VALLES CALDERA NATIONAL PRESERVE

Hydrology

Existing Condition Report

VALLES CALDERA TRUST

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Introduction

Water quality is strongly influenced by surficial geology and deeper, structural elements. The temperature of some caldera stream water may be naturally warmed. Faulting controls valley and channel development, and has led to particular erosion sensitivity of certain slopes. Remnant ashflow along the footslopes of the resurgent domes and older caldera rim has secondary alluvial and landslide deposits which are particularly susceptible to erosion.

The upland slopes of the caldera are connected by surface flow with the valley bottoms only through gullied swales or degraded 1st order draws that are entirely within the slope deposits mentioned.

The 1935 aerial photographs show all of the present gully forms and that many were then actively scouring. These photos predate the industrial logging and road building and 1960's stock tank construction. Historic sheep grazing may have been the single most important management activity that contributed to gully starts.

The possibility is raised that the extent of perennial wet valley bottoms (fens do still exist) was much greater in pre-settlement times, and surface flow on the valley bottoms was more dispersed. In general the present stream channels are in an upward trend with regards to bank stability although the process is slowed by a paucity of transported material.

Physical Setting/Geology

The Jemez River begins in the Jemez Mountains, which includes the Valles Caldera complex. Resurgent volcanic domes and associated high angle faulting creates an unusual predominance of low gradient and broad meadow valleys in the headwater/source area of the river, within the VCNP. These distinct reach types frame the following discussion of land-use impacts on channel morphology and water quality.

The Jemez Mountains are a group of volcanoes formed largely during an episode of volcanism beginning in the early Tertiary, and extending to the Pliocene. The volcanoes intruded up through earlier sediments: shale, sandstone and limestone that range widely in age. The oldest rocks in the area, with very limited surface exposure are much older granitics that are pre-Cambrian in age. The volcanic rock formations; pyroclastic rhyolites, and rhyolite, andesite and basalt flows are interbedded in places with coarse gravel. Fans of eroded material from the rising volcanoes skirt the lower slopes of the Jemez. The pre-volcanic sedimentary rocks are exposed largely in the southwest portion of the project area in the main stem Jemez River valley, and then up the deeply eroded valleys of San Antonio Creek, Rio Guadalupe and the Jemez River.

The Valles Caldera was created about 1.25 million years ago during an explosive volcanic event or series of events that obliterated the earlier Toledo Caldera (State of New Mexico, 2005); (State of New Mexico, 2007) and widely deposited the Upper Bandelier Tuff (Tshirege Member), a rhyolitic ash flow that over-lays the older volcanic deposits around the rim of the caldera. The Redondo Peak resurgent dome followed the creation of the caldera by only about 27 thousand years. Rhyolitic domes followed substantially after caldera creation (0.5 million years ago) along the caldera ring fracture (South Mountain, Cerro la Jara, Cerro del Medio, etc.) (USGS, 1970).

There have been several episodes of lake formation when the East Fork of the Jemez River has been blocked by landslides. The valley fill of the caldera consequently are a complex of lake, alluvium and landslide deposits, including mudstones, siltstones, and conglomerates of pumice, tuff and lava.

For the purposes of this report the physiology of the caldera may be divided into three broadly grouped parts based on surficial geology mapping: (1) the volcanic rock of the resurgent domes and older caldera rim, (2) the ash flow deposits and secondary deposition fans along the footslopes, and (3) the valley bottoms themselves.

The first group consists of volcanic rocks forming the caldera rim (older Tertiary and early Quaternary) and the resurgent domes within the caldera rim (later Quaternary). These rocks are within the rhyolite-andesite mineral composition range, have various textures and origins (i.e, lava flows and ash fall) and the differing types are inter-bedded and inter-fingered throughout the caldera. The surface exposures share the similarities of steep slopes evolved through the quite recent mountain building eruptions and uplift (the resurgent domes) or the catastrophic formation of the caldera itself that left the steep interior rim rock slopes.

The second group is composed of the slope deposits that skirt the steep slopes of the domes and rim. These deposits formed as various patterns such as alluvial fans, lake deposits, and landslides, but are similar in that they are composed of deep, unconsolidated material on moderate to shallow slopes.

The major valley bottoms within the caldera make up the last grouping due to the direct connection with water quality. These valleys are 3rd stream order or higher, that separate the domes, rim rock and other topographic rises from one another. In the valleys slope wash is sorted, ground down and eventually transported away from the caldera. The valleys initially formed as the resurgent doming and associated high angle faulting created low gradient reaches that were once basins, and are now bottle-necked behind narrow gorges. The valley slopes are not above 2%, though exceptions are Rito de los

Indios, Sulfur and Redondo Creeks, 2nd or small 3rd order, fault aligned or controlled streams with steep, mountainous morphology.

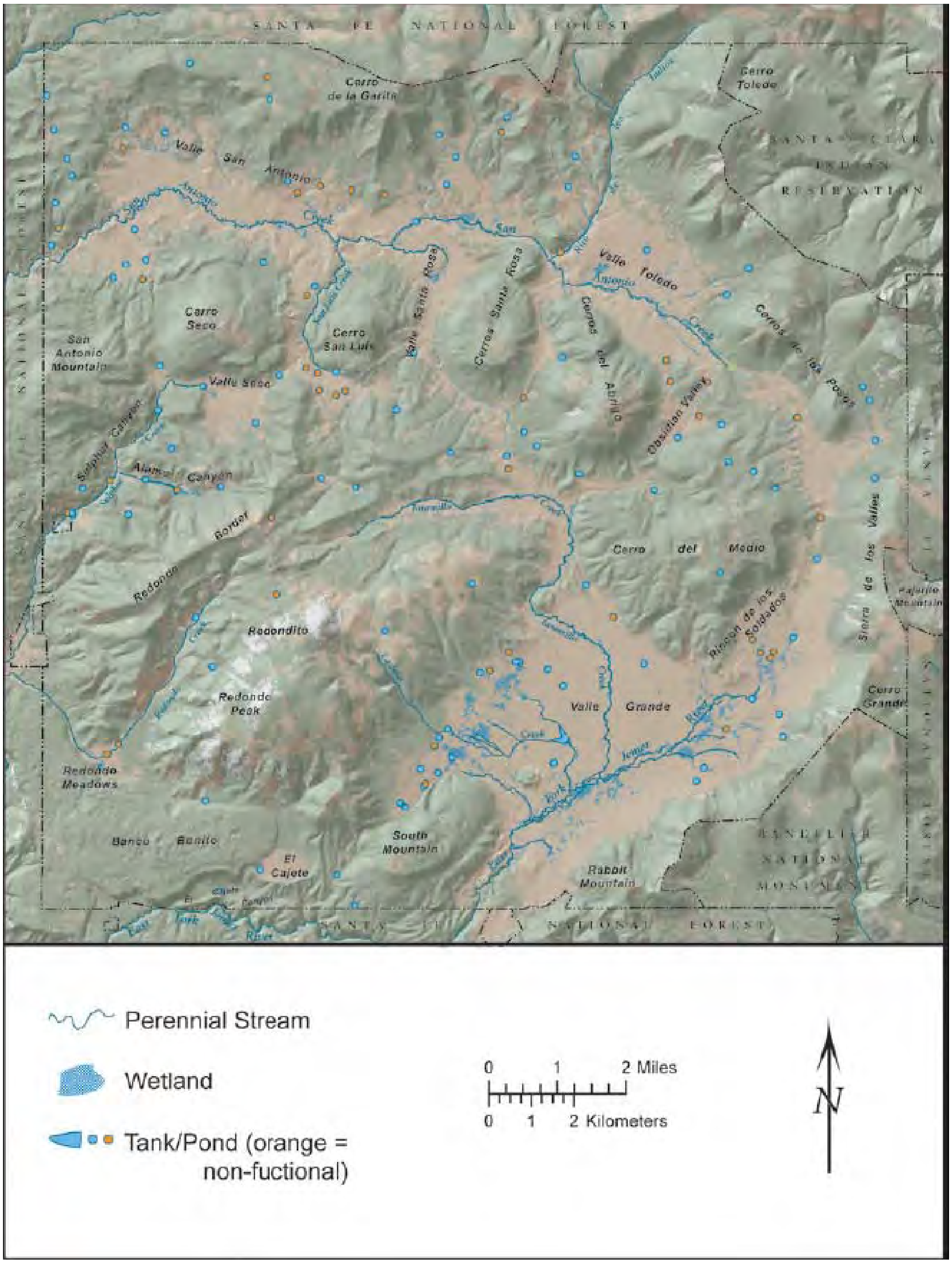

Figure 1 – Streams and water features of the Valles Caldera National Preserve

Stream Flow

The southwest is influenced by two general climate patterns. The first is a semi-permanent high pressure system off the coast of California that produces a general pattern of wet winters and dry summers east and west of the Cascades/Sierra Nevada mountain ranges. The second is an Atlantic sub-tropical high pressure system extends into the Gulf of Mexico creating a flow of moist air onto the plains and eastern Rockies throughout the summer creating the so-called "monsoon" season (Arkell & Richards, 1986). The summer month events are characterized by intense short rainstorms that may amount to significant totals. Add to this general description the modifying influence of high elevation with typically cool summers and cold winters that induce prolonged snow pack.

Low order tributary draws, and upper reaches of main streams are swale-like, or at least generally lack active scour channels. Flow is present as dispersed wet areas, seepy ground or in discontinuous and short gully-like troughs that may be created by animal disturbance, or be the eventual degradation through avulsions in the valley long profile from one-time deposition events.

Exceptions are Redondo Creek, Rito de los Indios and Sulphur Creeks which are likely aligned with fault trends. They are steep gradient perennial streams with cobble/boulder predominate beds, incised in valley fill or confined in deep V-shaped valleys. Rito de los Indios longitudinal profile is affected by faulting, reducing gradient and creating meadows in reach staring about 1 mile below preserve northern boundary. In all these cases there is considerable influence from roads built in the valley, further constraining the channel and occasionally delivering sediment to the channel.

Precipitation water passes from the most general recharge zone, the caldera rim and domes, to the valleys largely by ground interflow. The large valley fill constitute a prodigious storage capable of maintaining an even base flow very much as might be expected from a system driven by large spring input.

There are two stream flow gages operated by the U.S. Geological Survey in area streams. Redondo Creek (Station # 8319945) with 4 year of record between 1981 and 1985 and Jemez River below its confluence with the East Fork Jemez River (Station # 8321500), with 28 years of record between 1960 and 1989. Both streams are driven more by snow melt than summer rains. For both the largest annual peak flows occurred between late March and mid May, with some smaller order peaks of the year coming in August and September. By far the greatest volume of water also ran in the spring months. Figure 2 shows hydrograph of period of record for Redondo Creek, which is representative of both systems in regards to peak flow runoff.

Response to a precipitation event in areas of natural cover is usually due to hydraulic effect on soil pore water. As rainfall in recharge areas, the valley slopes, infiltrations and percolates down into the vadose zone of the soil, it builds hydraulic head that acts upon antecedent soil water forcing it down and eventually out in the low areas of the valley and channel, in the near channel slopes and banks. Inflow into channels from direct overland runoff is rare except on ground that is naturally impervious or bare of cover, such as rock outcrops or talus slopes.

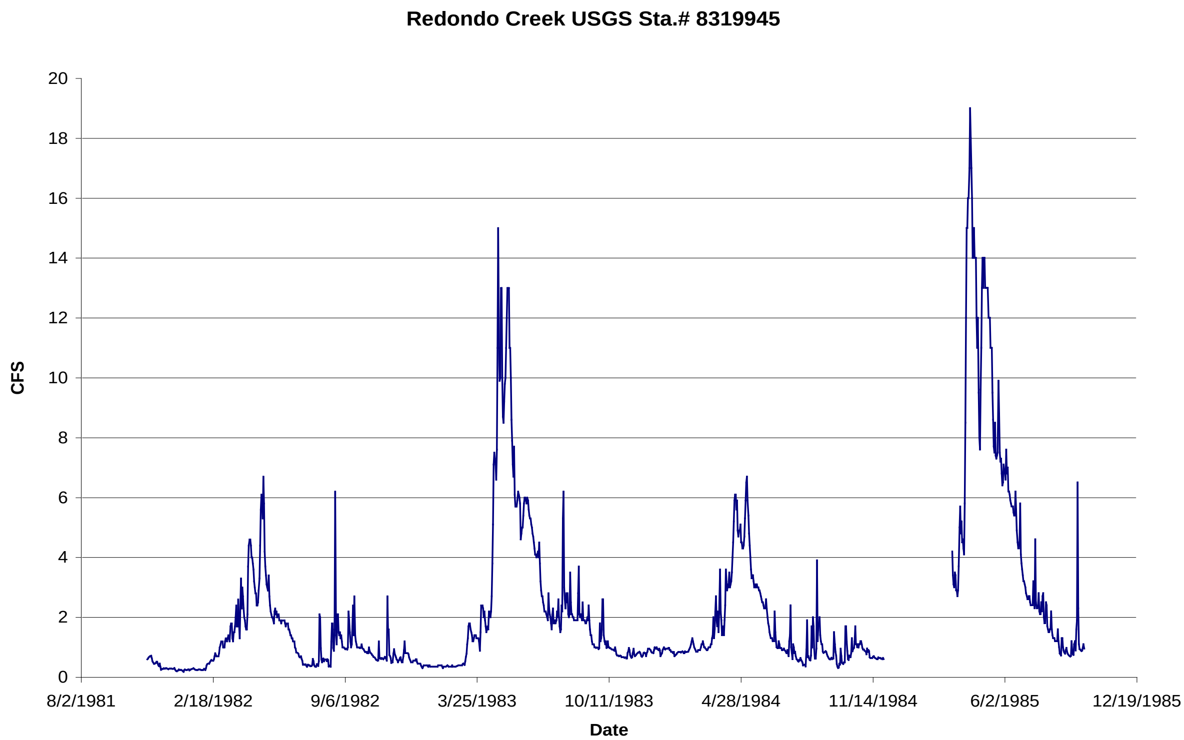

Figure 2 - Redondo Creek hydrograph of period of record

Figure 3 and Figure 4 show flow duration curves for Redondo Creek and Jemez River, respectively. The vertical axis is mean daily flow and the horizontal axis shows percent of time (for the entire period of record) for a corresponding flow value. The very steep portion of the lines on the left hand side of the graphs, are high flow events, mostly snow melt. The long shallow tail is base flow period, dry season runoff, when flow is driven by ground water storage seeping into the channels. For Redondo Creek which drains from the dome, steep hillsides with minimal storage in relatively shallow soils, the tail portion has a constant and significant decline, showing that base flow, over the summer months also has steady decline as limited soil water storage is depleted.

The tail on the graph for the Jemez River is virtually flat indicating very little decline in summer base flow due to massive ground water storage in Valle Grande and Valle San Antonio, the principle tributaries to the watershed.

It is interesting to note that the low percentage end of the Jemez River graph is atypically steep and constricted, indicating the somewhat tenuous surface flow connection of the main stem channels of Valle Grande and Valle San Antonio to upland recharge area;

surface flow events are quickly attenuated by waters infiltrating and percolating deep into ground water storage.

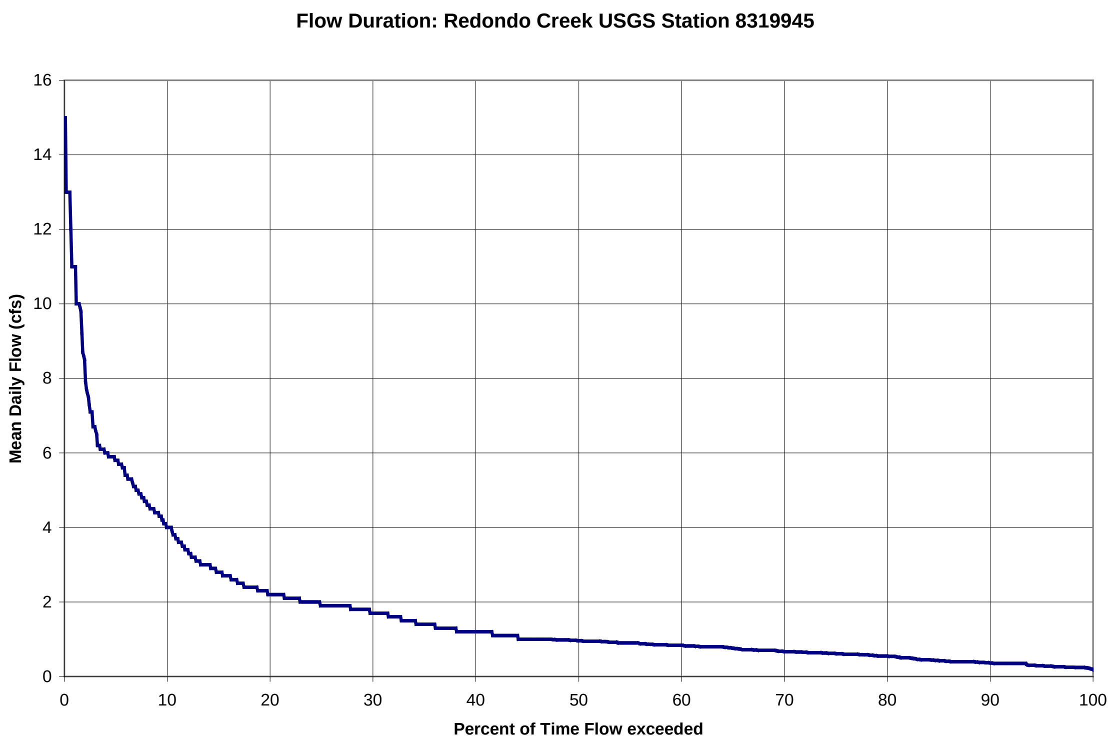

Figure 3 - Flow duration curve for Redondo Creek

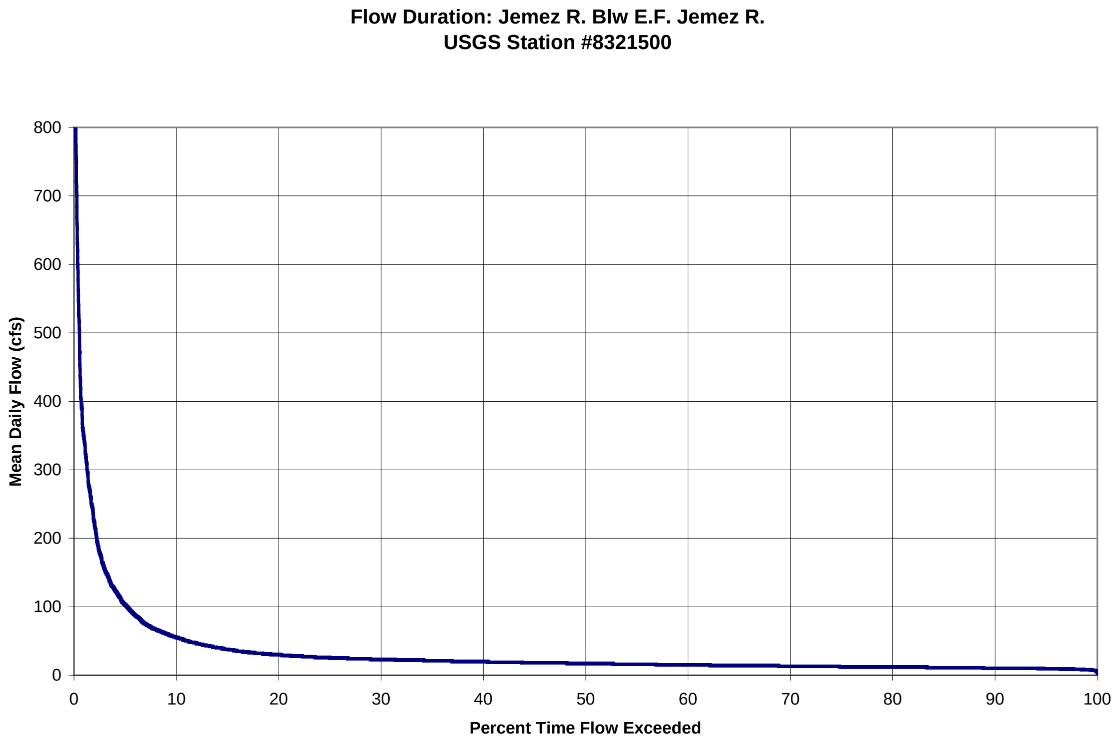

Figure 4 - Flow duration curve for Jemez River below the East Fork of the Jemez River

Channel Morphology

The upper soil layer observed in bank cuts of the channels is mostly a silty loam. The beds of the perennial stream, throughout the preserve, appear dominated by coarse grain particles that are large gravel to cobble in size (16 to 64 mm on intermediate axis). The distributions of particle size that compose the beds appear to be bi-modal. Fines of medium sand to silt size are embedded within the interstitial spaces of the larger particles, with a distinct lack of intervening particle sizes. Surveys of the caldera streams (State of New Mexico, 2006), noted that gravel to cobble size material made up 60-70 percent of the bed on average across the caldera. Fish habitat surveys (USDA-Forest Service, 2002); (USDA-Forest Service, 2003)of the East Fork Jemez and San Antonio Creek noted a high proportion of fines in riffles, and lack of pool habitat, that it was speculated within those reports as possibly due to filling. The same reports, however, noted the distinct lack of large woody debris, or even woody riparian species which are typically crucial for creation of pool habitat in channels of similar settings.

The shape of large particles on the bed range from sub-angular to sub-rounded, and are not well imbricated and loose, indicating that particles beyond coarse sand size is not frequently transported by flow. The large material presence in the valley may be the result of landslide from surrounding hill slopes or fluvial transport during wetter climate regime with correspondingly larger flows. Given the obvious degree of bank retreat it seems likely that the fines still entrained in the channel is largely from bank erosion.

Perennial streams in the broad valleys are sinuous, with narrow width to depth ratio on average of less than 10 (USDA-Forest Service, 2002), (USDA-Forest Service, 2003), low to moderate gradient, 0.1 to 1.5 percent, with consistent base flow conditions (see discussion below under Stream Flow section). Banks are mostly undercut and present vertical faces, where stable. Bank stability in East Fork Jemez River, and San Antonio Creek ranged from 80 to 95 percent (USDA-Forest Service, 2002), (USDA-Forest Service, 2003). Elsewhere they have collapsed, probably over the previous undercuts, undoubtedly because of trampling by livestock. Mostly the slumped banks have re-vegetated with grasses or forbs. Channel bed margins in deposit areas (such as the inside portion of bends) are often grown over with sedges. A consequence of the bank slumping has been an increase in channel width. Imposed sediment load from the collapsed banks can also lead to channel widening, mostly as the load is dropped out and deposited at bends, constrictions and various other irregularities in channel pattern and form

A channel widened by any means has by a consequence an increased cross-section and increase capacity to carry flow, which frequently leads to scour of the bed. Nevertheless, there appears to have been little scour within channels in the caldera. The predominate size of bed material and its resistance to average conditions of peak flow may limit scour in any case. When a channel widens the flow column is shallower for a given volume with a greater area proportionally, exposed to resistant bed material. Total resistance to flow is therefore increased, which impedes velocity and reduces stream power, or the ability to do work. Limited channel down cutting has maintained stream flow connection with the valley bottom floodplains, retaining the conditions that supported original valley vegetative community and vigor.

Recovery of channel form and function within the Valles Caldera is slowed by dearth of coarse and medium sand size, which can rapidly build banks at deposit points, such as point bar accretion on the inside of bends. Instead recovery, primarily by narrowing of the channel, appears dependent on sedge growth on the channel margins and slow capture of suspended sediments for upward accretion.

Another process concomitant with bank trampling that may lead to increased channel capacity is high intensity rainfall on ground with reduced cover. The impact force of raindrops on bare ground is many hundreds of the times the force as on ground with vegetative or litter cover. The impact dislodges fine particles and as they re-settle causes reduction of soil surface porosity and decrease of infiltration capacity. During high intensity rainfall, particularly summer thunderstorms, infiltration capacity may be exceeded and overland flow, in the form of sheet wash occurs. Occurrence of overland flow could substantially increase immediate inflow into the channel during an event; it would in other words, advance and increase the response of the system, especially in a system such as the Valles Caldera where inflow and response was naturally attenuated by the large grassy expanse, and thick sequence of valley fill.

If peak flows are increased for any given sized event because of increased inflow, then eventually channel size will increase to accommodate, even had it not been widened by other processes, such as bank trampling by livestock. Typically the channel bed will scour first, and in fine grain valley alluvium the degree of down cutting can be rapid and great. Within the caldera, as discussed above, the channel beds are resistant to scour, though widening is accommodated by retreat of banks already weakened by livestock trampling.

The outside of bends may have active vertical bank cuts, but this is entirely consistent with high energy low transport streams working in cohesive alluvium. The inside bend of an unconstrained alluvial channel typically would have accreting point bars that would rise to the level of the valley bottom. Instead this deposition area is a wide point occupied by slack water and sedge growth that catches fines infilling from the outside margins inward. In this manner the Valles Caldera streams are evolving from their degraded condition of over-widened and shallow, and somewhat straightened, channels to narrower, deeper and more sinuous forms.

Hydrologic Connection with Uplands

With few exceptions, one being the Rito de los Indios, the upland slopes of the caldera are connected by surface flow with the valley bottoms only though gullied swales or degraded 1st order draws that are entirely within the slope deposits at the foot of the resurgent domes and caldera rim (Figure 6 and Error! Reference source not found.). These features certainly seldom, if ever, have any expression in the steep slopes of the dome and rim rock. The mountainous slopes erode almost entirely by weathering of parent material into a mantle of overburden that moves down slope under influence of gravity and pore-water as soil creep, and either landslides or slumps (Figure 7). Within the slope deposits, however, there are many

Figure 5 – San Antonio drainage, draw gulley

Figure 6 - San Antonio drainage, healing swale gulley

occasions of gullies.

Although road density is very high in the caldera in general and on the domes in particular, there are few instances of deep or persistent rilling or fill failure above the slope deposits. Logging roads run up many of the swales and connect to the uplands through radiating skidding trails. Many larger swales have stock tanks and roads that subsequently were used for logging may have been originally placed as access to the tank site. As well, many swales may have likely been compacted first by livestock, particularly sheep, as some wide trails up swales and lower hill slopes may be have once been driveways.

Gulley Location

There are any number of apparent reasons for gully formation in any given location: drainage from fans of steep logging trails terminating at the head of a swale, a steep logging haul road parallel to a draw, a stock tank that has been partially filled with sediment and cut around by spring runoff, wide compacted and weedy swaths from grazing livestock, but the locations themselves have specific characteristics:

Figure 7 - Cerro del Medio slump topography in area of vitrified rhyolite.

- Slope deposits from certain formations or formation members appear to be the most susceptible to gully formation: ryholite tuffs of the Valle Grande member of Valles Rhyolite Formation in the lower Valle San Antonio, around San Antonio Mountain, Cerro Saco and Cerro San Luis; a vitric member of the volcanic dome rhyolite forming Cerro del Medio, also of the Valles Rhyolite. This last member occurs on the lower slopes on the north side of the dome above Obsidian Valley and on the south side above Valle Grande and in line with the springs feeding the East Fork Jemez. In both cases the typical rhyolite debris is liberally littered with obsidian pieces. Lastly a cliff exposure of the Bandolier Tuff, at the upper end of Valle de Los Posos (and precisely were the gas pipeline crosses) is a remarkably unstable slope that has induced massive land sliding about 150 years ago.
- Gullies occur in landslide material and in the high clay slope wash as with the sandy loam ash on the foot slopes along the south side of San Antonio. Soil differences do not necessarily explain varying risk to gully formation from slope deposits, as resistance to erosion may be related more to parent material. Most of these slope forms have relatively high rock contents irrespective of soil development. The truly alluvial slopes like along upper Valle Grande have high

rock content, but may also have more layered consolidated form leading to a robust surface against erosion. Along the north side of San Antonio, the slope deposit has older buried alluvial surfaces from landslides above. Soils on these forms have high rock content, but lack the integrity and resistance against erosion of the pure erosion forms.

Gully starts occur primarily at the breaks in slope above the slope deposit toe slopes just above a swale or valley bottom. Down-cutting of the swales proceeds either down-slope or up-slope as head-cuts. By contrast the very long, wide and uniform fans that form the slopes of the older Tschicoma Formation- the massive dacite and latite flows that built the Jemez Mountains- have a low density of natural drainage features and resist gullying by road runoff.

Topsoil in the gully bottoms and gully deposit fans are typically light colored, sandy or gravelly indicating very recent, historic deposit. Organic accumulation suggests at least 30 years of time for soil development. Aerial photographs from 1935 confirm most if not all of the present gullies were in place and therefore prior to the industrial logging. With less use, chronic erosion ceased though vegetation re-establishment varies according to the site potential. Re-vegetation and organic coloration indicate recovery.

The banks of gullies and incised channels in draws are predominantly re-vegetating, appear at stable angle of repose, and have floodplains development along the active channel, all indicating a degree of healing and decreasing impacts. Very often the gully form does not directly connect to a perennial or intermittent channel if it ever did, but ambiguously ends in fan of alluvium in a large valley margin

Gully Initiation

Surface scour that initiate gullies obviously requires a source of overland flow. Forested floors and grassy slopes do not, as a rule, produce overland flow except under the most extreme precipitation events. Such events are typically highly localized and short-lived. The extent of gullying in the caldera, and the relatively even-aged appearance suggests a more consistent and pervasive cause.

The 1935 aerial photographs show most if not virtually all of the present gullying. These features are visible as bright spots on valley bottoms and deposit fans indicating that at that time most were actively scouring (Figure 8). Many gullies also reached farther down slope and into valley bottoms than they do in the 1996 digital ortho-quads. These photos predate the industrial logging and road building and 1960's stock tank construction. In absence of other evidence it appears that the historic sheep grazing was the single most important management activity that contributed to gully starts. Based on the recent history detailed of the preserve, the sheep grazing was magnitudes greater than any of the livestock numbers in recent history. Also, conditions in 1935 would have already been influenced by 70 years of ranching.

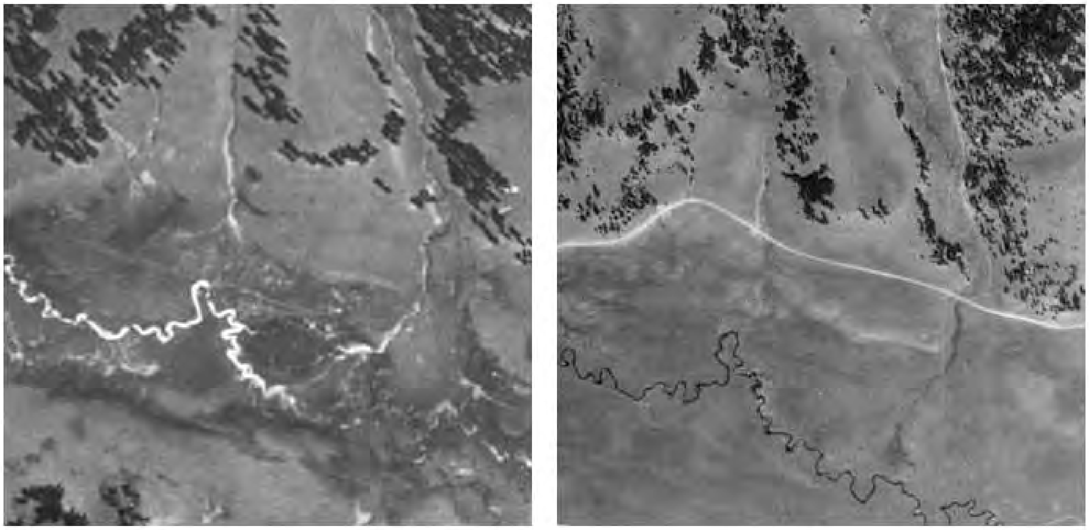

Figure 8 - Aerial photograph from 1935 (left) depicts the initiation of gullies in the Valle San Antonio; Image on the right shows the same location in 1996

Comparisons with 1996 DOQ images and the 1935 photographs give more evidence that erosion was far more prevalent in the past. The most striking differences are in Jaramillo and San Antonio Creek valleys. The San Antonio channel in the 1935 photographs shows a wide, fresh (or bright in image) flood plain of point bars and medial bars in places giving a somewhat braided appearance (Figure 9). Clearly the channel is overburdened with bed load and recently so, most probably some of it is effluent from the numerous active gullies reaching the valley. Most of the sediment in the channel bottoms is likely from the eroded channel itself. However, surface runoff from hill slopes through gullies may have initiated scour in the valley bottom. High sediment input will cause bar deposits, rapid channel migration and an overall widening of the channel, as the flow pushes out on the banks. To the extent that peak flows are available to fill the channel the situation becomes a kind of feedback loop as new sediment eroded now from banks exacerbates the situation. Eventually the channel expands to a maximum cross-section beyond which available peaks can no longer move bed load. Measurements of channel length from images show that the 1996 channel path is 25 percent longer than the 1935 path. This is a very large change and in agreement with general observations that very aggraded channels usually straighten (and shorten) their pathway, but also that the last few decades have been mitigating ones.

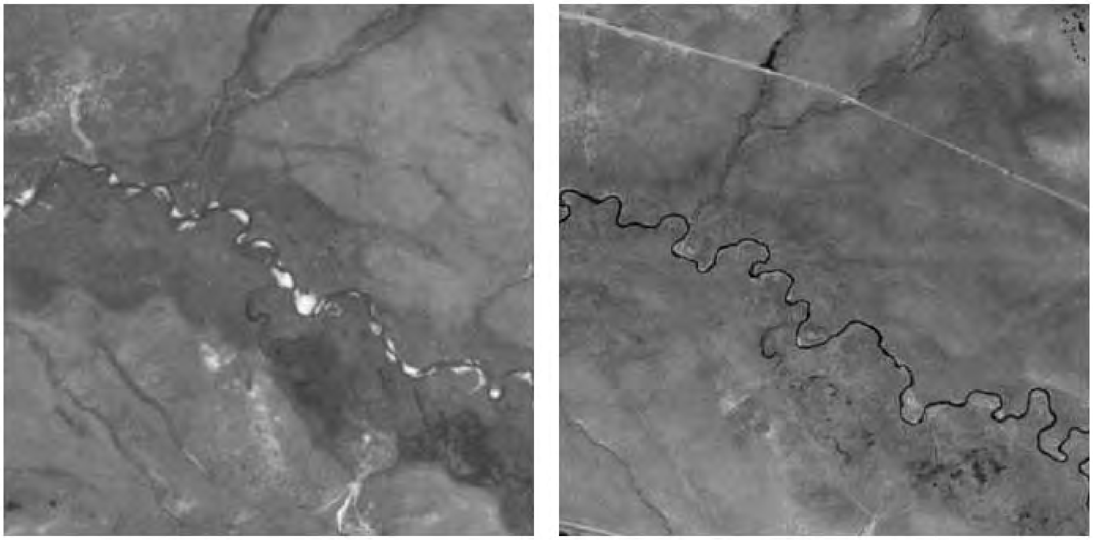

Figure 9 - Aerial photograph from 1935 (left) depicts channel degradation in the lower San Antonio likely caused by intensive grazing by sheep. The photo on the right is of the same location in 1996.

Degraded channels indicate an excess of peak flow water, fully capable of moving all available sediment from upland sources and also scouring the bed and banks. If the peaks were also carrying sediment in volume correspondent to flow then an elevated valley bottom and a braided channel pattern dominated by fresh deposition would probably have occurred. There is no indication that this happen recently. Most likely sediment that was moved from a gully was largely deposited at the slope toe at the valley margins. In fact that is exactly what the photographic evidence shows, although some fans did intrude far enough into the valley to physically alter stream pattern and obviously connect to channels.

Lower Jaramillo Creek valley in the 1935 photographs shows a broad wet bottom, with multiple and barely discernible dark channel traces indicating a very dispersed flow through many very slightly incised channels possibly with partially vegetated bottoms, and as much flow likely as ground interflow as on the surface (Figure 10, left). By 1996 the valley section has a single thread channel (Figure 10, right). Ground observations have shown that the channel is also recovering from an over-widened, aggraded state.

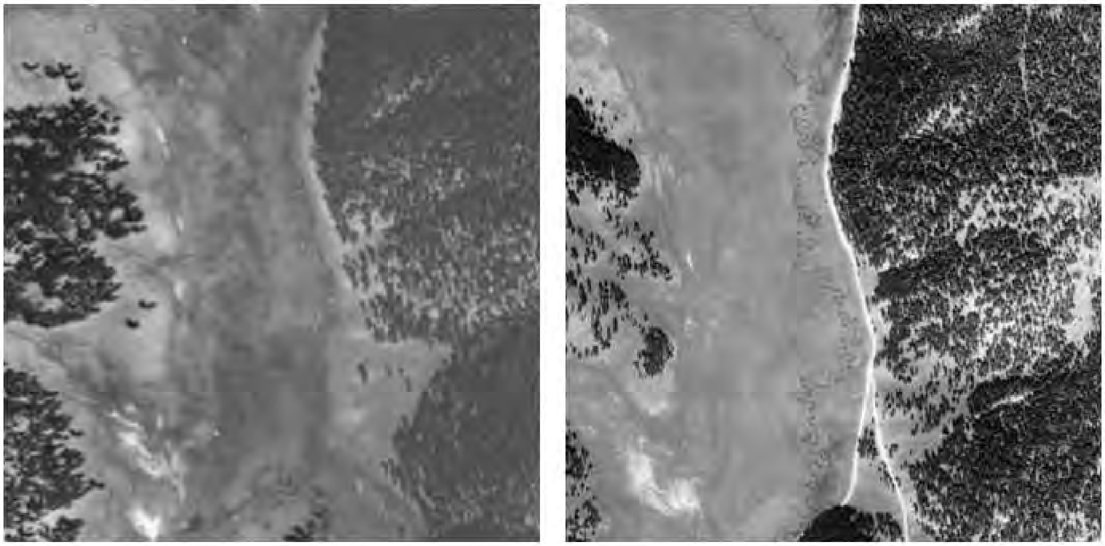

Figure 10 - Aerial photograph from 1935 (left) depicts Jaramillo Creek in an over-widened, aggraded state. Aerial photograph from 1996 (right) shows the Jaramillo flowing as a single thread.

Similar differences in channel morphology were found in the upper section of San Antonio valley. The 1935 photos reveal wetland-like valley bottoms with dispersed flow compared to the incised channeling in the 1996 photos. These observations do raise the possibility that the extent of perennial wet valley bottoms (fens do still exist) was much greater and surface flow was more dispersed. Thus, though single-threaded channel reaches show recovery now, the very pattern may represent a large shift from a wetter, dispersed flow environment.

A suggested sequence of degradation events is:

1. Near valley slope deposits gullied from grazing pressure.
2. Increased runoff and sediment is delivered to the valley that scours channel beds, eventually selectively directed into a single path that is incised into the valley alluvium, and frequently has a braided appearance.
3. Finally, in time, because of recovery of the slopes, runoff and sediment delivery is attenuated and slowly the channel reduces width to accommodate new flow regime. Because these reaches were not high sediment transporting to begin with, recovery of width is very slow, accomplished mostly by capture of fines by marginal sedge growth and upward accretion of banks.

Water Quality

Turbidity

During a site visit in September of 2007, several springs were observed on the margins of Valle San Antonio and Valle Grande. Spring water was universally clear, no observable turbidity. Springs were all within alluvium valley fill, and at the foot of slopes. The perennial main stem flow of East Fork Jemez River, San Antonio Creek and Jaramillo Creek; however, all have noticeable cloudiness, rather milky in appearance, from colloidal particles, which appeared to progressively increase in the downstream direction. Conversely Rito de los Indios and Redondo Creek run clear. The difference may be the extensive fill of the main valleys containing very fine grain, clay-like particles of volcanic ash. While this type of material is present on the domes and Redondo Peak, the residence time of the water as ground interflow before emerging in the channels as surface flow is undoubtedly much less than in the lower valleys.

Monitoring for turbidity and temperature was conducted during the spring through fall of 1998 by the New Mexico Environment Department (State of New Mexico, 2002) on East Fork Jemez River, San Antonio Creek and Redondo Creek. Turbidity was measured seven times at each station, between April and November.

Exceedences of turbidity standards of 25 Nephelometric Turbidity Units (NTU) were recorded for the streams on bold dates shown in Table 1 below. The origins of sediment causing turbidity for East Fork Jemez River appeared to the field crews recording data to be lacustrine from the floor of Valle Grande.

Table 1– Values of NTU on selected dates. Standard limit is 25 NTU

Dates	Streams		
	East Fork Jemez River	San Antonio Creek	Redondo Creek
4/22/98	18.6	26.5	17.2
4/23/98	20.0	27.5	29.5
7/13/98	42.6	8.4	42.1
11/2/98	31.5	34.7	11.9

Flow recorded at the U.S. Geological Survey stream gage on East Fork Jemez (Station #8321500) was 109 cubic feet per second (cfs) on 4/23/98. Bank full flow, or approximately the average annual peak flow, for the station is calculated as 54.7 cfs (State of New Mexico, 2002). The 4/23 flow, and by inference flow on 4/22 is probably driven by snow melt runoff, and is unusually high as well. No flow data was recorded for the other dates.

Temperature

Stream temperature was monitored at two and five discrete locations on the East Fork Jemez and San Antonio Creeks, respectively, by Santa Fe National Forest fishery staff (USDA-Forest Service, 2002), (USDA-Forest Service, 2003). Both locations on the East Fork Jemez were not properly functioning (exceeding state water quality standards) for cold fish habitat, on both a seven and three day moving average during summer months. Two of the San Antonio Creek sites were not properly functioning, and three functioning at risk. The upper location measured was influenced by Rito de los Indios.

A 2006 report on 2001 data by the state Surface Water Quality Bureau (State of New Mexico, 2006) monitored for a summer several sites within the VCNP: East Fork Jemez River, Jaramillo Creek, Redondo Creek, Rito de los Indios and San Antonio Creek. There were minor numbers of occurrences of temperatures above standards on Redondo Creek and Rito de los Indios (1 to 2 percent of the period of record), which are steep gradient, fast running streams in narrow steep sided valleys. Incidences were much higher on the other streams (10-20 percent of the record), all of which are entirely or dominated by broad, meadow valleys.

In 2001 numerous water chemistry parameters were measured at 17 sites in caldera, as well as flora, fauna and channel morphologic indicators of stream health (State of New Mexico, 2006). The sites were on the East Fork of the Jemez River, Jaramillo, La Jara, Redondo, Rito de los Indios, San Antonio and Sulphur Creeks. Samples were taken at all or some of the sites on 23 occasions between May 2001 and April, 2002. As well thermographs were deployed in the streams which automatically recorded water temperature every hour.

From observations of steam pattern and spot measurements taken for this report, and data from state and forest service monitoring sites, it appears that the warm water temperature of the perennial streams of the caldera may be influenced by bedrock source area. Reasoning are: unusually warm temperatures are recorded for high elevation sites with good forest cover, stream valleys are largely created by faulting associated with volcanism, and warm and mineralized springs occur throughout the VCNP drainages.

Similar to the streams emanating from the VCNP are Rio Guadalupe and its tributary, Rio Cebolla, which have strong fault control, bedrock reaches and temperatures often exceeding standards for cold water fishery, even in high elevation headwater areas with good forest cover. On the other hand, Vallecito Creek south of the preserve is largely derived from slope deposits, indicated by elongated drainage pattern and field verified. Spot sampling of stream temperature during field visit in June, 2009 gave temperatures only one half that of the other streams draining the caldera and its rim.

Dissolved aluminum, an element which is naturally high in the rock type of the caldera, was consistently found to be in exceedence of state water quality standards in all the streams. There were also numerous exceedences of dissolved oxygen, water temperature and pH standards. DO and pH are controlled by growth rate and respiration of aquatic plants, which in turn is somewhat controlled by relatively high levels of phosphorus that were also measured. There was a high degree of exceedence of turbidity standards for samples taken for Jaramillo Creek, East Fork Jemez River and Sulphur Creek, but not the other streams. Water temperature exceeded standards to some extent on all streams, but particularly, in terms of total duration of record, on East Fork Jemez River, and Jaramillo and San Antonio Creeks. Table 2 below summarizes the data collected during the 2001 to 2002 water quality surveys.

Table 2 - Results of 2001-2002 water chemistry surveys. All values = % of samples taken that exceeded standards.

Watershed	Parameters			
	Turbidity	*Temperature*	*pH*	*Dissolved Oxygen*
Jaramillo	40	10	0	14
E.F. Jemez R.	14	21	37	35
La Jara	0	N/A	N/A	N/A
Redondo	5	2	0	0
Indios	1	1	0	0
San Antonio	1	23	51	39
Sulphur	11	N/A	N/A	N/A

Streams in the 2008-2010 integrated 303(d)/305(b) (State of New Mexico, 2008) list of assessed surface waters are Jaramillo, Redondo and Sulphur Creeks. For reasons of turbidity and water temperature these streams are do not fully support designated use of high quality aquatic life. Since 2004 Total Maximum Daily Load (TMDL) has been established for the above mentioned parameters for the Jemez River within the preserve.

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