

Effects of livestock grazing on nutrient retention in a headwater stream of the Rio Puerco Basin

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Abstract.—Sediment and nutrient loss from headwater streams of sedimentary basins in the semi-arid Southwest have been attributed to both over-grazing by livestock and to climatic cycles that influence arroyo formation. Considerable effort has been directed toward the influence of livestock grazing on riparian species abundance and diversity. Less work has concentrated on the influence of livestock on in-stream processes and communities. In contrast, considerable research has described the importance of floods as ecological organizers of riparian and benthic communities in lotic ecosystems. Here, we consider the interaction of flooding and livestock grazing on hydrologic and nutrient retention in a headwater stream of the Rio Puerco Basin, NM. We propose that grazing decreases retention of water, sediments, and nutrients by changing physical and biological features of the stream that cause the system to be less resistant to natural floods and by decreasing recovery rates when floods do occur (i.e. less resilience). This work presents our initial studies of the differing nutrient and hydrologic environments created by cattle exclosures on the Rio Señorito, a tributary of the Rio Puerco. Preliminary results indicate that benthic biomass and transient hydraulic storage are greater in reaches protected from cattle influences. Finally, we propose a conceptual model that predicts the implication of disturbance interaction for streams impacted by flash floods and grazing practices.

INTRODUCTION

Livestock grazing is the most widespread land-use practice in the Southwest (Lusby et al. 1971, Wagner 1978, Crumpacker 1984, Fleischner 1994). In semi-arid environments, the effects of grazing are concentrated in riparian zones and environmental impacts include increased bank erosion (Szaro 1989) and sediment transport (Lusby et al. 1971), soil compaction (Lusby et al. 1971, Fleischner 1994), loss of riparian species

(Szaro 1989, Fleischner 1994), and decreased water quality (Szaro 1989).

Sediment transport is also influenced by arroyo formation in sedimentary basins. The most likely causes of arroyo formation include long term climatic cycles (i.e. flooding), livestock grazing and the interaction between these features (Mainguet 1994). Little is known about the effects of grazing on nutrient dynamics in streams impacted by arroyo formation. Biological and hydrologic processes that retard nutrient transport contribute to nutrient retention, a fundamental measure of stream ecosystem functioning (Vitousek and Reiners 1975, Grimm 1987). We propose that hydrologic and nutrient retention are useful indicators of ecosystem stability (resistance and resilience) in the face of disturbance by land

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use practices (i.e. livestock grazing) and natural flood events.

Flood events are one of the most common naturally occurring disturbances in semiarid stream and riparian ecosystems. Extensive mortality (a loss of biomass and diversity) of riparian and benthic organisms occurs (Gray and Fisher 1981), but communities recover and reorganize quickly (Campbell and Green 1968, Fisher et al. 1982, Grimm and Fisher 1989). Livestock grazing also causes mortality, but disturbance effects are more chronic (Fleischner 1994). Trampling and grazing removes biological retentive structures (e.g. plant cover or debris dams) which causes a loss of hydrologic, sediment, and nutrient retention (Szaro 1989, Trotter 1990, Fleischner 1994).

In southwestern streams, temporal organization of flooding and grazing disturbances affects ecosystem structure and function for aquatic and riparian subsystems. Floods occur as a result of natural annual climactic cycles during spring runoff and late summer monsoons (Graff 1988, Molles and Dahm 1990). Historically, southwestern riparian and benthic species have adapted to survive seasonal flood events (Campbell and Green 1968). They may, however, be less well adapted to human-organized livestock grazing (Szaro 1989).

Timing of livestock grazing is dictated by human concerns and often leads to constant land use. As a result, livestock may impact organisms and processes during times when they must also recover from natural flood disturbance. The extent of ecological damage to semi-arid southwestern ecosystems is related to the change in species type and population densities of grazers. Historically, effects of trampling were minimal because natural grazers existed in these ecosystems at low population densities (Hastings 1959, Cooper 1960, Fleischner 1994). During modern livestock grazing, high populations are maintained, and overgrazing often occurs. Many have argued that overgrazing has led to incision and arroyo formation. Mainguet (1994) specifically describes the Rio Puerco basin in a case study implicating livestock grazing as a primary cause of erosion, arroyo formation, and sediment loss. Because of its physical impact on stream beds, its influence on vegetation and its impact on hydrologic characteristics of streams, livestock grazing may be the primary

determinant of sediment and nutrient transport in streams draining sedimentary basins in the semi-arid Southwest.

RESEARCH OBJECTIVES

This research focuses on how livestock activity and annual flood events influence nutrient retention in headwater streams of the Rio Puerco basin that are impacted by arroyo formation. We hypothesize that by disturbing in-stream communities and reducing riparian biomass and diversity, livestock grazing results in lower nutrient retention and lowers stability to annual flood events. Regions of the stream protected from grazing influences are predicted to be more resistant to flood events and also recover more rapidly. Our preliminary research goals included:

1. Mapping of reach type and distribution along the Rio Seiorito,
2. A survey of the nutrient concentrations in surface and groundwater, and
3. Characterization of the hydrologic storage in reaches representative of exclosures and watering gaps (i.e. reaches where cows have access to the stream). Here we report on the results of these initial projects.

STUDY SITE

Land-use practices along the Rio Puerco, a tributary of the Rio Grande in north central New Mexico, are of particular interest because the Rio Puerco has one of the highest suspended sediment loads of any river in the world (>267, 000 mg/L, Mainguet 1994). Our study site along the Rio Señorito (fig. 1) is located at the headwaters of the Rio Puerco where the Bureau of Land Management (BLM) has constructed four 600-meter grazing exclosures separated by three 200 meter gaps for watering livestock. Two grazing exclosures (exclosures # 1 & # 2) were installed in the winter of 1993, the third (#3) during the winter of 1994 and the fourth (#4) was completed in October of 1994. Thus, riparian communities in the four exclosures have been free of grazing for 3, 3, 2 and 1 growing seasons, respectively. The exclosures are

visibly more vegetated than the water gaps and species of forbs, grasses and willows are found in the active stream channel. The exclosures are part of an experimental management plan developed by the BLM to assess restoration and recovery of semi-arid riparian ecosystems from concentrated livestock grazing disturbance (Pers. Comm, Duane Vincent, Rio Puerco Resources Division, BLM, Abq, NM).

METHODS

Surface and Groundwater Biogeochemistry

The spatial distribution of exclosures and gaps (fig. 1) provides an excellent opportunity to experimentally determine the influence of livestock on nutrient retention in the Rio Señorito. Eventually, replicated treatments and control plots will be used as experimental units and comparative solute injections will be used to test the hypothesis that

grazing and livestock disturbance decrease the retention of nutrients and sediments in the Rio Puerco headwaters. Here, we provide initial comparisons of “gap” and “exclosure” structure and function without relying on inferential statistics except when appropriate within experimental units.

The study site was mapped in December of 1994 using 100 m tapes walked along the stream bed. Measurement of total length and distribution of reach types (exclosures and gaps) were included in mapping efforts. At the time of mapping, stream water samples were collected at 100 m intervals and at the beginning and end of each gap and exclosure. Comparison of stream water nutrients (see below for nutrient analysis techniques) in gaps and exclosures were performed using ANOVA with reach type as a single factor with two levels (gap and exclosure).

In March of 1995, shortly after a high flow event, we established six sampling transects over 50 m within the stream in Exclosure #2 to assess longitudinal and vertical distribution of solutes in the Rio Señorito (fig. 2). Wells were constructed of 3/4" PVC pipe and were used to obtain water samples and as piezometers to determine the direction of vertical hydrologic exchange between the groundwater and stream. Positive hydraulic heads from these wells (data not presented) indicated that groundwater flowed vertically upward throughout the study reach. Wells were established to sample



Figure 1. Study site locations on the Rio Señorito, NM. Numbers refer to the “exclosures” (i.e. stippled polygons) that average 600 m length. Watering “gaps” are 250 m long and occur between the exclosures. The Rio Señorito enters the Rio Puerco just west of NM State Highway 44.

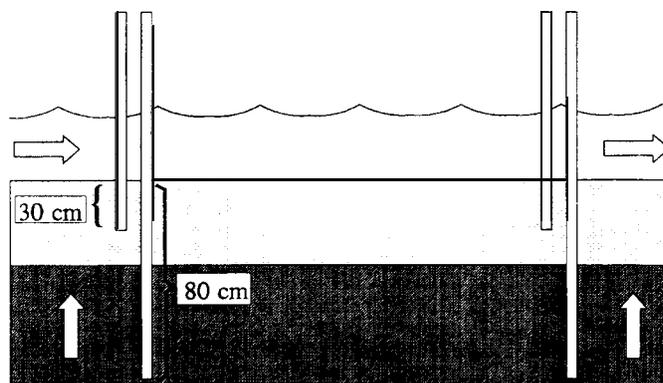


Figure 2. Schematic representation of water sampling transects established along a 50-m reach of exclosure #2. Wells were installed to sample shallow and deeper groundwater for biogeochemical characterization. Direction of water flow is denoted by the arrows.

surface water, shallow groundwater (depth = 20 cm) and deep groundwater (depth = 80 cm). This reach was also used for hydrological studies (see below).

Water samples were analyzed for biogeochemically active solutes including nitrate-nitrogen ($\text{NO}_3\text{-N}$), ammonium-nitrogen ($\text{NH}_4\text{-N}$), and phosphorous in the form of soluble reactive phosphate (SRI) using a Technicon Autoanalyzer II. $\text{NO}_3\text{-N}$ was determined by colorimetric analysis following reduction to nitrite in a cadmium-copper column (Wood et al. 1967). The phenyl-hypochlorite method was used to measure $\text{NH}_4\text{-N}$ (Soloranzo 1969) and we used the molybdate-antimony analysis to measure SRI (Murphy and Riley 1962). Dissolved oxygen (DO) was determined in well and surface water by the Winkler titration method. A Pearson correlation coefficient was calculated for DO and $\text{NO}_3\text{-N}$ for samples collected from groundwater environments. Dissolved organic carbon (DOC) was determined by CO_2 evolution following persulfate oxidation (Menzel and Vaccaro 1964) using an 0.1. Corporation Model 700 TOC Analyzer.

Hydrologic Retention

During Summer of 1995, a 50 m reach was established in the water gap (Gap #1) adjacent to and upstream of Enclosure #2 where the previous 50 m reach was established for biogeochemical surveys. We hypothesized that livestock activities would reduce channel complexity and decrease hydrologic retention (i.e. result in less transient storage of water and solutes, Stream Solute Workshop, 1990). To assess differences in hydrologic retention, we estimated transient storage in the two reaches using solute injections of hydrologically-conservative tracers. In July of 1995, a single tracer injection was completed at each of the experimental reaches (i.e. first in the downstream reach within Enclosure #2 and then in the water gap immediately upstream). A sodium bromide (NaBr) solution of approximately 60 g/L was dripped into the stream at the top of each reach as a biologically and chemically unreactive (conservative) tracer. Before the injection, concentration of Br in surface water was approximately 100-150 ppb and the concentrated Br solution was added at a rate that increased in-stream concentrations to approximately 3 ppm for sixty minutes. Bromide levels were measured 50 m downstream

of the injection site by collecting water samples for Br analysis at 15-second intervals until the solute reached a plateau concentration in the stream.

Bromide concentrations were determined analytically using a Dionex DX-100 ion chromatograph.

Solute response curves generated from the time course of Br samples can be compared with theoretical square-wave responses that would have been observed if no dispersion or storage occurred during transport. We determined water velocity

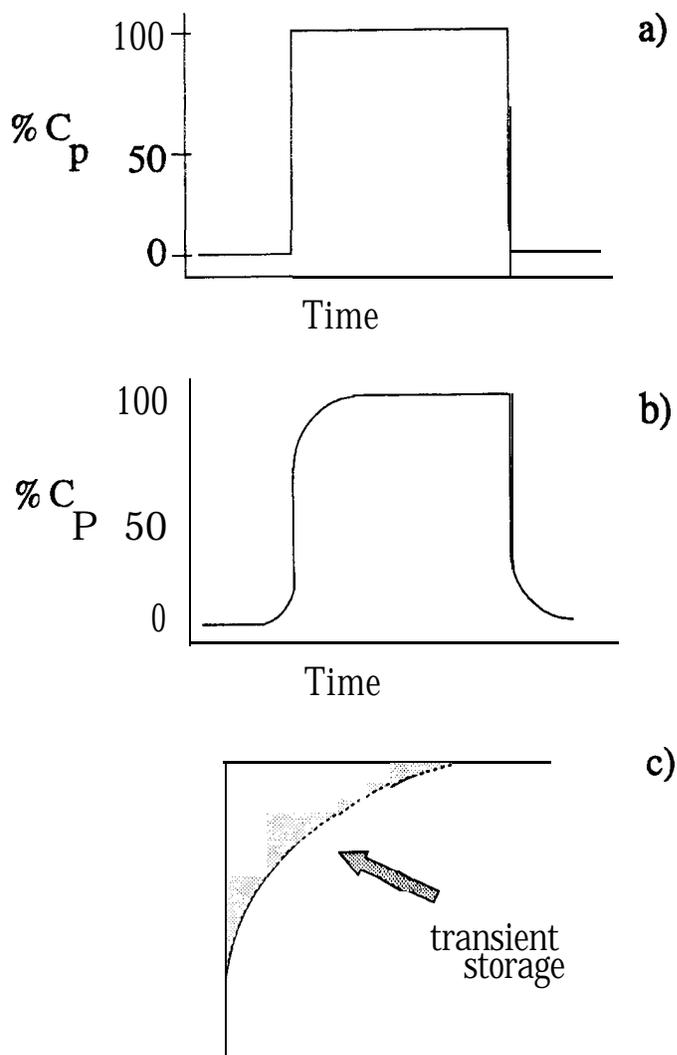


Figure 3. Typical solute-response curves generated during a tracer-addition experiment: a) the ideal square-wave curve that results if transport occurs without dispersion or transient storage, b) a curve more typical of empirical results illustrating the “rounding” produced by dispersion and storage, and c) the portion of the curve used to estimate transient storage. See text for further explanation.

from the nominal travel time (i.e. amount of time required for Br to reach half of its plateau concentration) and reach length. In addition, we estimated transient storage by determining the area generated when empirical solute response curves were superimposed on ideal curves (fig. 3, Stream Solute Workshop 1990). Areas were compared as a qualitative assessment of transient storage in the two reach types.

RESULTS

Concentrations of biogeochemically-active solutes did not differ significantly ($P > 0.05$) between gaps and exclosures during the longitudinal survey of December 1994. Surface water in gaps and exclosures was rich in $\text{NH}_4\text{-N}$, but $\text{NO}_3\text{-N}$ in surface water was below detection level (Table 1). DOC concentrations were greater than 10 mg/L in each plot type and SRP concentrations were 8 and 7 ppb in gaps and exclosures, accordingly (Table 1). Atomic N:P ratios were high reflecting low SRI levels and plentiful $\text{NH}_4\text{-N}$.

During March of 1995, deep groundwater in the instrumented exclosure was rich in $\text{NH}_4\text{-N}$ (average concentration 300 ppb, fig. 4a), and concentrations dropped as water flowed upward towards the stream/groundwater interface. In contrast to the high concentrations observed in surface water during winter, surface $\text{NH}_4\text{-N}$ concentrations were low (near detection level of ca. 10 ppb) during the spring survey. Conversely, while no $\text{NO}_3\text{-N}$ was measured in surface water during winter, concentration averaged 135 ppb during spring sampling (fig. 4b). Nitrate-nitrogen in shallow and deep groundwater varied with distance downstream and ranged from less than 20 to more than 170 ppb (fig. 4b). Deep groundwater was generally anoxic, but only two of six shallow groundwater wells

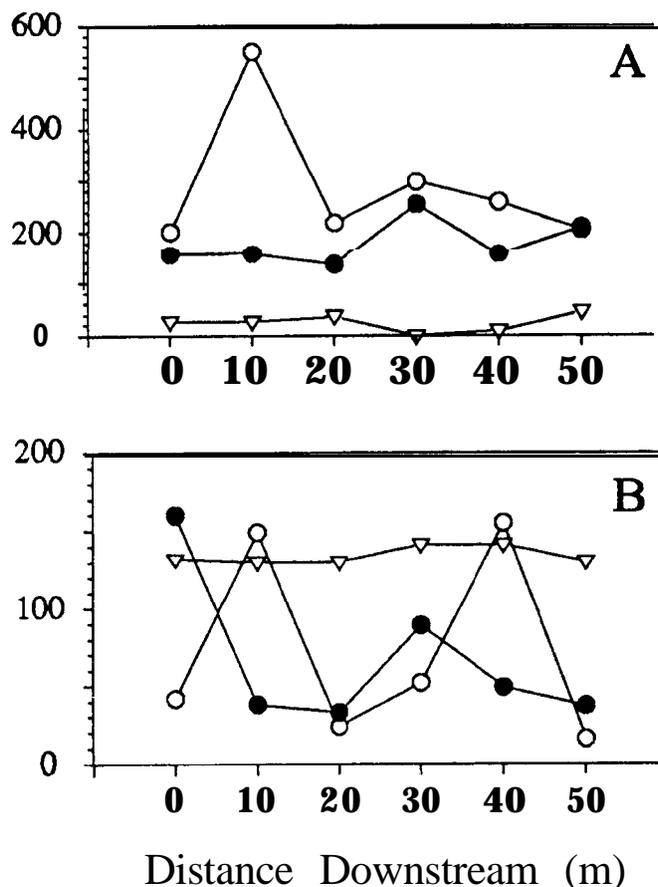


Figure 4. inorganic nitrogen (ppb) in surface and groundwater during March of 1995: A) $\text{NH}_4\text{-N}$ and B) $\text{NO}_3\text{-N}$ in surface water (inverted triangles), shallow groundwater (filled circles, depth = 30 cm) and deep groundwater (open circles, depth = 80 cm).

lacked oxygen. Nitrate-nitrogen concentrations in groundwater were significantly correlated with DO content ($r = 0.55$, $P < 0.05$).

Solute injections carried out at each experimental reach illustrated differences in hydrologic transport and retention (fig. 5). Nominal travel times in the exclosure and gap reaches were ca. 16

Table 1. Selected stream water solute concentrations from Rio Seiorito, NM. Data are means \pm SE and were collected on December 19, 1994. Mean concentrations did not differ between grazed watering gaps and cattle exclosures ($P > 0.05$).

	$\text{NO}_3\text{-N}$ ($\mu\text{g/L}$)	$\text{NH}_4\text{-N}$ ($\mu\text{g/L}$)	SRP ($\mu\text{g/L}$)	DOC (mg/L)	N:P Ratios
Grazed Plots: (n = 15)	0 \pm 0	299 \pm 61	8 \pm 1	13.0 \pm 5.0	82 \pm 6
Exclosures: (n = 27)	0 \pm 0	253 \pm 20	7 \pm 1	11.2 \pm 3.2	104 \pm 16'

and 19 min, respectively, corresponding to water velocities of 5.2 and 4.3 cm/s. Despite arriving earlier, solute concentrations in the enclosure were still rising after the injection was terminated sixty minutes after its initiation. In contrast, solute concentrations rose rapidly in the water gap and reached plateau abruptly after approximately 25 minutes of injection. Estimates of transient storage indicate that hydrologic retention in the enclosure was 4-5 times greater than in the adjacent water gap.

DISCUSSION

These preliminary results suggest that the Rio Señorito and other similar headwater streams of the Rio Puerco basin are spatially and temporally dynamic. Groundwater environments are anoxic and the fine mudstones that comprise the aquifer sediments are rich in $\text{NH}_4\text{-N}$. During winter, the stream is frequently ice-covered and in-stream and riparian communities are relatively inactive. Under these conditions, ammonium-rich sediments and groundwater contribute $\text{NH}_4\text{-N}$ to the

surface stream. In contrast, sediments are more biologically active during warmer times of the year and appear to be sites of nitrification as evidenced by the strong relationship between dissolved oxygen and $\text{NO}_3\text{-N}$ in groundwater.

Metabolically-active sediments may, therefore, account for the elevated $\text{NO}_3\text{-N}$ and low $\text{NH}_4\text{-N}$ in surface water during spring. At the time of sampling, surface water was turbid, and there were ample signs of a recent flood throughout the study reach. More extensive monitoring over time and among different reach types is necessary to determine if elevated $\text{NO}_3\text{-N}$ concentrations reflect the influence of flooding or more long-term seasonal changes.

There were evident differences in the vegetational structure of enclosures and watering gaps. In addition to having greater cover of woody riparian species, stream-side herbaceous vegetation was extensive within the enclosures, and forbs often inundated the wetted channel making open water only rarely visible. In contrast, the experimental reach within the watering gap was sparsely vegetated, and stream-side banks were often bare of vegetation. Channel width was obviously greater

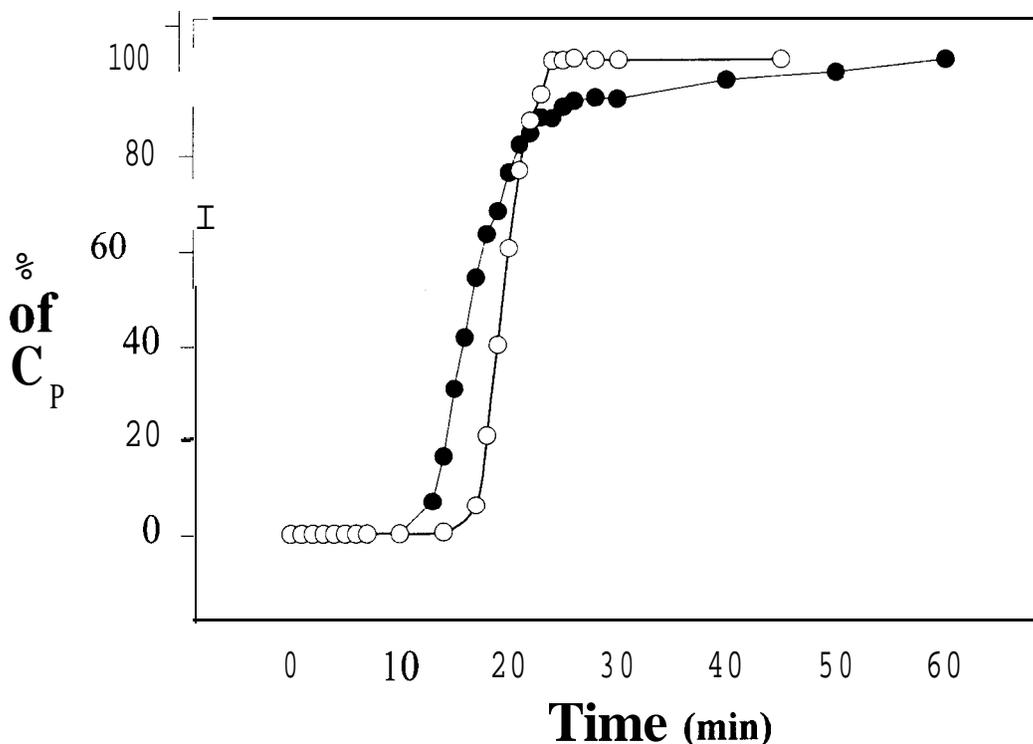


Figure 5. Solute response curves for the enclosure reach (filled circles) and for an adjacent reach in the watering gap (open circles). Values are plotted as percent of plateau concentration (% of C_p) against injection time.

in the water gap. Within the enclosure, channel width was reduced, and the wetted perimeter included a central deeper channel and shallow lateral areas heavily inundated by semi-aquatic vegetation. These differences in channel structure translated to different hydrologic behavior. Broader and shallower cross-sections within the watering gap resulted in slower water velocity (i.e. calculated velocity in the gap was *ca.* 83% of that in the enclosure). More restricted channel structure in the enclosure increased average linear velocity, but solute response curves clearly indicated that extensive areas of hydrologic storage existed in the enclosure and that these areas were lacking in the adjacent watering gap.

We propose that the lateral areas of shallow water that are inundated by vegetation are responsible for the transient storage measured in the enclosure. These lateral areas of increased residence time are crucial for increased biological processing and may also influence sediment transport and deposition. This is not the first study to suggest that grazing decreases the retention of water in semi-arid basins. Lusby et al. (1971) showed that eliminating livestock grazing in a western Colorado system decreased sediment and water yield to 66% of that in paired plots where grazing was continued. Their study, however, emphasized

sediment and water yield in an intermittent wash. Our study suggests that grazing alters the hydrologic features of transport and retention in perennial systems by changing the physical and biological features that contribute to total retention.

CONCLUSIONS

Decreased plant cover, extensive areas of exposed sediments, and altered transport dynamics may make grazed reaches more susceptible to the effects of flash floods. In this context, flooding and grazing are expected to interact as natural and anthropogenic events to exacerbate disturbance in headwater streams of the Rio Puerco. Here we present a conceptual model (fig. 6) reflecting the interaction of livestock grazing and flash floods as ecological disturbances and provide three hypotheses regarding the differential functioning of grazed/non-grazed reaches. At any time, non-grazed reaches are expected to (1) exhibit greater retention than comparable reaches influenced by livestock. In addition, because of the decreased plant cover, watering gaps are predicted to be (2) less resistant to flash floods and these high flow events will more severely alter biological and geomorphic **aspects** of the stream channel.

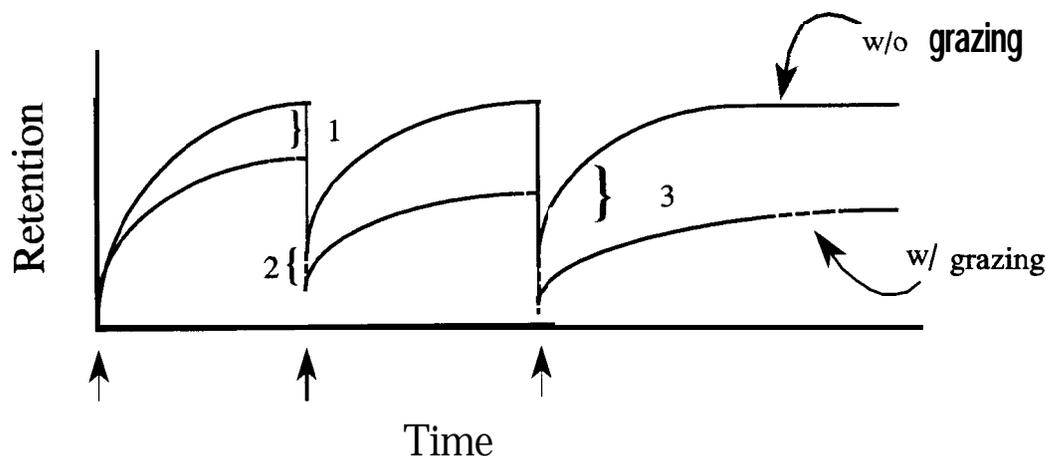


Figure 6. Conceptual model of disturbance interaction for streams impacted by floods and livestock grazing. Retention is plotted against time and flood events are depicted as arrows along the X-axis. 1) At any given time, grazed reaches (dashed line) are less retentive than reaches without grazing (solid line). 2) Because of pressure on biological and hydrologic agents of retention, grazed plots will be less resistant to flooding, and 3) rate of recovery (i.e. resilience) will be lower in grazed plots following disturbance by flash floods.

Finally, we hypothesize that successional responses to flash floods will be retarded by live-stock grazing resulting in (3) lower resilience and contributing to decreased ecosystem stability.

ACKNOWLEDGMENTS

This study is funded by Cooperative Agreement No. 28-C4-833 with the USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

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