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Effects of Bovine Exclosure Fencing on Water Quality and Vegetative Conditions, Bluewater Creek, New Mexico

by

Darrell Kundargi

Committee

Dr. Michael E. Campana, Chair
Dr. Roy Jemison, Co-Chair
Dr. Cliff Dahm

A Professional Project Report Submitted in Partial Fulfillment of the Requirements
for the Degree of

Master of Water Resources
Hydroscience Option

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August 2005

Committee Approval

The Master of Water Resources Professional Project Report of **Darrell Kundargi** is approved by the committee:

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ABSTRACT

Livestock grazing can have a profound effect on water quality and vegetation of riparian ecosystems. In this study, the impacts of livestock grazing on surface water quality and vegetation was investigated along Bluewater Creek in the Zuni Mountains of New Mexico. The impacts of grazing were studied by comparing three areas enclosed with bovine fencing in 2003 against unenclosed adjacent areas. A section free of grazing since the 1980s served as a reference area. Sampling sites were further stratified by the dominant geomorphology of incised and stable stream banks. Surface water temperature, conductivity, pH, dissolved oxygen (DO), turbidity, NO_3^--N + NO_2^--N, phosphorous as total P, and fecal coliform were measured in the fall, winter, and spring. Snow NO_3^--N + NO_2^--N and phosphorous as total P levels were also measured. Surface and ground water measurements made in the spring also included NH_4^+-N. Vegetation frequency, percent cover, and biomass were also measured. During the spring snowmelt runoff, mean turbidity levels were higher (37.1 NTU) than fall (12.8 NTU) and winter (3.8 NTU). Turbidity demonstrated a spatial pattern of downstream reduction during the spring runoff. It is possible that this reduction stemmed from the combined effect of the three exclosures. All other water quality parameters were not different between grazed, ungrazed, and the reference area. Seasonal climatic differences such as insolation and precipitation were important controls on water quality parameters. Fall surface water measurements were warmer, slightly more basic, less oxygenated, and contained higher concentrations of total P and fecal coliform (9.9 °C, 7.5, 7.6

mg/L, 0.06 mg/L, 10 cfu/100 mL) than winter (3.5 °C, 7.4, 9.0 mg/L, 0.00 mg/L, 0 cfu/100mL) and spring (2.4 °C, 7.3, 12.0 mg/L, 0.01 mg/L, 0 cfu/100mL).

Surface water and ground water measurements taken in spring demonstrated that ground water was colder, hypoxic, and more conductive (6.9 °C, 1.0 mg/L, 0.6 mS/cm) than surface water (11.3 °C, 9.8 mg/L, 0.2 mS/cm). Nitrate-N + Nitrite-N, ammonium, and total P were not different between surface water and ground water. Vegetation data suggest that desirable species such as *Elymus trachycaulus* and *Salix exigua Nutt.* were more commonly found in the reference and exclosed areas, however low frequencies did not allow a definitive conclusion. Vegetative cover was not significantly different between treatments. Overall biomass was higher in exclosed areas, and may have played a role in downstream reductions in turbidity.

Future study of Bluewater Creek would be well served to include a comparison of channel geomorphology between grazed, ungrazed, and reference areas. Channel width to depth ratio and channel complexity are useful indicators of stream and riparian health. An analysis of piezometer and stream flow elevation data will provide a better understanding of ground water flow paths and the dynamics of ground water and surface water exchange. Analysis of water chemistry should include all forms of inorganic nitrogen. Phosphorous data should be stratified by organic and inorganic phosphorous.

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Definitions

Aggradation: To fill and raise the level of (the bed of a stream) by deposition of sediment.

Allochthonous: Originating from outside a system, such as the leaves of terrestrial plants that fall into a stream.

Autochthonous: Originating from within a system, such as organic matter in a stream resulting from photosynthesis by aquatic plants.

Bailer: A tubular device equipped with a bottom check valve used to remove a volume of water from a piezometer.

Exclosure: An area of land enclosed by a barrier, such as a fence, to protect vegetation and prevent grazing by domestic animals.

Hyporheic: subsurface zone under a river or stream where hydrologic flow paths cause mixing between ground water and surface water.

Herbivory: The state or condition of feeding on plants.

Hysteresis: The lagging of an effect behind its cause.

Nonparametric: Parameter-free or distribution-free method of statistical analysis used for non-normally distributed data.

Piezometer: A nonpumping well, generally of small diameter, for measuring the elevation of a water table or potentiometric surface.

Quadrat: A square geometric instrument for close study of the distribution of plants in an area.

Riparian health: The ability of the interface area between terrestrial and aquatic zones to perform its normal functions, including, but not limited to: sediment filtering, stream bank building, storing water, aquifer recharge, providing fish and wildlife habitat, and dissipating stream energy.

INTRODUCTION

Debate surrounds the ecological effects of cattle grazing on arid rangelands. Research has yielded conflicting, even contradictory data (Jones 2000; Sarr 2002). For example, an upland grazing study in Utah found that vegetative cover was higher in grazed areas while a study conducted on an adjacent valley reported that vegetative cover was greater in ungrazed areas (Brotherson and Brotherson 1981, Johansen and St. Clair 1986). Studies on riparian areas, however, have demonstrated a clearer indication of damage as a result of grazing disturbance (Beck 1980, Belsky et al. 1999, Martin and Chambers 2001, McEldowney et al. 2002). Part of the debate results from different recovery rates of grazed riparian areas. Recovery rates vary widely from system to system, and generally display a hysteresis loop recovery pathway; that is, the rate of recovery is different, often slower, than the rate of disturbance (Sarr 2002).

Revegetation of grazed riparian areas plays an important role in stream water quality recovery rates. Highly grazed areas are "associated with the loss of features that protect the soil surface from rain splash erosion and obstruct or divert overland flow...with evidence of sheet erosion being common," thereby increasing sediment loads to stream channels (Yates et al. 2000). Areas with greater vegetative cover contribute substantially less sediment to stream channels (Yates et al. 2000). Additionally, increased adjacent and in-stream riparian vegetation can decrease water velocity, resulting in sediment aggradation and floodplain formation (Wolman and Leopold 1957; Thornton et al. 1997).

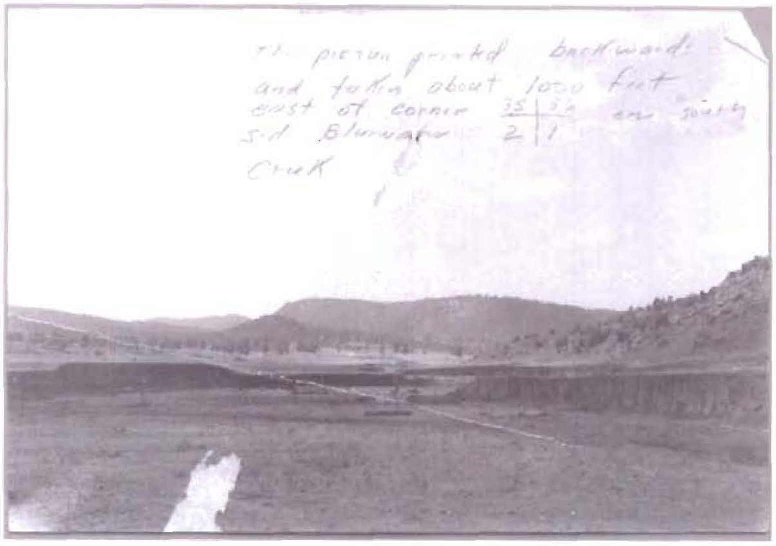
Interactions between surface water and ground water are little studied in relation to riparian health and cattle grazing. It has been shown that hydrologic conditions play an important role in the rate of ecosystem recovery from grazing disturbances to water quality parameters and to increased riparian vegetation. As an example, incised stream channels, common to many low gradient, alluvial basins, can de-couple the stream from pre-grazing hydrology. As a result, the steep, dry banks prevent riparian vegetation from re-establishing (Zonge and Swanson 1996). Describing the effects of cattle grazing on water quality should include an analysis of surface/ground water exchanges and nutrient dynamics.

The nutrient spiraling concept has changed the scientific community's understanding of ground water effects on elemental nutrient metabolism in streams. The spiraling length of nutrients describes the length of a river reach necessary for a chemical nutrient to complete a full cycle of transformation from a solute to a solid (Newbold et al. 1981). Ground water is now understood to be more than a "sink" of aqueous nutrients, such as nitrate and orthophosphate, commonly used to estimate water quality. Hyporheic waters especially are seen as important metabolically active environments (Battin 1999; Malard et al. 2002; Valett et al. 1996). Depending upon the direction of flow, hyporheic waters can be an important source of sequestration or release of nitrogen or phosphorous (Malard et al. 2002). In many streams, productivity is limited by the availability of nitrogen or phosphorous. Thus, the hyporheic zone's role in nutrient spiraling through the sequestration or release of limiting nutrients is important to the recovery rate of exclosed streams (Newbold et al. 1981). The literature suggests that stream and riparian recovery following grazing disturbances is a complex interaction between geomorphology, vegetation, and surface water/ground water interactions (Belsky 1999, Jones 2000).

To better understand the effects of cattle grazing and geomorphology on surface water, ground water, and riparian vegetation, a study was conducted along Bluewater

Creek. The study area was privately owned by the Breece Lumber Company prior to acquisition by the U.S.D.A. Forest Service (Forest Service) in 1947. Under Breece ownership, the entire watershed was heavily logged, and grazed by sheep and cattle (Lava Soil and Water Conservation District 1983). In the early 1980s, the Forest Service conducted riparian restoration treatments on a 2.5 km reach of Bluewater Creek (Lafayette and Pawalek 1989; Lava Soil and Water Conservation District 1983). Critical restoration components included: 1) installation of fencing to prevent bovine grazing, 2) re-vegetation of riparian areas with Coyote Willow, *Salix exigua Nutt.*, and 3) elimination of vehicular traffic. Additionally, University of New Mexico researchers reintroduced beaver, *Castor canadensis* (Figure 1) (U.S.D.A. Forest Service 1987). These measures were expected to improve riparian health and water quality; however no data were collected to document changes. As a result, a quantitative evaluation of riparian health and water quality improvements were impossible. However, a visual analysis suggests significant riparian area recovery over time, including more abundant vegetation and reduced slope angle of incised stream banks (Figure 2). Comparative photographs of upland conditions suggest that conditions have changed over time. From these photographs, improvement or deterioration in upland condition is unclear. Arroyo formation, however, is apparent (Figure 3).

Figure 1. One of multiple beaver dams (above) and beaver lodges (below) within the study area. Beaver were reintroduced to the stream system in the 1980s by University of New Mexico researchers. (U.S.D.A. Forest Service 1987)



1957 Condition

2004 Condition

Figure 2. Comparative photographs of the riparian area exclosed in the 1980s, taken from approximately the same location. Note that the steeply incised banks in the 1957 photograph have begun to attain a gentler slope angle, and more abundant vegetative cover exists. Climatic variables during the time of photograph for both pictures were similar. Fall of 1957 and 2004 were preceded by several years of sustained drought. The subsequent winters of both years were much wetter than average, providing drought relief.

1957 Condition

2004 Condition

Figure 3. Comparative photographs of an upland area at Bluewater Creek. Note the encroachment of shrubs in the 2004 photographs. Additionally, the area circled in red in the 1957 photograph has just begun to erode. By 2004 this area had down cut 2-3 meters.

In 2003, an additional 3.4 km of fencing was installed in three areas upstream of the original Bluewater Creek rehabilitation site. The lengths of the three exclosed areas are: 0.91 km in Area 1 (upstream), 1.68 km in Area 2 (middle), and 0.46 km in Area 3 (downstream) (See Appendix). Coyote Willow was planted in all exclosed areas in April 2004. Additionally, grazing on portions of Bluewater Creek adjacent to exclosed areas is limited to three just weeks during the fall of each year for five consecutive years and rested every sixth year (U.S.D.A. Forest Service 2000). This presented an opportunity initiate an ongoing, systematic analysis of changes in riparian health and water quality resulting from the removal of livestock grazing from sections of Bluewater Creek.

This study shares a trait common to many post-grazing restoration studies in that a suitable control area is not available. The study area has been grazed for decades, and pre-grazing data are unavailable. This necessitated an adaptation of the typical control-treatment approach by using the 2.5 km stretch exclosed in the 1980s as a reference area (Rinne 1988). Reference area data provide an indication of the types of changes that may be expected over time. It does not, however, provide data for a pristine, ungrazed stretch of stream.

Objectives

The purpose of this study was to estimate the effects of bovine exclosure fencing on surface water quality in three newly exclosed areas of Bluewater Creek by comparing water quality changes in exclosed areas with adjacent unexclosed areas and the reference area downstream. Two major objectives comprise the scope of this study.

1. Describe the effects of bovine exclosure fencing on surface and ground water, measured by water chemistry, specifically concentrations of phosphorous as total phosphorous (total P), nitrate+nitrite (NO_3^--N + NO_2^--N), ammonium (NH_4^+-N), fecal coliform, dissolved oxygen (DO), and turbidity.

   H_0: Exclosure fencing has no effect on water quality.
   H_1: Exclosure fencing has an effect on water quality.

2. Estimate the impact of bovine exclosure fencing on vegetative characteristics.

   H_0: Exclosure fencing has no effect on vegetative characteristics.
   H_1: Exclosure fencing has an effect on vegetative characteristics.

METHODS

Site Description

Bluewater Creek is located in the Cibola National Forest, Zuni Mountains, approximately 177 km west of Albuquerque, New Mexico (Figure 4). An intermittent headwater stream, it is one of two main tributaries to Bluewater Lake (DuBey 2003). The stream runs through a valley bordered by bisected Precambrian granite overlain by Yeso Formation sandstone. Hillslope soils are composed of Jeckley rocky complex or Jeckley stony loam (Williams 1967). Soils exposed by channel incision are typically Argillic Aridsols and Mollisols with an argillic layer ranging in thickness from 3 cm to over 1 m. The major geomorphic features of the study area are incised and stable stream banks. The study area ranges in elevation from 2330 meters to 2307 meters above mean sea level.

The study area is instrumented with two Remote Acquisition Weather Stations (RAWS). One station (Bluewater Creek) is located in the valley floor, adjacent to the stream and the other station (Bluewater Ridge) is located near the top of the watershed. Precipitation data are gathered at both stations by tipping bucket rain gauges. During

2004, the upper watershed received 120.47 cm of precipitation, and the valley floor received 86.41 cm (Figure 5). Both values are above the region's annual precipitation of 80 cm (Lafayette 1986). Stream depth at Bluewater Creek measured by a stream gauge that records stage height at fifteen minute intervals. The study site contains 11 well nests; each well nest contains five piezometers, for a total of 55 piezometers. All piezometers were placed within the shallow alluvial aquifer. Within each well nest, piezometers are arranged as quadrangular arrays, allowing for the construction of ground water flow paths.

Study Design

In the study reach there were three exclosed (ungrazed) sections, four unexclosed (grazed) sections, and the reference section (See Appendix). These stream sections combined for eight total sampling areas. Sampling areas were further stratified by the dominant geomorphology of the stream channel: incised banks and stable banks. Stream sections of incised and stable banks that had perennial flow were numbered sequentially, and selected by random number generation such that each exclosed and unexclosed area included an incised and a stable bank. Sixteen total sampling points were established; six ungrazed sections, eight grazed sections, and two reference sections.

Surface water quality samples were taken at the terminal downstream point of geomorphic features. Piezometers were hand bailed with a PVC bailer, and allowed to recover for one hour prior to sampling. Vegetation transects were placed perpendicular to the stream channel at a length sufficient to capture all identifiable stream terraces. Therefore, transects were different lengths.

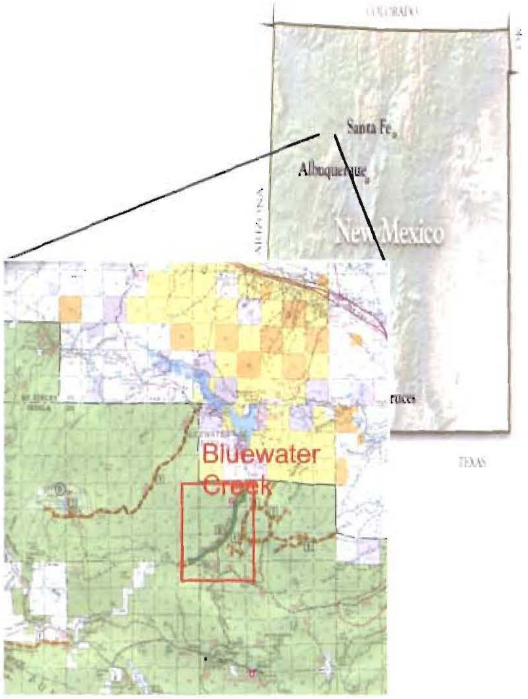


Figure 4. Location of Bluewater Creek, Cibola National Forest, New Mexico. The study area is outlined in red.

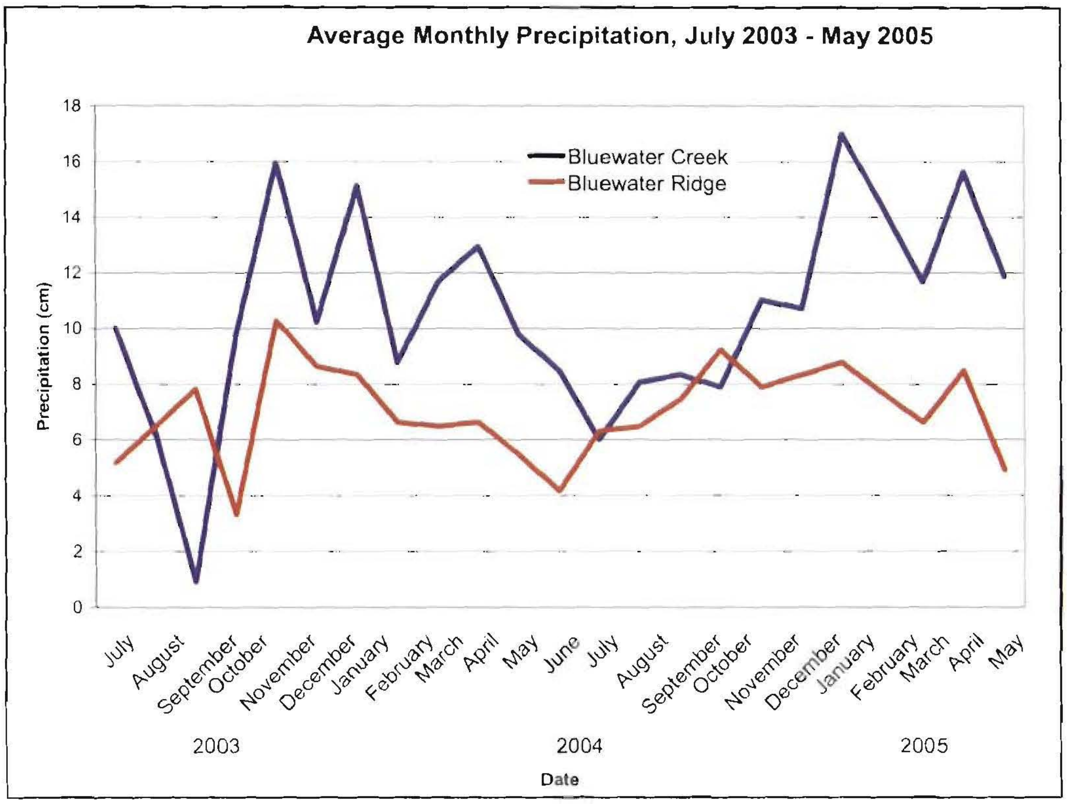


Figure 5. Average monthly precipitation for Bluewater Creek recorded using RAWS. The Bluewater Ridge station is located in the upper watershed, and the Bluewater Creek station is located on the valley floor.

Surface Water

Sampling locations were marked with rebar benchmarks and GPS waypoints to facilitate replication. Sampling occurred in the fall (September and October) of 2004, and the winter (December) and spring (March) of 2005. All surface water samples were taken in the thalweg at 60% of total depth, collected in plastic sample bottles, and transferred to the laboratory within six hours for analysis. Bottles for nutrient samples were acid washed and rinsed three times with de-ionized water. Fecal coliform sample bottles were sterilized in the lab, and required no field rinsing. Lastly, bottles were refrigerated during transport to minimize metabolic transformations. Table 1 provides an overview of parameters measured and methods of analysis.

In the field, water samples for fecal coliform analysis were collected in 120 mL bottles, and preserved with $NaHSO_4$ (sodium bisulfate) and analyzed following EPA Method 9223 B. Two 125 mL water samples were also collected to determine NO_3^--N + NO_2^--N concentrations. One bottle contained 0.25 mL of 80% H_2SO_4 (sulfuric acid) as a preservative. The second sample bottle contained no preservative. One sample per site for total P was collected in a 250 mL bottle containing H_2SO_4 as a preservative. Dissolved oxygen (DO), water temperature, pH, turbidity, and flow rate were measured on site, concurrent with sampling for laboratory analysis. Turbidity was measured on site. A Marsh-McKinney Inc. FlowMate™ 2000 flow meter was used to measure flow rate.

Table 1. Test methods used to characterize water quality parameters.

Parameter	Method	EPA Method No.
Total Phosphorous	Automated Colorimetry	365.1
Nitrate-Nitrite	Ion Chromatography	300.0
Fecal Coliform	Chromogenic Substrate Coliform Test	9223 B
Dissolved Oxygen	YSI Inc. 556 MPS probe	n/a
Temperature	YSI Inc. 556 MPS probe	n/a
pH	YSI Inc. 556 MPS probe	n/a
Conductivity	YSI Inc. 556 MPS probe	n/a
Turbidity	LaMotte 2020 Turbidimeter	n/a
Flow Rate	Marsh-McKinney FlowMate™ 2000	n/a

Ground Water

Ground water samples were taken during the spring flood hydrograph. Prior to sampling, piezometers were hand bailed with a PVC bailer to extract standing water, and allowed to recover prior to sampling. Samples were taken using the same PVC bailer. Storage and handling of all ground water samples were identical to storage and handling of surface water samples. Analysis for all parameters followed the procedures outlined in Table 1.

Vegetation Survey

Vegetation transects were located 10 m upstream of surface water sampling sites. Six transects were placed in ungrazed treatments, eight were placed in grazed treatments, and two transects were placed in the reference area. Transects were sampled during September 2004. The survey used line-intercept methodology (Bonham 1989). Transects were placed across the full width of the channel, and 1 m onto the first terrace. Rebar benchmarks were placed at the terminal points of each transect to provide a fixed reference point and referenced with a GPS waypoint. A 0.1 m^2 nested frequency quadrat was placed 1 m on either side of the cross sectional transect at approximately bankfull height and 1 m on either side of the transect adjacent to and on all stream terraces (Chambers and Miller 2004).

Within each quadrat, nested frequency, estimated ground cover, and biomass as ash free dry weight (AFDW) were measured. Biomass as AFDW was determined by harvesting live materials only, clipped at ground level, and placed in paper sample bags. Samples were oven dried for 48 hours at 60°C (Coulloudon et al. 1999). Species were identified using the taxonomic keys listed in Table 2. Nested species frequency was determined by placing the 0.1 m^2 nested plot frame on each sampling location. Species were given a value of one to four using the following scheme: species occurring in the smallest frame are given a value of four, the next smallest frame (twice as large) a value of three, etc. Using a 0.1 m^2 plot frame, relative species abundance was established by using aerial cover categories, where importance codes are assigned by estimating percentage of aerial cover: 1<1, 2=1-5, 3=6-15, 4=16-25, 5=26-35, 6=36-45, 7=46-55, 8=56-65, 9=66-75, 10=76-85, 11=86-95, 12=96-100.

Table 2. Vegetation taxonomic keys used in this study.

Author(s) or Editors	Title
Allred (1993)	A Field Guide to Grasses of New Mexico
Barkworth et al. (1997)	Flora of North America: North of Mexico. Volume 3
Cronquist et al. (1994)	Intermountain Flora: Vascular Plants of the Intermountain West, U.S.A. Volume 5
Hurd et al. (1998)	Field Guide to Intermountain Sedges
Ivey (2003)	Flowering Plants of New Mexico *4th Ed.*
Martin and Hutchins (1980)	A Flora of New Mexico

Statistical Analysis

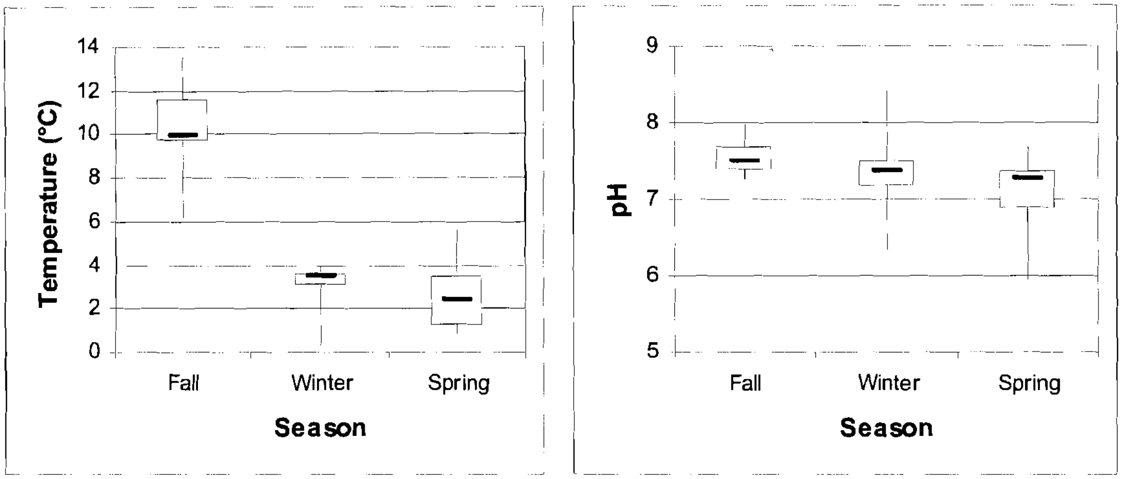
All data were analyzed using SAS statistical software (SAS Institute 1999). Surface water data were analyzed by analysis of covariance using the Proc Mixed procedure. The analysis structure looked at treatment, geomorphic features, and the interaction between the two. Sampling date was included as a third factor, supporting analysis of patterns of seasonal response. Correlation structures present in the turbidity data were assessed and modeled using the alternative residual covariance structures in the Mixed procedure. Differences between ground and surface water data were tested using paired t-test analysis of variance. Group comparisons of nonparametric vegetative nested frequency data were compared between treatments and geomorphic features using Fischer's Exact Test. Biomass measured as AFDW was analyzed with analysis of covariance using the Proc Mixed procedure.

RESULTS

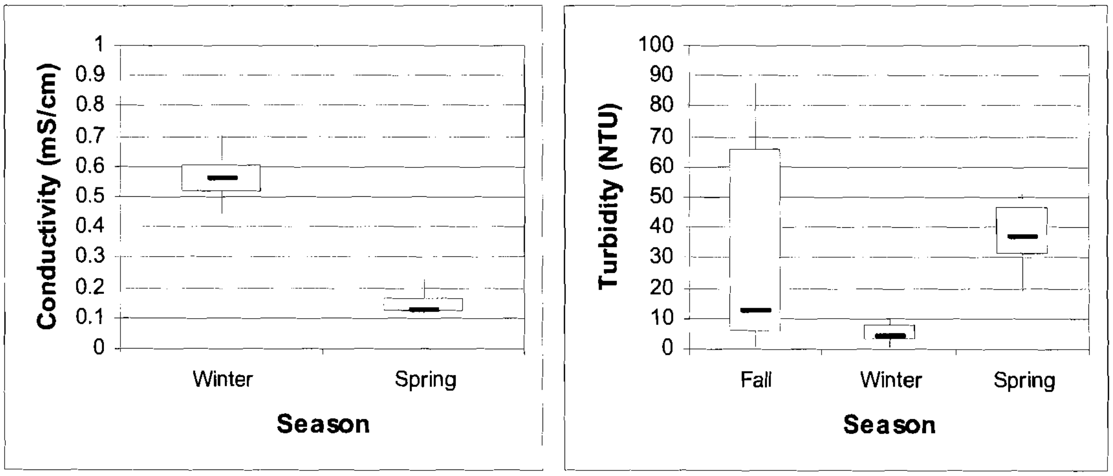
Surface Water

No significant differences were found in water quality parameters - temperature, conductivity, turbidity, DO, pH, NO_3^--N + NO_2^--N, total phosphorous, and fecal coliform - measured in grazed, ungrazed, and reference areas. The measured parameters did not differ in reaches of incised channel geomorphology compared to reaches of stable channel geomorphology. The stream system did display significant seasonal variability in all measured parameters (Figure 6). Mean values of temperature, pH, total phosphorous, and fecal coliform were higher in the fall than winter or spring. Conversely, dissolved oxygen, NO_3^--N + NO_2^--N, and turbidity were higher in the spring than fall and winter (Table 3). Conductivity was not measured in the fall, but mean values in winter were higher that spring. Due to spatially intermittent flow, volumetric discharge data were unobtainable for fall and winter sampling. Average stage height during fall sampling was 19.1 cm, and was 24.6 cm during winter sampling. Discharge during the spring sampling period was 0.23 m^3/s, measured at the stream gauge.

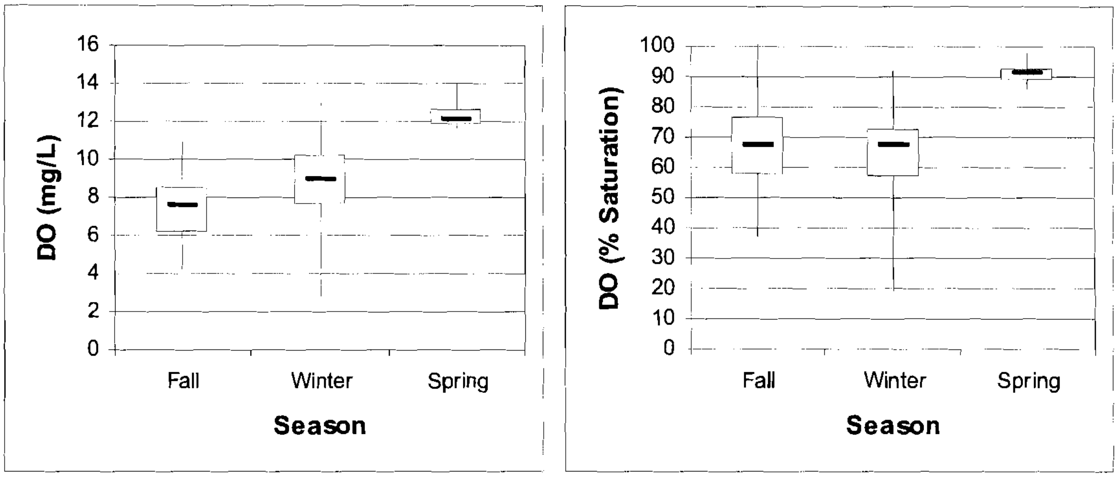
Autoregressive correlation modeling demonstrated that for winter and spring, there was a general downstream trend in turbidity values (Figure 7). The distance from an upstream site to the next site directly downstream are listed in Table 4. All other parameters did not demonstrate a correlation with stream position.



P < 0.0001 P = 0.0016

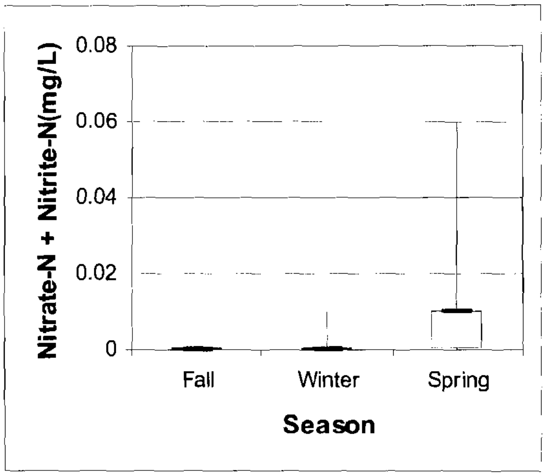


P < 0.0001 P < 0.0001

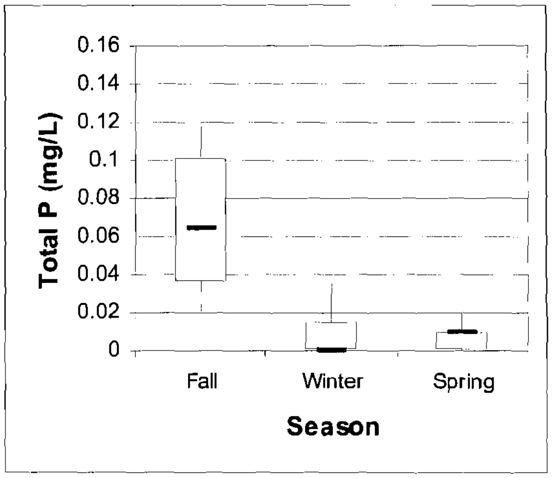


P < 0.0001 P = 0.0006

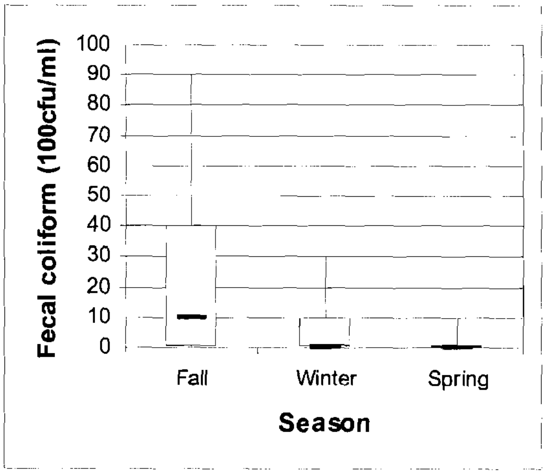
Figure 6. Box plots of statistically significant seasonal variability of water quality parameters, fall 2004 through spring 2005. P values for each parameter are listed under its corresponding graph. Number of observations are n=16 per season, n=48 samples for the entire three season period.



P = 0.0039



P < 0.0001

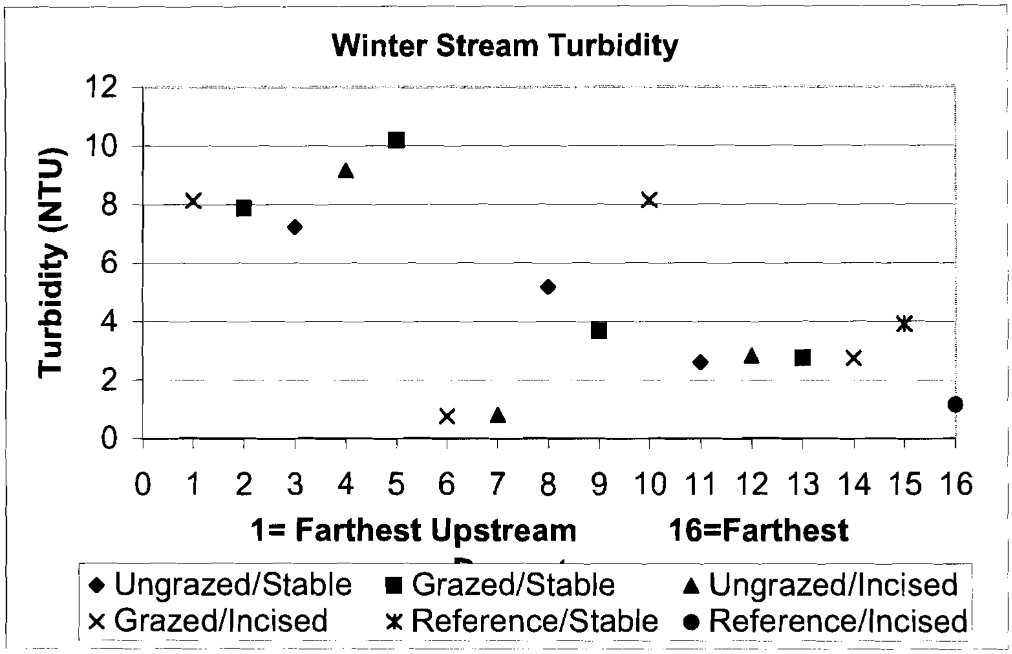


P<0.0001

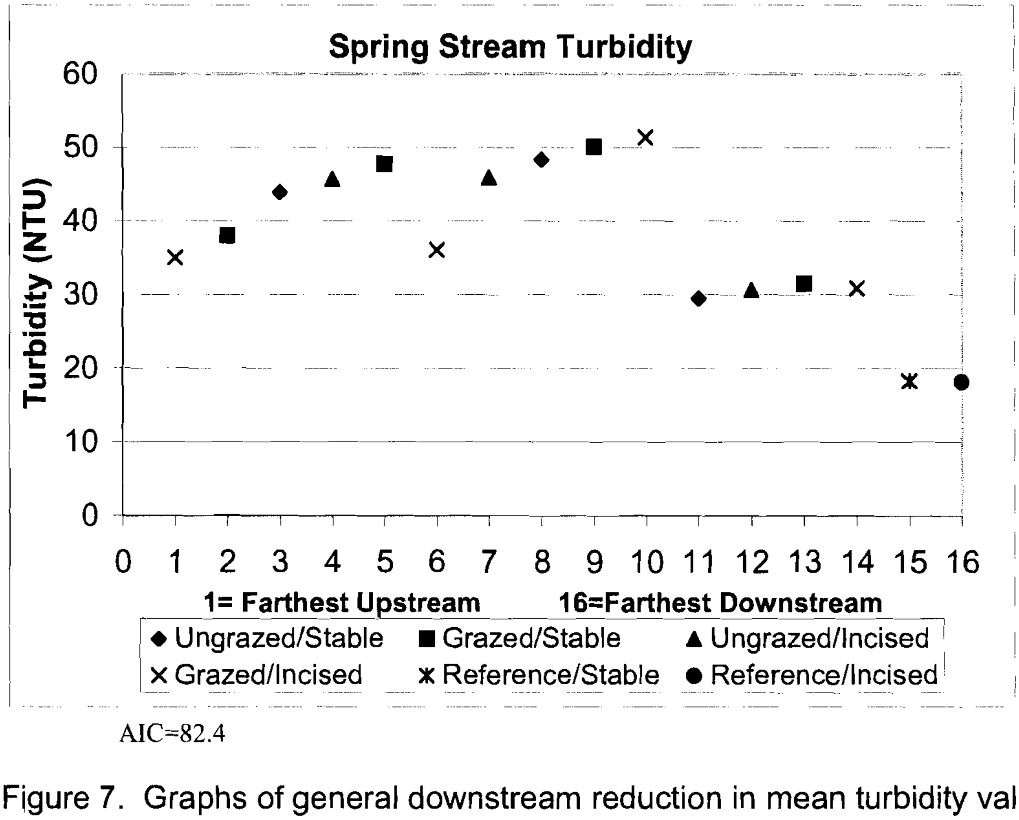
Figure 6. Continued.

Table 3. Season when samples were taken, number of observations, mean values, and standard error of water quality parameters.

Parameter	Season	N	Mean	Standard Error
Temperature (°C)	Fall	17	9.9	0.4
	Winter	16	3.5	0.3
	Spring	16	2.4	0.3
Conductivity (mS/cm)	Winter	16	0.56	0.02
	Spring	16	0.12	0.01
DO (mg/L)	Fall	17	7.6	0.5
	Winter	16	9.0	0.6
	Spring	16	12.0	0.2
DO (% Saturation)	Fall	17	67.3	4.1
	Winter	16	67.5	4.3
	Spring	16	91.2	0.8
pH	Fall	17	7.5	0.0
	Winter	16	7.4	0.1
	Spring	16	7.3	0.1
Turbidity (NTU)	Fall	17	12.8	6.3
	Winter	16	3.8	1.8
	Spring	16	37.1	1.0
NO_3^--N + NO_2^--N (mg/L)	Fall	17	0.00	0.00
	Winter	16	0.00	0.00
	Spring	16	0.01	0.00
Total Phosphorous (mg/L)	Fall	17	0.06	0.01
	Winter	16	0.00	0.00
	Spring	16	0.01	0.00
Fecal coliform (cfu/100 mL)	Fall	17	10	6
	Winter	16	0	2
	Spring	16	0	1
Stage height (cm)	Fall	6	19.1	0.3
	Winter	10	24.6	0.3
Discharge (m^3/s)	Spring	3	0.23	0.03



AIC=65.9



AIC=82.4

Figure 7. Graphs of general downstream reduction in mean turbidity values during winter and spring. The low value at position six may be due to the site's proximity to a transition zone from subsurface to surface flow. The estimated correlation (AIC) for each season is listed under each graph.

Table 4. Distance of sampling sites from Site 1. Site 1 is the farthest upstream site, Site 16 is the farthest downstream.

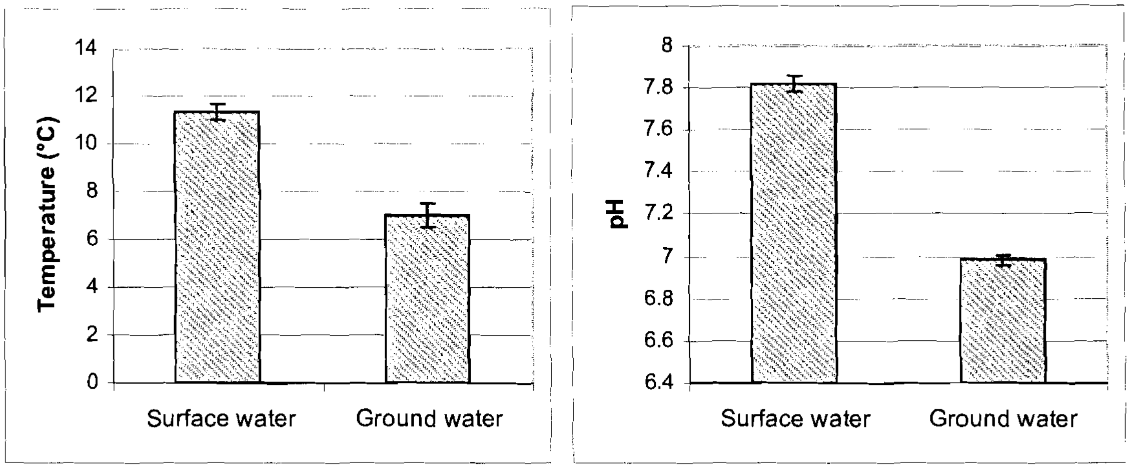
Site	Treatment	Geomorphology	Distance from Site 1 (m)
1	Grazed	Incised	0
2	Grazed	Stable	73
3	Ungrazed	Stable	129
4	Ungrazed	Incised	397
5	Grazed	Stable	1703
6	Grazed	Incised	1933
7	Ungrazed	Incised	2301
8	Ungrazed	Stable	3061
9	Grazed	Stable	3624
10	Grazed	Incised	3678
11	Ungrazed	Stable	3958
12	Ungrazed	Incised	4045
13	Grazed	Stable	4228
14	Grazed	Incised	4380
15	Reference	Incised	8588
16	Reference	Stable	8973

Ground Water

Four sites were instrumented with shallow alluvial ground water piezometers and were sampled on April 16, 2005, during the spring runoff period. Discharge at that time was 0.27 m^3/s. Ground water flow direction was not established quantitatively, but saturated soils throughout the study reach suggest a high probability of ground water contributions to the stream system.

Significant differences for dissolved oxygen, temperature, conductivity, pH, and total P existed between ground water and surface water samples (Figure 8). Differences between ground water and surface water values of nitrogen, measured as NO_3^--N + NO_2^--N and NH_4^+-N were not statistically significant. Ground water was hypoxic, with mean values of dissolved oxygen at 7 % saturation and 1.0 mg/L, while surface water was well saturated with mean values of dissolved oxygen at

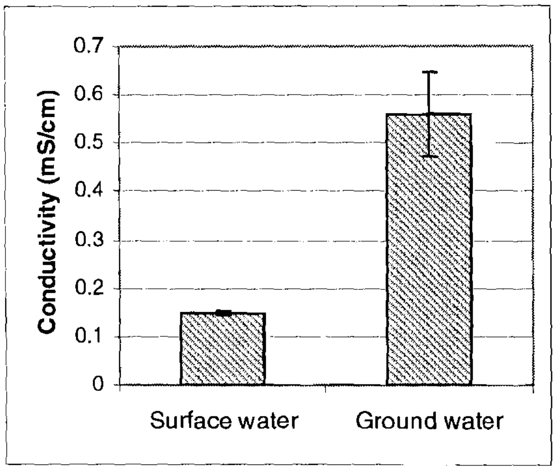
89.6 % saturation and 9.8 mg/L. Additionally, ground water was cooler (6.9 °C) than surface water (11.3 °C), and more conductive (0.6 mS/cm) than surface water (0.2 mS/cm). The pH of ground water samples was relatively neutral at 6.9, while surface water samples were slightly more basic at 7.8. Differences between surface water and ground water concentrations of total P, NO_3^--N + NO_2^--N, and NH_4^+-N were not statistically significant. Total P was absent from all ground water samples, whereas surface water samples had mean values of 0.02 mg/L, and displayed high variability (Figure 8). Mean ground water values of NO_3^--N + NO_2^--N were 0.02 mg/L and 0.09 mg/L for NH_4^+-N. Surface water concentrations of NO_3^--N + NO_2^--N were 0.005 mg/L and for NH_4^+-N were 0.03 mg/L. The mean N:P ratio for the stream reach was 1.77, with a high of 9.00 and a low of 0.00.



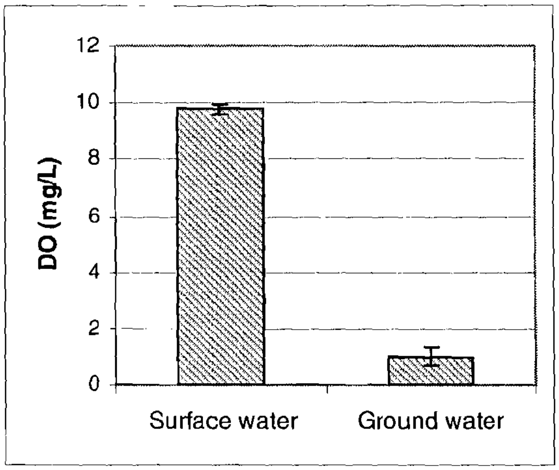
P = 0.0017

P = 0.0010

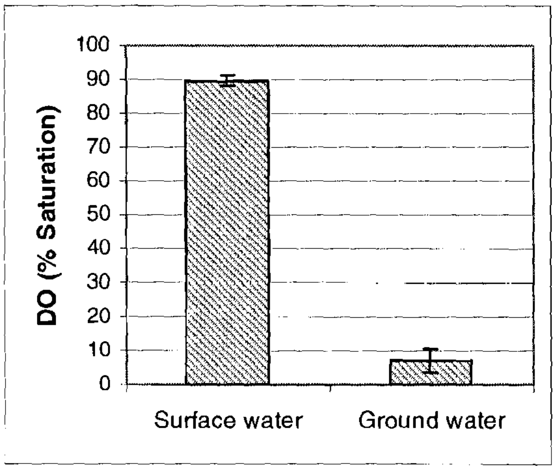
Figure 8. Comparative graphs of water quality parameters for ground water and surface water, measured April 16, 2005. P values for each parameter are listed under its corresponding table. Observations for surface and ground water: n=8, n=4 for surface water and n=4 for ground water. Error bars represent standard error.



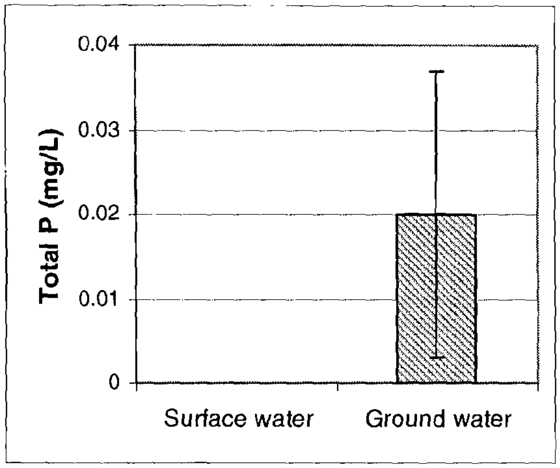
P = 0.0196



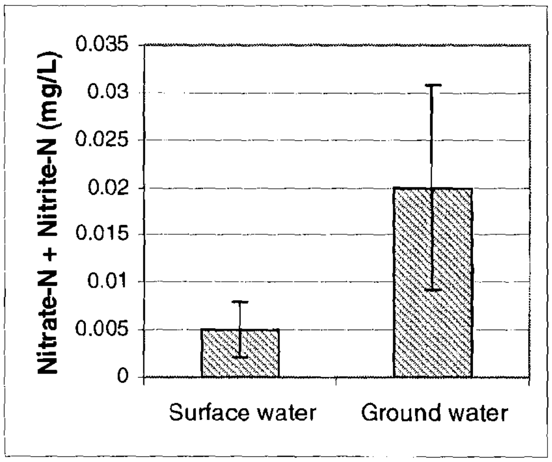
P=0.0002



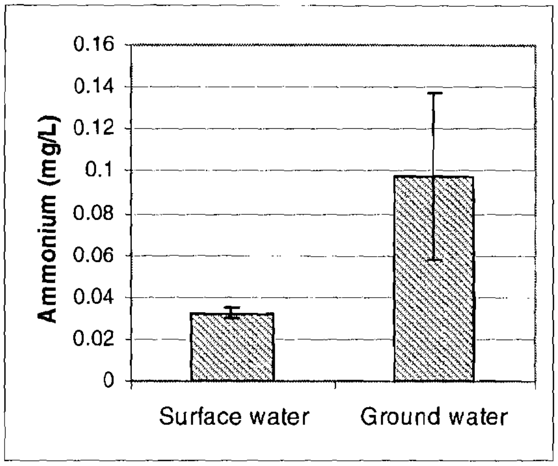
P < 0.0001



P=0.3203



P = 0.3189



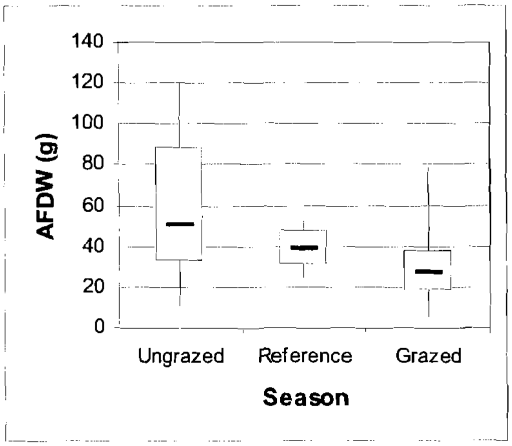
P = 0.1928

Figure 8. Continued.

Vegetation

The different treatment areas (grazed, ungrazed, and reference) and channel reaches (stable and incised) had similar plant species richness, but different amounts of plant biomass. Vegetation consisted primarily of riparian grasses and a few forbs (Table 5). Vegetation frequency results suggested that treatment type and geomorphology acted as main effects; desirable species such as *Elymus trachycaulus*, a grass common in late successional stages, were found in less disturbed areas, while non-native species were more common in disturbed areas (Table 6).

Above ground plant biomass was significantly higher in exclosures (60.1 g), than in unexclosed areas (32.4 g). Reference area vegetative biomass (38.8 g) did not differ significantly from grazed and ungrazed treatments. Biomass did not differ between geomorphology as a main effect, nor did interactions between geomorphology and treatment type play an important role in plant biomass (Figure 9).



P=0.0112

Figure 9. Ash free dry weight (AFDW) was significant for treatment as a main effect. Ungrazed areas supported more biomass than the reference or grazed treatments.

Table 5. List of species for all plots, grouped by treatment. There were a total of 16 transects, six transects were placed in ungrazed areas, eight in grazed areas, and 2 in the reference area.

	Treatment					
	Reference		Grazed		Ungrazed	
Plant Species	n	Percentage of total transects	n	Percentage of total transects	n	Percentage of total transects
*Agrostis**	2	13%	5	31%	6	38%
Ambrosia artemesia	0	0%	4	25%	2	13%
Aster foliaceus	1	7%	4	25%	5	31%
*Carex occidentalis**	1	7%	0	0%	2	13%
*Carex vesicaria**	2	13%	2	13%	0	0%
*Eliocharis macrostachya**	2	13%	5	31%	5	31%
*Elymus trachycaulus**	1	7%	0	0%	0	0%
Equisetum laevigaetum	2	13%	5	31%	5	31
Gentian	2	13%	1	7%	0	0%
Juncus articulatus	0	0%	5	31%	2	13%
Juncus bufonius	0	0%	2	13%	0	0%
Juncus filiformis	1	7%	0	0%	0	0%
Juncus mexicanus	2	13%	6	38%	6	38%
Medicago lupilina	0	0%	2	13%	1	7%
Mentha arvensis	1	7%	2	13%	0	0%
*Muehlenbergia asperfolia**	0	0%	1	7%	1	7%
*Pascopyrus smithii**	1	7%	0	0%	0	0%
Plantago lanceolata	1	7%	2	13%	1	7%
*Poa pratensis***	0	0%	4	25%	0	0%
Potentilla	0	0%	3	19%	1	7%
Sage	0	0%	2	13%	0	0%
*Salix exigua Nutt.**	1	7%	0	0%	0	0%
Scirpus americanus	0	0%	0	0%	1	7%
Scirpus olneyi	1	7%	5	31%	4	25%
Solidago missouriensis	0	0%	1	7%	0	0%
Thermopsis pinetorium	0	0%	2	13%	1	7%
Trifolium	2	13%	8	50%	3	19%
Yarrow	0	0%	1	7%	0	0%

* Desirable or later successional stage species.

** Non-native species.

Table 6. Species composition of all plots, grouped by effect.

Species	Effect	P
*Carex vesicaria**	Treatment	0.0038
*Eliocharis macrostachya**	Treatment	0.0499
*Elymus trachycaulus**	Treatment	0.0182
*Juncus filiformis**	Treatment	0.0182
*Juncus articulatus**	Geomorphology	0.0464
*Medicago lupilina**	Geomorphology	0.0231
*Poa pratensis***	Geomorphology	0.0160
*Scirpus olneyi**	Geomorphology	0.0411

* Desirable or later successional stage species.

** Non-native species.

DISCUSSION

Surface Water

The most prominent finding in this study was the general downstream decrease in turbidity values during the spring runoff. The spring pattern of downstream reduction in turbidity suggests that decreases in mean values may not be continuous, but may instead be a step function (Figure 7). Stepped decreases in spring turbidity may be a result of the ungrazed areas. The reach scale reduction in turbidity may due to the combined effect of the three ungrazed treatments (Ankcorn 2003; Case 1997; Thornton et al. 1997). It may be that advective transport mechanisms prevented making a clear distinction of differences in turbidity between grazed and ungrazed areas. For example, sediment may be mobilized in an upper, grazed area, but a downstream measurement in an ungrazed area may be artificially high due to the upstream input.

This finding has strong implications on the role of exclosure fencing on water quality. State and federal watershed analyses have indicated that erosion and sedimentation problems are severe at Bluewater Creek (Jacobi and Smolka

1983, Lava Soil and Water Conservation District 1983). Sediment inputs from instream channel incision, bank sloughing, and upper watershed erosion combine to create high levels of turbidity within Bluewater Creek. Similar conditions exist in a stream reach downstream of the study site. An earlier study of this downstream reach found an increase in turbidity in the downstream direction (Jacobi and Smolka 1983). The turbidity reductions found in this study indicate that the hypothesized improvements to water quality as a result of excluding grazing may be measured after only one year of recovery. Over time, improvements to water quality may take place at the reach scale (Rinne 1985; Robertson and Rowling 2000; Scrimgeour and Kendall 2002). Of the parameters measured in this study, turbidity may be the best indicator of ecosystem recovery.

A 1995 grazing study of four New Mexico streams found that stream channel geomorphology is a useful indicator of riparian recovery from grazing disturbance (Moyer 1995). The ratio of channel width to depth (w/d) is one geomorphic indicator of stream health. A high w/d ratio is characteristic of streams that been grazed, while narrower and deeper channels are more common in stream systems protected from grazing. Additionally, ungrazed streams more often posses higher channel complexity (e.g. undercut stream banks and higher channel roughness) than grazed streams. The w/d ratio and channel complexity combine to create cooler stream temperatures and more diverse habitat for aquatic biota. These data may be used in conjunction with turbidity data to provide some indication of channel stability and necessary conditions to support higher amounts of aquatic biota.

The results from Bluewater Creek did not reveal significant differences between grazed and ungrazed treatments, nor with the reference area. Non significant results were not unexpected. The lack of significant findings may be partially attributed to the short time since treatment application and to the nature of the study site. Only one year has passed since the removal of cattle grazing from sections of Bluewater Creek. There may not have been sufficient time for the riparian ecosystem to recover from disturbance, and for changes to water quality to take place. The geographic layout of the exclosures may have been an additional factor. The three exclosures and reference area are located on the same stream system, and separated by grazed areas. Interactions between the different treatment areas may have been the cause of the non-significant findings. Two important components of this interaction are the advective transport mechanisms of surface water flow and nutrient uptake by primary producers (Gold et al. 2001; Vannote et al. 1980). Nutrients and particulates may be mobilized in one treatment area, but quickly flushed to a different, downstream treatment area. Thus, nutrients and particulates measured in one treatment area may have been initially mobilized in an upstream treatment area. Similarly, nutrients mobilized in an upstream treatment area may be utilized by plants, algae or microbes prior to downstream measurement. The effect of these interactions compounds the difficulty in making a distinction between the effects of different treatment areas.

Season was the dominating influence on surface water quality. During the fall sampling period water temperatures were higher and dissolved oxygen levels were lower than winter and spring sampling periods. Higher ambient air temperatures and greater insolation during the fall are likely to explain the higher fall water temperature (Danehy et al. 2005). Oxygen is less soluble as temperatures increase, and is a partial explanation for the lower concentrations of dissolved oxygen during the fall, relative to the winter and spring (Bales et al. 1993; Wetzel 2001). Additionally, Bluewater Creek was spatially intermittent during the fall and winter, and microbial respiration in the slow moving waters contributes to the reduced fall and winter concentrations of dissolved oxygen. Conductivity of the stream system was higher in winter than in spring. Flow was much higher in spring and it is likely that dilution during the spring snowmelt runoff period had an important effect on the reduced level of conductivity (Bales et al. 1993).

Turbidity was significantly less (p=0.0139) during the winter than during the fall and spring. Surface water froze to a depth of 10 to 15 centimeters during the winter, resulting in slow velocities and deposition of suspended fine sediments (Ritter 1978; Thornton et al. 1997). Periodic inputs of fresh sediment from brief rainfall/runoff events were the main cause of higher fall turbidity levels than winter levels. The high variability of turbidity may be related to different environmental conditions present at each study site, and intensified by spatially intermittent surface flow conditions during the fall. Soil type, vegetation, presence of ephemeral channel sediment inputs, and flow velocity differed between intermittent sections of surface flow. Samples taken during the spring runoff period held the predictably highest value of mean turbidity (Ritter 1978; Thornton et al. 1997). Many side channels are actively head cutting (Figure 10) and contributing sediment to Bluewater Creek. Periods of sustained flow during spring resulted in higher spring levels of turbidity (McEldowney et al. 2002).

Figure 10. Several head cut side channels enter Bluewater Creek in the study area and are a source of sediment during runoff events.

Nitrogen as NO_3^--N + NO_2^--N and phosphorous as total P showed an inverse relationship relative to season. The mean N:P ratio of 1.77 strongly suggests that nitrogen is the limiting nutrient at Bluewater Creek. It is important to note that the nitrogen data from this study were a measure of inorganic nitrogen, while the phosphorous data were a combination of organic and inorganic nitrogen. Thus, the N:P ratio may be artificially high. However, nitrogen limited stream systems are not uncommon in New Mexico. A study of a tributary stream system to Bluewater Creek found nitrogen limitation in that system (Coleman and Dahm 1990). NO_3^--N + NO_2^--N concentrations in the fall were below detection level, while concentrations of total P were the highest of all seasons measured. Nutrient inputs can come from allochthonous or autochthonous sources, which are difficult to discern in this study. With that said, one possible explanation for high concentration of total P in the fall is that nitrogen available for microbial processes was completely utilized, leaving remaining phosphorous in excess. During the winter, the mean concentration of NO_3^--N + NO_2^--N was 0.01 mg/L in surface water samples, while snow samples had mean concentrations of 0.27 mg/L. Although snow samples were not measured for NH_4^+-N, it is likely that ammonium constituted a significant portion of inorganic nitrogen contained within snow. Data collected over fifteen years at the Sevilleta Long Term Ecological Research Program reveal that ammonium constituted 57% of inorganic nitrogen found in precipitation (Moore 2005). While not an exact comparison, the Sevilleta data may be taken as a rough proxy of possible NH_4^+-N content of snow within the Bluewater Creek watershed. During the spring runoff period, snowmelt contributions of NO_3^--N + NO_2^--N to surface water had a strong effect on the relatively high spring concentrations of NO_3^--N + NO_2^--N. As a potentially limiting nutrient, the abundance of inorganic nitrogen during the spring may have allowed for increased microbial utilization of all available nutrients, resulting in lowest concentrations of total P (0.006 mg/L) during this period (Wetzel 2001).

Surface Water and Ground Water Interactions

Sampling of surface and ground water during spring runoff revealed expected differences in pH, conductivity, temperature, dissolved oxygen, and nitrogen. The pH of ground water samples was more neutral (6.9) and more conductive (0.6 mS/cm), while surface water was slightly more basic (7.8) and less conductive (0.2 mS/cm). While the pH of ground water corresponds to lower levels of the bicarbonate ion (HCO_3^-) than the pH of surface water, conductivity is a measure of all charged particles found within the sample (Wetzel 2001). The higher ground water pH can be attributed to the presence of ions other than bicarbonate within the samples. Ground water was cooler (6.9 °C) than surface water (11.3 °C) and hypoxic (1.0 mg/L of dissolved oxygen) compared to the well-oxygenated surface water (9.8 mg/L). Dissolved oxygen is regulated by temperature, microbial activity, atmospheric exchange, and hydrology (Wetzel 2001). Cooler temperatures increase the solubility of oxygen, while microbial activity utilizes dissolved oxygen for respiration. The diffusion of oxygen from surface water to ground water through the sediment water interface causes a reduction in dissolved oxygen in ground water (Carr 1989; Dahm et al. 1998; Valett et al. 1996; Wetzel 2001). Microbial respiration and limited oxygen diffusion through the sediment layer probably had the greatest effect on ground water hypoxia. In turn, hypoxic conditions play a role in the forms of nitrogen found in ground water, which is typically in its reduced form of NH_4^+-N (Gold et al. 2001).

Mean ground water concentrations of nitrogen in its oxidized forms of NO_3^--N + NO_2^--N, its reduced form as NH_4^+-N, as well as phosphorous as total P, were non-significant compared to surface water. The presence of NH_4^+-N in surface and ground water could be the result of ammonification of organic nitrogen to NH_4^+-N (Wetzel 2001). In addition to ammonification, ground water hypoxia may have supported dissimilatory nitrate reduction to ammonium, resulting in higher levels of NH_4^+-N in ground water (Schade et al. 2002). It would seem at first glance that nitrate reduction would correspond to lower NO_3^--N + NO_2^--N levels in ground water. However, the supply of this potentially limiting nutrient during floods has been found to outstrip ground water utilization (Gold et al. 2001; Schade et al. 2002). As a result, NO_3^--N + NO_2^--N in excess of demand can remain in ground water during spring runoff. Numerous processes are involved in phosphorous cycling (Wetzel 2001). A combination of processes may result in the overall loading of ground water by surface water, especially during periods of high levels of total P, such as the fall. Morrice et al. (1997) have found that climatic influences on stream discharge and the hydraulic conductivity of alluvial materials are important controls on the exchange between surface and ground water. The rate and direction of this exchange are further controls on nutrient cycling.

Vegetation

The data suggest that the presence of desirable and undesirable species is related to treatment, and that interactions exist between treatment type and geomorphology. Overall, plant biomass responded to treatment after one year of recovery from livestock grazing.

It is difficult to make a precise determination of the effects of treatment, geomorphology, and interactions between the two, due to low frequencies in the data. However, later successional stage species (*Carex vesicaria, Elymus trachycaulus,* and *Juncus filiformis*) were found in statistically significant amounts primarily in the reference area, while *Eliocharis macrostachya* occurred in significant amounts in both exclosed and reference areas. This finding suggests that the reference area, ungrazed for approximately 20 years, has had sufficient time to recover from grazing disturbance (Pykälä 2003; Robertson and Rowling 2000; Skartvedt 2000; Yates et al. 2000). While the non-native grass *Poa pratensis* was found more often in incised sections of river, other desirable species (*Juncus articulatus* and *Medicago lupilina*) were also found in these sections. Thus, it becomes difficult to assess the relative effects of geomorphology on vegetation (Belsky et al. 1999; Yates et al. 2000).

Plant biomass was higher in statistically significant amounts in ungrazed areas than in grazed areas, while biomass in the reference area was not significantly different than the grazed and ungrazed areas. Higher biomass in the ungrazed areas is consistent with the findings of other studies, and the annual consumption of vegetative biomass by cattle is linked to lower amounts of biomass in grazed areas (Beck 1980; Martin and Chambers 2001; Oba et al. 2001; Shiyomi et al. 1998). While a qualitative measure, the classic "fence line contrast" of grazed versus ungrazed areas is readily apparent throughout the study site (Figure 11). The effect of differences in biomass may play a role in the downstream reduction in turbidity discussed in the previous section. Greater amounts of vegetation in ungrazed areas increases the roughness coefficient of the stream system, and reduces surface water velocity (Thornton et al. 1997; Wolman and Leopold 1957). Increased vegetation also acts as a filter, promoting greater deposition of suspended sediments and the reduced turbidity.

It is important to note that areas exclosed from cattle were not completely free of grazing. Herbivory by wild ungulates occurred in grazed, ungrazed, and reference areas. Additionally, burrowing rodent activity caused disturbances to soils and vegetation in all areas. Reach scale differences in morphology, geology, and hydrology can play a significant role in vegetative patterns (Bridge and Johnson 2000). Additionally, the number of reference area vegetation transects was not equal to the number of transects in grazed and ungrazed areas. These factors may partially explain why reference biomass was not higher than grazed and ungrazed biomass.

Figure 11. The classic "fence line contrast" of a grazed area on the left versus the ungrazed area to the right. This visual depiction of differences in plant biomass is consistent with findings of this study.

CONCLUSIONS

Of the parameters measured, turbidity was the best indicator of ecosystem recovery in this stream system. It had an overall reduction in the downstream direction. The reduction in turbidity may have been due to the combined effects of the three grazing exclosures. After only one year of exclusion from grazing by domestic livestock, the increased vegetative biomass in the ungrazed areas was reducing flow velocities and increasing sediment deposition. Comparisons of ungrazed areas to adjacent grazed areas did not reveal differences in turbidity at the treatment scale. Analysis of data over the entire study reach did indicate a downstream reduction in turbidity. As such, trends in ecosystem recovery from grazing disturbance may be apparent at the reach scale, not at the treatment scale.

In many respects, other data from this study proved inconclusive in determining the effects of bovine exclosure fencing on surface water, ground water, and riparian vegetation. As a study in change over time, inconclusive results from these early data were to be expected. Bluewater Creek did display seasonal trends in surface water parameters. These findings suggest that, over short time periods, environmental factors such as insolation and precipitation may be controlling. Data from continued monitoring may reveal more conclusive trends in ecosystem recovery.

A comparison of surface and ground water during the spring runoff revealed expected differences in temperature, dissolved oxygen, and conductivity. Ground water samples were colder, less oxygenated, and more conductive. Ground water hypoxia has been found to have a significant effect on nutrient cycling and nutrient concentrations, but these differences were not significant in this study.

Plant species distribution results were less conclusive than biomass results. Some later successional stage species were found in statistically significant amounts primarily in the reference area, while other late stage species occurred in significant quantities in the exclosed and reference treatment areas. This finding suggests that the reference area, ungrazed for approximately 20 years, has had sufficient time to recover from grazing disturbance. While a non-native grass was found in an incised stream section, other desirable species were also found in these sections. The presence of invasive and desire species in significant amounts in the same area make it difficult to assess the relative effects of geomorphology on vegetation. Future studies at this site would be well served to focus on the role of geomorphology on ecosystem recovery.

Vegetative biomass was significantly higher in areas recently exclosed from grazing relative to grazed areas. Grazed areas have to recover from high intensity grazing for three weeks by domestic livestock on an annual basis, while ungrazed sections only have to recover from intermittent, and interspersed grazing from wild herbivores. The increased vegetative biomass in ungrazed areas may have the effect of decreasing flow velocity and trapping suspended sediment. Decreased flow velocities may also reduce nutrient spiraling length and increase nutrient cycling. Plant biomass in the reference area was not significantly different than that in the grazed and ungrazed areas. Reach scale geomorphology, and hydrology may have played a role in this finding.

Recommendations for Future Research

Continued study of Bluewater Creek would be well served to implement alterations to this study. Comparisons of channel geomorphology between grazed, ungrazed, and reference areas may provide important data to help land managers better understand ecosystem recovery. Channel width to depth ratio and channel complexity are useful indicators of stream and riparian health. Analysis of water chemistry should include all forms of inorganic nitrogen. Phosphorous data should be stratified by organic and inorganic phosphorous. An analysis of piezometer and stream flow elevation data will provide a better understanding of ground water flow paths and the dynamics of ground water and surface water exchange. Future studies may also be well served to implement reach scale monitoring schemes that look for downstream reductions in turbidity as an indicator of ecosystem recovery.

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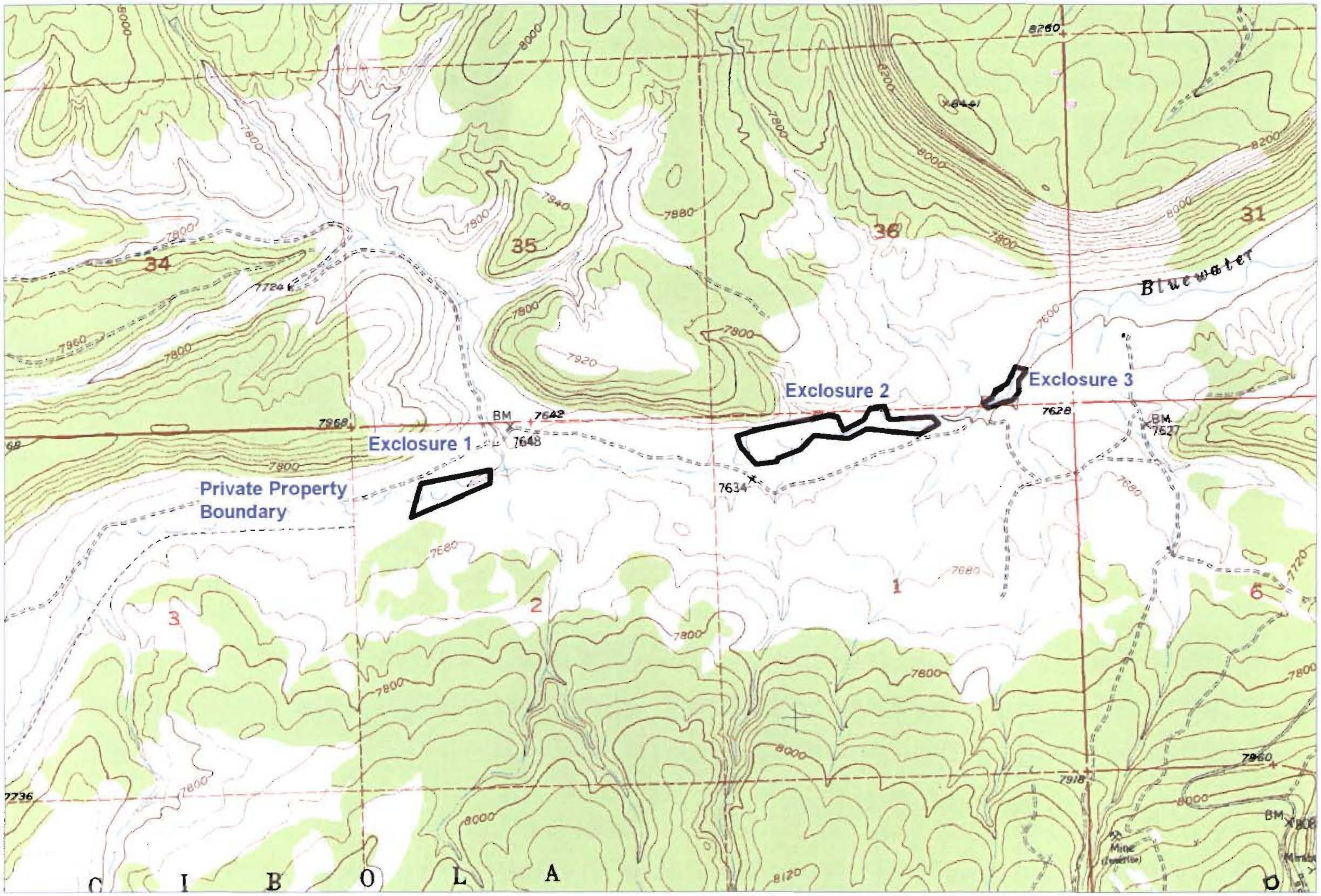
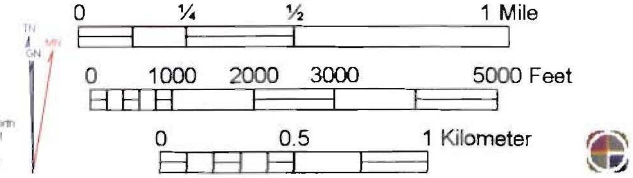
Appendix

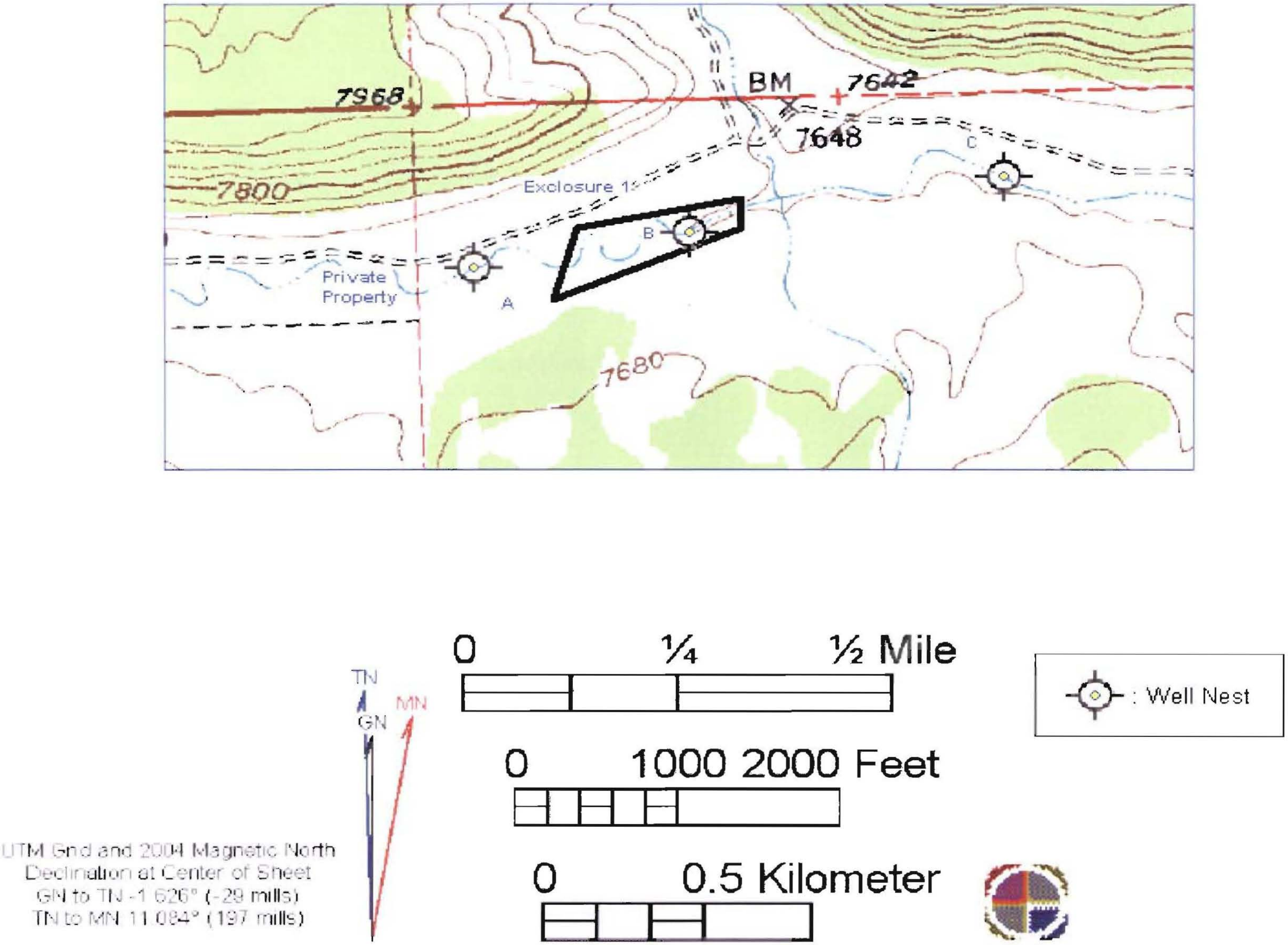
Maps of Exclosure Placement





1927 North American Datum;
Generated by BigTopo7 (www.igage.com)
Map compiled from USGS Quads: Post
Office Flat; NM

BigTopo Map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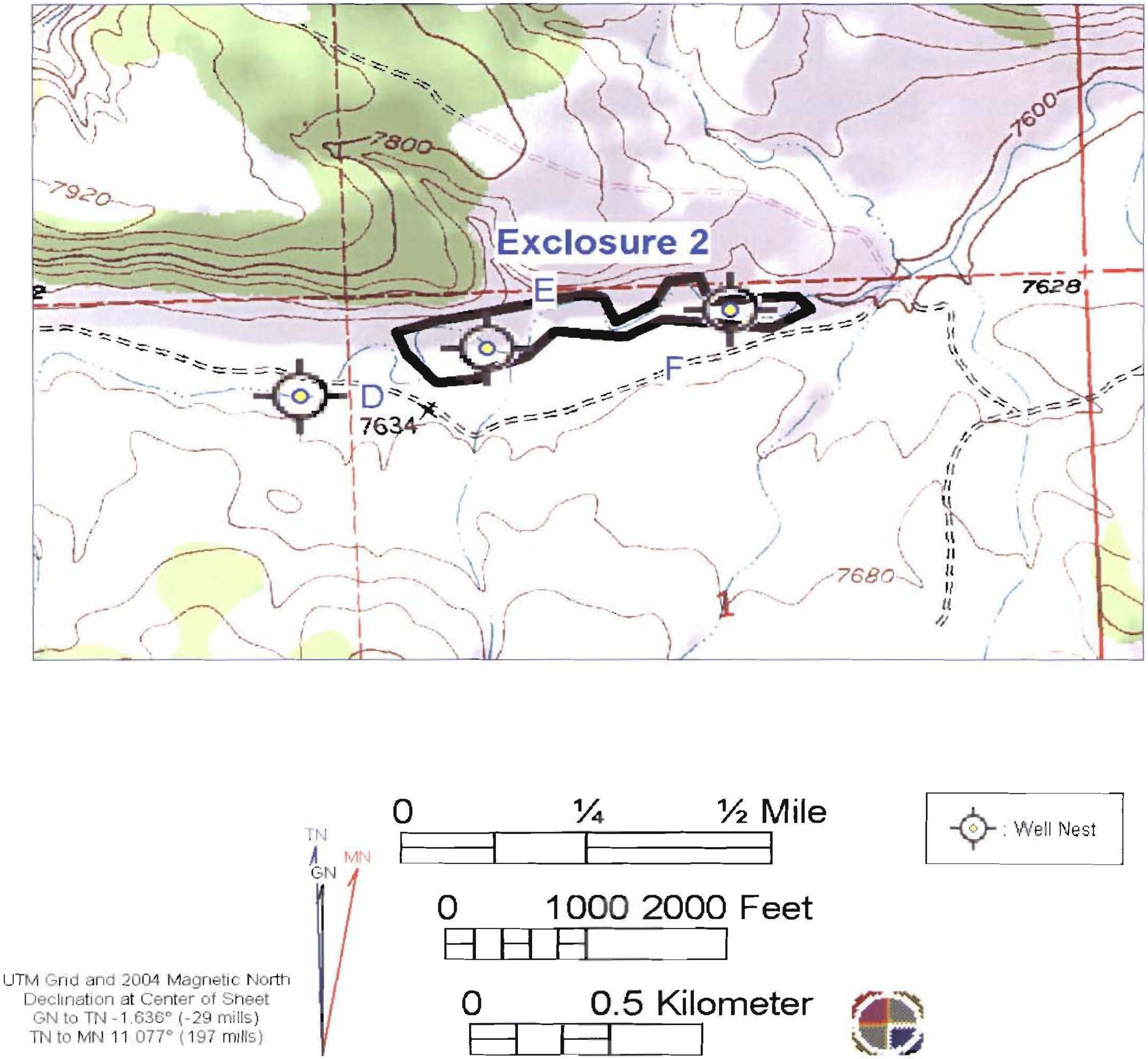
GN
MN
UTM Grid and 2004 Magnetic North
Declination at Center of Sheet
GN to TN -1.626° (-29 mills)
TN to MN 11.084° (197 mills)


Exclosure 2
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0 0.5 Kilometer
: Well Nest
TN
GN
MN
UTM Grid and 2004 Magnetic North
Declination at Center of Sheet
GN to TN -1.636° (-29 mills)
TN to MN 11.077° (197 mills)