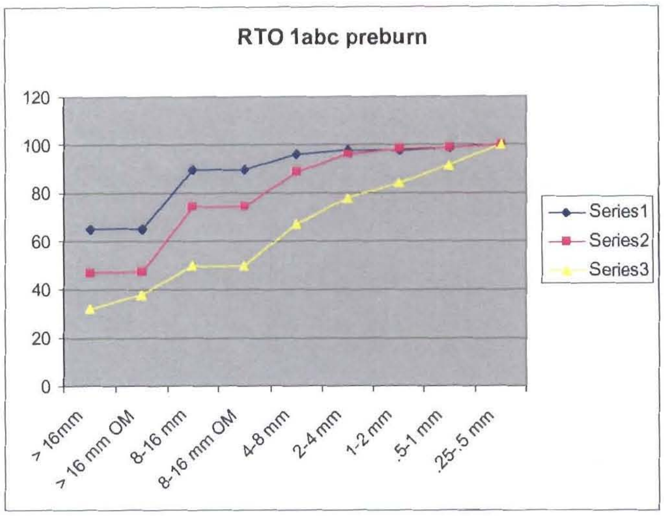
100
80
60
40
20
0
> 16 mm
> 16 mm OM
8-16 mm
8-16 mm OM
4-8 mm
2-4 mm
1-2 mm
.5-1 mm
.25-.5 mm
Series1
Series2
Series3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> 16mm
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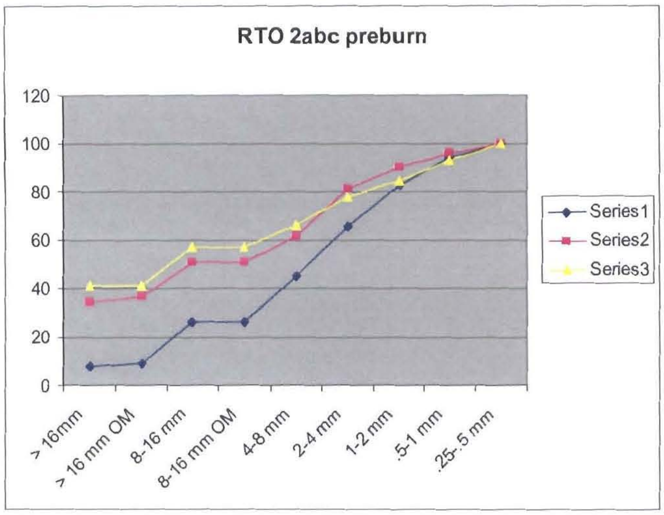
8-16 mm
8-16 mm OM
4-8 mm
2-4 mm
1-2 mm
.5-1 mm
.25-.5 mm
Series1
Series2
Series3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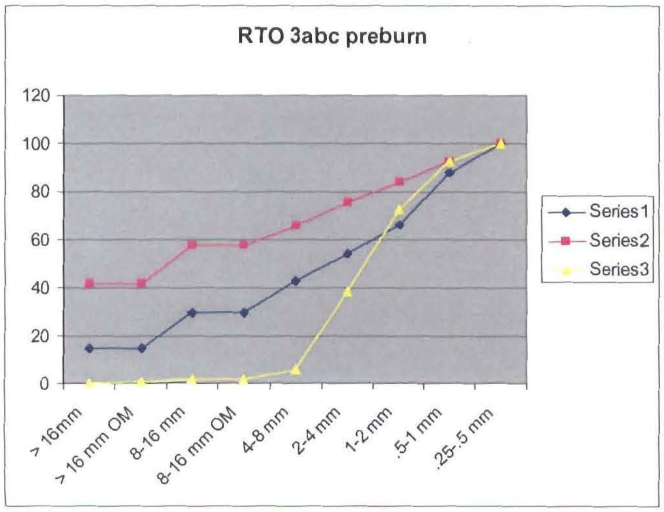
80
60
40
20
0
> 16mm
> 16 mm OM
8-16 mm
8-16 mm OM
4-8 mm
2-4 mm
1-2 mm
.5-1 mm
.25-.5 mm
Series1
Series2
Series3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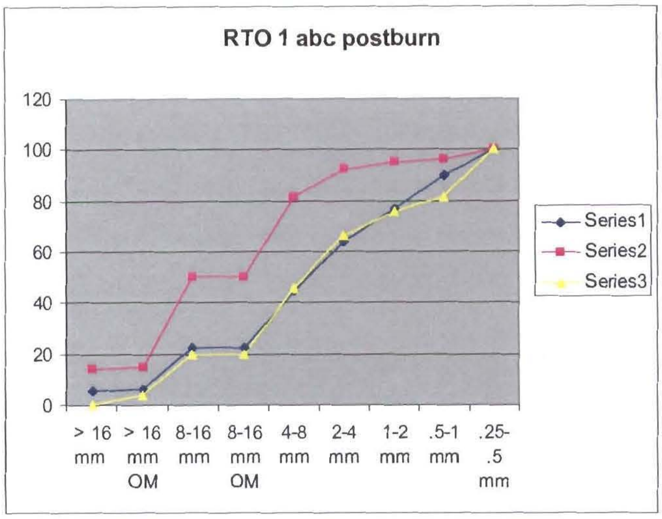
100
80
60
40
20
0
> 16mm
> 16 mm OM
8-16 mm
8-16 mm OM
4-8 mm
2-4 mm
1-2 mm
.5-1 mm
.25-.5 mm
Series1
Series2
Series3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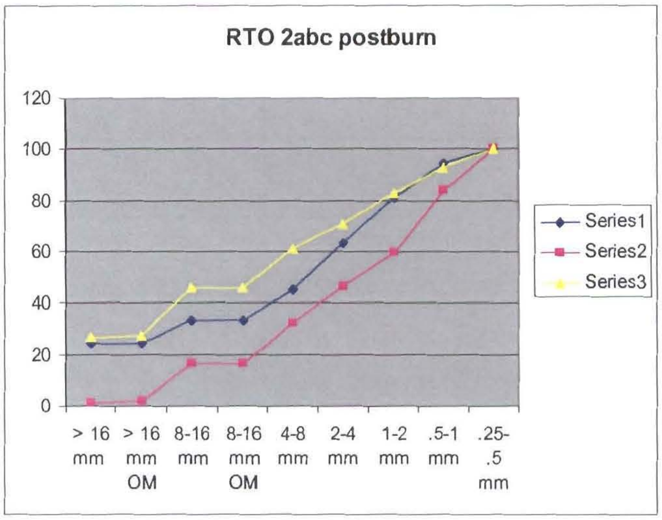
100
80
60
40
20
0
> 16 mm
> 16 mm OM
8-16 mm
8-16 mm OM
4-8 mm
2-4 mm
1-2 mm
.5-1 mm
.25-.5 mm
Series1
Series2
Series3


RTO 2abc postburn
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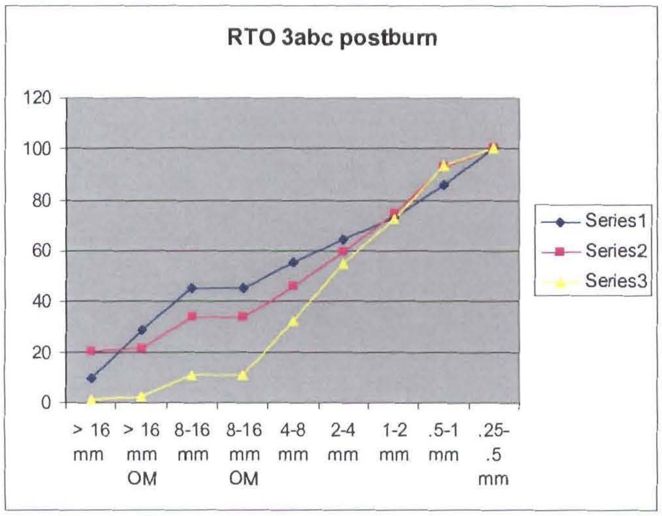
100
80
60
40
20
0
> 16 mm
> 16 mm OM
8-16 mm
8-16 mm OM
4-8 mm
2-4 mm
1-2 mm
.5-1 mm
.25-.5 mm
Series1
Series2
Series3


RTO 3abc postburn
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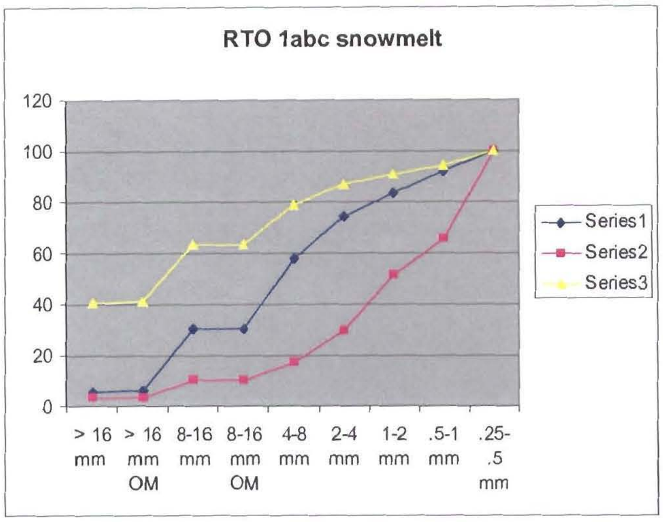
100
80
60
40
20
0
> 16 mm
> 16 mm OM
8-16 mm
8-16 mm OM
4-8 mm
2-4 mm
1-2 mm
.5-1 mm
.25-.5 mm
Series1
Series2
Series3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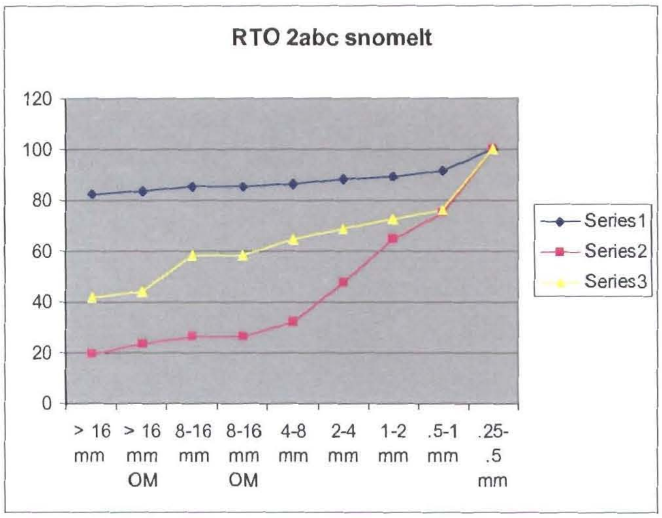
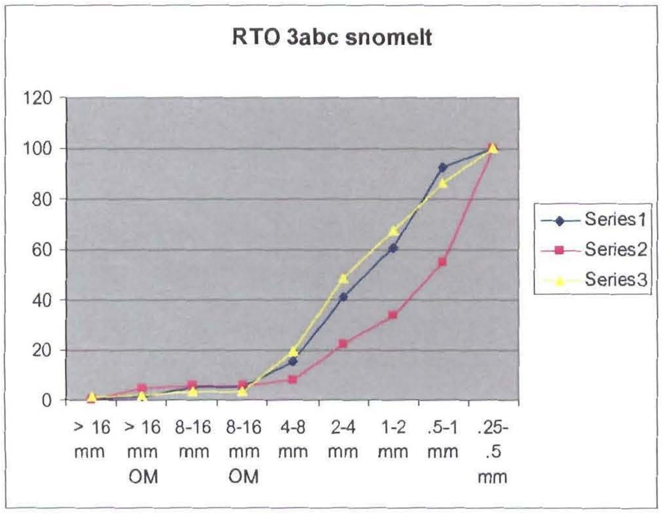
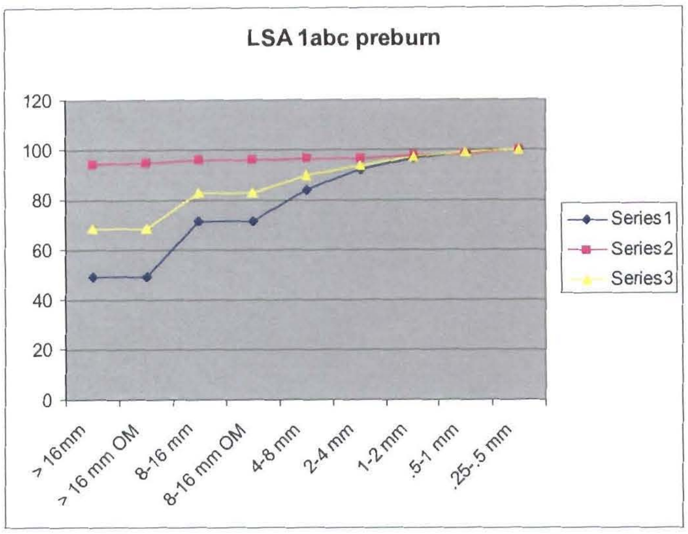
100
80
60
40
20
0
> 16 mm
> 16 mm OM
8-16 mm
8-16 mm OM
4-8 mm
2-4 mm
1-2 mm
.5-1 mm
.25-.5 mm
Series1
Series2
Series3


RTO 2abc snomelt
120
100
80
60
40
20
0
> 16 mm
> 16 mm OM
8-16 mm
8-16 mm OM
4-8 mm
2-4 mm
1-2 mm
.5-1 mm
.25-.5 mm
Series1
Series2
Series3


RTO 3abc snomelt
120
100
80
60
40
20
0
> 16 mm
> 16 mm OM
8-16 mm
8-16 mm OM
4-8 mm
2-4 mm
1-2 mm
.5-1 mm
.25-.5 mm
Series1
Series2
Series3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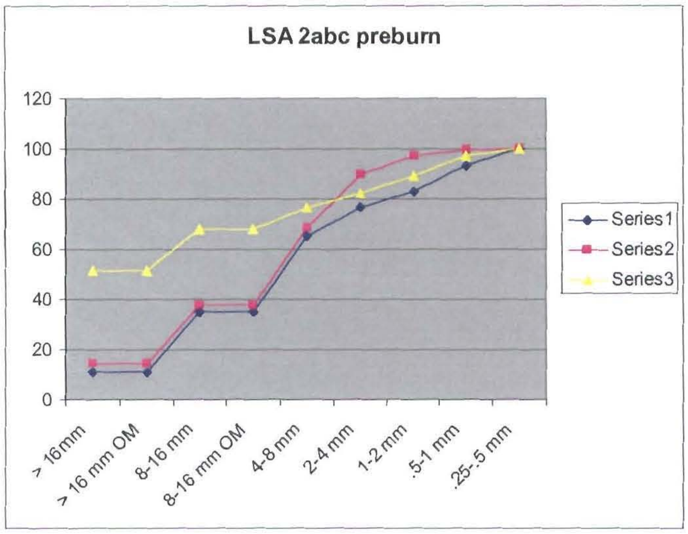
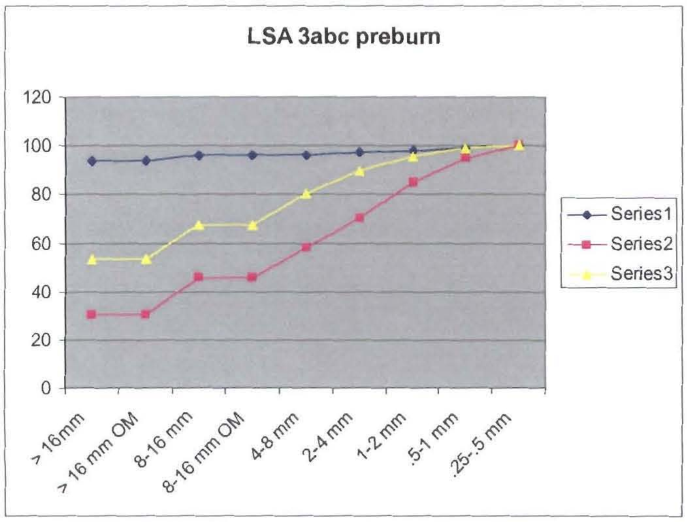
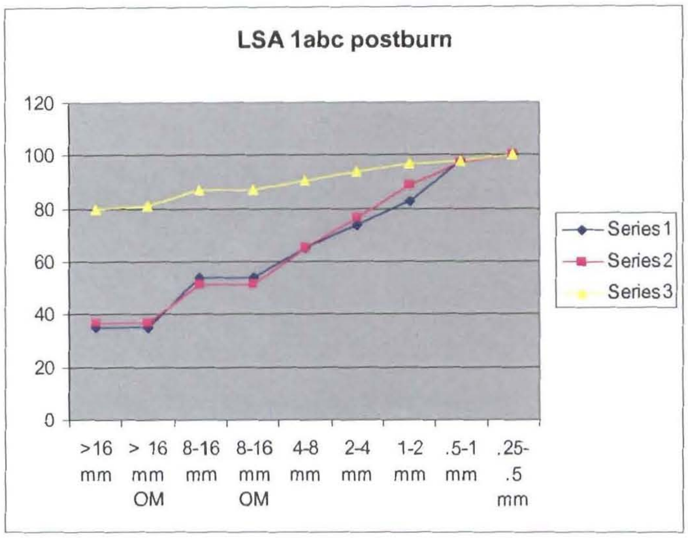
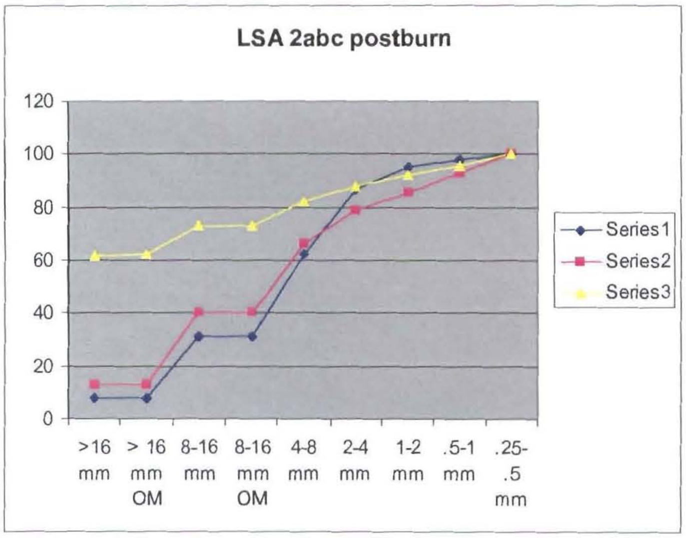
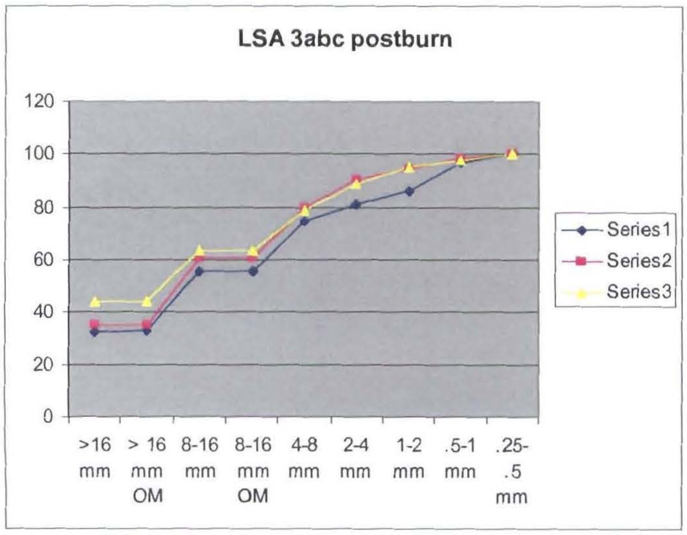
100
80
60
40
20
0
> 16mm
> 16 mm OM
8-16 mm
8-16 mm OM
4-8 mm
2-4 mm
1-2 mm
.5-1 mm
.25-.5 mm
Series1
Series2
Series3

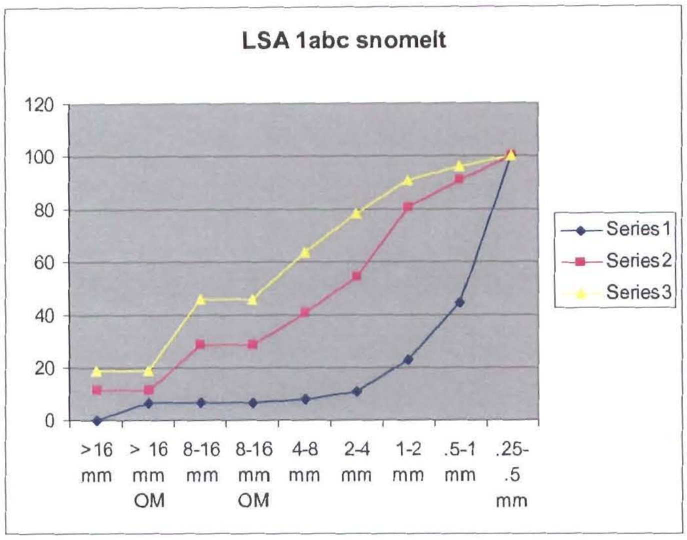

LSA 2abc preburn
120
100
80
60
40
20
0
> 16mm
> 16 mm OM
8-16 mm
8-16 mm OM
4-8 mm
2-4 mm
1-2 mm
.5-1 mm
.25-.5 mm
Series1
Series2
Series3

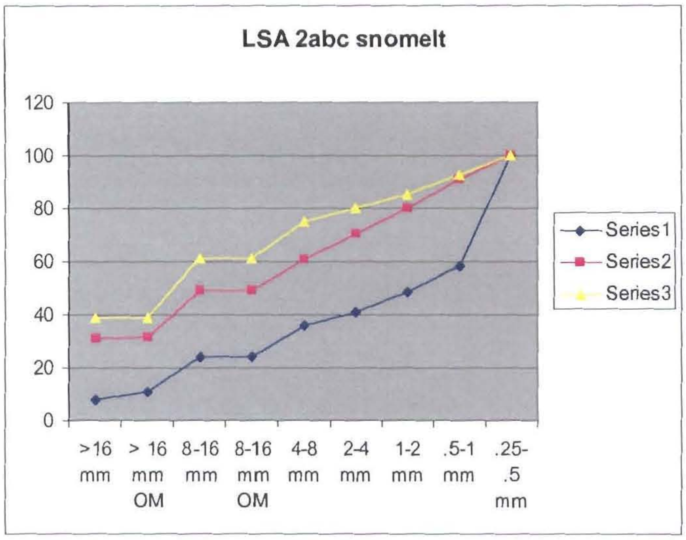

LSA 3abc preburn
120
100
80
60
40
20
0
> 16mm
> 16 mm OM
8-16 mm
8-16 mm OM
4-8 mm
2-4 mm
1-2 mm
.5-1 mm
.25-.5 mm
Series1
Series2
Series3

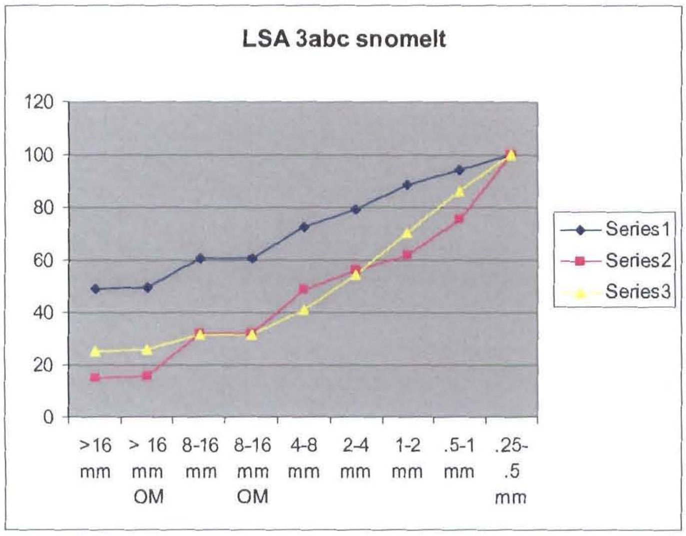

LSA 1abc postburn
120
100
80
60
40
20
0
>16 mm
> 16 mm OM
8-16 mm
8-16 mm OM
4-8 mm
2-4 mm
1-2 mm
.5-1 mm
.25-.5 mm
Series1
Series2
Series3


LSA 2abc postburn
120
100
80
60
40
20
0
>16 mm
> 16 mm OM
8-16 mm
8-16 mm OM
4-8 mm
2-4 mm
1-2 mm
.5-1 mm
.25-.5 mm
Series1
Series2
Series3

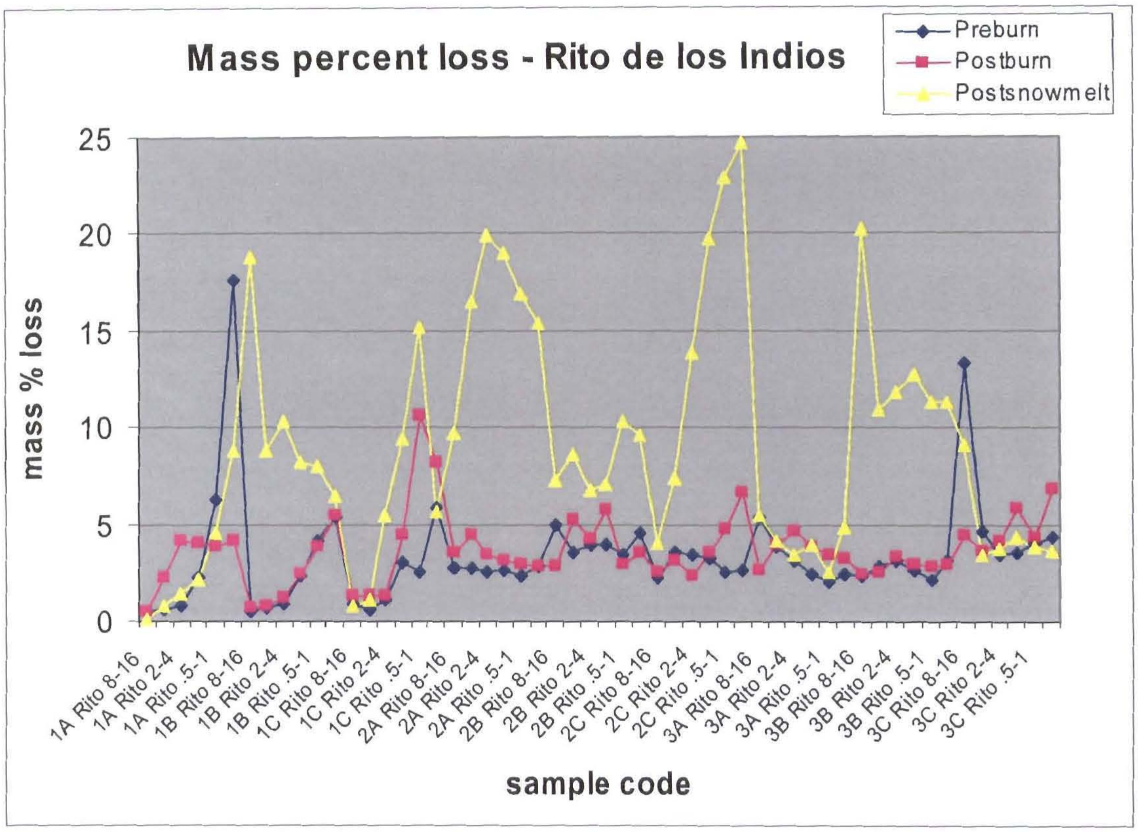

LSA 3abc postburn
120
100
80
60
40
20
0
>16 mm
> 16 mm OM
8-16 mm
8-16 mm OM
4-8 mm
2-4 mm
1-2 mm
.5-1 mm
.25-.5 mm
Series1
Series2
Series3

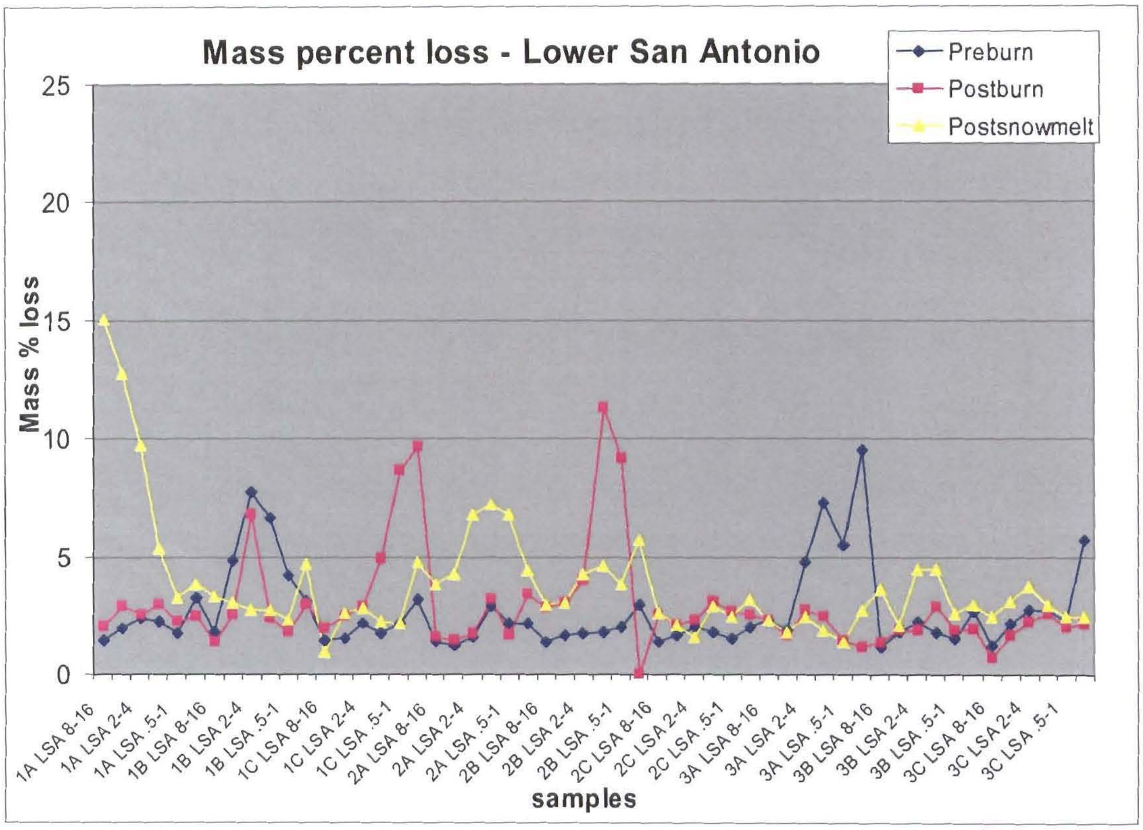

LSA 1abc snomelt

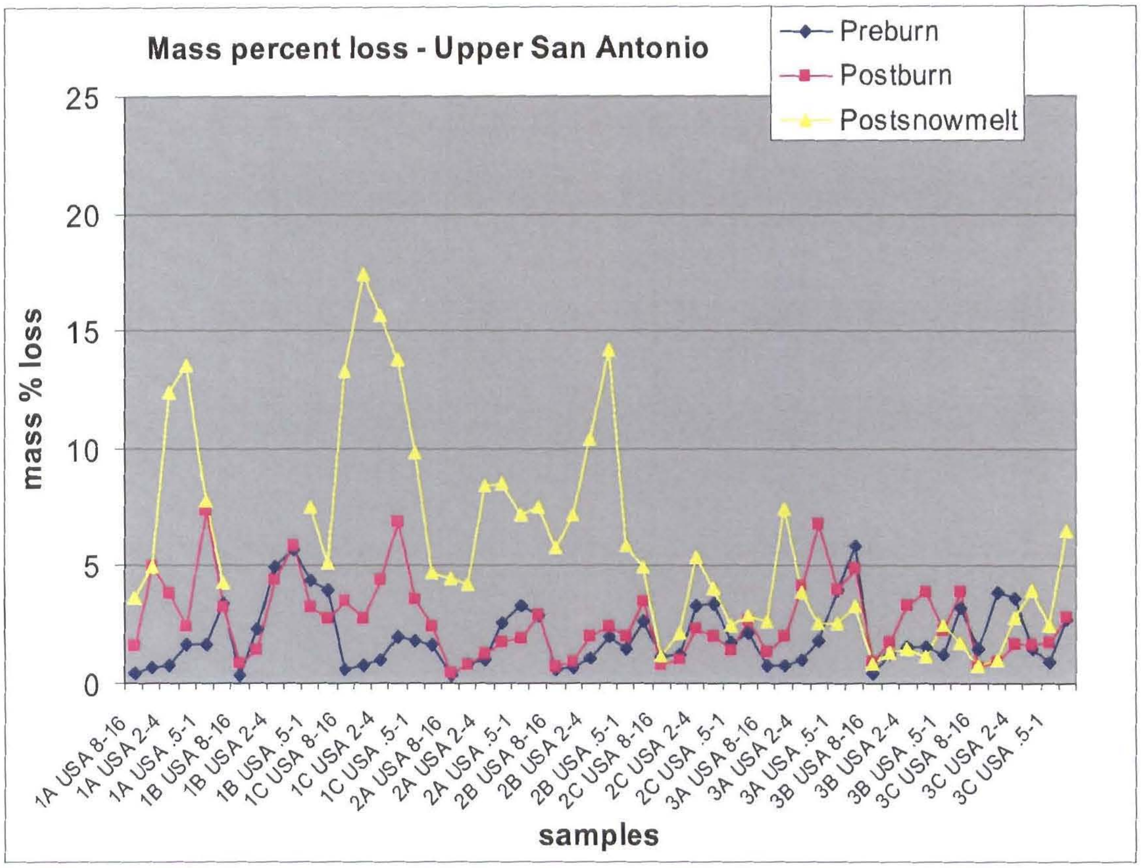

LSA 2abc snomelt


LSA 3abc snomelt

Appendix D – Mass percent loss graphs




Mass percent loss - Lower San Antonio
Preburn
Postburn
Postsnowmelt
25
20
15
10
5
0
Mass % loss
1A LSA 8-16
1A LSA 2-4
1A LSA .5-1
1B LSA 8-16
1B LSA 2-4
1B LSA .5-1
1C LSA 8-16
1C LSA 2-4
1C LSA .5-1
2A LSA 8-16
2A LSA 2-4
2A LSA .5-1
2B LSA 8-16
2B LSA 2-4
2B LSA .5-1
2C LSA 8-16
2C LSA 2-4
2C LSA .5-1
3A LSA 8-16
3A LSA 2-4
3A LSA .5-1
3B LSA 8-16
3B LSA 2-4
3B LSA .5-1
3C LSA 8-16
3C LSA 2-4
3C LSA .5-1
samples


Mass percent loss - Upper San Antonio
Preburn
Postburn
Postsnowmelt
mass % loss
25
20
15
10
5
0
1A USA 8-16
1A USA 2-4
1A USA .5-1
1B USA 8-16
1B USA 2-4
1B USA .5-1
1C USA 8-16
1C USA 2-4
1C USA .5-1
2A USA 8-16
2A USA 2-4
2A USA .5-1
2B USA 8-16
2B USA 2-4
2B USA .5-1
2C USA 8-16
2C USA 2-4
2C USA .5-1
3A USA 8-16
3A USA 2-4
3A USA .5-1
3B USA 8-16
3B USA 2-4
3B USA .5-1
3C USA 8-16
3C USA 2-4
3C USA .5-1
samples

Appendix E – Major ion concentrations in Valles streams (with San Antonio and Rito highlighted)

Stream	Date	Time	P	Nitrate + Nitrite	K	Ca	Mg
Redondo Creek	4/29/2005	17:30	0.076	<0.1	<5	7.29	<1
Redondo Creek	5/18/2005	16:40	0.114	<0.1	<5	8.10	<1
Redondo Creek	6/1/2005	16:30	0.131	<0.1	<5	<1	<1
Redondo Creek	6/16/2005	8:15	0.147	<0.1	<5	8.06	<1
Redondo Creek	6/30/2005	15:00	0.200	<0.1	<5	8.02	<1
Redondo Creek	7/14/2005	14:00	0.170	<0.1	<5	8.20	<1
Redondo Creek	7/28/2005	8:30	0.137	<0.1	<5	8.80	<1
Redondo Creek	8/11/2005	16:45	0.118	<0.1	<5	8.47	<1
Redondo Creek	8/24/2005	8:15	0.104	<0.1	<5	9.21	<1
Redondo Creek	9/8/2005	8:00	0.096	<0.1	<5	9.62	<1
Redondo Creek	9/22/2005	8:30	0.076	<0.1	<5	10.40	<1
Redondo Creek	10/5/2005	16:45	0.098	<0.1	<5	10.80	<1
Redondo Creek	10/20/2005	10:00	0.073	<0.1	<5	14.10	<1
Redondo Creek	11/3/2005	15:00	0.070	<0.1	<5	9.32	<1
Redondo Creek	11/16/2005	18:30	0.077	<0.1	<5	11.00	<1
Redondo Creek	1/5/2006	17:00	0.068	<0.1	1.99	8.95	1.1
Redondo Creek	2/1/2006	15:30	0.064	<0.1	3.15	10.20	1.39
Redondo Creek	3/6/2006	15:30	0.035	<0.1	2.25	8.24	1.16
Redondo Creek	4/3/2006	16:15	0.038	<0.1	1.74	5.93	<1
Redondo Creek	5/2/2006	16:45	<0.1	<0.1	2.33	9.51	1.46
East Fork Jemez River	4/29/2005	16:00	0.062	<0.1	<5	7.08	<1
East Fork Jemez River	5/18/2005	16:00	0.055	<0.1	<5	6.74	<1
East Fork Jemez River	6/1/2005	17:30	0.046	<0.1	<5	6.18	<1
East Fork Jemez River	6/16/2005	9:00	0.069	<0.1	<5	6.61	<1
East Fork Jemez River	6/30/2005	16:00	0.041	<0.1	<5	6.04	<1
East Fork Jemez River	7/14/2005	7:15	0.031	<0.1	<5	6.64	<1
East Fork Jemez River	7/28/2005	10:00	0.034	<0.1	<5	6.61	<1
East Fork Jemez River	8/11/2005	16:00	<0.030	<0.1	<5	5.43	10.3
East Fork Jemez River	8/24/2005	9:45	<0.030	<0.1	<5	6.19	<1
East Fork Jemez River	9/8/2005	14:00	0.034	<0.1	<5	6.21	<1
East Fork Jemez River	9/22/2005	9:30	0.350	<0.1	<5	5.87	<1
East Fork Jemez River	10/6/2005	16:00	<0.030	<0.1	<5	6.27	<1
East Fork Jemez River	10/20/2005	15:00	0.036	<0.1	<5	6.60	<1
East Fork Jemez River	11/3/2005	9:00	<0.030	<0.1	<5	5.41	<1
East Fork Jemez River	11/16/2005	17:45	0.030	<0.1	<5	5.81	<1
East Fork Jemez River	12/28/2005	16:30	0.033	<0.1	1.2	5.24	1.07
East Fork Jemez River	2/1/2006	14:45	0.033	<0.1	<1	5.19	1.07
East Fork Jemez River	3/6/2006	9:30	<0.03	<0.1	1.4	5.68	1.13
East Fork Jemez River	4/3/2006	15:45	0.076	<0.1	1.49	5.91	1.26
East Fork Jemez River	5/2/2006	15:45	0.060	<0.1	1.2	6.39	1.62
East Fork Jemez River	6/7/2006	11:00	0.067	<0.1	1.16	5.24	1.41
East Fork Jemez River	7/5/2006	10:30	0.042	<0.1	1.14	5.57	1.57
San Antonio - West	5/18/2005	13:00	0.057	<0.1	<5	9.04	1.31
San Antonio - West	6/1/2005	11:00	0.036	<0.1	<5	8.14	<1
San Antonio - West	6/15/2005	16:00	0.038	<0.1	<5	8.86	<1
San Antonio - West	6/30/2005	12:00	0.130	<0.1	<5	9.05	<1
San Antonio - West	7/14/2005	10:30	<0.030	<0.1	<5	8.88	<1
San Antonio - West	7/28/2005	14:00	<0.030	<0.1	<5	8.06	<1
San Antonio - West	8/11/2005	14:30	<0.030	<0.1	<5	7.90	<1

San Antonio - West	8/24/2005	15:00	<0.030	<0.1	<5	8.90	<1
San Antonio - West	9/8/2005	11:00	<0.030	<0.1	<5	9.82	<1
San Antonio - West	9/22/2005	12:15	<0.030	<0.1	<5	8.84	<1
San Antonio - West	10/6/2005	13:00	<0.030	<0.1	<5	9.52	<1
San Antonio - West	10/20/2005	14:30	<0.030	<0.1	<5	8.99	<1
San Antonio - West	11/3/2005	11:00	<0.030	<0.1	<5	8.29	<1
San Antonio - West	11/16/2005	15:45	0.033	<0.1	<5	8.77	<1
San Antonio - West	12/21/2005	15:30	<0.030	<0.1	2	8.73	1.07
San Antonio - West	2/1/2006	13:30	<0.03	<0.1	1.95	8.52	1.03
San Antonio - West	3/6/2006	14:00	0.042	<0.1	2.24	8.99	1.32
San Antonio - West	4/3/2006	10:30	0.058	<0.1	2.39	11.70	1.76
San Antonio - West	5/2/2006	14:00	0.057	<0.1	2	8.87	1.63
San Antonio - West	6/7/2006	16:15	0.063	<0.1			
San Antonio - West	7/5/2006	15:45	0.040	<0.1			
San Antonio Creek - Toledo	5/18/2005	11:15	<0.030	<0.1	<5	5.91	<1
San Antonio Creek - Toledo	6/1/2005	14:00	<0.030	<0.1	<5	5.41	<1
San Antonio Creek - Toledo	6/16/2005	16:45	<0.030	0.11	<5	5.25	<1
San Antonio Creek - Toledo	6/30/2005	11:00	<0.030	0.13	<5	6.17	<1
San Antonio Creek - Toledo	7/14/2005	9:30	<0.030	0.13	<5	5.91	<1
San Antonio Creek - Toledo	7/28/2005	13:30	<0.030	<0.1	<5	5.39	<1
San Antonio Creek - Toledo	8/11/2005	13:30	<0.030	<0.1	<5	5.35	<1
San Antonio Creek - Toledo	8/24/2005	14:00	<0.030	<0.1	<5	5.77	<1
San Antonio Creek - Toledo	9/8/2005	12:30	<0.030	<0.1	<5	5.90	<1
San Antonio Creek - Toledo	9/22/2005	14:00	<0.030	<0.1	<5	5.61	<1
San Antonio Creek - Toledo	10/6/2005	11:30	<0.030	<0.1	<5	5.78	<1
San Antonio Creek - Toledo	10/20/2005	13:30	<0.030	<0.1	<5	5.44	<1
San Antonio Creek - Toledo	11/3/2005	12:15	<0.030	0.13	<5	5.12	<1
San Antonio Creek - Toledo	11/16/2005	13:30	<0.030	0.17	1.18	5.18	<1
San Antonio Creek - Toledo	12/21/2005	14:15	0.033	0.21	1.23	5.28	<1
San Antonio Creek - Toledo	2/1/2006	12:15	<0.03	0.21	1.19	5.14	<1
San Antonio Creek - Toledo	3/6/3006	12:45	<0.03	0.14	1.5	5.60	<1
San Antonio Creek - Toledo	4/3/2006	11:15	0.045	0.13	1.39	5.90	<1
San Antonio Creek - Toledo	5/2/2006	12:45	0.053	0.1	1.21	5.47	<1
San Antonio Creek - Toledo	6/7/2006	13:15	0.036	<0.1			
San Antonio Creek - Toledo	7/5/2006	13:00	<0.03	<0.1	1.21	4.91	<1
Indios Creek	5/18/2005	12:00	0.054	<0.1	<5	6.24	1.26
Indios Creek	6/1/2005	10:30	0.031	<0.1	<5	6.59	<1
Indios Creek	6/16/2005	16:30	0.052	<0.1	<5	5.68	<1
Indios Creek	6/30/2005	10:09	0.030	<0.1	<5	6.37	<1
Indios Creek	7/14/2005	9:00	<0.030	<0.1	<5	5.82	<1
Indios Creek	7/28/2005	13:00	0.036	<0.1	<5	5.28	<1
Indios Creek	8/11/2005	13:00	<0.030	<0.1	<5	5.08	<1

Indios Creek	8/24/2005	13:45	<0.030	<0.1	<5	5.16	<1
Indios Creek	9/8/2005	12:15	<0.030	<0.1	<5	5.39	<1
Indios Creek	9/22/2005	15:00	<0.030	<0.1	<5	5.05	<1
Indios Creek	10/6/2005	12:00	<0.030	<0.1	<5	5.45	<1
Indios Creek	10/20/2005	13:00	<0.030	<0.1	<5	5.37	<1
Indios Creek	11/3/2005	12:00	<0.030	<0.1	<5	6.65	<1
Indios Creek	11/16/2005	14:00	<0.030	<0.1	2.04	4.68	1.2
Indios Creek	12/21/2005	14:00	0.043	0.13	2.37	4.37	1.1
Indios Creek	2/1/2006	12:00	0.039	0.16	1.92	4.02	1.01
Indios Creek	3/6/2006	12:30	<0.03	<0.1	2.09	3.90	<1
Indios Creek	4/3/2006	11:30	0.041	<0.1	0.48	63.50	7.64
Indios Creek	5/2/2006	13:00	0.058	<0.1			
Indios Creek	6/2/2006	13:00			1.87	4.60	1.41
Indios Creek	7/5/2006	14:00	0.036	<0.1	1.8	4.31	1.41

Appendix F – Supplementary macroinvertebrate data

Order	Family	Common Name
Trichoptera	Leptoceridae Brachycentridae Limnephilidae Odontoceridae Hydropsychidae Rhyacophilidae	Caddisfly
Ephemeroptera	Ephemerellidae Leptohyphidae Leptophlebiidae Baetidae	Mayfly
Plecoptera	Perlodidae Chloroperlidae	Stonefly
Coleoptera	Elmidae	Riffle beetle
Amphipoda	Hyalellidae	Scud
Rhynchobdellida (Hirudinea)	Glossiphoniidae	Leech
Megaloptera	Corydalidae	Dobsonfly
Diptera	Chironomidae Tipulidae Syrphidae Simulidae Tabanidae Ceratopogonidae	Midge Cranefly Hoverfly Blackfly Deerfly Biting midge
Veneroidea (Mollusca)	Sphaeriidae	Fingernail clams
Bassommatophora (Mollusca)	Physidae	Pouch snails
	Oligachaeta	Aquatic worms

Additional macroinvertebrate ID information found at:

Leech ID
http://dnr.metrokc.gov/wlr/waterres/Bugs/Leeches.htm and http://en.wikipedia.org/wiki/Leech
http://animaldiversity.ummz.umich.edu/site/accounts/classification/Glossiphoniidae.html

Amphipod ID
http://fwie.fw.vt.edu/states/nmex_main/species/070160.htm

Clam ID
http://www.faunaeur.org/full_results.php?id=11494

Dobsonfly ID
http://eny3005.ifas.ufl.edu/lab1/Megaloptera/Megaloptera.htm

Snail ID
http://www.itis.usda.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=76437
http://animaldiversity.ummz.umich.edu/site/accounts/classification/Physidae.html

October 13, 2005

USA 1		**order**	**family**
caddis	10	Trichoptera	Leptoceridae, Limnephilidae, Brachycentridae
leeches	3	Rhynchobdellida	Glossiphoniidae
other	1		
midge larvae	4	Diptera	Chironomid
aquatic earthworms	2		Oligacaeta
amphipods	33	Amphipoda	Hyalellidae
beetle larvae	6	Coleoptera	Elmidae
	59		
LSA 1			
caddis	55	Trichoptera	Brachycentridae, Limnephilidae
mayfly	1	Ephemeroptera	Ephemerellidae
crane fly larvae	5	Diptera	Tipulidae
leech	1	Rhynchobdellida	Glossiphoniidae
midge larvae	1	Diptera	Chironomid
amphipods	5	Amphipoda	Hyalellidae
dobsonfly larvae	5	Megaloptera	Corydalidae
	73		
RTO 1			
caddis	23	Trichoptera	Odontoceridae, Brachycentridae, Hydropsychidae. Limnephilidae
worms/leeches	3	Rhynchobdellida	2 Glossiphoniidae, 2 aquatic earthworms (Oligochaeta)
beetles	2	Coleoptera	Elmidae
amphipods	4	Amphipoda	Hyalellidae
stonefly	1	Plecoptera	Chloroperlidae
cranefly larvae	1	Diptera	Tipulidae
	34		
USA 2			
caddis	11	Trichoptera	Limnephilidae, Bracycentridae
worms/leeches	7	Rhynchobdellida	1 Flatworm, 6 Glossiphoniidae
clams	5	Veneroidea	Sphaeriidae
amphipods	44	Amphipoda	Hyalellidae
mayfly	9	Ephemeroptera	Leptohyphidae
beetle	1	Coleoptera	Riffle beetle adult
midge larvae	2	Diptera	Chironomids
riffle beetle larvae	2	Coleoptera	Elmidae
	81		
LSA 2			
caddis	59	Trichoptera	Leptoceridae, Brachycentridae, Limnephilidae
riffle beetle larvae	3	Coleoptera	Elmidae
crane fly larvae	5	Diptera	Tipulidae
midge larvae	5	Diptera	Chironomids
clam	1	Veneroidea	Sphaeriidae
mayfly	1	Ephemeroptera	Leptohyphidae

amphipods	32	Amphipoda	Hyalellidae
dobsonfly larvae	1	Megaloptera	Corydalidae
	107		

RTO 2

caddis	24	Trichoptera	Limnephilidae, Brachycentridae, Leptoceridae, Odontoceridae
worms/leeches	12	Rhynchobdellida	9 Oligochaeta, 3 Glossiphoniidae
amphipods	4	Amphipoda	Hyalellidae
midge larvae	4	Diptera	Chironomids
	44		

USA 3

caddis	7	Trichoptera	Limnephilidae, Brachycentridae
worms/leeches	10	Rhynchobdellida	Glossiphoniidae
clam	1	Veneroidea	Sphaeriidae
amphipods	19	Amphipoda	Hyalellidae
midge larvae	2	Diptera	Chironomids
aquatic earthworms	2		Oligacaeta
cranefly larvae	1	Diptera	Tipulidae
	42		

LSA 3

caddis	22	Trichoptera	Brachycentridae, Leptoceridae
leeches	37	Rhynchobdellida	Glossiphoniidae
amphipods	27	Amphipoda	Hyalellidae
mayfly	1	Ephemeroptera	Leptohyphidae
other	1		
	88		

RTO 3

caddis	31	Trichoptera	Limnephilidae, Leptoceridae, Hydropsychidae, brachycentridae
worms/leeches	7	Rhynchobdellida	5 Oligocaeta, 1 Tipulidae, 1 Glossiphoniidae
midge larvae	4	Diptera	Chironomids
clam	1	Veneroidea	Sphaeriidae
other	2		
	45		

November 15, 2005

USA 1		**order**	**family**
caddis	12	Trichoptera	Leptoceridae, Brachycentridae, Limnephilidae
leeches	11	Rhynchobdellida	Glossiphoniidae
midge larvae	12	Diptera	Chironomidae
mayfly	6	Ephemeroptera	Leptohyphidae (Or Ephemerellidae), Baetidae
amphipods	85	Amphipoda	Hyalellidae
	126		

LSA 1					
caddis	110	Trichoptera	1 Leptoceridae	50% Brachycentridae	50% Limnephilidae
leeches	34	Rhynchobdellida	Glossiphoniidae		
midge larvae	7	Diptera	Chironomids		
aquatic earthworms	17		Oligochaeta		
clams	2	Veneroidea	Sphaeriidae		
mayfly	1	Ephemeroptera	Ephemerellidae		
amphipods	6	Amphipoda	Hyalellidae		
	177				

RTO 1			
caddis	49	Trichoptera	Limnephilidae, Brachycentridae, Hydropsychidae, Leptoceridae
worms/leeches	7	Rhynchobdellida	10 Glossiphoniidae, 1 Syrphidae
midge larvae	5	Diptera	Chironomids
aquatic earthworms	2		Oligochaeta
mayfly	2	Ephemeroptera	Leptophlebiidae
amphipods	2	Amphipoda	Hyalellidae
riffle beetle larvae	2	Coleoptera	Elmidae
black fly larvae	1	Diptera	Simulidae
	70		

USA 2				
caddis	6	Trichoptera	1 Leptoceridae	5 Bracycentridae
leeches	24	Rhynchobdellida	Glossiphoniidae	
midge larvae	14	Diptera	Chironomids	
mayfly	10	Ephemeroptera	Leptohyphidae, Ephemerellidae	
clam	2	Veneroidea	Sphaeriidae	
snail	1	Basommatophora	Physidae	
amphipods	69	Amphipoda	Hyalellidae	
	126			

LSA 2

caddis	41	Trichoptera	9 Brachycentridae	32 Limnephilidae	1 Hydropsychidae
crane fly larvae	5	Diptera	Tipulidae		
leeches	2	Rhynchobdellida	Glossiphoniidae		
midge larvae	40	Diptera	Chironomids		
amphipods	19	Amphipoda	Hyalellidae		
riffle beetle larvae	5	Coleoptera	Elmidae		
	112				

RTO 2

caddis	30	Trichoptera	Leptoceridae, Brachycentridae, Limnephilidae
leeches	1	Rhynchobdellida	Glossiphoniidae
midge larvae	10	Diptera	Chironomids
clam	1	Veneroidea	Sphaeriidae
stonefly	1	Plecoptera	Perlodidae
amphipods	6	Amphipoda	Hyalellidae
cranefly larvae	2	Diptera	Tipulidae
	51		

USA 3

caddis	7	Trichoptera	Limnephilidae	Brachycentridae
leeches	52	Rhynchobdellida	Glossiphoniidae	
midge larvae	9	Diptera	Chironomids	
aquatic earthworms	2		Oligochaeta	
clams	10	Veneroidea	Sphaeriidae	
mayfly	3	Ephemeroptera	Tricoryithidae	
amphipods	19	Amphipoda	Hyalellidae	
	102			

LSA 3

caddis	106	Trichoptera	Brachycentridae, Limne, Hydropsy, Rycophil
cranefly larvae	10	Diptera	Tipulidae
midge larvae	25	Diptera	Chironomids
leeches	9	Rhynchobdellida	Glossiphoniidae
amphipods	1	Amphipoda	Hyalellidae
riffle beetle larvae	1	Coleoptera	Elmidae
	152		

RTO 3

caddis	59	Trichoptera	Brachycentridae, Hydropsychidae, Leptoceridae, Limnephilidae
leeches	25	Rhynchobdellida	Glossiphoniidae
midge larvae	5	Diptera	Chironomids

clam	2	Veneroidea	Sphaeriidae
mayfly	2	Ephemeroptera	Ephemerellidae
amphipods	2	Amphipoda	Hyalellidae
aquatic earthworms	1		Oligochaeta
riffle beetle larvae	1	Coleoptera	Elmidae
	97		

April 14, 2006

USA 1		**order**	**family**		
caddis	9	Trichoptera	3 Odontoceridae	6 Limnephilidae	
leeches	9	Rhynchobdellida	Glossiphoniidae		
aquatic earthworm	5		Oligochaeta		
mayfly	1	Ephemeroptera	Ephemerellidae		
midge larvae	23	Diptera	Chironomidae		
	47				
LSA 1					
caddis	37	Trichoptera	30 Bracycentridae	7 Limnephilidae	
leeches	10	Rhynchobdellida	Glossiphoniidae		
aquatic earthworm	7		Oligochaeta		
horse/deerfly	1	Diptera	Tabanidae		
clams	2	Veneroidea	Spaeriidae		
amphipods 1	1	Amphipoda	Hyalellidae ***Reduction In Amphipods In This Sample May Be Attributed To Life Cycle Stage (Voshell)		
	58				
RTO 1					
caddis	65	Trichoptera	21 Bracycentridae	10 Limnephilidae	34 Odontoceridae
leeches	34	Rhynchobdellida	Glossiphoniidae		
cranefly larvae	2	Diptera	Tipulidae		
midge larvae	28	Diptera	Chironomidae		
clams	4	Veneroidea	Spaeriidae		
amphipods	5	Amphipoda	Hyalellidae		
	138				
USA 2					
caddis	2	Trichoptera	1 Leptoceridae	1 Limnephilidae	
leeches	19	Rhynchobdellida	Glossiphoniidae		
aquatic earthworms	6		Oligochaeta		
snails	2	Basommatophora	Physidae		
midge larvae	5	Diptera	Chironomidae		
amphipods	22	Amphipoda	Hyalellidae		
	56				
LSA 2					
caddis	48	Trichoptera	10 Bracycentridae	15 Odontoceridae	23 Limnephilidae
leeches	80	Rhynchobdellida	Glossiphoniidae***Large Number Of Leeches In This Sample Attributed To Spring Breeding (Many Leeches With Egg Sacs And Many Very Small Specimen) (Voshell)		
aquatic earthworms	2		Oligocaeta		
cranefly larvae	1	Diptera	Tipulidae		
clams	7	Veneroidea	Sphaeriidae		
midge larvae	3	Diptera	Chironomidae		
mayfly	1	Ephemeroptera	Ephemerellidae		

amphipods	2	Amphipoda	Hyalellidae		
	144				
RTO 2					
caddis	10	Trichoptera	4 Brachycentridae	3 Limnephilidae	2 Odontoceridae
leeches	6	Rhynchobdellida	Glossiphoniidae		
aquatic earthworms	1		Oligocaeta		
clams	10	Veneroidea	Sphaeriidae		
deerfly larvae	1	Diptera	Tabanidae		
midge larvae	17	Diptera	16 Chironomidae	1 Ceratopogonidae	
riffle beetle larvae	3	Coleoptera	Elmidae		
amphipods	2	Amphipoda	Hyalellidae		
	50				
USA 3					
caddis	27	Trichoptera	3 Limnephilidae	24 Brachycentridae	
leeches	8	Rhynchobdellida	Glossiphoniidae		
midge larvae	10	Diptera	Chironomidae		
clams	3	Veneroidea	Sphaeriidae		
amphipods	7	Amphipoda	Hyalellidae		
	55				
LSA 3					
caddis	68	Trichoptera	23 Brachycentridae	10 Limnephilidae	35 Odontoceridae
leeches	25	Rhynchobdellida	Glossiphoniidae		
aquatic earthworms	3		Oligochaeta		
midge larvae	28	Diptera	Chironomids		
clams	2	Veneroidea	Sphaeriidae		
mayfly	1	Ephemeroptera	Ephemerellidae		
amphipods	15	Amphipoda	Hyalellidae		
	142				
RTO 3					
caddis	30	Trichoptera	1 Brachycentridae	28 Limnephilidae	1 Odontoceridae
leeches	3	Rhynchobdellida	Glossiphoniidae		
aquatic earthworms	2		Oligochaeta		
clams	2	Veneroidea	Sphaeriidae		
midge larvae	8	Diptera	Chironomids		
amphipods	2	Amphipoda	Hyalellidae		
	47				

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