LIVESTOCK GRAZING: A TOOL FOR REMOVING PHOSPHORUS FROM IRRIGATED MEADOWS

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ABSTRACT

Elevated phosphorus (P) loading of wetlands, streams, lakes, and reservoirs can occur from nonpoint sources such as grazing of irrigated or naturally wet meadows and palustrine wetlands. The water entering Cascade Reservoir of west-central Idaho sometimes has elevated P concentrations (>0.050 ppm) and provides a P load of 54 tons P/yr. The use of best management practices such as rotational grazing, buffer strips next to wetlands, and proper irrigation management should reduce overland flow and streambank erosion. Livestock grazing should harvest and remove a significant amount of P from the ecosystem from incorporation into bone and tissue mass of growing animals and beef export from the basin. About 44,000 ac of mostly flood-irrigated pasture land exists in the Cascade Reservoir watershed. The Phosphorus Uptake and Removal from Grazed Ecosystem (PURGE) model uses three separate methods to estimate P retention in cattle and using limits of the input variables, predicted that from 4 to 57 tons P could be removed annually from the Cascade watershed. With proper grazing management, cattle should be part of a long term solution to P loading and improvement of water quality in Cascade Reservoir.

INTRODUCTION

Nonpoint source effects on water quality have become an important issue in recent years. Croplands and grazing lands are increasingly scrutinized for their contribution to nutrient loading of water bodies. While improvements in grazing management usually can reduce nutrient loading, the nutrient loading contribution by grazing animals may be overestimated and goals for reduction of nutrient loading may be unrealistic. Determining background levels is difficult but critical to setting realistic goals for nutrient loading.

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A case study of the Cascade Reservoir watershed (Fig. 1) will be used in the development and application of a conceptual simulation model of P export by cattle. Eutrophication of Cascade Reservoir in west-central Idaho is attributed to excess P and other nutrients entering the shallow reservoir through tributaries and irrigation return flows (Entranco Engineers 1991). Besides the point sources of pollution, large loadings have been measured from stream segments through croplands, pasture, and forest lands in the watersheds. Nonpoint sources are estimated to contribute 60% of the P load (VSCD 1991). However, the "natural" or background levels are unknown. Abrams and Jarrell (1995) concluded that the contribution of P from native soil sources needs to be evaluated as well as those from anthropogenic sources of stream P. They found that high native P levels and P adsorption characteristics of soils in a tributary watershed of the Willamette River were an important nonpoint source of P.

The fast-growing population of vacation home owners and recreationists has become convinced that the environmentally correct solution is the removal of livestock grazing from the watershed. However, their opinions may result from a flawed perception of the ecosystem dynamics of grazing.

Proper grazing management is essential to reducing nutrient loadings to streams. In Oklahoma, Olness et al. (1980) reported that total P concentrations in surface runoff from continuously-grazed watersheds ranged from 1 to 1.8 ppm, and they were about three times higher than those from rotation-grazed watersheds because of greater soil loss. Average annual losses in runoff from the same rotationally-grazed and continuously-grazed watersheds were 0.5 and 1.7 lb total P/ac, respectively (Menzel et al. 1978), over a four-year period. In northern Idaho, Jawson et al. (1982) reported annual total P losses in runoff from a grazed watershed over three years ranged from 0.09 to 1.2 lb/ac and from 0.09 to 0.15 lb/ac for the check watershed. However, the watershed effect may be confounded in the studies and comparisons are difficult because of differences in topography, vegetative cover, and intensity of precipitation.

Assuming best management practices (BMPs) for grazing pasture and rangelands are applied, a simple mass balance confirms that livestock grazing can remove significant amounts of P from the ecosystem. This is accomplished through cattle harvesting the forage and exporting P from the land in bone and soft tissue growth.

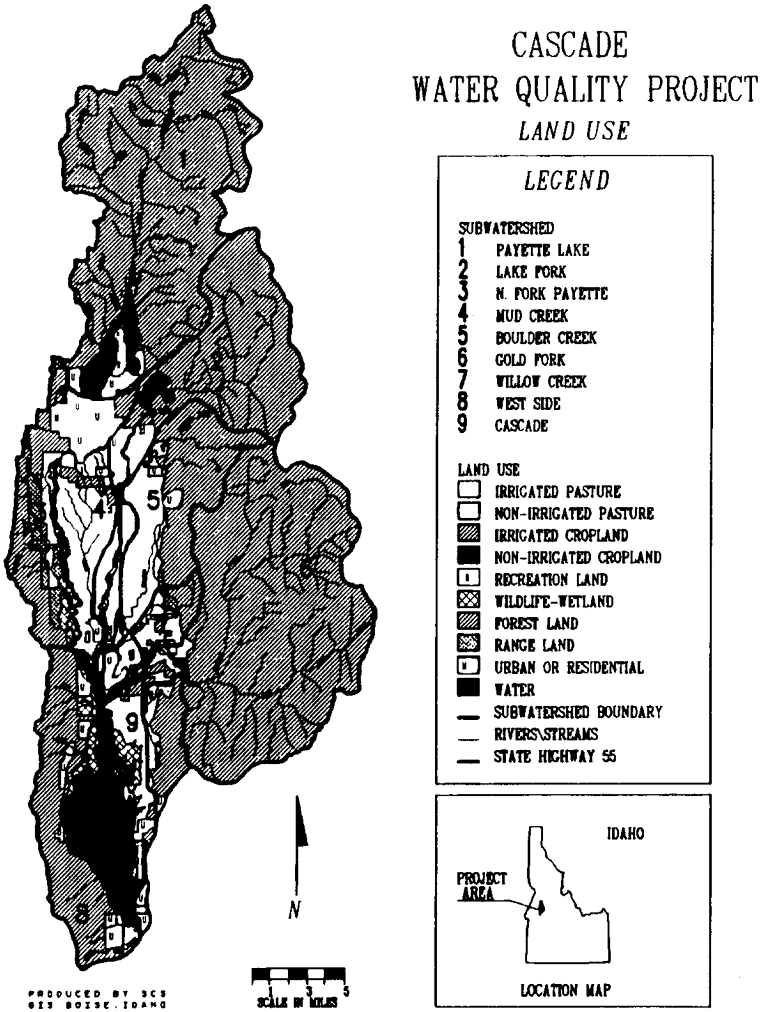

Fig. 1. Cascade Reservoir Watershed Land Use

Several monitoring studies on this site are an inappropriate basis from which to infer the effects of grazing management on P loadings. For example, the comparison of one grazed watershed with an ungrazed watershed has a confounding effect with no measure of experimental error. The confounding effect is that the watershed itself may be a larger source of variation than the treatment; i.e., different soils, aspects, slopes, vegetative cover, etc. In another case, the comparison of P concentration above and below grazed and nongrazed pastures is also not appropriate to infer management effects because of confounding by stream and soil differences. Monitoring studies are only useful in recording what happened, not why it happened. Critical studies are needed that test hypotheses of cause and effect in addition to monitoring.

Climate is the overriding variable in the process. Separating climatic effects from any treatment of the watershed is difficult. Much of the P enters the wetlands as a pulse during snow melt. Thus, it is dangerous to infer trends because of the yearly weather effects and probable interactions. For example, during water year 1993, the watershed received 115% of normal precipitation and produced a load of 60 tons of total P (DEQ 1995). During water year 1994, the watershed received 60% of normal precipitation and produced a load of 22 tons of total P (DEQ 1995).

The transport of P by overland flow depends on the desorption, dissolution, and extraction of P from soil, and mineralization of plant material and feces. Temperature, precipitation, presence of anaerobic soil conditions, and evapotranspiration rates further influence the process. Plant species composition and rate of decay affect the P leached from plant material. Soil loss of P is dependent on the capacity and charge of ion exchange sites on minerals and organic matter, pH, and the concentrations and interactions of other elements (Broberg and Pearson 1988).

Degraded water quality is not beneficial to recreationists, wildlife, homeowners, or agricultural producers. It behooves us to use BMPs and other tools--based on science rather than perceptions--to reduce P loading. Recreational and grazing activities that accelerate erosion will increase total P loadings because of P adsorption to soil particles. We should also recognize that properly managed livestock grazing operations will export P from the basin. The following conceptual model, with some constraints, estimates P removed from the ecosystem by grazing cattle.

METHODS

Site Description

The watershed of Cascade Reservoir is 390,000 acres and is located in the west-central mountains of Idaho. The watershed has forested mountains at the headwaters and wide flat valleys along the reservoir and stream channels. Soils are glacial tills of decaying granite from the Idaho Batholith. Irrigated pasture lands are sandy, mixed Humic Cryaquepts and fine-loamy, mixed Typic Cryumbrepts (Rassmussen 1981). Water table depths are generally > 6 ft and soils are generally well-drained; however, saturated conditions due to spring flooding or irrigation can produce anaerobic conditions and some soils with high clay along riparian areas are not well drained. The Donnel sandy loam and Archabal series--major components of the pasture lands--have soil reactions from 4.5 to 6 pH and water soluble P levels from 0.10 to 0.20 ppm (mg/L) in the surface horizon (McGeehan 1996). The P concen-tration and P sorption capacity decrease significantly with profile depth. The maximum P sorption of the surface horizon varies from 93 to 580 ppm (mg/kg) in the Donnel series and from 540 to 760 ppm (mg/kg) in the Archabal series (McGeehan 1996). In acid soils, inorganic P precipitates as Fe/Al-P secondary minerals and/or is adsorbed to surfaces of clay minerals and Fe/Al oxides (Tisdale et al. 1993).

The Cascade Basin has 44,000 acres of irrigated and 8,000 acres of nonirrigated pasture land. Pasture land is typically leased for summer grazing by cattle. There are an estimated 30,000 livestock in the basin during summer (VSWCD Board & Roach 1995 referenced in DEQ 1995). During spring, cattle are trucked into the basin and in the fall they are trucked out. Very little fertilization is done and most pastures are continuously grazed, resulting in heavy and selective utilization of forage. Sub-irrigation practices produce saturated soil conditions and when pastures are continuously grazed, soil compaction results. Carex and rushes have increased in abundance due to over-irrigation. Potential pasture yields support stocking rates of 4 to 7 animal unit months (AUMs) per acre with a high level of management (VSCD 1991). Production limitations are low soil pH, high water table and saturated conditions, and short-growing season of 70 frost-free days (Rassmussen 1981).

Many riparian areas suffer from accelerated streambank erosion. Overland erosion rates are estimated at 0.1 tons per acre annually (VSCD 1991). Approximately 54 miles of critically eroding stream-bank have been identified that are estimated to yield 4,850 tons of sediment annually to the reservoir. In addition to having been the number one fishery in the state of Idaho, the area supports wildlife resources like waterfowl, raptors, deer, moose, and elk.

Model Development

The Phosphorus Uptake and Removal from Grazed Ecosystems (PURGE) simulation model is developed to estimate P uptake by grass and P retention in bodies of grazing cattle. The variables include known, approximate, and assumed values based on measurements, the literature, and personal experience. Three methods within the model estimated P exported in cattle tissue. The PURGE model was developed in a Quattro Pro spreadsheet.

Method #1: The input variables are:

Net P absorption by animal (%)	Daily DM consumption (% body wt)
Cattle weight (lbs)	P concentration in the grass (%)
Stocking rate (hd-mon/ac)	Area grazed (ac)

The net P absorption by cattle is about 90% efficient in young calves and 55% efficient in cows (ARC 1980, Miller 1979). The P concentration of the forage can vary between 0.18 and 0.30% (Kincaid 1993) depending on soil series, temperature, interactions with other nutrients, fertilizer treatments, soil moisture, plant species, and phenological stage of the plants. The variables calculated are:

Carrying capacity = stocking rate X area grazed (1)

Total weight gain per season = rate of gain X carrying capacity X (30 days/mo) X (ton/2000 lbs) (2)

Grass consumed per day = cattle weight X daily DM consumption (3)

P consumed per hd-day = P conc. X grass consumed per day (4)

P retained per hd-day = P digestibility X P consumed per hd-day (5)

P removed by cattle = P retained per hd-day X carrying capacity (6)

Method #2: Input variables are forage production, P concentration of grass, and the ratio of *P mass removed by cattle / plant P uptake.* Forage production can be varied but values from 2,000 to 6,000 lbs/ac are in the moderate range for irrigated pasture in this area. The P concentration of forage may vary from 0.3% in early spring to 0.15% in tropical mature plants (McDowell et al. 1983). Cohen (1980) estimated the ratio of P retained in animal tissue removed to plant-P uptake at 3.6% for cattle grazing unsupplemented native range in Australia and 11.2% for range that had been seeded and fertilized with superphosphate. In contrast, Pieper (1974) reported the ratio at 23.3% on the arid southwest rangeland. The variables calculated are:

P removed by cattle gain per acre = forage production X P concentration X (ratio of P removed/plant uptake) (7)

P uptake in cattle = P removed by cattle gain X acreage (8)

Method #3: This method was suggested by R.C. Bull, animal scientist at the University of Idaho (personal communication 1996). The P composition of bone and soft tissues in cattle is highly predictable and therefore the P export is easily calculated from cattle weight gain while on the pastures. The P content of wet bone tissue is from 4 to 4.5% (Church 1971) and from 75 to 80% of total body P is found in the skeleton and teeth. The acreage and weight gains used are those described in Method #1.

Model Constraints

No constraints are built into the model for these variables. Thus, user discretion is needed. Realistic values have been used in this example and recommended constraints are listed in Table 1.

Validation

The PURGE model has not been validated by predicting P export and subsequent measurement of P export. However, the values predicted seem reasonable and are corroborated to a degree by the literature (see Discussion). The main purpose of the model is to help land managers understand concepts of mineral cycling.

Table 1. Recommended Constraints for Input Variables Used in the PURGE Model.

Variable	Minimum	Moderate	Maximum
Method #1			
Net P absorption (%)	55	70	90
Cattle weight (lbs)	400	600	1000
Daily DM consumption (%)	2	2.5	3
P conc. in grass (%)	0.15	0.25	0.30
Stocking rate (hd-mon/ac)	1	2	4
Area grazed (ac)	0	--	infinity
Rate of gain (lb/hd-day)	0	1.5	4
Method #2			
Forage production (lb/ac)	0	4,000	10,000
P conc. in grass (%)	0.15	0.25	0.30
Ratio of P removed/plant uptake (%)	3.6	7.5	10

RESULTS

Three simulations of PURGE are shown in Table 2 representing low, moderate, and high P export scenarios.

Method #1

The simulations shown in Table 2 varied the net P absorption by cattle from 80 to 60%, which is inversely related to cattle weight as varied from 500 to 800 pounds. Daily dry matter consumption varied from 2.5 to 3%, the P concentration in grass from 0.25 to 0.30%, the stocking rate from 1.5 to 2 hd-mon/ac, and the rate of gain from 1.5 to 2 lb/hd-day. The area grazed was held constant at 43,640 acres. The simulation produced a range of estimated P export with cattle from 25 to 57 tons P annually. A moderate value was 39 tons P removed annually.

Table 2. Simulations of P Export Produced by the PURGE Model.

	A	B	C	D	E
1	PURGE.WB1	P Uptake and Removal from Grazed Ecosytems			
2					
3	Plant material on dry matter basis	Formula		Scenario	
4	**Method #1**		1	2	3
5	***Inputs (assumptions):***				
6	Net P absorption (%)		80%	70%	60%
7	Cattle wt (lb)		500	650	800
8	Daily DM consumption (%)		2.50%	2.75%	3.00%
9	P conc. in grass (%)		0.25%	0.28%	0.30%
10	Stocking rate (hd-mon/ac)		1.5	1.75	2
11	Area grazed (ac)		43,640	43,640	43,640
12	Rate of gain (lb/hd-day)		1.5	1.7	2
13	***Calculations:***				
14	Carrying capacity (hd-mon)	+B10*B11	65,460	76,370	87,280
15	Total weight gain (ton)	+B14*B12*30/2000	1,473	1,947	2,618
16	Grass consumed/hd-day (lb)	+B7*B8	12.50	17.875	24
17	P consumed/hd-day (lb)	+B16*B9	0.031	0.049	0.072
18	P retained/hd-day (lb)	+B17*B6	0.025	0.034	0.043
19	**P removed with cattle (ton)**	+B18*B14*30/2000	25	39	57
20					
21	**Method #2**				
22	***Inputs (assumptions):***				
23	Forage production (lb/ac)		2,000	4,000	6,000
24	P conc. in grass (%)		0.25%	0.28%	0.30%
25	Ratio of P removed/plant uptake		4.00%	8.00%	12.00%
26	***Calculations:***				
27	**P uptake in cattle (lb/ac)**	+B23*B24*B25	0.2	0.88	2.16
28	**Exported P (ton)**	+B11*B27/2000	4	19	47
29					
30	**Method #3**				
31	***Assumptions:***				
32	Same total weight gain as above		fresh bone contains 4.5% P		
33	Bone growth is about 20% of the animal growth		bone P = 80% of total body P		
34	***Calculations:***				
35	Weight gain as bone (ton)	+B15*0.2	295	389	524
36	P in bone growth (ton)	+B35*0.045	13	18	24
37	Non-bone P from gain (ton)	+B36/4	3	4	6
38	**Total P from gain (ton)**	+B36+B37	17	22	29

Method #2

The simulations held the area grazed constant but varied forage production from 2,000 to 6,000 lb/ac, P concentration in the grass from 0.25 to 0.30%, and the ratio of P removed/plant uptake from 4 to 12%. Estimates of P removed from the watershed were from 4 to 47 tons (Table 2). The moderate value was 19 tons P removed annually. Method #2 estimates were roughly half those using Method #1 for the moderate scenario.

Method #3

Results shown from Method #3 (Table 2) are produced by varying weight gain as in Method #1. This method produced estimates from 17 to 29 and a moderate value of 22 tons P removed by cattle from the ecosystem. Method #3 estimates were more stable across scenarios because P concentration is constant within the body and only increased tissue mass will increase the P export.

DISCUSSION

Nutrient Cycling

In a system without herbivores, the nutrients cycle from soil to soil water, to plants, to litter and back to soil (Fig. 2). Erosion of the soil or leaching through the ground water transports P to the streams and reservoirs. When herbivores are added to the ecosystem, P may be found in more chemical forms with varying solubility. Urine and feces return unabsorbed or unretained P to the soil surface to continue cycling.

However, patterns of dung and urine deposition are not uniform. Such patterns may be more distinct with sheep where from 1 to 2 lb P/ac annually were transported to raised levees where sheep camped at night (Haynes & Williams 1993). Theoretically a BMP of high-intensity and short-duration grazing should provide more uniform dung distribution. However, in a Florida study, soil P redistribution was not different among short-duration, long-duration, and continuous grazing systems on Bermuda grass, but accumulated in the third of the pastures closest to shade and water, probably a result of urine and feces deposition by cattle (Mathews et al. 1993).

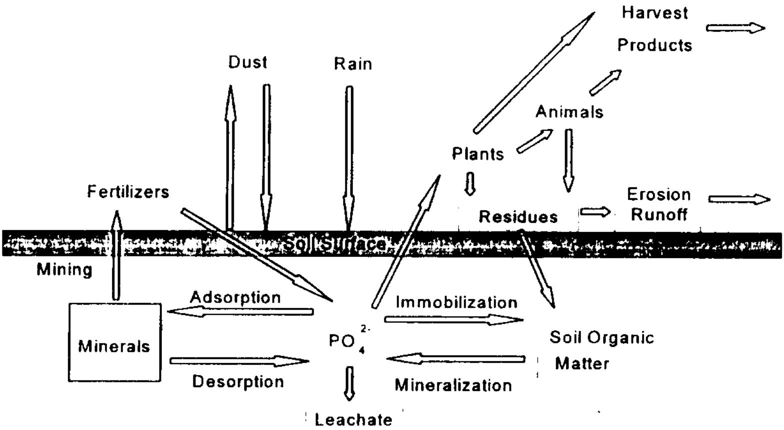

Fig. 2. The P Cycle on a Grazed Pasture

The effects of livestock grazing on nutrient loading is reported with mixed conclusions. Darling and Coltharp (1973) studied several watersheds in the Bear River Mountains of northern Utah and concluded that cattle and sheep grazing of mountain watersheds through which live streams pass increased the coliform bacteria counts but had no measurable effect on the phosphates, nitrates, temperature, turbidity, or pH in streams. Lavado and Taboada (1985) reported that grazing had no measurable impact on the N and P pools in soils of infrequently flooded, upland grasslands. Some nonrefereed papers report that grazing increases P in streams. However, these monitoring studies have inappropriate designs and are confounding. It is clear that any activity that accelerates erosion will increase the total P load. It isn't clear what effects grazing has on the soluble P loading to streams and reservoirs.

Export of P

Haynes and Williams (1993) reported that sheep removed 46 lb P/ac from P-fertilized perennial ryegrass (*Lolium perenne* L.) in association with white clover (*Trifolium repens* L.) pastures in New Zealand. Pieper (1974) estimated that sale of calves removed 0.6 lb P/ac from the arid range in New Mexico. Using moderate values calculated by Method #3, the model produced an estimate of 22 tons P removed from the basin, or 1 lb P/ac removed. Linqian and Tingcheng (1993) reported that native range in northeastern China dominated by *Leymunes chinenses* could have 1.3 lb P/ac exported annually as forage (hay) which was 21% of the P balance.

The PURGE model clearly demonstrates that grazing livestock that are gaining weight in soft tissue and bone--either stocker calves or cows with developing fetuses--will export P from the ecosystem when the cattle are removed from the area. Hypothetically, the amount of P exported is significant and could be equal to the average load entering the reservoir. However, whether this export of P actually reduces P loadings to the reservoir depends on good grazing management to protect stream banks from erosion and to limit deposit of feces and urine in the water. Cattle can remove P from the ecosystem, but improperly managed grazing can simultaneously increase P loading to the tributaries of the reservoir. Even at the above-predicted rates of P export, erosion and large runoff events would produce big P loads because of the enormous mass of the P-pool in the soil and minerals. The P cycled through grazing cattle may also be more bioavailable than through decaying vegetation.

Recommendations of Best Management Practices

Grass buffer strips can be effective in reducing P transport from pastures (Lee et al. 1989) by increasing infiltration, sedimentation, and decreasing overland flow. Off-stream water development and fencing of riparian areas should reduce (1) streambank degradation, and (2) direct deposit of feces and urine in streams. High-intensity rotational grazing systems should provide for a healthier pasture.

Recommendations for Further Research

1. Determine the effect of grazing by using a design of randomized and replicated treatment areas within the same watershed, and multiple years and watersheds.
2. Measure the volume and nutrient concentration of overland flow and leachate on these plots as often as every other day during peak snow melt conditions, and as often as twice per week during the grazing season.
3. Monitor overland flow and leachate during high, medium, and low runoff years.

4. Measure total and soluble P concentration in the soil, forage, and feces in temporal and spatial scales.
5. Record cattle gains to verify the input variables used in this model. By using a mass balance approach, accounting for most of the P cycling in the ecosystem should be possible.
6. Use radioactive isotopes to trace P cycling in extracted soil cores. Knowing the cycling times and forms should provide insight into adjusting BMPs.

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