MODELING IMPACTS OF GRAZING ANIMALS ON NUTRIENT MOBILIZATION INTO SMALL RESERVOIRS

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ABSTRACT

Models were developed to simulate impact of ungulate grazing on nutrient mobilization from watersheds into permanent waters. The models simulate dung nutrient deposition rate, dung and soil nutrient erosion, loading rate of soil and dung organic matter, and dung effect on oxygen concentration in hypolimnia of small reservoirs and mobilization of phosphorus from eroded watershed materials.

Our studies provide first approximations of coefficients needed for model function to augment data already available. The compositions of cow and deer dung nutrient, although age dependent, generally were similar. In infiltrometer studies, dung contributions to the amounts of organic matter, phosphorus, and nitrogen exported from watersheds was usually less than 10 percent and varied with location, mostly as the amount of dung material deposited and the relative fraction of bare soil varied. From infiltrometer studies and observations during natural storms, we deduced that most of the dung material washed out of watersheds consists of dried particulates rather than material eroded directly from the dung or associated with soils following its contamination by dung.

Dung deposits were dislodged and disappeared during natural rainstorms at a rate greater than predicted by the Universal Soil Loss Equation. More than 95 percent of the dung mobilized was old (more than four weeks), dry, and relatively easily dislodged. Deer dung was mobilized more readily than cow dung. Up to 12 percent of the organic matter, phosphorus, and nitrogen mobilized from watersheds may be in the form of ungulate dung. Studies of oxidation demand revealed that mixture of fresh dung and soil (25 percent dung) briefly increased oxidation rates by five times what was predicted by the demand of the separated materials. Oxygen demand in mixtures of 5 percent cow dung and soil was not stimulated. Phosphorus mobilization increased once oxygen concentration dropped to below 1 mg l^{-1}. To the extent that organic matter in dung increases the probability of oxygen concentration less than 1 mg l^{-1}, dung organics also increase the amount of phosphorus mobilization.

Preliminary models were used to develop a set of reference tables for a first attempt at predicting impacts of ungulates on runoff to hypolimnia in downstream reservoirs. Their purpose is to form a base
of a number of the coefficients used in the models
reference tables illustrate relationships between
availability, stocking schedule and dung deposition
and fraction of plant production in suitable
ization and soil mobilization; (4) dung deposition
nutrient deposited; (5) timing of rainfall and
grazing; (6) the amounts of nutrient eroded with soil, and the fraction eroded as dung material; (7) erosion rates of soil and dung materials and the oxygen demand exerted in a hypolimnion; and (8) phosphorus loading of a reservoir and the potential availability of phosphorus for plant uptake.

Key words: small watersheds, grazing, dung, nutrient loading, infiltrometer studies, runoff, erosion models, small reservoirs, cattle, mule deer, erosion, nutrient export, oxygen demand, organic loading, nutrient transport, organic transport, Western U.S., New Mexico, Wyoming, Universal Soil Loss Equation.

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INTRODUCTION

Nutrient Mobilization by Large Ungulates--A Potental Problem

Much of the watershed in the western United States serves valuable stream or reservoir fisheries downstream. In 1975 the fisheries in New Mexico alone were valued at \$90 million yr^{-1} (United States Fish and Wildlife Service 1977); and western inland fisheries were valued near \$2 billion yr^{-1}. Three-fourths of the watersheds in the western United States are grazed, with a large fraction of that on public lands managed for multiple use. Proper management of this range is required to maintain or increase the value of recreational fisheries because the quality of fishery habitat depends on rates of nutrient and other material loading into streams, lakes, and reservoirs.

A need exists to predict the impacts of range management on water quality and other fish habitat needs. The Joint Task Force of the Western Regional Planning Committee (1977) has identified this area as a priority research need for improved range management. Leopold (1975) and Behnke and Zorn (1976) suspected that range over-grazing was the single greatest negative impact on stream fisheries. Most of the relevant data concerns the impacts of sediment loads generated by increased sheet and channel erosion (e.g., Lusby 1970 and Branson 1975) and the effects of ungulate-altered stream morphology on maintenance of fish stocks (e.g., Platts 1981a). Less information has been gathered to determine the effect of ungulate management on nutrient mobilization in watersheds outside the floodplains and its effect on downstream aquatic environments. This report presents a preliminary approach to predictive modeling of the impact of nutrient mobilization by ungulates on downstream waters.

Review of Ungulate Effects

Research into the direct effect of ungulates on fisheries habitat has been thoroughly reviewed by Platts (1981a and 1981b) and Buckhouse et al. (1981) who concluded that overgrazing along streams inhabited by salmonids can depress carrying capacity for salmonid stocks mostly by reducing availability of cover. Specifically, livestock trampling has been shown to increase riffle area and decrease pool area, overhanging banks, and riparian shade.

Because of their potential for introducing nutrient, domestic livestock have long been considered important contributors to stream enrichment (Holt et al. 1970, Robbins et al. 1971, and Omernik 1976). Even so, few studies have evaluated grazing impacts on nutrient mobilization. Numerous studies have been conducted on the effect of other disturbances on nutrient runoff (Bormann et al. 1969, Dillon and Kirchner 1975, McColl and Gugal 1975, Duffy et al. 1978, Timmons and Holt 1977, Timmons et al. 1977, Baker et al. 1978, and Tiedemann et al. 1978). These studies indicate, in general, that watershed disturbance usually leads to increased exports of nutrients and increased downstream loadings.

Intense grazing can significantly increase runoff (Sharp et al. 1964, Rauzi and Smith 1973, and Sartz and Tolstead 1974) and accelerate sediment mobilization (Meeuwig 1965, Branson and Owen 1970, Hanson et al. 1970, Lusby 1970, Gifford 1972, Blackburn and Skau 1974, Smeins 1975, Buckhouse and Gifford 1976a, Buckhouse and Gifford 1976b, Gifford and Hawkins 1976, Wood et al. 1978, McGinty et al. 1979, and Wood and Blackburn 1981) and contribute to negative downstream impacts generated by sediment loading. Cordone and Kelly (1961), Cooper (1965), and Stall

(1972) have documented effects of dislodged sediments on stream life. It follows that intense grazing also can accelerate nutrient mobilization and loading in downstream ecosystems to whatever extent that nutrients are associated with the soil eroded from a grazed watershed. But little data on range nutrient runoff has been gathered to assess the degree of association between nutrient runoff and soil erosion. The numerous studies designed to determine the potentially degrading effects of nutrient loading from feedlot runoff (Scalf et al. 1970, Robbins et al. 1972, Porter et al. 1975, and Manges et al. 1975) concern conditions different from most managed range conditions.

Among the few range studies of nutrients, Johnson et al. (1978) found short-rotation grazing (21 days) along permanent streams caused some increased loading of orthophosphate, ammonia-nitrogen, nitrate-nitrogen and suspended solids. However, they concluded that the enrichment had little impact on stream productivity at that point in the stream. Schreiber and Renard (1978) could not definitely conclude what effect, if any, grazing had on phosphorus mobilization because of confounding influences from different soil types. Baker et al. (1978) found that runoff from grazed mesic conditions (eastern United States) had high orthophosphate concentrations (1.06 mg l^{-1}), which are higher than those found in runoff from nearby fertilized and tilled row crops. However, in mesic watersheds ungulates are usually more densely stocked than in xeric ranges. The influence from eroding dung might be expected to be less in drier pasture. Olness et al. (1975) found that grazed watersheds in Oklahoma exported small fractions of dissolved phosphorus (less than 12 percent of total phosphorus) and that continuous grazing exported four times as much total phosphorus as rotation grazing, presumably because of greater soil erosion.

None of the above investigations of nutrient mobilization considered the potential for cumulative impacts on downstream sites such as reservoirs. McConnel (1968), Rinne (1975), and Fisher and Minkley (1978) stressed the importance of flood runoff on loading of organic and nutrient materials in downstream reservoirs in the southwestern United States. To the extent that ungulate grazing aggravates erosion, the eroded material contributes something to nutrient loading downstream, but probably not in proportion to the amounts of inorganic sediment mobilized.

Based on bacterial counts (Morison and Fair 1966, Kunkle and Meiman 1967, Kunkle and Meiman 1968, and Skinner et al. 1974) and nutrient runoff (Johnson et al. 1978), much of the ungulate dung that reaches streams is mobilized during high water when significant surface runoff occurs, causing streams to top their banks and erode flood plains littered with dung. Because most nutrient washed from watersheds in arid landscapes passes downstream in high, turbid waters (Fisher and Minckley 1978), much of the nutrient may not be immediately available for plant uptake. Downstream reaches or reservoirs may be influenced more than the reaches of streams immediately downstream from the grazed area. However, little research has been doen to investigate that possibility. Numerous small reservoirs in New Mexico are overly enriched with nutrients; inappropriate grazing practices have been suspected to contribute in at least some watersheds (Potter 1982).

Presumably, dung deposited along stream banks is more susceptable to downstream mobilization than dung deposited above flood level. In many watersheds, most dung deposition occurs above the flood plain where, if it is mobilized, it could contribute large amounts of dung materials to aquatic ecosystems. The amount of dung eroded would depend on the amount of material deposited in sites where dung can be moved by overland flow and the amount that remains in place until eroding rains occur. If dung is mobilized in the way that soil is eroded from the watershed, then models used to predict soil mobilization may, with some modification, also serve to depict dung mobilization. Numerous empirical and process models have been developed to predict soil erosion, but the one most widely tested and most practical for large-scale regional management is an empirical model, the Universal Soil Loss Equation, developed over three decades (Musgrave 1947, Wischmeier and Smith 1960, McElroy et al. 1976, Stewart et al. 1976, Dunne and Leopold 1978, and Dissmeyer and Foster 1980). This empirical model has been developed mostly for tilled or forested mesic conditions and is less developed for the wild drier conditions of western ranges. Therefore, the model needs considerable testing and possible modification to serve the needs of range managers.

To complete the development of a tool that can be used to predict the erosion rate of dung materials from watersheds and the downstream impacts, we need to integrate a sequence of events starting with dung deposition and erosion in the watershed and leading to the effects of primary production and decomposition on fish yield in downstream aquatic systems. Figure 1 shows the major points that need to be considered. The Universal Soil Loss Equation predicts soil erosion from a watershed using measures of soil erodability, the effect of vegetative cover, the effect of hillslope length and angle, and the erosive force of precipitation (Boxes 1-4 in Figure 1). In the Southwest, the variables with the greatest range of effects are vegetation cover and slope. These same factors would influence the amount of dung eroded and transported

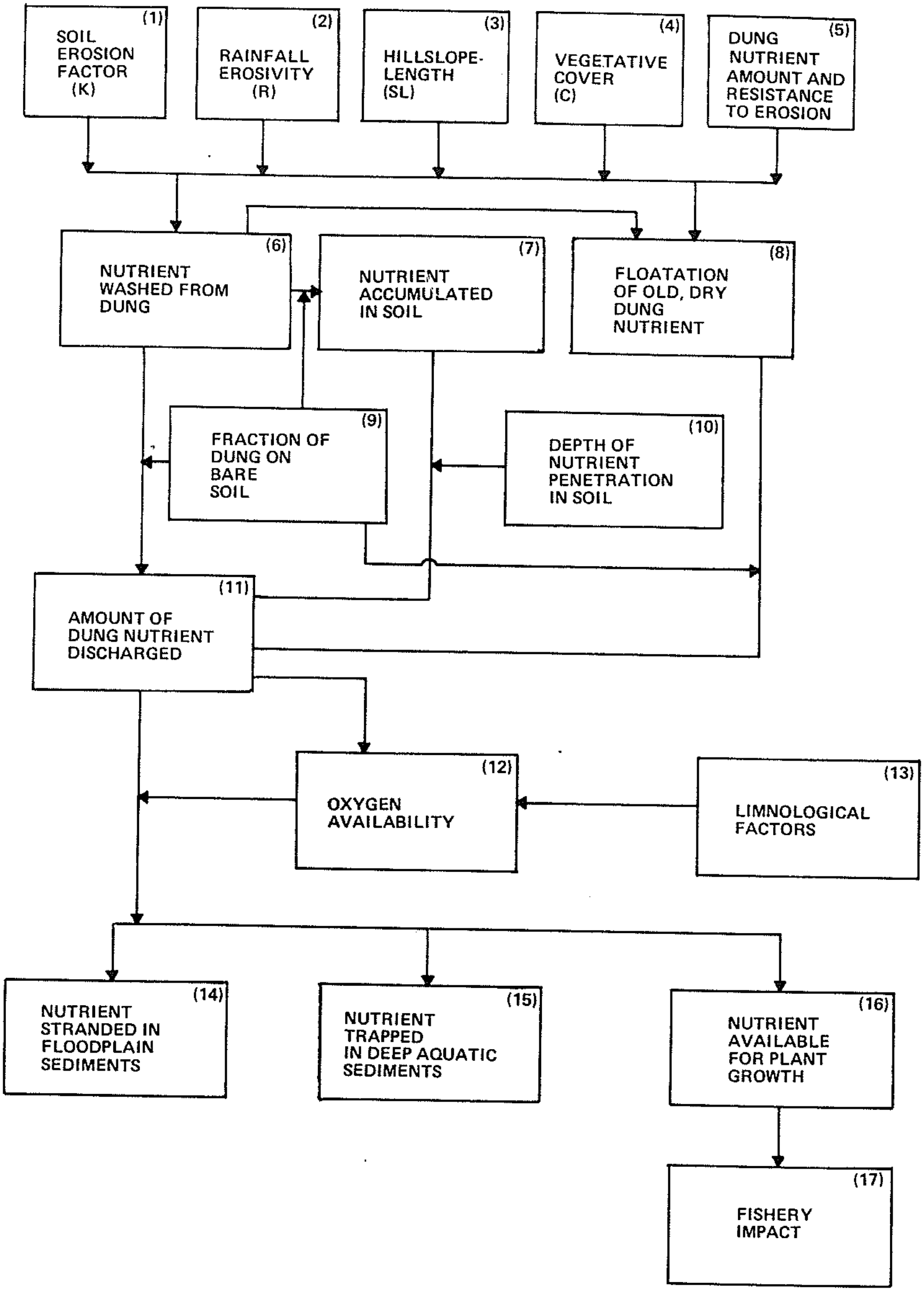

Figure 1. Major variables involved with predicting mobilization and downstream impact of dung organic matter and nutrient.

to permanent water, either directly from the dung (Box 6) or indirectly from the nutrient washed into soils which are later eroded (Box 7).

The amount of dung eroded will be determined by the amount deposited, its erodability, the amount of material volatilized before and between rains (Box 5), and the intensity and duration of the rain. Just as the amount of soil eroded from a watershed is controlled partly by the amount of ground cover (Dunne and Leopold 1978 and Dissmeyer and Foster 1980) in the form of vegetation or thick litter (more than 5 cm thick), nearly all dung deposited on dense ground cover is also expected to remain in the watershed, where its nutrients are recycled to the vegetation. Only that dung deposited on bare ground connected to a runoff system is expected to be eroded from the watershed (Box 9).

To the extent that grazing increases the amount of bare area, it may also proportionately increase the amount of dung and soil nutrient mobilized. Any dung material that penetrates deep below the zone of active erosion will not be carried off with the eroded soil, at least not in the near future (Box 10). Some of the dung may penetrate to ground waters and eventually influence downstream productivity from seepage into surface waters, depending on the ability of the soil to absorb the nutrient (Logan 1980). Other material may reach deep roots and be recycled, or it may simply accumulate deep below the surface and only after many years of further erosion be transported downstream.

Of the dung originally deposited, what is not eroded away by wind and water eventually disintegrates from trampling, other physical disruption, and decay. In semiarid to arid environments, dung generally dries to a specific gravity much lower than water and may be easily floated or rolled (Wallmo et al. 1962), like other litter, with sufficiently deep runoff (Box 8). Again, only dung likely to be transported out of the watershed to permanent waters downstream is that dung deposited on a bare soil surface connected to a runoff drainage network or on areas where overland flow develops appreciable depth over vegetation. The amount of organic matter or nutrient contributed by this old, dry dung depends on how much remains on erodible surfaces after leaching and erosion.

The amount of dung nutrient actually discharged (Box 11) from the watershed depends on the rates of change in dung-nutrient content before the dung is transported from the watershed. Organic nitrogen and carbon for example, are reduced to gaseous forms that escape the dung before and while it is carried off by overland flow. On the other hand, phosphorus and other sedimentary nutrients have no gaseous phase and should remain in the landscape. Following transport out of the watershed, the nutrient may be stranded in flood-plain sediments (Brinson et al. 1981) (Box 14), trapped indefinitely with deep lacustrine sediments (Syers et al. 1973) where it remains unavailable (Syers et al. 1973) for decomposer and plant uptake (Box 16). The extent to which the materials are partitioned into these three sinks depends on the morphology of the aquatic system and factors that determine rates of decomposition and mobilization of nutrients in an aqueous medium.

Oxygen availability is a particularly relevant factor that regulates decomposition and mobility of the nutrient because of its biological and chemical effects and the high oxygen demand often associated with dung (Box 12). Low oxygen concentration may reduce rates of decomposition, but, because of its influence on redox potential, increase the solubility of metallic complexes of phosphorus and release the nutrient for potential plant uptake. A material with high biological oxygen demand like dung may act as an ecological catalyst for mobilization of nutrient out of materials with low inherent oxygen demand. Soils with low organic matter may load downstream habitats with phosphorus which remains trapped in deep sediments until oxygen concentration and redox potential are reduced enough to dissolve complexes of phosphorus. Soil by itself may not be rich enough in organic matter to reduce oxygen concentration, but dung additions it may be. Such an interaction between soil and dung could increase the total availability of phosphorus (or other sedimentary nutrients) for plant growth by a factor larger than indicated by dung nutrient content alone.

The degree of impact that dung has on the fishery depends on the fertility of the pristine watershed and the requirement of the fishery for the deep, cool refuge waters particularly susceptible to severe oxygen depletion. Fisheries in watersheds of low fertility may benefit from accelerated erosion in watersheds because it leads to increased plant production and fish production as long as oxygen concentrations remain high enough to maintain the fishery. Fisheries in highly fertile watersheds are more likely to be limited in value because overenrichment causes environmental changes that increase chances for fish kills, decrease fish growth and vigor, or decrease yield for the fishing effort.

This research effort concentrated particularly on compartments 5-12 and 16 in Figure 1. Models either were adapted from past research results or devised to simulate the chain of events shown in Figure 1. Original research was designed to assess the predictiveness of the models and provide insight for their refinement. The research concentrated on effects of domestic cattle (Bos taurus) dung, but data were also gathered for the dung of major wild ungulate in southern New Mexico and eastern Wyoming, the mule deer (Odocoileus hemionus). Additional data were gathered for elk (Cervus elaphus). A fundamental question was to what extent do domestic livestock merely replace wild herbivores as agents for mobilizing nutrients, organic matter, and inorganic material into downstream waters.

METHODS

Proposed Model for Dung Nutrient Mobilization

A sequence of submodels was required to predict the amount of dung influence on oxygen demand and total phosphorus-nutrient availability in downstream ecosystems. The submodels predict dung loading rate, dung mobilization rate, soil mobilization rate, oxygen demand of dung and other materials, and phosphorus mobilization from eroded materials in confined segments of aquatic systems (e.g., hypolimnia of small reservoirs). The submodels are:

1. A dung loading submodel based on the time ungulates graze, biomass of grazing ungulates, forage processing efficiency of the grazers, and fractions of organic matter and nutrient in the dung, and the erosional loss of dung from the watershed is defined as:

$$N_L = (BIDEH) - N_v - N_e$$

Where:

N_L = Balance of dung nutrient or organic matter in the watershed at a specific time (kg ha^{-1}).

B = Mean biomass of grazer (kg ha^{-1}) in the time interval of concern and is estimated by sampling density or predicting density from range character using nutrition models.

I = Daily ingestion rate as a fraction of the grazer biomass, usually assumed constant based on established feeding rates.

D = Number of days grazed in time interval determined by sampling or by grazing schedules.

E = Fraction of grazer's daily ingestion that is egested during the time interval. It may be assumed to be constant or a function of forage quality and quantity, if significant.

H = Fraction of egested material that is nutrient or organic matter; may be assumed to be constant but probably varies with forage quality and quantity consumed.

N_v = Volatilization or other atmospheric loss of organic matter or nutrient during the time interval, which is a function of dung water, nutrient content and dung drying rate.

N_e = Erosional export out of the watershed down the drainage, described in more detail below.

2. A submodel that predicts the amount of dung organic matter and nutrients mobilized along with soil erosion is based on the Universal Soil Loss Equation. For purposes of testing, and developing coefficients for differential mobilizations rates, we assumed all dung material was eroded like soil, which erodes negligibly where heavy ground cover of vegetation or litter exists. Therefore, the model assumes that dung material must be deposited on bare soil surface if any appreciable amount is to be eroded. Hillslope length and angle, rainfall erosivity, and the susceptibility of the soil to erosion are other factors used to predict erosion in this model. The mobilization of dung nutrient or organic matter out of a watershed is defined by:

$$N_e = N_d A_n + N_s A_n + N_f A_n$$

Where:

N_e = Dung nutrient or organic matter eroded.

N_d = Fraction of total nutrient or organic matter eroded from the watershed that moves directly from the dung.

A_n = Total nutrient and organic matter exported predicted with the Universal Soil Loss Equation and concentrations of nutrients in the watershed.

N_s = Fraction of nutrient or organic matter eroded from the watershed, which is dung material that has become associated with surface soil that is eroded.

N_f = Fraction of nutrient or organic matter eroded from the watershed, which is floated or rolled from the watershed.

Where:

$N_d = bC_d/AC_a$

$N_s = aC_s/AC_a$

$N_f - cC_f/AC_a$

Where:

a, b, c = Empirical values used to correct for the differences between the predictions of soil erosion by the Universal Soi Loss Equation and dung material erosion by each of the three mobilization pathways.

C_a = watershed concentration of organic matter or nutrient in eroded soil.

C_s = dry material concentration associated with soil.

C_d = dry material concentration that can be reached directly from dry to permanent water.

C_f = dung material concentration that is floated from the watershed.

A = Total soil loss predicated by the Universal Soil Loss Equation.

Along with the prediction of dung nutrient mobilization, the amount of soil nutrient mobilized also needs to be predicted to establish the relative importance of dung nutrient in downstream waters. For purposes of testing, we assumed that the Universal Soil Loss Equation (Dunne and Leopold 1978 and Dissmeyer and Foster 1980) would serve as the basic model for predicting erosion rates of dung material and soil from watersheds, but with coefficients incorporated to account for differential rates of erosion. The Universal Soil Loss Equation for wild range is defined as:

$A = R(HS)KC$

Where:

A = the surface material eroded per unit area of watershed.

R = the rainfall erosivity determined by duration and intensity of rain.

HS = a hillslope factor determined by the length and degree of slope.

K = a soil factor that estimates the resistance of soil to erosion based on particle size, organic content, massive structure, and permeability to water.

C = a "crop management" factor which incorporates the effect of vegetation on substrate stability.

Through an extensively developed system of nomographs and tables, the necessary coefficients for predicting soil loss rate are made available, once the appropriate data for rainfall erosivity, soil K factor, hill-slope factor, and vegetative cover are determined. Although this model is the most widely used and best tested (Foster 1980), it has limitations expected of a practical empirical model that demands relatively few data. Model simulations of particular storm events or particular watersheds may vary considerably from observed results. Its usefulness as a predictive tool increases as the watershed area and the number of precipitation events contributing to erosivity increases and the data available are limited to routinely monitored soils and weather data. Other process erosion models are more reliable predictors for specific events and watersheds but require more data to operate satisfactorily (Simmons and Li 1980 and Foster 1980). Models used to predict grazing impacts on large expanses must be economical and rely on easily obtained data monitored routinely by various agencies. The Universal Soil Loss Equation seems to be generally best suited to this task because its major components are relatively easy to estimate from available information.

The rainfall erosivity factor (R), is defined as:

$$R = \sum_{i=1}^{n} \frac{E_i I_{30}}{100}$$

Where: $E = 916 + 331 \log_{10} I$

and E is energy in foot-tons $ac^{1} in.^{1}$ of rainfall and rainfall intensity (I) is in.hr^{1}. Where possible, rainstorms are divided into storm segments of "equal" intensity and E is calculated for each storm segment and summed over all segments (n). I_{30} is the maximum 30 minute intensity of the storm as in.hr^{1}. Rainfall erosivity is usually summed for a rainy season or a year. Annual rainfall erosivities vary between 25 and 100 or more in New Mexico. All english values were converted to metric equivalents for this report. For uniform comparison of erosion rates, the product of all erosion studies were reported as weight eroded per unit of Rainfall Erosivity.

The susceptibility of soil to erosion, K, is an average surface substrate loss in tons ac^{1}R^{1} (where R is rainfall erosivity), a function of substrate particle size, gross structure, organic content, and permeability. The K values have been estimated for many soil types, and are available from the U.S. Soil Conservation Service for regional predictions (although significant variation may occur within a soil type) and usually range from 0.1 to 0.5.

The length-slope factor is calculated from nomographs of slope and hill-slope length. This factor may vary from 0.01 on flats to 20 or more on steep hillsides. The crop-management factor incorporates the influence of rangeland practices in watersheds with a range of vegetational canopy cover, canopy heights, and ground cover amount and type (Dunne and Leopold 1978 and Dissmeyer and Foster 1980). Depending on the amount of canopy and its ability to intercept rainfall, the range management factor can increase surface material losses by 149 times (factor ranges from 0.003 to 0.42). Dissmeyer and Foster (1980) claim a forest floor covered by thick litter

(5 cm or more) will lose no material to erosion in any storm encountered in the United States. For areas where erosion improvements have been applied, an appropriate additional factor may be used to integrate their effects.

3. A submodel that predicts the amount of O_2 removal by the biological oxygen demand in the dung loading is based on the amount of organic matter in the dung, water temperature, reaeration coefficients (based on temperature, surface turbulence, oxygen concentration, elevation, and salinity) and volume of the affected water body. In this instance we were specifically concerned about the hypolimnion of small reservoirs (smaller than 100 ha) and were not concerned with reaeration coefficients for streams or epilimnetic systems.

The following is a submodel predicting the maximum possible oxygen that would be used (mg g^{1} eroded dung material) in a hypolimnion and the number of days over which oxygen would decline from introduced dung material until the demand was exhausted or oxygen concentration reached 0:

$$OL = TOA - TOD$$

$$ROD = aTD(OGD)2^{(C + 1)/10}$$

$$d_n = TOA/ROD$$

Where:

OL = Oxygen left ($g\ m^{-3}$) in hypolimnion after dung is totally decomposed.

TOA = Total oxygen available in hypolimnion ($g\ m^{-3}$).

TOD = Total potential oxygen demand of dung, if it all decayed (g m^{-3}) (assumes carbon takes up 3.1 times its weight in oxygen).

ROD = Rate of oxygen demand (g $m^{-3}d^{-1}$) in hypolimnion by dung.

a = An empirical value relating temperature and observed demand rate.

TD = Total loading of dung organic matter (g m^{-3}) into hypolimnion.

OGD = Oxygen demand by dung ($gO_2g^{-1}d^{-1}$).

$2^{(C + 1)/10}$ = The effect of temperature on relative rate of oxygen demand; in this case a Q_{10} of 2.0 is assumed.

d_n = Number of days needed to deplete hypolimnion of all the oxygen that dung is capable of removing from the hypolimnion or until no oxygen remains.

4. A submodel follows that generally accounts for the sources of dissolved phosphorus mobilized into water because of the presence of dung.

$$P_T = Pd + P_e + P_r + P_s(S_d) + P_1(S_d)$$

Where:

P_T = Total dissolved phosphorus mobilized into water from dung and dung-generated mechanisms.

P_d = Dissolved phosphorus leached directly from the dung in the watershed.

P_e = Phosphorus from dung eroded from the watershed with soil and later mobilized into solution.

P_r = Phosphorus released from organic matter as dung decays.

$P_s(S_d)$ = Phosphorus released into solution from soil because of increased decomposition and altered redox potential from dung loading.

$P_l(S_d)$ = Phosphorus released from plant litter into solution because dung was present.

The most important determinants for the coefficients are: (1) the decomposition rate, (2) the level of oxygen reached in the hypolimnion, the length of time a hypolimnion remains at very low or 0 oxygen concentration, the temperature, and the relative distribution of organic matter and phosphorus among dung, and other watershed constraints.

Estimating Organic Matter and Nutrients in Dung Runoff and Watershed Material

Chemical Analyses

To estimate dung material in watersheds, the fraction of dung comprised of significant materials needed to be estimated. The three fractions chosen for measurement were volatile solids, phosphorus, and nitrogen. Volatile solids is a commonly used estimate of organic matter, although it may slightly overestimate organic matter wherever inorganics are oxidized at prescribed ingestion points. With possible exception for soils, the materials analyzed in this study had low quantities of volatile inorganic solids. Volatilization was done as described in Greenberg et al. (1981). Although three measures of phosphorus were used: the one used most often was hydrolizable phosphorus; it was estimated as described by United States Environmental Protection Agency (1979). This estimates all phosphorus not integrated into organic material that is resistant to disruption by weak acidification. The total phosphorus, including most to all organic matter, was estimated by persulfate digestion (U.S.E.P.A. 1979) in a number of comparative cases to establish the fraction of the phosphorus generally associated with organic matter. Additionally, the dissolved inorganic phosphorus as orthophosphate phosphorus was estimated for certain surface-runoff studies. Total nitrogen was estimated by summing determinations for nitrate-nitrite nitrogen and Kjeldahl nitrogen, each as described in U.S.E.P.A. (1979). Ammonia nitrogen also was estimated for certain of the runoff studies as described in U.S.E.P.A. (1979). Total solids and volatile solids, wherever determined, were done as described by Greenberg et al. (1981). Most determinations were done in the Soils and Water Testing Laboratory at New Mexico State University (NMSU), with the exception of comparative samples done by the New Mexico Environment Improvement Division (Table A-1) and samples done at the University of Wyoming.

Estimating Volatilization

To estimate the degree of nutrient loss from dung, studies were conducted during September 1980 to assess the loss rate of water, volatile solids, nitrogen, and phosphorus from homogenous dung of known age and pat size. Fresh dung (less than 1 day old) was collected from dairy feedlots at NMSU and thoroughly mixed before a series of dung pats were made by filling a U.S.G.S. soil seive. The pats were about 4.5-cm deep by 20.0-cm in diameter and weighed 1800-1900 g (wet weight) at the initiation of the experiment. Each pat was placed on a thin sheet of wood veneer (150-180 g made impermeable with urathane) and exposed under clear and opaque canopies to protect them from uncontrolled natural rain and to test the effect of shade on volatilization of nutrients. The pats were dried for periods of 1, 3, 6, and 12 days at which times they were collected for chemical analyses. Two replicate dung pats and one empty veneer sheet (used for reference weights) were placed under each canopy for each exposure period.

After the fresh dung was mixed, four subsamples were drawn to determine hydrolizable phosphorus, total nitrogen, volatile solids, and percent water (Greenberg et al. 1981). After each subsequent drying period, pats were randomly chosen from each of the canopies and the same materials were again measured. Fractions of loss were calculated by comparison to the fresh pats. To further assess consistency of dung weight loss over time an experiment was conducted from July to October 1980. Dung pats weighing 900-1100 g (made in a pie pan) were exposed for eight weeks and weighed weekly to determine weight loss. Eight sets of eight-week exposures were observed. Pats were set out on veneer substrates in replicate pairs under opaque and clear canopies as described for volatilization studies.

Dung Material in Watersheds

The material fractions in dung of the dairy cattle, used in controlled erosion and volatilization studies, was compared to fractions of dung estimated for cattle and deer in natural watersheds and beef cattle maintained at NMSU. Fresh to old deer and cow dung was collected from seven plant communities (five in New Mexico and two in Wyoming) to assess the variation in the fraction comprised of volatile solids, hydrolizable or persulfate-digested phosphorus, nitrogen, and water content in different ecological conditions. Water content was measured in fewer samples. Dung was homogenized in a food-processor and aliquot subsampled for analyses. The analyses indicated that dung used in the experiments were similar with regards to the parameters measured to range dung.

Estimation of Erosion Rate

Simulated Rains on Impermeable Substrate

In January and February 1980 and September 1980 two separate experiments were conducted to assess the erosion of volatile solids, hydrolizable phosphorus, and total nitrogen from prepared dung pats. Fresh dung was prepared and made into pats and exposed under opaque and clear canopies as described previously for studies of material volatilization. Starting January 26, 1980, pats were exposed for periods of 1, 2, 4, 8, 16, and 32 days, and starting September 18, 1980 pats were exposed for periods of 1, 3, 6, and 12 days. Two replicate pats and one empty reference veneer sheet were placed out to dry under each canopy as described previously. Fresh pats, and pats exposed to prescribed drying times, were randomly drawn to be artificially rained on using a mobile infiltrometer described by Blackburn et al. (1974). Each pat and its veneer support sheet, or a reference veneer sheet, were placed in a waterproof plywood trough with a smooth bottom 30-cm wide by 90-cm long with a 5 percent slope. Three troughs were placed together beneath the simulated rain and rained on for measured periods. During each rain, the troughs held one pat exposed to shade, one pat exposed to light, and a veneer-sheet reference (without a pat) that had been exposed either to light or shade. Then a second set of pats and a veneer sheet were drawn to be rained on to complete the sets of two replicates.

Simulated rains were timed to deliver a 2-cm rain (an I_{30} of 5-cm). For the experiment in January-February 1980, the 2-cm rain was partitioned into three rains of 0.00-0.67, 0.67-1.33, and 1.33-2.00-cm to assess the relationship between runoff water quality and duration of simulated rain. Once the runoff was collected, the amounts of water in the buckets were measured, thoroughly mixed to suspend all particulates, and subsampled for chemical analyses. Dung, before and after rains, and runoff water were sampled for hydrolizable phosphorus, total nitrogen and volatile solids. From these data and data on dung weight and concentrations, the percentages of materials that ran off were calculated for each period of drying exposure in sunlight and shade.

Simulated Rain on Natural Substrate

To determine the impact of natural substrate on the net amount of nutrient and organic matter eroded from cow dung, a series of experiments using a mobile infiltrometer (Blackburn et al. 1974) were conducted in five plant communities of southern New Mexico: creosote at Las Cruces, desert grasses west of High Rolls, pinyon-juniper near Mayhill, and ponderosa pine and mixed conifers near Sunspot. The slope of sites selected for simulated rain varied widely. No attempt was made to hold the fraction of ground cover constant although this varied relatively little. Within a plant community, all samples were collected within several hundred meters of each other on similar soils. Sites with vegetation more than 0.5-m high were avoided. Soil samples were collected for K-factor calculations and the slopes and fraction of ground cover were estimated.

The water used for the infiltrometer was collected from springs and was subsampled to determine relative fractions of volatile solids, hydrolizable phosphorus, and total nitrogen. The runoff concentrations were calculated by substracting from the concentrations measured in the artificial rain.

Pairs of 1-m^2 plots, with and without dung pats, were rained on. The numbers of sample pairs ranged from 10 to 13 in each of the five plant communities.

The dung pâts were prepared from fresh range dung taken from paddocks in the vicinity (nutrient content and volatile solids in the dung were similar to those measured in a wide range of sites, but nitrogen was variable). Pats were formed like those described for the volatilization and erosion studies (a U.S.G.S. seive was used as a form). Simulated rain was delivered (I_{30} = 5 to 7 cm) for a period long enough to develop overland flow for chemical analysis, usually from 8 to 18 minutes. Hydrolizable phosphorus, volatile solids, total solids, and total nitrogen were estimated in runoff from each plot exposed to simulated rain.

All runoff water was collected and the total rainfall delivery was estimated by timing the rain and measuring the delivery rate, which varied little. Rainfall was simulated only on calm days to avoid drift off the plots. Fraction of rainfall that ran off and net mass of materials eroded were calculated from the recorded data.

For the soils in the sites selected, a soil-K factor was estimated using nomographs, tables, and techniques described by Dunne and Leopold (1978) and Dissmeyer and Foster (1980). The fraction of ground cover (thick vegetation or duff) was also estimated and the length-slope factor was estimated by extrapolating the nomograph (Dunne and Leopold 1978) from 10 ft to 3 ft (3 m to 0.85 m). The rainfall was converted to a Rainfall Erosivity Index for comparison with other natural and artificial rain events and to compare the runoff with predictions by the Universal Soil Loss Equation.

Natural Rainfall in Larger Watersheds

Watershed Description. The 12 watersheds chosen for study in 1979 were in the Lincoln National Forest (Mayhill District) 12-km north of Mayhill, New Mexico and 2-km south of the Mescalero Apache Reservation. The watersheds occurred along the north side of Sixteen Springs Canyon Road just east of its intersection with Carr Canyon Road. Table 1 summarizes the characteristics of the watersheds. All 12 were similar in most respects. The upper slopes were concave, steep (more than 30 percent) and rocky, and sparesely covered (less than 10 percent) with an overstory of juniper and pinyon pine. The lower slopes had a lower gradient (10-15 percent) and were covered by moderately dense stands (65-75 percent) of young ponderosa pine, pinyon pine, juniper and scrub oak. All watersheds faced south and were centrally drained by clearly defined drainage channels that were about 1 to 2 m wide at the lower end of each watershed. No permanent water occurred in any of the watersheds nd runoff lasted less than a day even from exceptionally large storm events. Upper-slopes were lithic arguistoll (clayey-skeletal) and the lower slopes were pachic argiboroll (fine-mixed, mollic eutroboralf). All but one watershed was adjacent to the others. The greatest distance between them was about 2.5 km. During the previous fall and winter the watersheds had received higher than seasonal mean amounts of precipitation but spring precipitation was lower than the mean.

Table 1. Watershed data for 12 watersheds monitored in summer 1979 along Sixteen-Springs Canyon (all aspects were southerly and within 60° of each other).

Watershed	Area (Ha)	Length of Slope Along Axis (m)	Slope of Upper Half	Slope of Lower Half	% Cover[1] of Trees Over 4m High	% Cover[2] of Brush Up to 2m High	%[3] Ground Cover	Fraction of Soil Types A[4]	Fraction of Soil Types B[4]	Elevation of Weir (m)
1	23.8	490	34.6	24.7	50	25		0.30	0.70	2050
2	23.6	515	42.0	23.3	50	25		0.50	0.50	2075
3	36.9	695	34.6	17.3	50	25		0.75	0.25	2075
4	26.3	560	45.4	21.6	25	25		0.80	0.20	2085
5	27.3	500	33.9	29.1	25	25		0.85	0.15	2090
6	44.3	610	47.7	17.9	25	25		0.85	0.15	2100
7	37.7	760	37.6	17.1	50	25		0.75	0.25	2100
8	74.4	790	24.5	15.3	50	0		0.65	0.35	2110
9	81.6	990	26.9	9.8	70	0		0.35	0.65	2100
10	45.7	915	28.9	13.2	75	0		0.25	0.75	2100
11	38.9	980	22.3	12.4	75	0		0.30	0.70	2100
12	29.8	890	15.0	8.2	100	0		0.10	0.90	2100

[1] To nearest 25%; mostly ponderosa pine.

[2] To nearest 20%; mostly scrub oaks (wavy-leaf).

[3] To nearest 20%; mostly grasses and thick forest litter (duff).

[4] A is a lithic argiustoll-skeletal mixed mesic; udic argiustoll-clayey skeletal mixed, mesic complex (16-40% slopes). B is a pachic argiboroll-fine, mixed, mollic eutroboralf, fine mixed complex.

Weir Installation. Notched plywood weirs were installed in the central drainage channels at the lower ends of each watershed. Each weir was notched with a cut that approximated the drainage channel shape to reduce the tendency to impound sediment and debris. The weir dimensions are shown in Figure 1. Weirs were constructed of braced exterior plywood, preserved, and set 30 to 50 cm into the bank and bottom of the stream channel. To prevent leakage around the weir, the bottom of the channel from the weir to about 4 m upstream was sealed with polyethethylene. Open-mouth rain gauges were installed within 100 m of each weir.

Weir Calibration. Weirs were calibrated to relate the level of flow through the weir opening to discharge through the opening. To calibrate, a weir temporarily installed next to a permanent stream (upper Rio Penasco) with similar slope and channel configuration then water was diverted through the weir. At small discharges, less than 0.25 l sec^{1}, the flow was timed as it was captured in a bucket below the weir. For larger discharges, a Price Pigmy Current Meter was used to measure velocity just upstream from the weir opening. Additional estimates of discharge were made at the weirs installed in the watersheds during a storm event. All data were used to develop calibration curves between water head at the weir and discharge through the opening.

Dung Sampling. Five transects were established in each of the 12 watersheds to sample cow and deer dung deposits. The transects were evenly spaced perpendicular to the axis of the main drainage channel and flagged for return sampling visits. The outer boundary of each transect was estimated using a clinometer to determine when the rim of each watershed was reached.

Dung deposits were counted in transects 2 m wide. Each transect was paced and the dung distance from the channel was estimated. Dung was categorized by species and age. Fresh dung was moist on the outside, recently deposited dung was still moist inside, and old dung was dry throughout the deposit. Based on our drying studies, fresh manure was usually less than two days old and recent dung was up to three to four weeks old. All deposits were marked with a painted spike for future reference.

The dung was sampled before the first summer storms in each of the 12 watersheds. The data were used to estimate density and distribution of dung in each watershed. After the first summer storms occurred, the dung was resampled on the first (near the bottom of the watersheds) and the fourth (near the top of the watershed) transects.

Dung also was collected from the watersheds to estimate mean weight per deposit. Two different transects were walked through the watershed and each deposit encountered along the transects was completely retrieved and placed in a plastic bag. Nine deposits were collected from one transect and 10 deposits were collected from the other. The deposits were later weighed in the laboratory. Dung samples also were collected for nutrient analyses from the watershed and other locations including the university farms at NMSU. Dung content of hydrolizable phosphorus, total nitrogen, and volatile solids were analyzed.

Water Sampling. Rain gauges were checked following each significant rainfall and the gauges were emptied for the next rain. Watersheds were visited whenever rain was anticipated. During a major rainstorm two vehicles were used to drive between the watersheds to measure water depth at each weir and take water samples. We intensively sampled at least one watershed and used it as a reference for estimating the shape of discharge-time plots (Appendix Figures E-1 to E-4). Because the storms were intense, the dirt road became slippery making sampling arduous. Despite these conditions, sampling was done as frequently as time and conditions allowed.

Water samples were placed in 250-ml polyethelene bottles. One set of samples was treated with 2-ml of concentrated H_2SO_4 for later analyses of orthophosphate, hydrolizable phosphorus, nitrate-nitrite nitrogen, ammonia-nitrogen, and Kjeldahl-nitrogen. Other samples were left untreated and later analyzed for total volatile solids and total solids. All samples were refrigerated and returned to NMSU within 24 hours to be analyzed at NMSU's Soils and Water Testing Laboratory. Additional samples were sent to the New Mexico Environmental Improvement Division (NMEID) for comparative analyses (Table A-1).

Other Dung Mobilization and Distribution Studies

Fresh deer and cow dung were artifically deposited in sites where they could be monitored for up to a year. In June 1980, five replicates of cow and deer dung were placed on gradual, moderate slopes in desert grasses, pinyon-juniper, ponderosa pine, and mixed-conifer watersheds. They were monitored for dislocation and disappearance over rainy seasons extending through September. Wherever deposits remained, the amount of scatter from the original deposit location was noted. In June 1981, deposits were set out in the same pattern in pinyon-juniper and mixed-conifer watersheds. Those deposits were monitored up to one year to determine scatter and loss rate. Weather data over the entire period of study was gathered from records of the U.S. Weather Service.

Dung distribution, both on vegetation and on bare soil, was estimated in the 12 watersheds studied for natural runoff. Estimates were made of the fraction of bare surface and the fraction of deposits on bare soil along transects one and four.

A pilot study of vertical mobilization of dung volatile solids and phosphorus was conducted on disturbed desert soils collected near Las Cruces, New Mexico. The soil was analyzed for particle size and organic content. Soil was well mixed and placed in 16 containers, 23 cm x 23 cm 4 cm deep, with plastic-screen bottoms (2-mm mesh). After each container was filled, an identical container was placed over it and filled. Then, a brace was fitted over each set to keep it in place. The soil was compacted to remove any unfilled space within the container. Fresh dung pats (1000 g pats) were placed on top of eight containers while eight containers without dung were maintained as references. All containers, with and without dung, were exposed to the equivalent of 50 cm hr^{-1} simulated rain for one minute using distilled water. This simulation was done when the dung was fresh and twice again at two-week intervals. The containers were exposed for a four-week period under a clear plastic canopy. After the last simulated rain, the containers were separated and a 1 cm layer of soil was removed from 7-8 cm below the surface, from 3-4 cm below the surface, and from the surface. All dung was removed before the surface layer was collected, including a film of displaced dung that collected during the first artificial rain.

Downstream Effects

Rio Penasco and Runoff Near Las Cruces, New Mexico

In 1979 and 1980, water samples were collected from the permanent stream that receives water from Sixteen Springs Canyon where the natural rain events were studied. In July and August 1979, the discharge was relatively low and clear at the time of sampling; discharge was higher and more turbid in June 1980 when sampled. Additional water samples were taken from groundwater sources to the Rio Penasco in June 1980 to establish the base-flow condition and compare it to the concentrations found in arroyo runoff, infiltrometer runoff and mainstream flows. Samples were preserved and analyzed for phosphorus, nitrogen, suspended solids, and volatile solids, as previously described.

Water samples also were collected from three runoff events in dry arroyos of creosote near Las Cruces, New Mexico. The discharge was estimated by measuring the velocity with a timed floating plastic bottle (half full of water) and by measuring stage at each sampling period. Later, stream-channel depth and width were measured for each stage. Hydrolizable phosphorus, volatile solids, total nitrogen, nitrate-nitrite nitrogen and ammonia-nitrogen were sampled as indicated previously. Weighted mean concentrations were calculated (discharge x concentration).

Oxygen Demand of Dung and Watershed Materials

The oxygen demand of dung, forest litter, and soil (from exposed bare areas) was estimated in laboratory studies conducted at NMSU. Samples of fresh and old cow dung, old deer dung, pine-needle litter, oak-leaf litter, and soil were collected from watersheds studied in Sixteen Springs Canyon in the Lincoln National Forest. Each material was analyzed for hydrolizable phosphorus, volatile solids, and percent water after homogenization in a food processor.

Rough estimates of the concentration of material that could be washed into a small reservoir were made and added to 300 ml of distilled water as indicated in Table 2. An initial addition was not enough to depress oxygen levels to less than 1 mg l^{-1} so it was followed by a second addition seven days later. The experiments were conducted under constant, usually dark conditions (light only when being processed) at 18°C (selected to represent hypolimnetic temperatures of small reservoirs at intermediate elevations in New Mexico). Combinations of soil and fresh cow dung, as well as pine-needle litter and fresh cow dung, were also exposed to similar conditions to test the effect of the mix on the oxygen demand. Two combinations were used as indicated in Table 2. The oxygen concentration was measured at two- to four-day intervals following the initial addition of material. Oxygen was measured with a calibrated BOD probe on a USI oxygen meter. Oxygen demand was estimated from the average decline in oxygen over a two- to four-day period. Six replicates were used for each treatment up to 16 days following initiation, followed by four replicates up to 32 days later and two replicates 48 days later.

Mobilization of Phosphorus

At points of 16, 32, and 48 days after the material was added to BOD bottles, two replicates were removed for analyses of orthophosphate phosphorus in water decanted from the tops of each BOD bottle. We were careful not to suspend any residues on the bottom. The decanted water was then analyzed for orthophosphate phosphorus as described previously.

Table 2. Dry weight of materials (mg l^{-1}) added to 300-ml BOD bottles in experiments on oxygen demand of dung, soil, and litter materials. All watershed materials were collected from Sixteen Springs Canyon in June 1982 and ground in a food processor. A relatively small concentration was added initially (with relatively low oxygen demand) which was augmented seven days later with a larger concentration to increase the oxygen demand.

	First Addition	Added 7 Days After First Addition	Percent Moisture
Old Cow Dung	167	341	6.95
Fresh Cow Dung	167	332	82.53
Pine Needles	166	339	7.32
Oak Leaves	166	336	8.36
Deer Dung	166	359	3.01
Soil	167	324	2.74
5% Dung, 95% Pine Needles	42, 119	332, 5026	
5% Dung, 95% Soil	42, 131	332, 5026	
25% Dung, 75% Pine Needles		125, 374	
25% Dung, 75% Soil		125, 374	

RESULTS

Organic Matter and Nutrients In Dung, Soil, and Litter

Dung Organic Matter and Nutrients

Volatile solids in dung is an estimator of organic matter with some potential for oxygen demand in water once it reaches streams or reservoirs. Organic matter also provides a source of carbon dioxide for aquatic-plant uptake. The volatile solids in cow dung comprised a reasonably consistent fraction regardless of dung age, water content, area obtained, or the breed of animal that deposited it. Table 3 shows that the mean percentage of volatile solids, in all situations measured, ranged from 69.9 to 87.3 percent of total solids and averaged nearly 75 percent with a standard deviation of less than 10 percent of the mean. The percentage of volatile solids of mule deer dung also was consistent over a wide range of habitats and ages. Deer dung evidently loses water quickly and therefore little fresh, moist dung was collected in New Mexico. It was more readily obtained in Wyoming. Deer dung was significantly (P = .05) richer in organic matter than cow dung.

The fraction of dung comprised of hydrolizable phosphorus in New Mexico was more variable than volatile solids and was not consistently predicted by species or breed, age, or location of the dung. Mean concentrations averaged about 0.20 percent of total solids with a standard deviation over half the mean value. Concentration ranged from 0.06 percent to 0.65 percent. Dung deposits collected from the same location with similar histories often varied as much as dung deposits from different localities or with different histories. In Wyoming, total phosphorus was measured instead of hydrolizable phosphorus, and therefore higher

Table 3. Percent of cow and deer dung of different ages and origins comprised of water, volatile solids, phosphorus, and nitrogen.

Dung Origin and Age	Percent of Dry Weight				Percent of Total Weight
	Volatile Solids	Hydrolizable Phosphorus	Total Phosphorus	Non-Gaseous Nitrogen	Water
Beef Cow					
Fresh (Ponderosa Pine) N.M.	83.7±0.3	0.07±0.00		1.99±0.09	82.5
Fresh (Ponderosa Pine) N.M.	72.3±1.2	0.65±0.23		14.83±2.20	--
Old (Ponderosa Pine) N.M.	65.2±1.2	0.23±0.00		1.84±0.05	6.9±2.40
Old (Ponderosa Pine) N.M.	71.7±1.2	0.10±0.05		2.20±0.59	--
Fresh (Feed Lot) N.M.	81.5±2.0	0.32±0.18		3.35±0.19	--
1-Yr Old (Ponderosa Pine) N.M.	72.4±1.4	0.12±0.05		2.05±0.26	--
Old (Ponderosa Pine) N.M.	70.9±0.3	0.08±0.06		2.35±0.94	--
Old (Ponderosa Pine) N.M.	69.9±7.7	0.12±0.10		0.57±0.04	3.9±0.17
Old (Mixed Conifer) N.M.	85.1±2.1	0.07±0.01		0.38±0.05	3.3±0.89
Old (Pinyon-Juniper) N.M.	74.8±2.1	0.06±0.01		0.40±0.11	4.4±0.90
Fresh (Aspen) Wyo.	79.8±2.6		0.37±0.09	1.61±0.08	79.8
Recent Cow (Aspen) Wyo.	76.7±12.5		0.39	1.92	62.1±13.50
Old Cow (Aspen) Wyo.	--		0.33	1.47	7.6±4.20
Mean All Beef Cow	75.3±6.1	0.18±0.18	0.36±0.03	2.68±3.74	
Dairy Cow (Creosote)					
Feedlot Fresh	87.3±0.9	0.32±0.07		3.82±0.41	--
Winter Studies (Feedlot Origin)					
0 Days	81.1±1.7	0.16±0.07		3.27±0.17	77.6±1.18
16 Days Old in Shade	78.7±0.3	0.23±0.23		2.09±2.31	62.0±0.00
32 Days Old in Shade	71.8±0.8	0.21±0.15		0.75±0.30	47.0±5.60
16 Days Old in Sun	77.5±1.7	0.22±0.08		3.48±--	53.5±2.10
32 Days Old in Sun	78.4±1.2	0.37±0.11		1.84±0.03	37.5±1.06

Table 3. Continued.

Dung Origin and Age	Percent of Dry Weight Volatile Solids	Percent of Dry Weight Hydrolizable Phosphorus	Percent of Dry Weight Total Phosphorus	Percent of Dry Weight Non-Gaseous Nitrogen	Percent of Total Weight Water
Summer Studies (Feedlot Origin)					
1-Day Old in Sun	72.7±0.6	0.15±0.02		0.99±0.01	71.5±0.71
12 Days Old in Sun	71.4±0.7	0.06±0.01		0.87±0.07	35.0±4.24
Mean All Dairy Cow	77.0±3.3	0.20±0.05		1.91±1.04	
Mule Deer					
Old (Ponderosa Pine) N.M.	83.1±0.4	0.36±0.03		2.02±0.06	3.0±0.50
Old (Ponderosa Pine) N.M.	86.8±3.2	0.08±0.05		1.80±0.81	--
Old (Ponderosa Pine) N.M.	89.0±3.0	0.20±0.05		1.48±0.40	7.4±0.80
Old (Mixed Conifer) N.M.	83.9±4.0	0.30±0.25		1.98±0.74	6.7±2.60
Old (Pinyon-Juniper) N.M.	80.5±9.3	0.15±0.05		1.76±0.52	8.0±2.96
Old (Desert Grasses) N.M.	82.8	0.34		2.57	8.2
Fresh (Aspen) Wyo.	81.3±5.2		0.43±0.13	2.38±0.01	66.0
Recent (Aspen) Wyo.	83.7±1.0		0.41±0.13	2.10±0.22	15.9±8.40
Old (Aspen) Wyo.	79.2±3.4		0.48±0.49	2.48±0.55	14.8±13.40
Fresh (Lodgepole Pine) Wyo.	77.2±12.3		0.80±0.48	2.82±0.04	72.3±6.80
Fresh (Lodgepole Pine) Wyo.	79.1±3.9		0.48±0.03	2.38±0.13	62.1±12.10
Mean All Mule Deer	82.4±3.5	0.24±0.11	0.52±0.16	2.07±0.62	
Elk					
Fresh (Lodgepole Pine) Wyo.	66.7±4.4		0.37±0.02	2.14±0.08	74.9±3.70
Fresh (Lodgepole Pine) Wyo.	84.7±4.4		0.37±0.04	2.39±0.04	56.2±12.50
Mean of Groups	75.7±12.7		0.37±0.00	2.26±0.18	

values were determined. Based on comparisons of hydrolizable and total phosphorus (Tables A-1 to A-3), hydrolizable phosphorus usually averages 50 to 65 percent of the total phosphorus, indicating that concentrations of hydrolizable phosphorus in New Mexico and Wyoming were comparable.

The fraction of dung solids composed of nitrogen also was more variable than the fraction of volatile solids, but usually more consistent within deposits of similar history than fractions of phosphorus. The fraction of nitrogen in all dung averaged about 2.5 percent but with high variation since the age of the dung was a critical influence. Very fresh cow dung from a ponderosa pine community was measured with as high as 15 percent nitrogen concentration. Old cow dung from a ponderosa pine community had as little as 0.4 percent nitrogen. Fresh dung was particularly variable, ranging from 2 to 15 percent, perhaps because large fractions of nitrogen gas or ammonia gas were lost within hours of deposition. In range studies, old mule deer dung often was richer in nitrogen than old cow dung, but not invariably. In old dung, the amount of nitrogen present could depend on microbial activity and, in turn, the amount of water in the dung. For old dung analyzed for water content, most of the deer dung had twice as much water as cow dung. In contrast with volatile solids and phosphorus, the age or moisture content of dung was needed in order to predict the total nitrogen in dung deposits of a watershed. The species and breeds of animals and their locations were relatively unimportant considerations for predicting the fraction of nitrogen in dung.

Soil and Litter Concentration of Nutrients.

Concentrations of nutrient materials in the surface soil and litter of the watersheds varied among the sites studied (Table 4). Volatile

Table 4. Percent of watershed materials comprised of volatile solids, phosphorus, and nitrogen obtained at locations of infiltrometer and material-runoff studies.

Plant Community Material State	n	Percent of Dry Weight			
		Volatile Solids	Hydrolizable Phosphorus	Total Phosphorus	Non-Gaseous Nitrogen
Aspen, Wyo.					
Organic Soils (composite)	3			0.019±0.013	0.46±0.35
Sand and Gravel (composite)	3			0.029±0.015	0.53±0.38
Litter	2			0.003--	0.69±0.02
Lodgepole Pine, Wyo.					
Organic Soils (composite)	3			0.023±0.008	0.20±0.14
Sand (composite)	3			0.019±0.008	0.04±0.02
Litter	1			0.031--	0.32--
Creosote, N.M.					
Soil (composite)	2	1.7±0.40	0.013±0.001	0.015±0.001	0.03±0.001
Desert Grass, N.M.					
Soil (composite)	2	2.7±0.67	0.001±0.000	0.002±0.001	0.09±0.01
Soil (bare surface)				0.005±0.000	
Pinyon-Juniper, N.M.					
Soil (composite)	2	7.3±0.29	0.004±0.002	0.005±0.001	0.13±0.04
Ponderosa Pine, N.M.					
Soil (composite)	2	14.0±10.85	0.012±0.006	0.015±0.002	0.20±0.17
Soil (bare surface)	3	7.4±0.42	0.060±0.000		0.18±0.00
Oak Leaves (litter)	3	99.8±0.01	0.070±0.000		0.75±0.03
Pine Needles (litter)	3	99.9±0.03	0.080±0.000		0.75±0.03
Mixed-Conifer, N.M.					
Soil (composite)	2	15.9±1.52	0.010±0.004	0.015±0.011	0.14±0.09
Litter		--	0.014±0.003	0.023±0.014	0.34±0.20

solids were low in creosote dominated surface soils and relatively high in soils of mixed-conifir formations, indicating a continuum related to intensity of organic production and litter accumulation. The richest surface soils had concentrations of volatile solids that were 30 percent of dung concentrations; the poorest soils had concentrations of about 2 percent of dung concentrations. Litter contributed substantially to surface material in ponderosa pine and mixed-conifer formations and was almost entirely volatile solids. Phosphorus concentration in soils and litter averaged about 30 percent of the concentration in cow and deer dung. Concentrations of nitrogen in the litter averaged about 30 percent of that in cow dung and concentrations in the soil averaged about 8 percent.

Mean concentration of volatile solids and nitrogen were related to the amount of precipitation received in watersheds of different climates in New Mexico ($R^2 = 0.96$). Phosphorus concentrations in soils varied without relation to the climate.

Accumulation of Dung Nutrients in Watersheds

Table 5 shows the amounts of cow and deer dung that had accumulated in different biomes of south-central New Mexico and south-central Wyoming. The relative amounts of dung material present are a function of the rates of deposition, volatilization, physical and biological decomposition, and erosion from the watershed. Variation seen in Table 5 could arise as a consequence of variation in any or all of these factors. Table 6 shows estimates of the relative amount of dung material in the watersheds in the uppermost 2 mm of soil assuming that concentrations measured in the soils were generally representative of surface concentrations. The

Table 5. Weight of volatile solids (kg ha^{-1}) in dung deposits in adjacent watersheds of different plant formations sampled in New Mexico and Wyoming before summer rains in 1980.

	Watershed 1		Watershed 2		Mean	
	July	August	July	August	July	August
Mixed-Conifer, New Mexico (80% forested)						
Deer	5.10	--	5.12	--	5.06±0.08	--
Cow	0.63	--	0.00	--	0.31±0.44	--
Pinyon-Juniper, New Mexico (20% forested)						
Deer	4.60	5.43	6.52	7.79	5.66±1.36	6.61±1.67
Cow	8.70	8.92	11.19	10.66	8.81±0.16	10.92±0.38
Aspen, Wyoming (30% forested)						
Deer	3.35	4.65	2.72	3.62	3.85±0.70	3.28±0.80
Cow	52.49	67.13	37.59	52.71	45.04±0.04	59.92±10.19
Lodgepole Pine, Wyoming (75% forested)						
Deer	4.65	3.62	4.97	3.40	4.81±0.23	3.51±0.16
Cow	8.33	10.08	6.24	6.60	9.20±1.24	6.42±0.25

Table 6. Estimated percentages of dung materials in surface soils of watersheds studied, based on data presented in Tables 2-4 and 18, assuming that the soil is 1-mm thick and has a specific gravity of 1.5. Large plant litter is excluded and the fraction of old, disintegrated dung in the watersheds is unknown.

Plant Formation	Volatile Solids	Total Phosphorus	Total Nitrogen
Pinyon-Juniper	1.30	9.24	2.52
Ponderosa Pine[1]	1.80	6.50	2.06
Mixed-Conifer	0.20	1.10	0.90
Aspen	--	6.50	2.26
Lodgepole Pine	--	2.10	2.70

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[1] From watershed studies reported in Table 18.

soil samples were up to 6 cm deep; therefore any surface accumulation of organics were diluted by the large samples and the relative estimated amount of dung contribution is likely to be high, if 1 mm depth is appropriate. Even so, the fractions of organic matter and nutrient comprised less than 10 percent of their soil counterparts. If a shallower fraction is more appropriate, then the relative contribution will be proportionately higher. A 1 mm loss rate is the equivalent of 15 ton ha^{-1}, a high annual erosivity for southwestern watersheds.

The total weight of dung in the watershed declined mostly as a consequence of drying (Tables 7 and 8) and volatilization. Rate of dung loss varied substantially as weather changed, at least in the creosote community where, in experimental analyses of dung changes under clear and opaque canopies, weekly weight losses were greatest in the summer (particularly in full sun) and least in the winter. Dung lost weight twice as fast in mid-summer as in mid-winter. Shade reduced drying rate an average of 20 percent, but inconsistently, indicating that solar radiation was not the sole regulator. Temperature and evaporation rate were closely related ($R^2 = 0.93$) and temperature alone predicted dung weight loss moderately well ($y = -33.8 + 1.74\ x$, $R^2 = 0.69$ for dung in sun; and $y = -33.5 + 1.57x$; $R^2 = 0.64$ for dung in shade). Evaporation rate was a better predictor ($y = 3.41 + 2.37\ x$, $R^2 = 0.78$) for dung dried in sun than was temperature but evaporation was a poorer predictor in shade ($y = 2.06 + 1.94x$, $R^2 = 0.60$).

Losses of dung weight were twice as great a maximum daily summer temperatures of 38°C and evaporation rate of 12.6 mm d^{-1} than at winter maximum daily temperature of 16°C and an evaporation rate of 2.9 mm d^{-1}.

Table 7. Rate of weight loss of dung exposed under clear and opaque plastic canopies during summer-fall 1980 in creosote at Las Cruces, New Mexico.

Period	Environmental Conditions in Initial Two Weeks		Initial Weight of Dung (g)	Equilibration Weight (g)	Weeks to Equilibrate	Total Decline in Weight (%)	Weekly Decline in Weight (%)
	Mean Maximum Daily Temperature (°C)	Mean Daily Evaporation (mm)					
8 July – 26 August							
Shade	37.30±1.65	12.29±1.80	1081±5	329±8	3	69.8	23.3
Light			1113±7	327±10	2	69.0	34.8
15 July – 2 September							
Shade	38.01±1.88	12.59±1.92	1104±47	320±8	3	69.0	23.0
Light			1058±11	339±10	2	67.8	33.9
22 July – 9 September							
Shade	37.65±1.77	11.68±1.89	1162±59	325±8	3	66.1	33.1
Light			1112±63	313±10	2	65.2	32.6
29 July – 16 September							
Shade	36.94±1.48	10.97±1.75	1045±96	341±10	3	69.9	23.3
Light			1086±59	339±12	3	70.1	23.4
6 August – 23 September							
Shade	33.00±3.76	8.68±3.07	1077±42	334±12	4	70.0	17.5
Light			1037±23	322±10	3	70.6	23.5

Table 7. Continued.

Period	Environmental Conditions in Initial Two Weeks		Initial Weight of Dung (g)	Equilibration Weight (g)	Weeks to Equilibrate	Total Decline in Weight (%)	Weekly Decline in Weight (%)
	Mean Maximum Daily Temperature (°C)	Mean Daily Evaporation (mm)					
12 August - 30 September							
Shade	31.34±2.78	7.80±2.69	1059±28	319±12	4	71.0	17.9
Light			959±25	315±8	3	71.0	23.8
18 August - 7 October							
Shade	32.26±1.39	7.36±1.37	902±24	333±14	5	68.0	13.7
Light			1136±47	337±10	3	70.5	23.7
26 August - 14 October							
Shade	30.78±3.15	6.53±2.42	1134±82	381±15	4	65.5	16.5
Light			1114±68	345±14	4	66.0	16.7

Table 8. Rate of weight loss in January-February and September-October under clear and opaque plastic canopies during 1980 in a creosote community at Las Cruces, New Mexico.

Period	Environmental Conditions in Initial Two Weeks		Initial Weight of Dung (g)	End Weight of Dung (g)	Weeks Exposed	Total Decline in Weight (%)	Weekly Decline in Weight (%)
	Mean Maximum Daily Temperature (°C)	Mean Daily Evaporation (mm)					
January 26–February 27							
Shade	16.59±4.36	2.93±0.80	1792±13	719±7	4.6	59.8	13.4
Light			1846±35	605±50	4.6	66.6	14.5
September 18–October 13							
Shade	29.32±4.80	4.96±2.94	1885±11	505±5	3.4	73.2	21.5
Light			1862±66	392±2	3.4	78.9	23.0

Table 9 shows only 10 percent of the water content, the nitrogen concentration declined by half, usually within a day or two. Shaded dung lost nitrogen more quickly, perhaps because the outer surface remained porous longer allowing more gases to escape. After two days, the rate of decline in nitrogen content slowed as the water content approached 35 percent. The fraction of volatile solids also declined, but less than nitrogen, and the decline stopped after the first two days of exposure. Phosphorus concentrations were somewhat variable, reflecting analytical error. However, the concentrations generally remained constant or increased slightly, as expected, because no significant volatilization of this nutrient occurred.

These data indicated that calculations of the amounts of phosphorus deposited in dung and eroded by rain should not be significantly influenced by time of dung exposure before rain. Exposure time, however, did influence concentrations of volatile solids and nitrogen. Once dung was two- to four-days old, depending on how shaded it was, the fraction of total solids comprised of nitrogen and volatile solids, like phosphorus, changed little.

Effects of Exposure Time on Fraction of Dung Eroded

Two studies were conducted in the coolest and warmest seasons in the creosote community, were conducted to determine how dung age influences the rate simulated rain erodes cow dung. All nutrients were eroded most effectively from fresh dung (Tables 10 and 11). After the first day of sunlight exposure (under a clear plastic canopy), the rate of erosion of volatile solids and phosphorus was about the same regardless of dung age or water content (which declined at a decreasing rate

Table 9. Percent retention (mean ± standard deviation) after aerial losses (by wind erosion and volatilization) of nutrients and organic matter from dung of different water contents (different ages) exposed under clear and opaque canopies in the creosote community near Las Cruces, New Mexico in September 1980. Fresh dung water content was 78 percent of total weight and initial percentages of dry weight averaged for volatile solids 72 percent, for phosphorus 0.16 percent, and for nitrogen 1.94 percent.

Mean Water Content (%)	Volatile Solids		Hydrolizable Phosphorus		Total Nitrogen	
	Shade	Sun	Shade	Sun	Shade	Sun
70–75	91.5±0.7	93.0±7.1	109.0±19.8	92.0±2.3	43.5±12.0	57.5±12.0
65–70	85.0±9.9	82.0±5.7	88.0±27.6	74.0±9.9	40.5±0.7	52.5±4.9
55–60	87.5±4.9		104.0±26.2		38.5±3.5	
50–55		79.0±5.7		109.0±33.3		51.0±1.4
45–50	82.0±5.7		111.0±15.6		40.0±11.3	
35–40		78.5±0.7		--		42.5±2.1

Table 10. Percent of fresh cow-dung material eroded per unit of Rainfall Erosivity from dung pats of different ages exposed to different durations of artificial rains. Dung was exposed to weather under clear and opaque plastic canopies during January and February 1980 in the creosote community at Las Cruces, New Mexico (mean ± standard deviation).

Age and Light	Total Solids 0.65-cm rain	Total Solids 1.3-cm rain	Total Solids 2.0-cm rain	Volatile Solids 0.65-cm rain	Volatile Solids 1.3-cm rain	Volatile Solids 2.0-cm rain
0 Days						
Light	.24±.14	.47	.56	.18±.06	.37	.47
Shade	.21±.06	.31±.04	.40±.01	.15±.05	.20±.04	.32±.03
1 Day						
Light	.13±.00	.12±.01	.08±.01	.09±.04	.09±.01	.07±.02
Shade	.16±.02	.12±.01	.11±.01	.12±.06	.11±.04	.12±.04
4 Days						
Light	.07±.02	.15±.10	.14±.06	.10±.02	.12±.05	.09±.02
Shade	.06±.03	.07±.03	.08±.02	.09±.04	.08±.03	.07±.01
8 Days						
Light	.05±.02	.08±.00	.09±.00	.06±.04	.07±.01	.08±.01
Shade	.09±.02	.08±.02	.08±.01	.06±.01	.09±.02	.07±.01
16 Days						
Light	.08±.01	.09±.00	.10±.01	.06±.00	.07±.01	.07±.00
Shade	.02±.01	.04±.01	.06±.00	.03±.03	.04±.00	.06±.01
32 Days						
Light	.13±.04	.20±.00	.26±.01	.12±.07	.13±.03	.16±.02
Shade	.08±.01	.11±.01	.11±.01	.09±.00	.09±.01	.10±.09

Table 10. Continued.

Age and Light	Hydrolizable Phosphorus 0.65-cm rain	1.3-cm rain	2.0-cm rain	Non-Gaseous Nitrogen 0.65-cm rain	1.3-cm rain	2.0-cm rain
0 Days						
Light	.58±.02	.99	1.25	.025±.002	.041	.050
Shade	.46±.33	.79±.32	1.00±.16	.026±.011	.029±.001	.036±.002
1 Day						
Light	.33±.23	.36±.26	.34±.27	.024±.002	.021±.001	.018±.000
Shade	.19±.04	.23±.04	.26±.01	.025±.001	.020±.003	.020±.003
4 Days						
Light	.45±.43	.45±.35	.42±.32	.015±.000	.017±.002	.015±.001
Shade	.19±.01	.20±.03	.21±.05	.015±.003	.015±.002	.015±.004
8 Days						
Light	.41±.22	.45±.28	.45±.30	.013±.000	.015±.001	.015±.001
Shade	.23±.15	.23±.11	.22±.09	.011±.000	.011±.000	.010±.001
16 Days						
Light	.25±.00	.46±.33	.41±.25	.015±.000	.013±.001	.014±.003
Shade	.16±.05	.17±.03	.20±.05	.010±.001	.010±.001	.012±.001
32 Days						
Light	.34±.30	.40±.30	.46±.27	.010±.009	.014±.006	.016
Shade	.14±.04	.17±.06	.19±.08	.015±.010	.015±.000	.016±.002

Table 11. Percent of fresh cow-dung material eroded per unit of Rainfall Erosivity from dung pats of different ages. Dung was exposed under clear and opaque plastic canopies during September 1980 in creosote community at Las Cruces, New Mexico (mean ± standard deviation).

	Total Solids	Volatile Solids	Hydrolizable Phosphorus
0 Days			
Light	1.42±0.15	0.84±0.06	2.68±0.33
Shade	1.86±0.12	1.08±0.10	3.33±0.38
1 Day			
Light	0.44±0.05	0.21±0.01	0.29±0.01
Shade	0.69±0.00	0.47±0.00	0.27±0.01
3 Days			
Light	0.31±0.13	0.55±0.50	0.18±0.04
Shade	0.30±0.02	0.12±0.01	0.16±0.01
6 Days			
Light	0.49±0.08	0.17±0.00	0.24±0.03
Shade	0.44±0.06	0.14±0.03	0.23±0.06
12 Days			
Light	0.41±0.01	0.12±0.00	0.21±0.03
Shade	0.48±0.04	0.18±0.04	0.26±0.06

as indicated in Figure 2). Under simulated rain, fresh cow dung lost 3 to 15 times as much phosphorus, and four to seven times as much organic matter as dung several days old. Nitrogen was lost from fresh dung at three times the rate it was lost from old dung (Figure 3). The percentage of hydrolizable phosphorus that was eroded averaged about three times the percentage of volatile solids eroded, suggesting that mineralized products of metabolism and decomposition were more likely to be eroded than organic phosphorus. Nitrogen erosion rates reached an equilibrium after four days. Shade nearly doubled the time required for the erosion rate to approach constancy. The erosion rate of nutrients equilibrated long before the moisture content of the dung (Figure 2) because the outer surface dried more rapidly than the center. Once the outer surface dried, forming a cohesive coat in a few days, the erosion rate remained constant and the internal center of moist dung was shielded from erosion.

The duration of rain, measured in winter studies, influenced erosion rate only when the dung was fresh (Table 10). With each 1 cm increase in duration of simulated rainfall, the fraction eroded per unit of Rainfall Erosivity doubled. An intense rainfall of 4 cm and a Rainfall Erosivity of 15, typically the biggest storm of the year in our study areas, could erode away half of the organic matter out of a fresh dung deposit. In this study, the intensity of artificial rainfall remained constant (up to an equivalent of a 2-cm rain) so the Rainfall Erosivity Index varied simply as a function of duration. Duration of rain on dung more than one day old or older had no measurable effect on the rate of nutrient erosion from cow dung. Older dung would lose only 2 percent from the storm. Once the outer surface had dried, it formed a cohesive

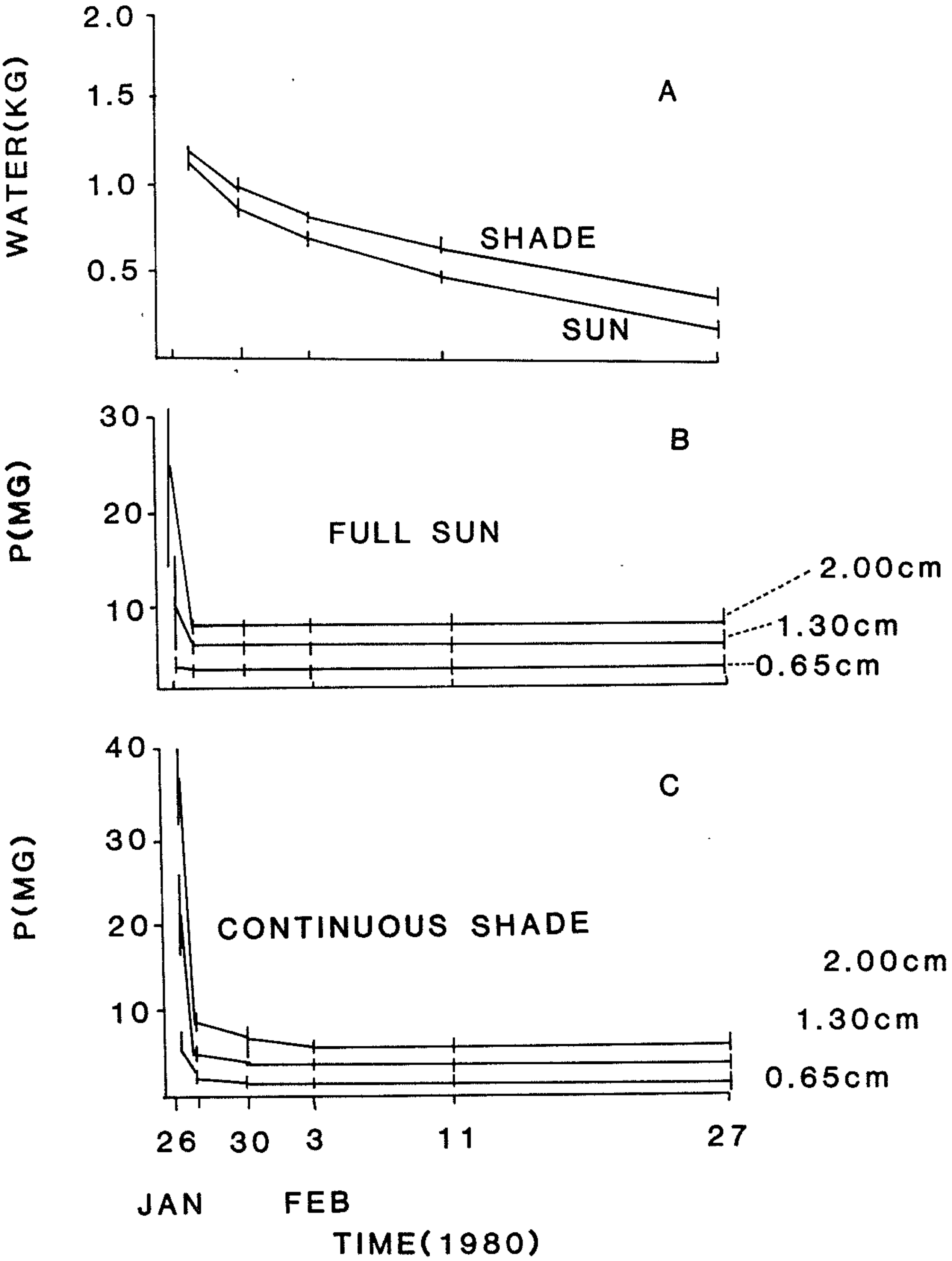

Figure 2. Loss of water from dung in shad and sun (A) and erosion rates of hydrolizable phosphorus from dung exposed to sun (B) and shad (c) and simulated rainfalls of 0.65, 1.30, and 2.00 cm. Mean ± one standard deviation are represented.

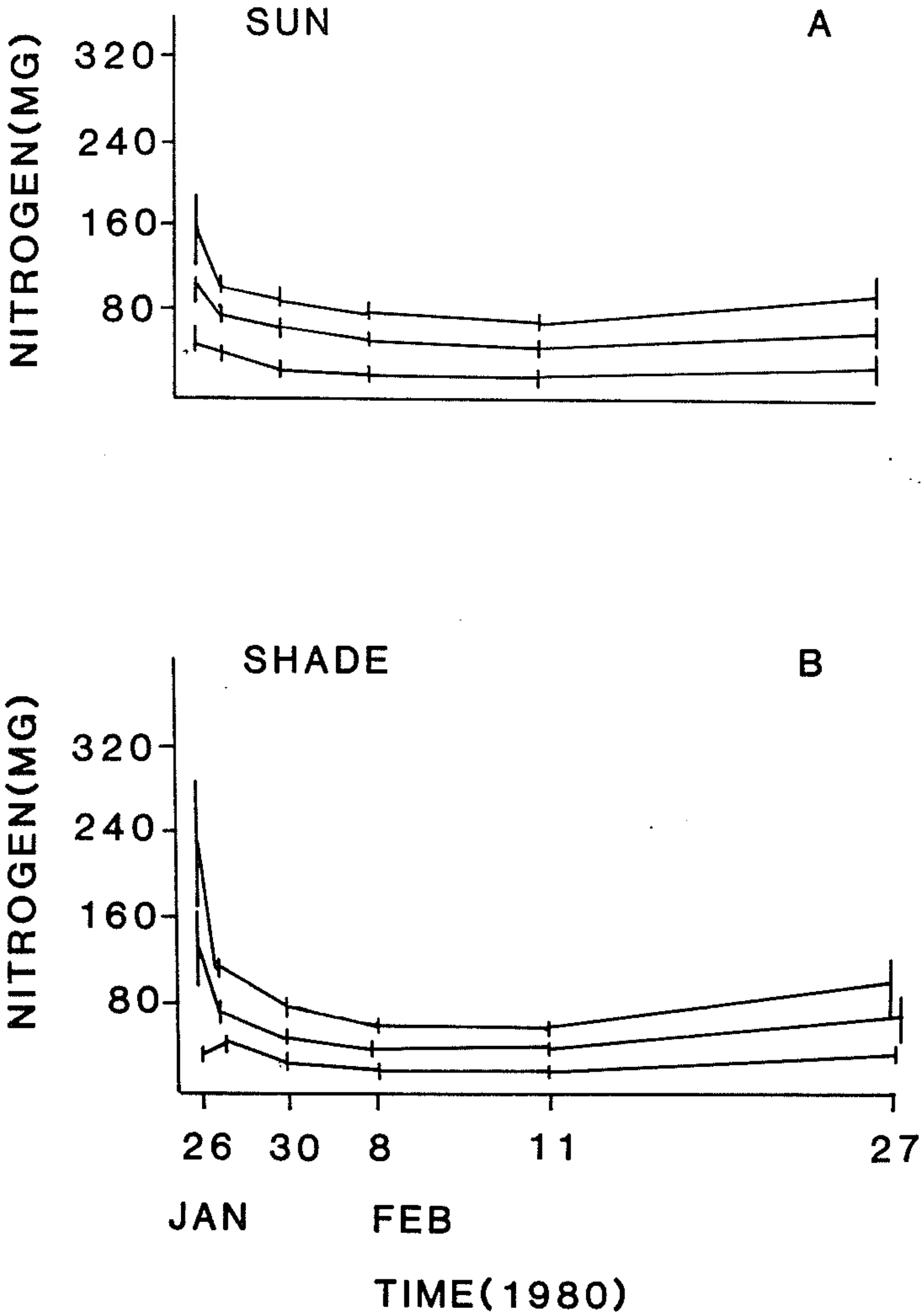

Figure 3. Erosion rate of nitrogen from dung exposed to sun (A) and shade (B) and simulated rainfalls of 0.65 (bottom), 1.30 (middle) and 2.00 cm (top). Means ± one standard deviation are represented.

structure quite resistant to solution in water. Simulated rains greater than 2 cm (30 minute rains = 10 cm) may have eventually dissolved the coat and increased the erosion to something similar to fresh material. But most rains in the Southwest are less than 2 cm so the probability of a greater erosion rate occurring because of longer storms is low.

Larger fractions of dung were eroded in the summer study than in the winter study at all comparable dung ages. Because weather should not have strongly influenced erosion when the dung was fresh (temperatures were well above freezing), some difference in the consistency of the dung material was more likely responsible. Grain comprised a greater fraction of the recognizable residue in summer and may have influenced the cohesiveness or surface area of the dung so that two to three times more was eroded per unit of Rainfall Erosivity. This substantial difference suggests that variations in diet could influence estimates of erosion significantly. Based on our summer study, for a Rainfall Erosivity Index of 25, about three fourths of the fresh dung phosphorus (hydrolizable) would be eroded away while, based on the winter study, only one fourth would be eroded away. The differences were most apparent in the fresh dung. Older dung, summer and winter, would lose about 10 percent of the phosphorus present in the dung in such a storm.

Effects of Substrate on Fraction of Dung Eroded

Experiments With Simulated Rain.

Summer and winter studies of dung erosion summarized in Tables 10 and 11 were conducted with the dung on impenetrable substrates (polyurethane covered plywood with 5 percent slope), so virtually none of the material could be retained by the substrate surface. Additional studies of fresh-dung erosion on natural substrates were conducted to determine the impact of natural substrate on cow-dung material runoff (Tables 12 and 13). Results were variable, perhaps partly because wide ranges in slope (2 to 50 percent) were included in the studies. But little relationship existed between slope and the amounts of solids produced per unit of artificial rainfall, so other factors also contributed to the variation in runoff characteristics.

The importance of the soil in retaining fresh dung is indicated in Table 13 where mean runoff of materials on natural soils is contrasted with the runoff on impenetrable substrates. From 61 to 93 percent of the volatile solids were retained by soils at different sites studied but with no immediately obvious pattern related to soil condition or amount of bare soil in the area. Study sites in ponderosa pine and creosote communities retained volatile solids about equally. These communities retained there volatile solids more than sites in mixed-conifer, pinyon-juniper, and desert grasslands. Nitrogen was retained similarly in most sites with no clear trends, partly because nitrogen's indicated retention was more variable than that of the other materials. This variability may have been caused by the relatively great variability in nitrogen concentration of fresh dung (Table 3). Phosphorus seemed mostly influenced either by the amount of bare soil ($R^2 = 0.91$) exposed to erosion or the amount of organic matter in the soil at each site. Because vegetative ground cover and percent organic matter in the soil were correlated, the individual effects of the two variables on phosphorus mobilization could not be sorted based on these experiments alone.

Table 12. Mean runoff of fresh cow-dung materials in mg m^{-2} R_1^{-1} (where R_1 is one unit of Rainfall Erosivity) artificially rained on with an infiltrometer in different plant formations of south-central New Mexico. Fresh dung was formed into mixed, uniform pats and placed at a density of 1750-1900 mg m^{-2}. The concentrations were measured on plots without dung (S) and plots with dung (SD) and the difference was calculated to be the contribution from dung (D).

Plant Formation	Total Solids SD - S = D	Volatile Solids SD - S = D	Hydrolizable Phosphorus SD - S = D	Non-Gaseous Nitrogen SD - S = D
Creosote n = 12	1560 - 1623 = -63	350 - 232 = 118	3.67 - 0.73 = 2.94	4.98 - 2.82 = 2.16
Desert Grasses n = 12	3195 - 3095 = 100	621 - 293 = 328	5.81 - 2.04 = 3.77	3.44 - 0.83 = 2.61
Pinyon-Juniper n = 13	1429 - 1319 = 110	384 - 213 = 171	1.84 - 0.37 = 1.47	2.41 - 1.14 = 1.27
Ponderosa Pine n = 10	472 - 166 = 306	138 - 50 = 88	1.27 - 0.30 = 0.97	0.92 - (-0.11) = 1.03
Mixed-Conifer (meadow) n = 12	1272 - 1031 = 241	862 - 481 = 381	1.46 - 0.80 = 0.66	14.6 - 10.1 = 3.90
Mean Dung Contribution And Standard Deviation	139±143	217±130	1.96±1.33	2.19±1.15

Table 13. Estimated percentages of fresh dung materials retained by soils artificially rained on in plant formations of south-central New Mexico based on comparisons with discharge from artificial rains on dung over impenetrable substrates conducted in January-February and September 1980 in creosote community (average with range) and relationship with percent bare area in the study site.

Plant Formation	Volatile Solids		Hydrolizable Phosphorus		Non-Gaseous Nitrogen		Percent Bare Soil Area
	Mean	(Range)	Mean	(Range)	Mean	(Range)	
Creosote	89.1	(88.0 - 90.2)	59.4	(54.1 - 64.6)	83.6	(71.2 - 95.9)	86.5
Desert Grasses	69.6	(66.7 - 72.7)	47.9	(41.2 - 54.6)	80.1	(65.2 - 95.0)	85.9
Pinyon-Juniper	63.6	(63.3 - 63.9)	79.7	(77.1 - 82.3)	90.3	(83.0 - 97.6)	49.3
Ponderosa Pine	91.9	(91.1 - 92.6)	86.6	(84.9 - 88.3)	92.1	(86.2 - 98.0)	16.3
Mixed-Conifer (meadow)	64.8	(61.3 - 68.3)	90.9	(89.7 - 92.0)	70.2	(47.9 - 92.5)	10.5

x = percent bare area.

y = mean percent of phosphorus retained = 96.9 - 0.483x, R^2 = 0.91.

y = mean percent of nitrogen retained = 82.2 - 0.020x, R^2 = 0.01.

y = mean percent of volatile solids retained = 74.3 - 0.031x, R^2 = 0.01.

Table 14 compares predicted runoff of the Universal Soil Loss Equation to observed runoff on infiltrometer-treated sites. Predictions agreed best with observed runoff from creosote communities, but increasingly under-estimated erosion as ground cover and organic content of the soils increased. In these tests, antecedent rainfall had been minimal for several weeks before application of simulated rain, reducing some of the variance associated with soil moisture. None of the tests were conducted under standardized conditions of wetness (e.g. saturated, covered with plastic, and then tested 24 hours later.

Several potential sources of error exist because of inadequate knowledge of wild range conditions. Because the nomographs available do not consider plots as small as 1 m (3 m is the smallest), for estimating hillslope length we had to extrapolate. Extrapolation may have introduced a small error, but more likely sources of error were the soil erodability, K, and the vegetation cover, C. The soils at higher rainfalls generally were higher in organic matter than considered by existing nomographs and the relative impact of organic matter may have been overestimated. Another possible source of error is overestimated amounts of ground covered by litter or vegetation. This parameter, which is easiest to estimate for desert conditions, becomes increasingly difficult to estimate as litter and ground cover increase at higher elevations. Overestimating cover by 10 percent more than the actual percentage reduces the predicted erosion by three to four times when the cover is grass or litter. Although recent antecedent rainfall was low in all areas studied, the areas with greater precipitation, clay, and organic matter in the soil may have retained greater moisture and therefore eroded relatively more per unit of rainfall erosivity.

Table 14. Prediction of erosion by the use of the Universal Soil Loss Equation on infiltrometer studies (10-13 plots per site) of plant formations in south-central New Mexico compared to observed erosion rates.

	Factors in USLE				Erosion g m^{-2}	
	Soil K	Vegetation	Hill Slope-Length	Artificial Rainfall Erosivity	Predicted	Observed
Creosote	0.15	0.26	1.53	10.23	26.9	19.5
Desert Grass	0.13	0.25	0.55	10.23	8.0	39.0
Pinyon-Juniper	0.20	0.10	0.25	10.60	2.3	16.2
Ponderosa Pine	0.12	0.03	0.45	12.85	0.9	2.5
Mixed-Conifer (meadow)	0.08	0.04	0.67	5.73	0.5	7.0

Table 15 summarizes the relationships between estimated annual rainfall and percentage of clay, organic matter, nitrogen, and phosphorus in soils and runoff from simulated rains. The mean percentages of clay, volatile solids, and nitrogen in soils were related to the estimated mean annual precipitation ($R^2 = 0.78, 0.95, 0.70$). Soil percentage phosphorus was not related to precipitation. Runoff percentages (percentages of total solids) were not clearly related to concentrations in the soil (15 cm deep), indicating that the materials comprising the erodible surface were either different in composition or differentially eroded. Volatile solids obviously were eroded from lower watersheds in much higher percentages of the total solids present than indicated by soil fractions. This erosion rate was probably a consequence of the lighter specific gravity of volatile solids and more organic matter concentrated in the soil surface.

Phosphorus concentrations in runoff also were higher, indicating higher concentrations in surface soils of all watersheds studied. Because much of the organic phosphorus is not included in hydrolizable phosphorus (Table A-3 indicates about 55 percent of total phosphorus is hydrolizable), most of the phosphorus appeared to be associated with soil particulates in polyphosphate or orthophosphate form. Unlike volatile solids, the hydrolizable phosphorus was concentrated in all surface soils including those in areas of higher precipitation.

Nitrogen concentration in runoff was greater than in soils in desert and montane sites but lower at the intermediate elevations. Kjeldahl nitrogen typically was 10 times more than the nitrate-nitrite-nitrogen indicating the relative importance of nitrogen associated with organic matter. Nitrate-nitrite-nitrogen varied little from one site to another.

Table 15. Percent of total solids, volatile solids, hydrolizable phosphorus, and nitrogen at sites exposed to simulated rains and relationship between mean annual rainfall and percent clay and organic matter in soil. These sites had been exposed to grazing but none had been treated artifically with cow dung.

Plant Community	Estimated[1] Mean Annual Rainfall (mm)	Mean Simulated Rainfall Erosivity	Percent Silt and Clay in Soil (0.1mm)	Percent Volatile Solids			Percent[2] Hydrolizable Phosphorus			Percent Nitrogen			Nitrate-Concentration
				Soil	Runoff Suspended Solids	Ratio Runoff: Soil	Soil	Runoff Suspended Solids	Ratio Runoff: Soil	Soil	Runoff Suspended Solids	Ratio Runoff: Soil	
Creosote	200	10.41	5.4	-1.7	14.3	8.4	0.0130	0.05	3.8	0.03	0.17	5.7	0.17
Desert Grasses	300	10.23	4.0	2.7	9.4	3.5	0.0006	0.07	116.6	0.08	0.03	0.4	0.29
Pinyon-Juniper	400	10.60	5.7	7.3	14.2	5.3	0.0040	0.03	7.5	0.13	0.09	0.7	0.28
Ponderosa Pine	500	12.85	15.2	14.1	30.1	2.1	0.0120	0.18	15.0	0.20	0.04	0.2	0.29
Mixed-Conifer	600	5.73	17.1	15.9	17.6	1.1	0.0100	0.08	8.0	0.14	1.03	7.4	0.18

[1] Estimates are based on data for weather stations in simlar plant formations in southern New Mexico. Ratios in Table A-2 indicate total phosphorus (persulfate) averaged 1.75 times more than hydrolizable phosphorus.

[2] Calculated from natural runoff at Sixteen Springs Canyon (see Table 21).

x = mean annual rainfall in mm.

y = percent clay in soil = $-4.37 + 0.035x$; $R^2 = 0.78$.

y = volatile solids in soil = $-7.58 + 0.040x$; $R^2 = 0.95$.

y = nitrogen in soil = $0.02 + 0.0003x$; $R^2 = 0.70$.
x = percentage volatile solids in runoff.

y = percent phosphorus in runoff = $-0.03 + 0.0066x$; $R^2 = 0.78$.

y = percent nitrogen in runoff = $-0.269 + 0.0002x$; $R^2 = 0.00$.

Table 16 shows the importance of bare area in the mobilization of materials. Slope had little, if any effect on the mobilization of runoff; bare soil area explained 93 percent of the variance in mean relationship between runoff and bare area on the five different plant formations. Bare soil also explained most of the erosion from the plots, particularly of volatile solids, but explained half or less of the variation in nutrient runoff. Differences in the relationships among bare area and total solids, volatile solids, and nutrients indicate that a substantial portion of the nutrient is behaving independently or organic matter or inorganic solids. The nutrient perhaps is mobilized as dissolved inorganics that have been "desorbed" from soils.

Vertical Distribution In Soil

Because 55 to 92 percent of the phosphorus and similar ranges of volatile solids and nitrogen are retained by natural substrate, the depth to which the dung material penetrates the soil can significantly influence how much of the material eventually will be eroded with the soil. If the dung material accumulates in superficial layers of bare soil that are easily eroded by the next major rainstorm, then the dung material still contributes to downstream loading of streams and reservoirs, but indirectly and possible in an altered state. On the other hand, if the nutrient penetrates deeply, or if it accumulates mostly in vegetated areas, then much of it is likely to be retained by the soil, recycled into vegetation, and prevented from moving into downstream waters.

Table 17 shows results of a preliminary study conducted to measure depth of penetration in alluvial soils collected from the creosote

Table 16. Relationships between percent bare area at sites exposed to simulated rains (R = 5.73 to 12.85) and the fraction and amount of water that ran off and the amounts of total solids, volatile solids, phosphorus, and nitrogen that ran off per unit of Rainfall Erosivity (R_1^{-1}). These sites had been exposed to grazing but none had been treated artificially with cow dung.

Plant Formation	% Bare Soil	Percent Slope	Fraction of Runoff R_1^{-1}	Total Rain	Total Solids mg R_1^{-1}	Volatile Solids mg R_1^{-1}	Hydrolizable Phosphorus mg R_1^{-1}	Total Nitrogen mg R_1^{-1}
Creosote n = 13	86.5	30.16	0.0469	2.18	1372	204	0.64	2.48
Desert Grass n = 12	85.9	15.10	0.0459	2.12	2599	246	1.71	0.69
Pinyon-Juniper n = 12	49.3	8.30	0.0330	2.12	672	95	0.19	0.58
Ponderosa Pine n = 10	16.3	12.40	0.0084	2.69	27	8	0.05	0.52
Mixed Conifer (meadow) n = 13	20.0	17.00	0.0175	2.48	371	65	0.28	3.85

x = percent bare soil.
y = fraction of rain that runs off = 0.008 + 0.0005x; R^2 = 0.93.

y = volatile solids (mg R_1^{-1}) = −3.02 = 2.54x; R^2 = 0.88.

y = total solids (mg R_1^{-1}) = −196.3 + 24.23x; R^2 = 0.75.

y = hydrolizable phosphorus (mg R_1^{-1}) = −0.106 + 0.0137x; R^2 = 0.54.

y = nitrogen (mg R_1^{-1}) = 1.84 + −0.0065x; R^2 = 0.02.

x = slope percent.

y = fraction of rain that runs off = 0.0141 + 0.0010x; R^2 = 0.22.

Table 17. Concentration (mean ± standard deviation) of volatile solids (percent) and total hydrolizable phosphorus (mg kg^{-1}) in containers of desert soil with fresh cow dung deposited on the surface and artificially rained on compared to soil plots without dung. Dung was rained on when fresh with a Rainfall Erosivity of 6.4 and subsequently two times at two-week intervals following the initial rain at a Rainfall Erosivity of 3.2 for a total erosivity of 12.8. The soil was well mixed and comprised of 34 percent silt and clay, 34.5 percent very fine sand, and 27.5 percent course sand.

	Top 1 cm.	2 3 cm Deep	4 5 cm Deep
Soil With Dung On It			
Hydrolizable Phosphorus	3.08±0.77	3.06±0.97	3.43±0.53
Volatile Solids	2.08±1.45	1.22±0.20	1.08±0.15
Soil Without Dung On It			
Hydrolizable Phosphorus	2.92±0.76	3.34±1.19	2.75±0.32
Volatile Solids	1.05±0.19	0.99±0.26	1.12±0.12

formation. Volatile solids accumulated more in the uppermost layer than in lower layer while phosphorus did not seem to stratify. Based on data in the Tables 10 and 11, the amount of phosphorus eroded from the dung probably was too little to appear in significant quantities in a 1 cm thick layer, the thickness analyzed in this study (23 x 23 x 1 cm). A film of fine particles from the dung formed over the soil surface without much observable penetration. This film was scraped from the surface layer before the concentrations of volatile solids and hydrolizable phosphorus were measured and did not contribute to our measurements.

Surface Distribution

If, as indicated by studies used to develop the Universal Soil Loss Equation, substrate occupied by rooted grasses or deep litter resists virtually all rainfall erosivity, then most if not all dung deposited on ground cover may be retained by the watershed, and only that dung deposited on bare soil can be eroded from the watershed. Table 18 shows that cow and deer dung was deposited without much relation to the distribution of bare soil and ground cover under the range conditions studied. Deer dung may have been deposited on bare ground somewhat more frequently, but it is also more difficult to observe on vegetated surfaces so some bias toward more observations on bare ground might be expected. To predict the amount of dung material mobilization, only the dung fraction deposited on bare soil needs to be considered, since the bare surface is the only surface eroded. Dung deposition tended to average 25 to 50 percent more on bare than on covered surfaces, but an accurate correction for bias in dung deposition probably needs more refined analyses of the factors controlling the location of deposition.

Table 18. The mean percentages of bare soil surface, cow dung, and deer dung in watersheds studied with simulated and natural runoff.

	Soil	Percent on Bare Soil	
		Cow Dung (#Deposits)	Deer Dung (# Deposits)
Desert Grass			
Site 1	55	56 (34)	none found
Site 2	56	86 (50)	none found
Pinyon-Juniper			
Site 1	50	46 (26)	80 (15)
Site 2	43	75 (12)	59 (66)
Ponderosa Pine	9	2 (35)	10 (12)
Mean Cow	43	53	
Mean Deer	34		50

Tables 19 and 20 also indicate that deer and livestock ranged about the same average distances away from arroyos in ponderosa pine (New Mexico), lodgepole-pine (Wyoming), and aspen (Wyoming) communities. Data collected in ponderosa pine indicated deer were more likely than cattle to be found on steep slopes and at the tops of ridges. This finding may suggest that more deer dung was vulnerable to erosion on the steep slopes, but more of it was also found on the tops of ridges where hill slope and length develop little overland flow. Therefore, in these types of watersheds, differences in deer and cow distributions on slopes seems to be lesser consideration.

Dung Mobilization by Natural Rain

Watershed Studies

Studies of dung mobilization conducted from 1979-1981 indicated that the dispersal of naturally deposited dung materials from points of deposition are not simply explained by rainfall erosivity. In summer 1979, during studies of 12 watersheds in ponderosa pine of south-central New Mexico, rainstorms occurring over a period of two-week period caused a mean rainfall erosivity of 125, an exceptional condition (nearly twice the usual annual rainfall erosivity) attributed mostly to four intense storms. As a consequence of those storms, the recognizable cow dung declined by 65 percent and recognizable deer dung decreased by 87.5 percent (Table 21). Before the storms, 95 percent of the dung in the watersheds had been old, dry, and of low density.

The calculated loss of dung phosphorus during the stormy period was twice as great as it would have been if the substrate were an entirely impenetrable bare soil and 20 times as great as it would have been if

Table 19. Distribution of cow and deer dung in 12 study watersheds (see description in Table 1) of Sixteen Springs Canyon (Lincoln National Forest) near Cloudcroft, New Mexico in relation to elevation, slope, and distance from main drainage channel. In July, 95 percent of the deer dung and 96 percent of the cow dung was old. Watersheds are described in Table 1.

	Transects					
	Lowest Elevation 1	2	3	4	Highest Elevation 5	Mean
Mean Percent Slope	10	18	35	45	32	28
Mean Number of Cow Dung Deposits	207	96	112	71	134	104
Mean Number of Deer Dung Deposits	366	413	341	447	1396	593
Distance from Main Drainage Channel (m)						
Midway Distance in Watershed	47.8	57.8	62.5	64.2	47.2	56
Mean Distance of Deer Deposits (m)	52.0	47.8	63.3	67.8	62.2	59
Mean Distance of Cow Deposits (m)	43.0	63.1	79.2	71.2	43.9	60

Table 20. Average distance (meters) of scats from the main channel and from the nearest cover at the time of the July sampling in Wyoming watersheds.

Watershed	Animal	Average Distance (meters) of Scat From the Channel (± Stan. Dev.)	Average Distance (meters) of Scat From Nearest Cover (± Stan. Dev.)
Aspen 1	Cow	56.63(±46.84)	10.54(±7.57)
	Deer	34.24(±28.51)	6.3(±4.53)
Aspen 2	Cow	130.3(±88.67)	8.12(±8.43)
	Deer	176.7(±78.31)	5.99(±7.43)
Lodgepole 1	Cow	4.35(±6.85)	4.35(±6.85)
	Deer	169.2(±93.3)	1.86(±1.32)
	Elk	6.20(±3.61)	1.1(±0.28)
Lodgepole 2	Cow	44.9(±60.4)	1.30(±0.47)
	Deer	90.9(±52.2)	1.51(±0.79)
	Elk	88.36(±67.08)	1.44(±0.77)

Table 21. Estimated amounts of dung material in watersheds of Sixteen Springs Canyon before summer rains began, the estimated decline in watershed dung during summer rains of 1979, and the predicted decline of dung in watersheds based on infiltrometer studies. All dung was assumed to be old dung similar to what occurred in the watersheds at Sixteen Springs Canyon, with an erodable surface of 30 percent.

	Cow				Deer	
		% Decline				
Dung Constituent	Dung Material Weight (g ha^{-1})	Observed (25% Slope)	Predicted from Infiltrometer on Impenetrable Surface (5% Slope)	Predicted from Infiltrometer on Natural Substrate (10% Slope)	g ha^{-1}	% Decline Observed
Volatile Solids	14,130	65.0	12.3	1.82	14,410	87.5
Hydrolizable Phosphorus	34.4	65.0	24.5	4.34	40.7	87.5
Non-Gaseous Nitrogen	265.3	65.0	3.5	2.70	327.2	87.5

conditions were similar to those in infiltrometer studies conducted in ponderosa pine (at a different location). Even greater differences occurred for losses of dung volatile solids and nitrogen. Substrate conditions in the watershed differed substantially from conditions that occurred in infiltrometer studies in the ponderosa pine. Slopes in the 12 watersheds were twice as great and, of course, much longer (Table 1) than 1-m plots used in the infiltrometer studies. The hill slope-length factor in the Universal Soil Loss Equation for the watershed averaged 10 times that estimated for the infiltrometer studies. Although vegetational differences were minor, the soil in the watersheds was close to saturated with water at times when two of the most erosive storms occurred. The storms had five to six times higher rainfall erosivity than applied in the infiltrometer studies. Therefore extensive and relatively deep overland flows were more likely to occur during the natural storm events than in the artificial events and old, dry dung, at least on bare soils, could have been dislodged and floated from the steep slopes when rainfall was most intense.

Dislocation of Dung of Known Age

Table 22 shows results of studies of fresh dung deposits placed in natural situations in south central New Mexico. Cow dung generally persisted through the rainy seasons of 1980 and 1981 up to six months without much loss. Even after 12 months most of the cow dung remained in the relatively dry Pinyon-Juniper zone, but more than half had disappeared from the wetter mixed-conifer site and most of what remained was broken up, scattered, or had slid downslope. Although deer dung was not broken up much, it was rapidly scattered (100 percent within four months) and disappeared much faster than cow dung, 35 times as fast during the first

Table 22. Percent of fresh dung lost or moved from sites where they were placed in June of 1980 and 1981 on low (8-10 percent), moderate (15-25 percent), and high (35-50 percent) slopes in different plant formations of south-central New Mexico. Five deposits were placed at each site of study.

Plant Formation/ Slope	Set June 1981				Set June 1980			
	1 Mo. Old		4 Mo. Old		6 Mo. Old		12 Mo. Old	
	Cow	Deer	Cow	Deer	Cow	Deer	Cow	Deer
Percent Lost								
Creosote								
Low	0	5	0	46				
Moderate	0	5	0	42				
High	0	5	0	10				
Pinyon-Juniper								
Low	0	56	0	97	0	15	32	60
Moderate	0	58	0	66	0	29	10	45
High	0	78	0	99	0	24	0	49
Ponderosa Pine								
Low	0	17	0	50				
Moderate	0	33	0	50				
High	0	52	0	91				
Mixed-Conifer								
Low	0	12	0	33	10	38	45	76
Moderate	0	30	20	46	20	41	55	68
High	0	24	0	54	10	45	62	83
Percent Scattered or Broken up in All Watersheds	2	57	33	100	32	100	73	100

four months and twice as fast during the first year. The change in relative rate of disappearance seems related to dung particle size which in turn influences dung mobility. Rains in 1980 and 1981 were less than that of 1979 and had a substantially smaller influence on relatively fresh dung less than six months old. In the watersheds at Sixteen Springs Canyon, just before the exceptional storms occurred, at least half of the dung was over six months old based on calculated rates of deposition, drying time, and the grazing intensity scheduled by U.S. Forest Service personnel (Mayfield District Office, U.S.F.S.). The intense rains of August 1979 could have floated most of it away.

Measurements of actual discharge of watershed material during summer storms on the watersheds at Sixteen Springs Canyon generally agree or are slightly less than predictions for discharge of total suspended solids by the Universal Soil Loss Equation (Tables 23 and 24). The sampling technique used to estimate total solids undoubtedly underestimated contributions of the largest particles of litter and dung and bed loads that moved along the bottom. In the material sampled (small, suspended and dissolved matter), the relative fraction of soil, litter, and dung contribution was reflected by comparisons of ratios of material in the runoff and materials in the watershed. Volatile solids comprised about 7 percent of the soils, 99 percent of the litter, and 75 percent of the dung. Volatile solids sampled in the runoff comprised about 7.9 percent of the total solids; very similar to the soil and much lower than it would have been if litter or dung had been an extremely abundant constituent.

Table 24 shows that knowledge of soil fraction and total predicted erosion closely predicted the runoff of volatile solids. Nitrogen

Table 23. Water and mean nutrient runoff measured in watersheds monitored in Sixteen Springs Canyon in summer 1979 (mean ± standard deviation). The total runoff estimation for this period is an underestimate because two other storm events which occurred during early morning hours were not monitored. Based on total precipitation that fell during this period, total runoff was nearly 60 percent more than indicated.

Date	Number of Watersheds	Water $m^3 ha^{-1}$	Hydrolizable Phosphorus $g\ ha^{-1}$	Total Nitrogen, $g\ ha^{-1}$	Volatile Solids $Kg\ ha^{-1}$	Total Solids $Kg\ ha^{-1}$
8/2/79	1	0.59	0.24	2.89	0.68	2.30
8/8/79	4	0.75±0.50	1.25±0.94	10.89±7.80	0.82±0.48	11.52
8/10/79	4	0.96±0.56	0.53±0.27	14.36±7.33	0.65±0.33	8.11
8/13/79	7	19.85±6.40	14.10±4.53	237.31±139.40	16.46±10.67	202.03
Total Measured		22.15	16.12	265.45	18.61	223.96
Adjusted Total[1]		34.99	25.46	419.41	29.30	353.85
Estimated Cow Dung Loss			22.36	172.44	9.18	12.24
Estimated Deer Dung Loss			35.40	286.30	12.60	16.80
Total Dung Loss From Ungulates			57.76	458.74	21.78	29.04

[1] Adjusted total includes an estimate of runoff from unmonitored storms based on the fraction of total rainfall that occurred during unmonitored runoff events.

Table 24. Comparison of the predicted erosion and the observed erosion for four watersheds in Sixteen Springs Canyon measured for the sum of three runoff events in summer 1979. The Universal Soil Loss Equation as described by Dissmeyer and Foster (1980) was used to predict runoff. Estimates of eroded material did not include measurements of bedload movement.

	Watershed				
USLE Factor	8	9	10	11	Mean
Length-Slope (HS)	8.0	9.8	8.1	4.9	
Soil Erosivity (K)	0.12	0.12	0.12	0.12	
Vegetation Cover (C)	.030	.020	.010	.010	
Rainfall Erosivity (R)	51.0	61.6	59.0	56.5	
Transform to Metric (440x)					
Total Solids (Kg ha^{-1})					
Predicted	646	637	252	146	420
Observed	413	401	554	119	372
Phosphorus (g ha^{-1})					
Predicted	10.7	10.6	4.3	2.5	7.0
Observed	18.7	16.7	24.0	17.7	19.2
Nitrogen (g ha^{-1})					
Predicted	1828	1927	779	446	1245
Observed	358	325	467	186	334
Volatile Solids (Kg ha^{-1})					
Predicted	43.7	48.8	20.1	11.4	31.0
Observed	25.0	22.7	32.0	12.8	23.4

averaged about 0.12 percent of the runoff, 0.29 percent of the soil, 0.75 percent of the litter, and 1.25 percent of the dung.

By using soil concentrations and predictions of total erosion to predict nitrogen runoff we overestimated by four times the actual nitrogen eroded. Nitrogen appears not to be as concentrated in surface soils eroded as it is in deeper soils even though litter and dung is much richer in nitrogen than were the soils. This may reflect the lower amount of nitrogen observed in bare soils where no vegetation occurred. Eroding soils may be less rich in nitrogen than soils in general. Table 4 shows that surface scraping of bare-area soil had higher phosphorus than was representative for deeper soils pooled from the entire watershed. Dissolved inorganic nitrogen comprised less than 25 percent of the total nitrogen, indicating the importance of organic nitrogen. Phosphorus comprised about 0.0016 percent of soil and litter, 0.20 percent of the dung, and 0.007 percent of the runoff material. Phosphorus appeared to be eroded from the watershed more effectively than other materials, probably because bare soils had higher concentrations at the surface than indicated by the nutrient concentration in soils throughout the watershed. The runoff phosphorus averaged 38 percent dissolved orthophosphate, 24 percent in polyphosphates and 38 percent in organic matter.

If all of the apparent loss of dung from the watersheds had actually reached the sampling weirs in the drainages as small particles of dissolved matter, the dung alone would have contributed at least twice as much phosphorus than was measured in the runoff concentration (Table 23). Some of the dung may have been scattered, disintegrated, and mixed with litter to the point of imperceptibility never reaching the sampling point in the runoff. Most of the spikes used to mark dung also disappeared during the storms, indicating many were dislodged and buried. At the very least, dung deposited in arroyo channels floated out of the watershed, perhaps in large chunks that went unsampled. Further studies are needed to determine just how effective this form of mobilization is in watershed surfaces outside the erosion channels. The fraction of dung that was lost during the August storms was more than twice as great as the mean fraction of bare area in the watersheds (averaged about 30 percent) indicating that even vegetated surfaces may export dung during extreme storm events.

Materials in Downstream Waters

Comparison of Arroyo Runoff with Permanent Stream Flow

The Rio Penasco is the permanent stream in the Sacramento Mountains of south-central New Mexico which receives runoff from the study watersheds at Sixteen Springs Canyon. Riverine nutrient concentration varied with discharge and location in the stream (Table 25) but revealed probable influence of overland flow during storm events. The Rio Penasco is fed by numerous springs that help maintain base flow. Summer rainstorms swell the Rio Penasco with arroyo runoff that can contribute substantially to material loadings (Table 25). The differences between concentrations measured in spring and arroyo runoff clearly illustrate potential impacts of arroyo runoff on stream-water quality. Arroyos substantially contribute to loading of total and suspended solids because the spring-water contributions of these materials is negligiable. Comparison of the Rio Penasco during relatively low flow in July 1979 with higher flow in June 1980

Table 25. Mean concentrations of materials (mg l^{-1}) in the Rio Penasco drainage including ephemeral drainage in watersheds monitored at Sixteen Springs Canyon and permanent springs contributing continuous ground water to maintenance of base flow.

	Total Solids	Volatile Solids	Hydrolizable Phosphorus	Non-Gaseous Nitrogen	Ammonia Nitrogen	Nitrate-Nitrite Nitrogen	Orthophosphate Phosphorus
Rio Penasco							
August 1979 (n=2-3)							
Upper	368±145	76±35	0.10±0.00	1.47±1.02	0.15±0.06	0.16±0.04	0.03±0.03
Middle	980±451	162±82	0.51±0.60	2.00±2.12	0.10±0.02	0.32±0.14	0.05±0.05
Lower	613±30	279±287	0.07±0.08	1.25±0.52	0.28±0.06	0.66±0.21	0.02±0.03
June 15, 1980							
Upper	5,360	1,170	0.10	1.89	0.18	0.19	0.01
Middle	12,990	2,200	0.90	3.52	0.09	0.22	0.02
Lower	5,350	4,820	0.01	1.61	0.32	0.01	0.01
4 Springs in Basin							
June 15, 1980	--	--	0.02±0.05	1.32±0.64	0.24±0.11	0.41±0.25	0.015±0.005
Ephemeral Watersheds in Sixteen Springs Canyon	9454±4725	936±222	0.83±0.57	11.56±4.63	0.22±0.09	0.13±0.13	0.51±0.30

shows how concentrations of solids can shift by an order of magnitude as a consequence of increased discharge.

Total hydrolizable phosphorus in the river varied widely, perhaps because it depended on contributions from relatively large particles of suspended soils which are more variably sampled for chemical analyses than smaller particles. Contributions from dissolved orthophosphate were small and showed less variation. Springs contributed only small quantities of hydrolizable phosphorus, not in the form of dissolved orthophosphate. The hydrolizable phosphorus in arroyos was also mostly dissolved orthophosphate; it averaged three to four times as much as in the river and 40 to 50 times as much as in springs. Based on these data, arroyo runoff and spring water by themselves could not be the sole source of phosphorus in inorganic complexes carried by the river with suspended matter. Unless the ephemeral runoff and groundwater flow we measured was atypical of most watershed runoff, much of the dissolved phosphorus entering the river appeared to form complexes with suspended matter or bottom materials as water passed downstream. Presumably this complexing makes phosphorus less available for algal uptake in the stream system.

The total nitrogen in springs was at least half inorganic nitrogen with relatively small contributions of organic nitrogen, from plant and soil contamination. Concentrations of nitrogen in the river averaged somewhat more than springs but not nearly as much as could have been contributed with the large fractions we observed in arroyo runoff. The difference may have been caused by settling of relatively large particulates. Springs contribute about as much inorganic nitrogen as arroyo runoff so the availability of inorganic nitrogen was not likely to be influenced greatly by arroyo inputs. Inputs of organic nitrogen, mostly in the form of organic particulates, was by far the major form in which nitrogen moved out of watersheds and downstream. That organic matter would have to decay before its nitrogen would be available for plant uptake. Therefore, in the upper permanent streams receiving the ephemeral drainage, it is likely that most of the phosphorus and nitrogen from the watersheds was passed downstream with relatively little influence on production in the streams.

Materials in Runoff From Creosote Dominated Watersheds

In overland runoff from creosote-dominated watersheds (Table 26), volatile solids tended to be similar or slightly lower than concentrations in watersheds at Sixteen Springs Canyon, and concentrations of total hydrolizable phosphorus and total nitrogen were similar or greater. Runoff of ammonia-nitrogen from desert watersheds was similar while runoff of nitrate-nitrogen was somewhat greater. Again, inorganic nitrogen comprised a small fraction of the total runoff. With one exception, the differences exhibited between runoffs from watersheds at Sixteen Springs Canyon (a mixture of pinyon-juniper and ponderosa pine) and creosote dominated watersheds near Las Cruces generally reiterated differences observed in infiltrometer studies (Table 12) of material mobilization. Unlike watershed results, infiltrometer treatments of desert plots discharged relatively more volatile solids than plots in ponderosa pine or pinyon-juniper zone exposed to simulated rain. Generally, however, both natural and simulated watershed studies confirmed the prediction, based on Universal Soil Loss Equation, that areas with the largest fractions of bare, exposed soil will discharge the most soil and nutrient per unit of Rainfall Erosivity.

Table 26. Weighted mean concentrations (corrected for changing discharge) of nutrients in runoff from creosote dominated watersheds collected July-September 1981 near Las Cruces, New Mexico (mg l^{-1}).

Sites/# Samples	Total Suspended Solids	Volatile Suspended Solids	Total Hydrolizable Phosphorus	Total Nitrogen	Ammonia-Nitrogen	Nitrate-Nitrite-Nitrogen
Three separate arroyos, sampled as discharge changed.						
1 (n=6)	3264	346	1.46	34.6	0.65	0.09
2 (n=6)	5832	641	6.69	17.8	0.20	0.05
3 (n=6)	10728	856	8.45	100.6	0.49	0.07
Single grab samples (late in discharges in three other arroyos).						
4 (n=1)	4160	452	0.77	25.0	0.01	0.01
5 (n=1)	7984	268	0.58	21.7	0.01	0.85
6 (n=1)	3956	324	0.91	20.0	0.05	1.08

Oxygen and Phosphorus in Downstream Waters

Oxygen Demand

Table 27 shows results of oxygen-demand studies in which materials from ponderosa pine and pinyon-juniper at Sixteen Springs Canyon were added to distilled water with less than 0.01 mg 1^{-1} of total hydrolizable phosphorus. In the first five days of exposure, fresh cow dung had the greatest oxygen demand, 2.5 times, 3.8 times, and 5.0 times greater than deer dung, oak leaves, and pine needles, and 30 times greater than old cow dung. Oak leaves and pine needles had six to eight times the demand of old dung. Soil had no measured demand in the first five days of exposure. Once the material had been exposed for 1 to 26 days and oxygen concentration had dropped to 2.5 to 4.4 mg 1^{-1}, the oxygen demand of each material tended toward similarity, with the exception of soil alone, (from bare surfaces in Sixteen Springs Canyon) which had 13 percent or less of the demand of any other material because it had relatively little organic matter (7 percent). When fresh cow dung was added to soil in 1:4 ratio (cow dung:soil), then aged in water, the rate of oxygen demand per unit of organic matter increased over five times greater than predicted by the sum of effects generated by soil or cow dung alone ($a = 0.05$). Apparently some interaction between soil and dung, possibly microbial, increased demand rates substantially at first. But when the ratio of cow dung:soil was reduced to 1:20, the oxygen demand was depressed to levels below that of dung or soil, possibly from a smothering effect from the accumulation of a layer of soil on dung. Because bottles were shaken only after oxygen was measured every one to three days, a smothering effect was possible. There is some error in

Table 27. Oxygen depletion rate in 350-ml BOD bottle caused by materials from watersheds in ponderosa pine and pinyon-juniper at Sixteen Springs Canyon exposed at relatively high and low oxygen concentrations, incubated at 18°C. Each treatment was replicated six times.

	Higher Initial O_2 (Lower Concentration Organic Matter				Lower Initial O_2 (Higher Concentration Organic Matter				
			mg O_2/g/day					mg O_2/g/day	
Material	#Days Exposed	Initial O_2	Organic Matter	Total Weight	#Days Exposed	Initial O_2	#Days In Water Previous To Exposure Period	Organic Matter	Total Weight
Old Cow Dung	5	5.2	0.18	0.12	4	3.3	5	2.61	1.74
Fresh Cow Dung	5	4.6	4.28	3.60	4	3.3	0	1.87	1.57
Deer Dung	5	5.1	1.73	1.44	4	3.7	1	2.34	1.95
Oak	5	5.1	0.97	0.96	4	2.9	2	1.50	1.48
Pine	5	5.3	0.73	0.72	4	3.1	4	1.37	1.35
Soil	5	5.4	0.00	0.00	14	4.4	26	2.43	0.18
5% Cow, 95% Soil					5	2.9	2	0.67	0.06
5% Cow, 95% Pine					4	2.5	1	0.07	0.07
25% Cow, 75% Soil	5	5.3	5.28	1.32					
25% Cow, 75% Pine	4	5.1	0.57	1.56					

estimates of rates of decline because of the low frequency of sampling, established to disturb the samples minimally. More frequent sampling needs to be done to develop increased accuracy. Cow dung, when initially mixed with pine-leaf litter (in 1:4 ratio), had no initial stimulatory effect and later the mixtures demand rate was also depressed below that of the other materials, as if it too had been smothered.

Old cow dung, once exposed to decay for several days, had slightly greater demand rates than fresh dung and exceeded demand rates of all other materials, although most demand rates were similar.

Phosphorus Mobilization

The availability of phosphorus to primary producers in downstream waters depends on the fraction of phosphorus that dissolves into orthophosphate. The rate and total amount that dissolves depends on the source material and the water chemistry, particularly the reduction--oxidation environment. In confined waters, such as hypolimnia of small reservoirs, decomposition of organic matter can reduce oxygen concentrations low enough to depress reduction-oxidation potentials and dissolve metal complexes (particularly iron and manganese) that would otherwise retain phosphorus in compounds associated with suspended particulates or bottom sediments.

The amounts of phosphorus released into the test water once oxygen concentrations declined below 1 mg l^{-1} either remained stable or increased slowly with time (Table 28). Over a period of 48 days, fresh cow dung released more phosphorus than was estimated to have been added to the water in the first place; most of that was released within the first 16 days. Older deer dung released 38 percent, most of it before 16 days was up. Old cow dung released 22 percent by 48 days and appeared to be

Table 28. Amounts of orthophosphate-phosphorus released from total (persulfate) phosphorus introduced to test bottles in experiments conducted at 18°C using 300-ml BOD bottles. Each value is the mean of two replicates.

Material	Total P Added[1] (mg)	O_2 Concentration and Total Orthophosphate-P in Solution								
		After 16 Days			After 33 Days			After 48 Days		
		O_2 (mg l^{-1})	PO_4-P (mg)	% Total P Added	O_2 (mg l^{-1})	PO_4-P (mg)	% Total P Added	O_2 (mg l^{-1})	PO_4-P (mg)	% Total P Added
Old Cow Dung	0.35	0.97	0.06	17.0	0.2	0.08	23.0	0.2	0.09	26.0
Fresh Cow Dung	0.11	0.60	0.16	145.0	0.2	0.18	163.0	0.3	0.18	163.0
Old Deer Dung	0.56	0.40	0.23	41.0	0.4	0.24	43.0	0.3	0.24	43.0
Oak	0.11	0.67	0.02	18.0	0.4	0.02	18.0	0.3	0.03	27.0
Pine	0.12	0.73	0.01	8.0	0.4	0.02	17.0	0.2	0.03	25.0
Soil	0.09	6.70	0.01	11.0	4.4	0.01	11.0	3.5	0.01	11.0
6% Fresh Cow, 94% Soil	1.02	0.70	0.39	38.0	0.1	0.49	48.0	0.2	0.36	35.0
(Expected)			(0.17)	(17.0)		(0.18)	(18.0)		(0.18)	(18.0)
6% Fresh Cow, 94% Pine	1.32	0.30	0.10	8.0	0.1	0.11	8.0	0.2	0.11	8.0
(Expected)			(0.18)	(14.0)		(0.30)	(22.0)		(0.42)	(32.0)
		After 26 Days			After 40 Days			After 61 Days		
25% Fresh Cow, 75% Soil	0.10	0.20	0.07	70.0	0.2	0.07	70.0	0.2	0.05	50.0
(Expected)			(0.05)	(50.0)		(0.05)	(50.0)		(0.05)	(50.0)
25% Fresh Cow, 75% Pine	0.12	0.20	0.04	33.0	0.2	0.05	42.0	0.2	0.03	25.0
(Expected)			(0.04)	(33.0)		(0.05)	(42.0)		(0.05)	(40.0)

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[1] Water used had less than 0.01 mg l^{-1} P.

continuing to release material slowly when the experiment was concluded. Oak leaves and pine leaves released phosphorus in rates similar to old cow dung. Soil alone released no more than 11 percent of the phosphorus in it, indicating a low potential for contributing greatly to phosphorus concentrations in reservoirs as long as waters remained aerobic. When soil was mixed with fresh cow dung it released more than was predicted by its release rate alone. The increased release rate apparently resulted from the increased total oxygen demand resulting from the combined dung and soil organic matter in amounts 20 times what was in the soil-alone experiment and 1.6 times what was in the dung-alone experiment. Up to two to three times the phosphorus was released from soil at oxygen concentrations below 1.0 than at oxygen concentrations above 1.0. Apparently, to the extent that cow dung, or any dung, contributes to causing low enough oxygen concentrations to reduce redox potentials enough for metal complex to dissolve, it will increase the amount of phosphorus potentially available for uptake.

If, with further testing, cow dung mixed with soil proves to stimulate oxygen demand, at least under certain conditions, then overgrazing not only will increase the total amounts of soil and dung eroded but also will increase disproportionately the amount of phosphorus released from all of the watershed materials that reach a reservoir hypolimnion.

A mix of cow dung and pine needles seemed to depress oxygen demand rates and phosphorus release, perhaps from some interferance with microbial activity. The extent litter interacts antagonistically and soil interacts synersistically with fresh and old cow dung and deer dung needs to be investigated further. The effect of aging of fresh and old dung on phosphorus mobilization in water also needs further examination.

DISCUSSION

Estimating Livestock Dung Contribution To Runoff

Assembling Model Coefficients

To simulate the effect of domestic ungulates on runoff quality, a series of relationships needs to be defined in the form of reference tables, nomographs, or mathematical functions. At this juncture, enough data exists to develop "first-cut" reference tables designed to illustrate an approach toward a workable, predictive technique. The technique is designed to predict mean annual effect over a long management period of several years or more in the five most common vegetational formations in New Mexico. The tables illustrate relationships between or among: (1) forage availability, stocking schedules, and dung deposition rate; (2) ground cover and the fraction of the plant production in suitable forage; (3) dung mobilization and soil mobilization, 4) dung deposition and the amount of dung nutrient deposited; (5) timing of rainfall and grazing rate within an annual cycle; (6) the amounts of nutrient eroded with soil and the fraction eroded as dung material from the watershed; (7) erosion rates of soil and dung materials and the oxygen demand exerted in a hypolimnion; and (8) phosphorus loading into a reservoir and the potential availability of phosphorus for plant uptake.

Forage Availability and Dung Deposition

Dung deposition rates of cattle can be estimated from advised grazing schedules based on amounts, qualities, and production of grass and forb forage. Table 29 is an example of a calculated cow-dung deposition rate based on the relationship between forage production and quality

Table 29. An example of a reference table designed with estimated rates of advised mean grazing intensity (wet kg $ha^{-1} yr^{-1}$) and dung loading rates (dry kg $ha^{-1} yr^{-1}$) in different plant formations with varying fractions of forage and the potential dung loading rate for grasses and forbes of different forage value. Advised grazing intensities were estimated from case studies described in Anonymous (1976). Dung deposition was based on conversion efficiencies summarized in Stoddard et al. (1975).

Plant Community/Forage Value (Total Plant Production)	Production Percentage as Grass and Forbes				
	20	40	60	80	100
Creosote (500 dry kg $ha^{-1} yr^{-1}$)					
Very High	4.4	8.8	13.2	17.6	22.0
High	3.6	7.2	10.8	14.4	18.0
Moderate	2.9	5.8	8.7	11.6	14.5
Low	2.2	4.4	6.6	8.8	11.0
Dung Loading Rate	3.0	6.0	9.0	12.0	15.0
Desert Grass (850 dry kg $ha^{-1} yr^{-1}$)					
Very High	7.4	14.8	22.2	29.6	37.0
High	6.1	12.2	18.3	24.4	30.5
Moderate	4.9	9.8	14.7	19.6	24.5
Low	3.7	7.4	11.1	14.8	18.5
Dung Loading Rate	5.0	10.0	15.0	20.0	25.0
Pinyon-Juniper (1200 dry kg $ha^{-1} yr^{-1}$)					
Very High	10.5	21.0	31.5	42.0	52.5
High	8.8	17.6	26.4	35.2	44.0
Moderate	7.0	14.0	21.0	28.0	35.0
Low	5.2	10.5	15.6	21.0	26.0
Dung Loading Rate	7.5	15.0	22.5	30.0	37.5
Ponderosa Pine (1800 dry kg $ha^{-1} yr^{-1}$)					
Very High	15.8	31.6	47.4	63.2	79.0
High	13.1	26.2	39.3	52.4	56.5
Moderate	10.5	21.0	31.5	42.0	52.5
Low	7.9	15.8	23.7	31.6	39.5
Dung Loading Rate	10.0	20.0	30.0	40.0	50.0

Table 29. Continued.

Life Zone/Forage Value (Total Plant Production)	Production Percentage as Grass and Forbes 20	40	60	80	100
Mixed-Conifer (2000 dry kg $ha^{-1}yr^{-1}$)					
Very High	17.4	34.8	52.2	69.6	87.0
High	14.5	29.0	43.5	58.0	72.5
Moderate	11.6	23.2	34.8	46.4	58.0
Low	8.7	17.4	26.1	34.8	43.5
Dung Loading Rate	12.0	24.0	36.0	48.0	60.0

in five plant formations commonly grazed in southwestern ranges. Table 29 does not consider the time of year grazed nor the strategy of grazing (continuous versus rest rotation, etc.), both of which may influence the amount of nutrient in dung deposits and should be considered in advanced development of models. Table 29 also specifies levels of primary productivity which will vary substantially with precipitation and edaphic factors so needs refinement for specific applications. The construction of such a table requires that: (1) upper limits on the advised grazing intensity and total deposition rate of dung are defined by total plant productivity, (2) the advised grazing intensity within a plant formation depends on the fraction of total plant productivity in the form of ground cover suitable for forage and the quality (digestibility and nutritional value) of the forage, (3) the advised grazing schedule results in maintenance of the same level of forage production, and (4) the dung deposition rate is predicted by total forage consumed with no effect from the quality of forage.

The fraction of plant production in the form of forage is highly variable and responsive to some extent to range management, which can conceivably increase livestock production by 5 to 10 times, depending on how forage quality is influenced. This in turn will influence the deposition rate of dung because the efficiencies with which forage is digested and egested are functions of forage value (indicated by fractions of lignin, nutrients, and water); the egested fraction appears to vary between 40 percent for high-value forage and 60 percent for low-value forage (Stoddard et al 1975) when the forage is grass and forbes. When significant fractions of the forage is browsed from woody growth, which occurs infrequently, the egested fraction may increase. The dung loading rate tends toward constancy for a specific forage production in spite of variations in forage quality. Livestock grazed on low-quality forage digest less and egest more of the production than livestock grazed on high-quality forage. The estimates of dung deposition assume that livestock grazed on forage of average value consume 2 percent of their body weight daily, while livestock grazed on low-value forage consume 2.4 percent, and livestock grazed on high-value forage consume 1.6 percent. These values will require some refinement for specific range conditions. Total production is basically a function of precipitation but may be modified greatly by edaphic variations. Nutrient levels in forage, influenced by edaphic variations, in turn influence the quality and quantity of the forage (N.R.C. 1970, Wallace et al. 1970).

Relationship Between Bare Area and Forage

A fundamental variable that needs to be assessed for modeling dung mobilization from the watershed is the fraction of bare-soil surface. A useful construction is a tabular reference to the relationship between the percentage of livestock forage (production in grass and forbes) present and the probable percentage of ground cover in different plant formations. Table 30 is a first approximation for such a reference table. The percentages illustrate that even with complete conversion to grass and forbes in all but mixed-conifer watersheds, at least some bare soil will occur, depending on the amount of precipitation. Where forests can grow, the amount of erodable bare soil surface is likely to be greatest at intermediate densities of trees where grass production is about half the total plant production. Where trees are dense, tree-leaf litter contributes a thick duff which is as effective as dense grass in preventing

Table 30. Estimated representative percentages of ground cover (including thick duff), tree cover, and shrub cover in southwestern biomes when the production is comprised of different fractions of grass and forbes for biomes on a gentle slope with deep, moderately well drained soils and grazed at advised rates.

	Percentage Production in Grass and Forbes				
Plant Community	20	40	60	80	100
Creosote (500 kg $ha^{-1}yr^{-1}$)					
Percent Ground Cover	5%	10%	15%	20%	25%
Percent Shrub	15%	10%	5%	2%	0%
Percent Tree	0%	0%	0%	0%	0%
Desert Grass (850 kg $ha^{-1}yr^{-1}$)					
Percent Ground Cover	8%	15%	25%	30%	45%
Percent Shrub	25%	20%	15%	8%	0%
Percent Tree	0%	0%	0%	0%	0%
Pinyon-Juniper (1200 kg $ha^{-1}yr^{-1}$)					
Percent Ground Cover	60%	50%	52%	66%	85%
Percent Shrub	25%	20%	15%	10%	0%
Percent Tree	75%	40%	20%	10%	0%
Ponderosa Pine (1800 kg $ha^{-1}yr^{-1}$)					
Percent Ground Cover	100%	75%	72%	82%	95%
Percent Shrub	20%	25%	15%	5%	0%
Percent Tree	90%	45%	25%	15%	0%
Mixed-Conifer (2000 kg $ha^{-1}yr^{-1}$)					
Percent Ground Cover	100%	90%	90%	95%	100%
Percent Shrub	10%	25%	20%	10%	0%
Percent Tree	95%	50%	30%	15%	0%

soil erosion (Dunford 1954, Dissmeyer and Foster 1980). With further research, a family of linear relationships may be devised that reasonably simulates the interaction between forage and bare area.

Relationship Between Dung Mobilization and Soil Mobilization

If we assume all dung but that volatilized will be eroded from the watershed eventually, then the relative fractions of soil and dung eroded over the long term can be predicted. The erosion rate of soil may be predicted by the Universal Soil Loss Equation to produce a reference table like Table 31. For this table, a certain soil K and length-slope factor is used, but these can be modified easily by arithmetic corrections described in table footnotes. The fraction of nutrient predicted to be eroded with the soil depends on the association of the nutrient with soil, a function of the clay and the organic matter in the case of phosphorus.

This simple model depends on several assumptions that may not always be met. It assumes that: (1) volatilization is the only important loss of dung material before it is eroded, (2) volatilization occurs rapidly and has little affect on the amount of nutrient eroded from dung in different rainfall regimes, (3) the only dung eroded is that deposited on bare soil surface, and (4) there is no appreciable vertical movement of dung below the eroding surface. A number of refinements need to be developed to account for possible exceptions.

If the Universal Soil Loss Equation is to satisfactorily predict dung runoff from a watershed, the constraints of existing knowledge need to be recognized and eventually reduced. The Universal Soil Loss Equation works best when Rainfall Erosivities are calculated for a long sequence of storm events such as for a rainy season or the whole annual

Table 31. Predicted mean annual erosion rate (kg ha^{-1}yr^{-1}) of soil and dung on moderate slope with slope-length factor of 2.2[1] and a high soil erosivity of 0.4[2] on ranges with different fractions of ground cover in grass and forbes and livestock grazed at advised rates (Table 24) for the forage produced (moderately good forage rates). See Table 25 for cover contributed by ground, overstory, and midstory vegetation[3]. Predictions of dung eroded assumes all organic matter, except that volatilized, deposited on bare area will eventually be eroded from the watershed.

Plant Community/ Substrate	Estimated Rainfall Erosivity	Percent Production in Grass and Forbes				
		20	40	60	80	100
Creosote	25					
Soil		3,875	2,875	2,375	1,940	1,685
Dung		2.85	5.40	7.65	9.60	11.30
Desert Grass	40					
Soil		4,050	2,800	2,300	2,200	1,300
Dung		24.70	8.67	11.48	14.28	18.78
Pinyon-Juniper	60					
Soil		950	1,600	1,650	700	250
Dung		2.88	7.20	10.36	4.37	5.40
Ponderosa Pine	80					
Soil		100	600	700	400	100
Dung		T	5.40	9.12	7.78	2.70
Mixed-Conifer	100					
Soil		100	200	300	150	50
Dung		T	2.40	3.60	2.40	T

[1] Soil erosivity commonly varies between 0.2 and 0.7 and is calculated as described in Dunne and Leopold (1978). Estimated rates can be corrected by multiplying by the fraction of observed soil k divided by 0.4.

[2] Slope-length factor commonly varies between 0.01 and 10 and is calculated as described in Dissmeyer and Foster (1980). Estimated rates can be corrected by multiplying by the fraction of the observed slope-length factor divided by 2.2

[3] Contributions of grazing vegetation cover in most plant formations vary widely. The erosion rate is shown in Dunne and Leopold (1978) and Dissmeyer and Foster (1980).

cycle (Stewart et al. 1976). Because the soil moisture is not a variable included in the model, variation in soil moisture at the time of any particular rain event causes unpredicted variation in the material runoff. The variance is integrated over longer sequences of storm events. Length of slope in the hill slope-length factor may be overestimated easily (Dissmeyer and Foster 1980), because breaks in a long slope cause material deposition including deposition of dung. Measurement of hill slope-length is a probable source of bias in model prediction once a long sequence of storm events is used to predict rainfall erosivity. Recent work reported by Dissmeyer and Foster (1980) provides a better understanding of effects of large-scale variations in slope (which can be calculated from topographic maps or aerial photos) on predictions by the the Universal Soil Loss Equation.

Also needed is a better understanding of the role of organic matter in soils because untilled soils tend to have higher amounts of organic matter than tilled soils. Further understanding of the associations of nutrients in erodable surfaces is needed to better develop nutrient enrichment ratios in the mobilized sediment so they may be incorporated in the Universal Soil Loss Equation to predict nutrient runoff (Logan 1980 and McElroy et al. 1976).

With regard to dung mobilization, the suitability of the Universal Soil Loss Equation depends mostly on how much dung behaves like soil in response to rainfall erosivity. If it behaves like soil, then only the basic limitations of the model affect prediction of dung erosion once deposition rates are known. But to behave like soil, the dung material must: (1) be associated with the soil surface actually eroded (the top few millimeters or less of bare-soil surfaces), and (2) have the same resistance as soil to erosive forces. Our data on horizontal distribution of dung indicate that dung, in some instances, may be deposited by deer and cows on bare areas more frequently than the bare areas occur, but our data is variable. Further calculation of the extent of such a tendency, if it exists, is needed to refine models.

The small amount of pilot data we developed for vertical distributions of volatile solids and phosphorus needs much amplification, particularly the relationship between soil K-factor and the probability of nutrients penetrating below the erodible surface. Our preliminary results indicate that most volatile solids remain in surface layers exposed to erosion, at least in those soils with 1.5 percent organic matter, 80 percent fine sands, and 17 percent clay and silt. However, our limited sampling of bare surfaces (1-cm deep) indicates no higher organic matter than in deeper soils gathered from vegetated and bare areas, while our infiltrometer studies indicate that the amount of organic matter in runoff is higher than in the average soil (15-cm deep). Our data indicated that phosphorus was at least several times more concentrated in surface soils and runoff. Other workers (Black 1970) reported that fertilizer phosphorus remains closely associated with surface soils. Sharpley et al. (1978) found that the phosphorus in stream runoff was correlated with the phosphorus concentration in the upper 1 cm of soil. With regard to dung mobilization, this dimension needs further research effort. Dung nitrogen particularly may be conserved by deep penetration below surface soils. The relatively low amounts of nitrate nitrogen runoff from our infiltrometer study plots may indicate that larger fractions of nitrate-nitrite nitrogen had been carried deeper into the soil.

On moderate slopes, a mean of 0.25-0.50 mm of soil may be eroded annually from a bare unvegetated surface based on predictions of the Universal Soil Loss Equation and our infiltrometer studies. Nutrients must be sorbed effectively to be trapped entirely in the upper 1 mm; sandy soils with little organic matter may pass most nutrient below the eroding horizon. Logan (1980) reviews the general problems associated with predicting sorbtion and desorbtion of phosphorus on soils and suspended sediments, indicating the great need for research in this area to develop predictive coefficients.

Further research may be needed to better define the role of biological activity in influencing dung distribution. In some circumstances, dung also may be transported below the erosion surface or into vegetated areas as a consequence of biological activity, particularly beetles and termites. In some areas, insect activity contributes substantially to rates of dung loss (Omaliko 1981). However, we saw little evidence of insect activity that would substantially move dung below the soil surface.

The differing structures of intact dung and most soils cause great differences in erodability. Dung quickly binds together as it dries creating cohesiveness in the dry dung, which may be more resistant to breakdown by rain than dry clay. Intact cow dung is less dense than inorganic soil and, as it dries, its specific gravity may drop as low as 0.75 (deer dung tends to retain a greater density of about 0.90). Therefore, where dung is broken up and does not adhere to the substrate, it floats easily. The probability that dung will float depends on the depth of overland flow in relation to the thickness of the dung particle. Enough overland flow must occur to buoy the mass of dung from the substrate and enough to roll or float it. For deer dung, floating is easily accomplished (a 9-mm deep surface flow can float a dry pellet of deer dung), and has been observed during rainstorms (Wallmo et al. 1962). For intact cow dung, the likelihood of floatation from areas outside deep erosion channels is negligible until dung particles physically break down to thicknesses similar to deer dung or smaller. Based on our studies of physical breakdown, that process is usually taken more than one year but once it is completed, virtually all old dung on bare soil surfaces float from the watershed wherever there is enough overland flow.

The dung mobilized in natural watersheds at Sixteen Springs Canyon, if it behaved like soil moved much faster than predicted. Because 95 percent of it was old, substantial amounts probably were floated (little leaches from old dung) out of position. More than twice as much dung disappeared during the rains than the dung predicted from the amount of bare area, suggesting that it was moved out of vegetation and litter as well as bare soil. Although some of the dung could have been buried in mobilized litter and soil, the dung on the bare area was moved at least off of the bare areas. Compared to the larger intact deposits, the smaller particle sizes are more likely to float entirely out of the watershed rather than to a new location in the watershed.

By whatever means the dung materials are moved faster than predicted by the Universal Soil Loss Equation, we can correct the prediction by the Universal Soil Loss Equation. The correction can be made using a first approximation of an empirical coefficient based on our observation in Sixteen Springs Canyon where phosphorus moved 2.65 times faster than predicted if all of it behaved like soil material, volatile solids moved 5.31 times as fast, and nitrogen moved 18.60 times as fast. Of course, this first approximation needs further refinement with observations on the behavior of dry dung deposited on vegetation, duff, and bare soil under simulated or natural rains. In the long term, depending on breakdown rate, the amount of dung eroded from the watershed may prove to be equivalent to the fraction of bare soil and the total amount deposited. However, the ability of the volatile solids to contribute biological oxygen demand and the mobility of phosphorus and other nutrients in aqueous solution will be determined partly by the characteristics of old, dry dung material. Predicting the age (size) that dung will be when it floats out of a watershed will improve on the predictions of nutrient loading and loading of organic matter in downstream environments.

Dung Deposition and Nutrient Concentration

The Universal Soil Loss Equation may be a suitable predictor of dung loss rates from rain-caused erosion. First, however, the relationship between dung floatation out of a watershed and this predictive equation has been investigated further, including concentrations of nutrients.

For specific forage conditions, exemplified in Table 32, a grazing intensity identified from a reference table like Table 29 may be chosen and from it the dung deposition calculated. The total dung nutrient deposited in the area of concern is calculated from the fraction of nutrient identified in the dung (Table 3). In drier areas, the fraction of nutrient in fresh dung exposed to rainfall usually is small, and a constant fraction based on older dung may be used accurately. In areas with greater rainfall, more frequent storms, and grazing more restricted to the rainy season, contribution from fresh dung may become significant.

Table 32. Amounts of cow-dung nutrient projected to be deposited in watersheds of Southwestern plant formations grazed at typical intensities advised and efficiencies based on data reported by Stoddard et al. 1975 (moderate to high forage value, 50 percent egestion and a daily consumption rate equal to 2.0 percent of body weight).

Precipitation (mm)	Plant Community	Livestock Grazing Intensity kg/ha/yr (wet)	Dry Dung kg/ha/yr	Volatile Solids kg/ha/yr	Hydrolizable Phosphorus kg/ha/yr	Non-Gaseous Nitrogen kg/ha/yr
150-250	Creosote 25% grass production	(3.4)	2.9	2.2	.0058	0.087
250-350	Desert Grasses 30% grass production	(8.3)	6.6	5.0	.0132	0.198
350-450	Pinyon-Juniper 35% grass production	(16.4)	13.2	9.9	.0264	0.396
450-550	Ponderosa Pine 40% grass production	(24.7)	19.8	14.9	.0396	0.594
550-650	Mixed Conifer 20% grass production	(54.8)	44.0	33.0	.0880	1.320

This contribution should be considered for the model because fresh dung has a greater potential for oxygen demand and nutrient release. The assumption that all dung on bare soil eventually floats from a watershed whenever runoff occurs needs to be tested. If dung material is washed out of vegetated areas then the prediction may be low. If vegetation filters flows from bare areas, then the estimate may be high. If vertical penetration is substantial, the estimate also will be too high. Further research with infiltrometers on a variety of substrates seems to be the most promising approach to solving this problem.

The Cooperative Studies Section, Hydrologic Service Division (1956) has synthesized research relating storm intensity, storm duration, and total annual precipitation. The seasonal or annual rainfall seems to vary reasonably in accord with the Rainfall Erosivity within the climatic region our studies were conducted. In the five most common plant formations in New Mexico, about 35-60 percent of the precipitation occurs from July through September. Because intense convective rain storms are most likely to occur then, summer rainfall erosivity comprises closer to 50-70 percent of the annual rainfall erosivity.

Differences in alignments of grazing and rainy seasons can potentially influence erosion rates of dung material substantially. Table 33 illustrates a preliminary estimate of how the timing of dung deposition in relation to precipitation patterns could influence the amount of dung eroded into downstream aquatic environments. For example, the seasonal rainfall erosivity in a mixed-conifer watershed may be 2.8 times the seasonal rainfall erosivity in creosote and the grazing season at the Mixed-conifer elevation almost completely overlaps the summer rainy

Table 33. An example of the effect of timing of grazing on the erodability of fresh dung volatile solids in areas with different rainfall erosivities and grazing schedules. Erosion of volatile solids from fresh dung is calculated for the summer period (July-September) when most rainfall erosivity occurs.

Plant Community	Grazing Schedule	No. Storms Per Month in Summer (over 2.5mm)	Monthly Dung Deposition Rate kg ha^{-1}	Age of Fresh Dung (days)	Fraction of Fresh Dung Rained On	Volatile Solids Eroded From Dung kg ha^{-1}	Rainfall Erosivity for Summer	Annual Rainfall Erosivity
Creosote	12 month	6	0.24	1.5	0.30	0.13	18	25
Desert Grass	12 month	7	0.55	2.0	0.47	0.43	26	40
Pinyon-Juniper	12 month	9	1.10	2.5	0.71	1.18	36	60
Ponderosa Pine	9 month April-Dec.	11	2.20	3.0	1.00	2.90	44	80
Mixed-Conifer (meadow)	4 month June-Sept.	14	11.00	3.5	1.00	16.50	50	100

season. When livestock deposits 0.25 kg ha^{-1} $mo.^{-1}$ in creosote-dominated watersheds during the summer rainy season, erosive rains (over 2.5 mm) will occur on a particular site about 20 percent of the days during the rainy season. Therefore, about 20 percent of the dung rained on will be fresh dung (up to 1.5 days old) and the equivalent of 0.13 kg ha^{-1} of volatile solids will be eroded during summer. In contrast, at the mixed-conifer site erosive rains could occur on all the fresh dung deposited and erode the equivalent of 16.5 kg ha^{-1} over the summer.

Fractions of Dung Leached, Eroded, and Floated

Table 34 estimates the relative fractions of dung material and soil eroded from watersheds such as those investigated in our infiltrometer studies. For Table 34, annual rainfall erosivity was estimated from Weather Service records of rain durations and related intensities (CSSHSD 1956) and dung deposition was estimated from advised grazing schedules. The percent of total material runoff comprised of dung was estimated based on the fraction dung made up in runoff from infiltrometer studies with the amount of dung present corrected to a realistic deposition rate (the ratio of dung mass to watershed surface area in infiltrometer studies was at least 300 times that found in any watershed sampled). Maximum amounts of dung were contributed at wetter, higher elevations because the advised grazing rate per unit of bare-soil surface and the fraction of fresh dung likely to be mobilized was greatest there. At least as much and usually a greater percentage of nitrogen appeared to be contributed by dung to the runoff than either phosphorus or volatile solids, although these estimates should be viewed as first approximations only. To refine these estimates, more studies of natural and simulated rain erosion should be done to assess the effect of different edaphic

Table 34. The maximum fraction of total runoff likely to be comprised of dung assuming that all dung nutrient deposited on a bare area eventually erodes or floats off the site and none penetrates below the erosional zone. The amounts of soil material were calculated from predictions by the Universal Soil Loss Equation and the fraction of total solids comprised of nutrient materials in infiltrometer studies (Table 10). The dung nutrient content was calculated based on the average age of dung in the watershed at times of erosive rains.

Plant Community	Dry Dung Deposited kg ha^{-1} yr^{-1}	Annual Erositivity Index	% Bare Soil	Amounts (g m^{2} yr^{1}) and Percentage of Nutrient Runoff from Soil and Dung and Percent of Material Runoff Comprised of Dung								
				Volatile Solids			Hydrolizable Phosphorus			Total Nitrogen		
				Soil	Dung	%	Soil	Dung	%	Soil	Dung	%
Creosote	2.9	25	85	32.3	0.15	0.5	0.100	.00049	0.5	0.387	.0020	0.5
Desert Grass	6.6	40	75	13.8	0.32	2.3	0.094	.00094	1.1	0.038	.0050	13.0
Pinyon-Juniper	13.2	60	50	40.9	0.44	1.1	0.072	.00066	0.9	0.022	.0079	3.6
Ponderosa Pine	19.8	80	20	6.0	0.27	4.5	0.036	.00029	0.8	0.036	.0055	15.4
Mixed-Conifer (meadow)	44.0	100	5	2.0	0.15	7.5	0.003	.00044	14.7	0.042	.0035	8.3

conditions (soil nutrient content, amount of bare soil surface, and soil k-factor) on the behavior of dung mobilization. Especially important are estimations of the movement of old dry dung exposed to variations in Rainfall Erosivity on different soil substrates.

Erosion and Oxygen Demand in Aquatic Environments

If most of the dung material eventually floats out of the watershed during storm events, a high percentage of all dung may be stranded in floodplains as high waters recede. However many arroyos are steep sided with little room for stranding of floating materials. In those arroyos, the loss of dung material should be negligible. In areas where stranding could be important, this fraction has yet to be assessed. One possible method would be upstream-downstream comparisons of litter and dung drift-net catches. Otherwise, the availability of dung materials as nutrients seems to depend greatly on what happens to old dung after it reaches a permanent aquatic environment.

In the Southwest, small reservoirs with less than a 100-ha surface area are constructed for a variety of purposes to be filled by ephemeral surface runoff. The size of the watershed needed to maintain water in a reservoir is a function of evaporation and the runoff fraction from precipitation. Although annual precipitation in mixed-conifer formations may average five times that in the Creosote community, the area required for a watershed in creosote may be 40 times that needed for a reservoir in the mixed-conifer. Table 35 illustrates how a small "typical" reservoir of 500,000 m^3 could respond to loadings with runoff from watersheds with different plant formations. This type of reservoir is simplified because it catches temporary runoff only and has no continuous tributary

Table 35. Estimated life expectancy and amounts of organic matter (volatile solids) and oxygen demand in a reservoir 20 ha in area and 2.5-m average depth which forms a hypolimnion in 40 percent of its volume of 200,000 m^3. Factors influencing erosion rate and fractions of nutrient runoff were assumed to be as measured in the infiltrometer studies. The Universal Soil Loss Equation was used to predict erosion rates.

Plant Community	Percent of Annual Precipitation That Runs Off	Watershed Area km^2	Life Expectancy of Reservoir[1]	Volatile Solids Loading (g/m^2)	mg O_2 G^{-1} Volatile Solids	Estimated Fraction of Cow Dung (%)[2]	to 0 O_2 in Hypolimnion (Days)[3]		Stratification Period (Days)
							With Dung	Without Dung	
Creosote	0.25	40	20 years	11,267	2.0	1.13	0.3	0.3	220
Desert Grass	0.75	13	50 years	968	4.0	8.77	2.0	4.5	195
Pinyon-Juniper	2.00	5	100 years	356	6.0	12.60	3.4	16.0	170
Ponderosa Pine	5.00	2	206 years	118	8.0	9.27	9.0	60.6	145
Mixed-Conifer	10.00	1	145 years	131	10.0	9.37	6.9	75.1	120

[1] Filling rate of reservoir with total eroded matter assumes eroded material has a specific weight of 1.5.

[2] Assumes that all cow dung deposited on bare soil erodes off the watershed in the long run.

[3] Oxygen demand was based on determinations in Table 22; assumed that temperature controlled decomposition rates by $Q_{10} = 2.0$ and mean hypolimnetic temperature varied from 8°C at Mixed-Conifer to 20°C at Creosote.

or ground water to dilute the surface runoff. Numerous small reservoirs of this kind occur in the Southwest.

Based on the predictions of the Universal Soil Loss Equation and our infiltrometer studies, the reservoir in creosote would receive tremendous loading of organic matter but with only a small fraction of it in the form of domestic ungulate dung (if grazed at prescribed rates). Based on our studies (Table 27), oxygen demand would be extreme, particularly if all the material entered in a single extreme runoff event. Oxygen depletion in the hypolimnion would occur quickly after the hypolimnion formed. At higher elevations, the amount of material loading diminishes as a consequence of the stability of the watershed and smaller watershed size, but the fraction of volatile solids comprised of domestic dung increases up to about 10 percent of the runoff. The fraction of the material that is fresh dung increases for the reasons illustrated in Table 33. Therefore BOD g^{-1} organic matter increases to reflect the mix with fresh dung as we observed it (Table 27), at least under one set of conditions. The relative contribution of cow dung has virtually no influence on deoxygenation at lower elevations but may substantially increase the rate at higher elevations, particularly if overgrazing occurs. Since erosive storms often come late in the summer stratification period, the substantial increase in demand rate indicated for reservoirs at higher elevations could make the difference between a reservoir that is severely oxygen depleted and one that is not. Of course this degree of influence depends greatly on whether or not fresh dung causes appreciably higher oxygen demand rates than old dung. More research needs to be directed at dung's interaction with soil and litter. Table 35 assumes no livestock dung deposit directly in a reservoir. To whatever degree direct deposition occurs, the effect of fresh dung on oxygen demand will increase.

The prediction in Table 35 that these hypothetical reservoirs will have deoxygenated hypolimnia for at least part of the stratification period is collaborated by data gathered for real reservoirs in New Mexico. The results indicate that, for small reservoirs fed by ephemeral runoff and deep enough to stratify, hypolimnetic deoxygenation is the rule regardless of lake elevation (Potter 1982), although much of the oxygen demand may be caused by decomposition of plants produced in the reservoirs. How much the runoff materials contribute to decomposition in the hypolimnion depends on how much enters during stratification seasons. For practical purposes, virtually all erosive surface runoff occurs during the period of summer stratification because the most erosive storms occur from June to September. Snow melt induces relatively little erosive runoff, at least on gentle slopes (Haupt 1967). Therefore we assume that runoff of organics contributes mostly to lake deoxygenation during summer stratification. At higher elevations, where winter stratification occurs, a lesser winter impact is anticipated because much of the organic material introduced during summer already has decayed by the time ice forms and low temperatures depress decomposition rates.

Phosphorus Loading and its Relationship to Primary Productivity

Our data indicate that old dung must age in water of 18°C for several days before it develops an appreciable oxygen demand, but it eventually develops the same demand as fresh dung after oxygen levels have been reduced substantially. Old dung released substantially smaller quantities of orthophosphate-phosphorus than fresh dung over a period of 48 days. This may have been because a larger fraction of the phosphorus in old, dry dung was incorporated in organic matter which was more resistant to decay than organic matter in fresh dung. If the interaction we observed between fresh cow dung and soil, which stimulated a loss of phosphorus from the soil, is a consequence of microbial innoculation associated with active rates of decay, then old cow dung may be less likely to cause an accelerated loss of phosphorus from soil when it is mixed with soil. Our data suggest that the lowest level of oxygen reached may be at least as important. In that case, the total organics loading, in whatever form, may be the primary consideration in determining how much phosphorus will be mobilized. Because the total amount of phosphorus eroding from a watershed mostly depends on the soil load, the impacts of of dung on soil phosphorus mobilization is important. Clarification of an apparent stimulatory effect is needed, and investigation of old dung in this regard is paramount. Table 36 shows the estimated total phosphorus and nitrogen loadings in reservoirs placed in each of the plant communities under conditions described for Table 35. The estimates indicate that nitrogen is increasingly likely to limit aquatic plant production in arid situations. However, where phosphorus remains the limiting nutrient, large growths of algae are potentially possible and these growths can exert great oxygen demand. Of course, only a fraction of that oxygen demand will be realized. The amount that potentially is realized depends mostly on when dung and other material are introduced to the reservoir, the rates of decomposition and the duration of anoxic stratification.

To the extent that overgrazing causes bare areas, livestock may change the relative amount of phosphorus mobilization from the watershed by a combination of trampling and dung depositional effects. As long as

Table 36. Estimated loadings of total phosphorus and nitrogen into a reservoir similar to that in Table 32 and the potential for plant growth and biological oxygen demand after algal death if all phosphorus is incorporated into algae and all algae is oxidized. Dung is likely to contribute at least the fractions indicated in Table 34 and additionally to the degree its oxygen demand increases mobilization out of soils.

Plant Formation	Total Loadings ($g\ m^{-3} yr^{-1}$)		Ratio	Potential Growth of Algae Where P is Limiting Organic Matter (m^{-3})	Potential Oxygen Removal[1] by decay ($g\ m^{-3}$)	Initial Oxygen Concentration ($g\ m^{-3}$)
	Phosphorus	Nitrogen				
Creosote	36.2	139.20	3.8	3600	4530	7.0
Desert Grass	6.8	2.78	0.4	660	1500	7.5
Pinyon-Juniper	0.6	1.89	3.2	60	190	8.0
Ponderosa Pine	0.7	11.53[2]	16.5	60	190	8.5
Mixed-Conifer	0.2	2.73	13.7	30	95	9.0

[1] Assumes a respiratory quotient of 1:2 (Wetzel 1975).

[2] Based on ratio of nitrogen to phosphorus observed from the natural watersheds at Sixteen Springs Canyon.

herd size is held constant as amount of bare area increases, dung and soil phosphorus erosion rates probably will increase disproportionally with number of cattle grazed. Branson and Owen (1970) have shown relationships among grazing, bare areas, and soil runoff rates which suggest that a disproportionate increase in runoff of nutrient associated with eroded soils would occur as grazing and bare soil area increased. Several studies have indicated relationships among grazing intensity, trampling, and the amount of bare area developed in a watershed (Packer 1953, Linnartz et al. 1966). Based on the Universal Soil Loss Equation, grazing a pinyon-juniper range with 60 percent grass production down to nearly no grass production would more than double the phosphorus associated with soil losses.

Wild Ungulates

Estimation of dung input rates by wild ungulates depends on estimates of density, which are not as reliable as those defined for livestock. Crude estimates of densities in various plant formations have been compiled and may be used for estimates until better techniques evolve. Nutrition models are being developed (Medin and Anderson 1979, Swift et al. 1979 and Wallmo et al. 1977) that are similar to the model generally used for livestock, which should enable predictions of potential ungulate-density based on the forage available. More data on daily ingestion rates and digestion efficiencies are needed to define formulations for different qualities of forage. In the meantime, density may be estimated several ways, including studies of rates of dung deposition and disappearance (Batchelor 1975), which is basically a back calculation from the measured inputs of dung. Our nutrient data indicate remarkable similarities between dung of wild and domestic livestock. More thorough investigation of changes in nutrient concentrations as dung ages is needed to refine estimates of watershed export from the two groups.

No data as yet have been collected to determine how deer dung erodes under artificial applications of rain. A larger fraction of deer dung than cow dung was mobilized by natural events in watersheds, possibly because of its small size and how easily it is moved by surface runoff or other surface disturbance. Based on its densities, old deer dung should readily floated from watersheds where substantial overland flow develops. Because deer dung has a much higher ratio of surface area to volume than cow dung, we would expect deer dung to dry more quickly than cow dung and proportionately more of it would be mobilized by floatation rather than leaching or mobilization with contaminated soil particles. To confirm this deduction and estimate rates of movement, studies of old deer dung should be conducted with an infiltrometer on a variety of slopes and soil conditions. The studies would determine the fractions floated from the watershed, just as with cow dung.

Our studies of oxygen demand and phosphorus mobilization indicate that old deer dung behaved similarly to old cow dung. However, tests are needed, as for cow dung, to determine the interaction, if any, between old deer dung and soil in stimulating oxygen demand and increasing phosphorus mobilization in water.

In some life-zones, wild ungulates such as elk and pronghorn (_Antilocapra americanus_) are more likely to contribute to nutrient mobilization than deer. In other life zones domestic ungulates, such as sheep (_Ovis aries_) or goats (_Capra hircus_) are more likely to occur than other ungulates. Further study of the dung characteristics of animals other than deer and cattle is needed to determine if the characteristics are substantially similar.

We have assumed, for preliminary model development, that the fraction of cow- and deer-dung organic matter mobilized is equivalent to the fraction of bare-soil area, based on our observations of dung disappearance in natural storms. At higher, lightly grazed elevations, a small fraction of the dung is projected to be mobilized because the bare-soil surface area is small. If livestock grazing at advised rates maintains larger bare areas than would otherwise exist without domestic grazing, then deoxygenation rates by deer and cow dung would be aggravated further by the denudation caused from livestock grazing, as long as deer remained in similar abundances. Also, if more dung material reaches the lakes than is predicted by the fraction of bare soil alone, livestock contribution will become more important than the model indicates. Obviously, if livestock form eroded paths leading to a source of water in a reservoir, and spend much time around water, as indicated by Julander and Jeffrey (1964), the amount of dung introduced would be much greater than indicated by bare area. A larger fraction of the dung would be fresh with a high oxygen demand. It is also possible that as deer dung dries it may be washed or blown out of areas with good ground cover and into erosion channels (whole pats of cow dung have been observed to cartwheel in high winds). On the other hand, the net effect of ground cover may be to filter deer dung out of flows from bare areas and reduce the downstream impact. These questions need to be addressed to refine the models described.

What Difference--Deer or Cows?

If removal of livestock from a range will result in wild herbivores moving in to take their place, will rates of dung mobilization out of the watershed remain the same? Empirical data contrasting livestock-grazed and livestock-ungrazed watersheds (Lusby 1970) suggest the answer is no. However, wild animals were not censused in these studies to determine if they had returned to carrying capacity following withdrawal of livestock.

Studies designed to assess competition for food between mule deer and cattle show that, for the most part, deer and cattle on the same range eat different things and use different areas in a watershed (Julander and Jeffrey 1965, Skovlin et al. 1968, Mackie 1970, Constan 1972, Dusek 1975, Hansen and Reid 1975, Hubbard and Hansen 1976, Hansen et al. 1977, Olsen and Hansen 1977, Stuth and Winward 1977, Mackie 1978, and Luchich and Hansen 1981). This finding suggests that the deer population in watersheds we studied would not expand much as a consequence of reduced numbers of cattle. The finding also suggests that deer will continue to deposit dung in watersheds at similar rates even though it is severely overgrazed by cattle.

Other wild herbivores probably would eat grasses left ungrazed by livestock. Elk would be likely to use such areas at higher elevations and, in fact, because of the similarity in their diets (Julander and Jeffrey 1965, Skovlin et al. 1968, Mackie 1970, Hansen and Reid 1975, Hansen and Clark 1977), areas grazed, and animal size, elk may cause about the same impact as cattle on nutrient mobilization if elk were to graze at the same biomass advocated for cattle.

In most Southwestern plant communities elk do not occur frequently, and pronghorn, rodents, and rabbits are more likely to supplant livestock once they are removed. Pronghorn foods may partially overlap with foods of livestock (Severson and May 1967). Even if livestock were entirely replaced by herbivores, to the extent that all forage production were consumed, the trampling effect would be much reduced because the turnover of smaller mammals per unit biomass is greater than cattle. This relationship between body size and trampling effect stems from the energy needed to maintain mammals of different sizes, usually expressed as $R = Wt^{0.75}$ (Stoddard et al. 1975). Adult cattle require about 30 percent of the respiratory energy of mammals 1 percent of their size, and about 17 percent of the energy of animals that are 0.01 percent of their size. If the entire herbivore population averaged 4.5 kg in weight (mostly rodents, rabbits, and a few pronghorn), the biomass maintained to consume all available forage would be 30 percent of the cattle biomass needed to consume the same forage. If trampling were directly proportional to weight, the wild populations would be 30 percent as effective. Trampling also depends on how weight is distributed, i.e., the amount of weight cm^{-2} of foot contact area. Table 37 shows estimates of herbivore weight, track area, and calculated weight cm^{-2} of foot surface in contact with the ground. The table shows that small mammals exert between 0.001 and 0.01 times the pressure of larger mammals. Generally the largest mammals generate 1000 to 2000 g cm^{-2}. Cattle have large feet compared to large native ungulates, therefore they exert somewhat less pressure per unit of body weight than mule deer or elk (these estimates are averages from average track size of large animals; there will be at least some variance among animals). As a

Table 37. Estimated weight cm^{-1} of foot contact based on observed sizes of tracks for cattle and herbivorous wildlife likely to occur in southwestern biomes. Track sizes and animal weights are from Murie (1954) and Whitaker (1980).

Species	Animal Wt (g)	Total Track Area (cm^2)	Trampling Pressure g cm^{-2}
White-Footed Mouse *Peromyscus leucopus*	45	1.4	32
Mexican Vole *Microtus mexicanus*	45	0.6	75
White-Throated Woodrat *Neotoma albigula*	250	3.5	71
Desert Cottontail *Sylvilagus auduboni*	1,000	23.5	42
Blacktail Prairie Dog *Cynomys ludovicianus*	1,200	6.0	200
Black-Tailed Jack Rabbit *Lepis californicus*	4,000	44.0	91
Collared Peccary *Dicotyles tajacu*	25,000	19.5	1,300
Pronghorn *Antilocapra americanus*	45,000	35.0	1,300
Mule Deer *Odocoileus hemionus*	150,000	104.0	1,440
Elk *Cervus elaphus*	400,000	150.0	2,660
Cow *Bos taurus*	450,000	400.0	1,100

consequence, a biomass of elk or mule deer equal to that of cattle would exert more pressure and trampling effect than cattle.

Distribution is a third factor that must be considered. Of mule deer, elk, and cattle, cows tend to concentrate in herds in localized parts of a range wherever heterogeneity in slope, vegetation (forage, shade, cover, etc.), or water-availability exists. Predicting the relative trampling impact becomes much more complicated in such situations. Packer (1953) indicates that a threshold level of trampling may be needed before there is measurable impact on runoff. Establishing that level depends on how concentrated the biomass of grazers is and on what mean slope and vegetal conditions the animal grazes. According to our data and Julander and Jeffrey (1964) livestock tend to concentrate on low slopes (less than 10 percent) where length-slope factor is low but near major runoff channels, perhaps five to one in favor of high slopes (40-50 percent). Deer, in contrast, tend to concentrate less, and are most concentrated on tops of ridges where the length-slope factor is low and the distance to major runoff channels is great. Elk seem to be intermediate between cattle and deer (Julander and Jeffrey 1964). Multiple regression models for predicting distribution of deer, elk, and cattle (Julander and Jeffrey 1964) provide a base for a first approximation of the relative impact of trampling by domestic and wild ungulates. Perhaps the most difficult entity to assess is biomass (and production) of wild ungulates. One promising method of estimating a carrying-capacity biomass of wild ungulates is a nutrition model formulated similarly to the calculations needed to estimate the appropriate livestock grazing intensities. Knowledge of production of appropriate forage conversion efficiencies and cropping by predation will be the fundamental input required to predict biomass.

If it is assumed that deer and cattle do not compete for the same forage, total carrying capacities for large ungulates may be "easily" calculated once nutrition models for deer are operational. With that information and other information previously discussed, the relative impacts of trampling and dung deposition by wild and domestic livestock on nutrient mobilization into downstream water can be more reasonably simulated than at present.

CONCLUSIONS AND RECOMMENDATIONS

1. Mathematical models can be used to simulate and predict dung deposition by ungulates and erosion of dung organic matter, nitrogen, and phosphorus into downstream reservoirs. Mathematical models also can be used to predict the relative effect of dung organic matter on oxygen concentrations in small watersheds and on phosphorus mobilization out of all watershed materials that are carried into a reservoir. The accuracy of prediction depends on the accuracy of coefficients used to simulate effects. Although this study and others have developed most of the coefficients needed for first approximations of effects, more information will be needed to refine the accuracy of model prediction.

2. The organic matter, total nitrogen, and phosphorus in recently deposited cow and deer dung, although somewhat variable among individuals, is similar for the two species in a wide variety of ecological conditions in New Mexico and Wyoming. Mean percentages of materials in range-cow dung is 75.3 percent organic matter, 0.36 percent total phosphorus (0.18 percent hydrolizable phosphorus) and 2.68 percent total nitrogen. Mule Deer dung was, for the same constituents: 82.4 percent, 0.52 percent (0.24 percent), and 2.07 percent. A smaller amount of elk dung studied revealed 75.7 percent, 0.37 percent, and 2.26 percent, respectively. For calculations of fresh organic matter, phosphorus, and nitrogen in fresh dung deposited in a watershed, the location and species are minor variables compared to estimates of ungulate biomass and other variables that influence the erosion of dung material into downstream waters.

3. The amount of organic matter and nitrogen in cow and deer dung declined as it lost water and aged. Dung lost 60 percent of its nitrogen (as a fraction of dung initially a few hours old) over 12 days and may have lost up to 80 percent over a longer but indeterminate time (old range dung). Organic matter measurably declined by at least 20 percent over 12 days but declined little thereafter. Most organic matter and nitrogen were lost within four days of deposition in shade and two days of deposition in full sun. Phosphorus was variable but revealed no consistent trends in its fraction as dung aged. No highly fractured, small fragments of dung were analyzed to determine their composition. Because small particles are easily eroded, and dung may remain in the watershed until finely fractured, the organic and nutrient content of the particles should be determined in future research.

4. Concentrations of organic matter, total nitrogen, and phosphorus in fresh dung were greater than those in soils, although soil concentration varied widely with differences in climate and amount of vegetation in the watersheds studied. Fractions of organic matter in soil ranged from 2 percent to 20 percent of that in dung, phosphorus ranged from 10 percent to 40 percent of that in dung, and nitrogen ranged from 8 percent to 20 percent of that in dung. Approximations of the amount of dung organic matter and nutrient in the upper 2 mm of soil surface did not exceed 5 percent. This estimate did not include finely disintegrated dung which could have been present. Litter in the watershed had more organic matter but less nitrogen and phosphorus than recently deposited dung. Mean amounts of volatile solids and nitrogen in soils of watersheds of different

climates in New Mexico were correlated with mean precipitation, but the amounts in runoff were not correlated with climate. For phosphorus, neither concentrations in soils nor runoff were related to climate.

5. Rates of cow-dung weight loss varied with temperature and evaporation rate which was related to temperature ($R^2 = 0.93$). Dung weight losses were twice as great at maximum daily temperatures of 38°C and evaporation rate of 12.6 mm d^{-1} (summer in creosote community) than at maximum daily temperature of 16°C and evaporation rate of 3.9 mm d^{-1} (winter in creosote community). Because dung weight loss is a function of temperature ($y = -33.8 + 1.74x$; $R^2 = 0.69$) and nutrient erosional loss is a function of drying weight, the rate that organic matter and nutrient is eroded from dung exposed to known rainfall erosivity can be predicted from temperature and evaporation rate. Deer dung was not tested but should be because it has a much greater ratio of surface area to volume.

6. Erosion rate of dung under simulated rains was greatest when dung was fresh, but, like volatilization, declined to an equilibrium rate quickly, within two to four days for phosphorus erosion, depending on time of year and shade. Under simulated rain, fresh dung lost 3 to 15 times as much phosphorus, and four to seven times as much organic matter as dung several days old. Nitrogen was lost from fresh dung at three times the rate of old dung. Whether or not rain falls on fresh dung less than two-four-days old can be a variable of significance in determining how much nutrient is carried directly from dung which has been rained on. Where most rainfall erosivity

occurs in summer, as it does in New Mexico, dung equilibrates to the lowest rate of erosion quickly, within one to two days at lower elevation and three to four days at higher elevations, depending on the amount of shade.

7. For cow dung dried more than three to four days in summer, the duration of a rain has no effect on the rate of dung erosion, but the erosion rate of fresh dung material doubles with each 1-cm increase in precipitation (assuming the same intensity). Based on these relationships, an intense 4-cm rain (mean maximum summer rain in much of New Mexico) with a rainfall erosivity of 15 could erode away half the fresh organic matter in dung deposited within the last two days. In such a storm, older, dry dung up to at least four-weeks old (period measured) would lose only 2 percent via direct mobilization from the dung. Because grazing schedules may overlap closely with summer stormy periods (particularly at higher elevations), and be spread out in other areas (particularly lower elevations), the relative contribution of runoff from fresh dung can vary widely and needs to be assessed for accurate models. Erosion rates of dung in simulated rain have not been conducted for wild ungulates but should be to determine if they differ from cow dung.

8. Of the dung material washed directly from dung, at least half was retained by soils in five different plant formations at mean rainfall erosivities of 5 to 12. Although the percent of bare soil in the watershed predicted the amount of total dung phosphorus retained by soils ($R^2 = 0.91$), neither total volatile solids ($R^2 = 0.01$) nor

total nitrogen ($R^2 = 0.01$) behaved similarly. This finding may indicate that no general mobilization model will be suitable for all. To understand their runoff better, dissolved and particulate (organic and inorganic) fractions will have to be determined in further studies over dry and saturated surfaces, with particular reference to soil qualities such as particle size and organic matter and very accurate estimates of the amount of bare soil surface.

9. The percent bare area in watersheds artificially rained on (0.85 m^2 plots) was a much better predictor ($R^2 = 0.93$) of the fraction of the rain that ran off than was slope ($R^2 = 0.22$). Percent bare area also predicted the export of volatile solids ($R^2 = 0.88$), total solids ($R^2 = 0.75$), and phosphorus ($R^2 = 0.54$) moderately to very well, but not nitrogen ($R^2 = 0.02$). This result indicates the relatively great impact that the percentage of vegetational ground cover has on erosion of surface materials, but other factors, such as the relative ratios and forms of phosphorus and nitrogen in the soil and litter, also contribute substantially to predictions of nutrient runoff.

10. Although mean annual rainfall was a good ($R^2 = 0.96$) predictor of the percentage of volatile solids in the soil, it was not a good predictor of the percentage in the runoff ($R^2 = 0.30$). The fractions of volatile solids measured in the runoff were up to 8.4 times that found in the soil in the drier landscapes, indicating that superficial litter contributed more than predicted by fraction in a soil sample 15-cm deep. Neither the percentage of nitrogen

nor phosphorus in the runoff was predicted by precipitation. Apparently the concentration of organic matter and nutrient in the erodable surface is different from subsurface concentrations and behaves differently than total solids when soil is eroded by overland flow. Pilot studies indicate that phosphorus on bare surface soils is more concentrated than in subsurface soils pooled from entire natural watersheds, organic matter is similar in bare surface and subsurface soils from the whole watershed, and nitrogen is less concentrated in bare surface soil than elsewhere. In runoff studies, phosphorus concentrations always were higher than predicted by soil concentrations (15-cm deep) but nitrogen was variable, sometimes higher and sometimes lower than predicted by soil concentrations. Experiments with dung on bare soil indicated that volatile solids concentrated on the surface. Refinement of models predicting nutrient erosion will require more information on the amounts of nutrient in erodable surfaces. The available general information on subsurface soils appears to be inadequate.

11. The Universal Soil Loss Equation was not designed to predict erosion of soil (total solids) from short intervals of time or small plots, but the equation reasonably predicted mean soil runoff from infiltrometer plots on creosote formation and underestimated runoff in other ecosystems by up to an order of magnitude. Because the amount of bare soil area is one of the most effective factors in the model, we believe that a tendency to underestimate it in areas with higher amounts of vegetation is a possible explanation for our underestimation of predicted erosion. Variability associated with soil moisture also may have contributed.

Predictions based on runoff from natural watersheds over three storms and rainfall erosivity totalling about 60 were much more accurate, perhaps because the variations in soil moisture becomes less of a factor as the rainfall erosivity accumulates.

12. Vertical movement of dung volatile solids in a disturbed sandy loam was low, most of it remaining in the upper-most cm of soil. Observations of phosphorus movement were inconclusive because of low quantities diluted by the soil. Because the extent to which dung materials penetrate below an erodable surface could greatly influence the export rate, the relationship between soil permeability, particle size, organic matter and gross structure and vertical movement of dung material needs further research attention.

13. Cow dung distribution on bare and vegetated parts of the watershed was variable, but the mean fraction of dung deposited on bare soil over a variety of sites was about 25 percent greater on bare area than predicted by the fraction of the bare area in watersheds. Deer appeared to be even more likely to deposit dung on bare soil (50 percent more on bare area), but it is also easier to miss deer dung deposited on ground cover. Cattle tended to avoid the steepest slopes while Mule Deer concentrated on the highest ridges. Because slope and the amount of bare soil surface greatly influence the rate soil and dung erodes, the extent to which ungulates deviate from random deposition is important. This area of knowledge requires further refinement to develop better models of ungulate distributions.

14. Mobilization of dung in natural watersheds indicates that dung matter deposited on the soil surface may be moved out of watersheds much more effectively than if it behaved like soil particles. Old dung nutrients in watersheds were mobilized at a rate faster than predicted by infiltrometer studies of the mobilization of fresh dung. This difference is caused by two factors: (1) first a soil-water saturation factor, and (2) a floatation factor associated with dung matter equal to or less dense than water. The predicted amounts of mobilization of old, dry dung volatile solids, phosphorus, and nitrogen were 5.31, 2.65, and 18.6 times what would occur from fresh dung on a smooth, impermeable surface. These multipliers provide a first-cut estimate of a "floatation" coefficient, which may be applied to the Universal Soil Loss Equation to predict dung mobilization. Because the fraction of old dung mobilized by natural rains was more than the fraction found on bare soils, some dung on vegetation and litter also was moved by floatation.

Deer dung was 34 percent more erodable (as measured by fraction which disappeared) than cow dung. Presumably, deer dung floated or rolled more readily because of its smaller size and spherical shape, even though its dried density tended to be heavier than cow dung (0.90 versus 0.75). Estimates of multipliers for deer dung would be 7.14 for volatile solids, 3.57 for phosphorus, and 25.0 for nitrogen, if deer dung otherwise behaves like cow dung. However, knowledge of drying rates and resistance to direct erosion of deer dung pellets have not yet been assessed. Further study of the behavior of dried dung on dry and saturated soils in natural and artificial rain is needed to refine floatation coefficients.

15. Based on studies of permanent stream flows that receive natural arroyo runoff from the study area in Sixteen Springs Canyon, arroyo contribution to base flows is a particularly important contributor of dissolved phosphorus and particulate solids, including particulate nitrogen and phosphorus. Dissolved phosphorus appeared to become associated with particulates in the river. Therefore, most nutrient in the river may remain unavailable, either sorbed to or an integral part of particulates carried in suspension until decay and environmental changes in downstream reaches or reservoirs releases it for potential plant uptake.

16. In creosote and ponderosa pine dominated watersheds, ratios of total nitrogen to total phosphorus were 1.5 and 7.2 and the ratio of dissolved inorganic nitrogen to dissolved phosphorus in ponderosa pine was 0.7. For infiltrometer studies, ratios of total nitrogen to phosphorus in the watershed were: creosote, 3.8; desert grass, 0.40; pinyon-juniper, 3.05; and mixed-conifer, 13.75. These ratios suggest that the probability of nitrogen-limited primary production in aquatic systems increases with increasing aridity, but even at higher elevations the immediate availability of dissolved phosphorus was high compared to dissolved nitrogen. Such ratios favor development of blue green algae that can use atmospheric nitrogen. Because ratios of nitrogen to phosphorus in fresh dung are high, about 13:1, fresh dung may help to relieve the limitation of nitrogen. But the concentration in old dung is close to 3-4:1. If most dung is old when it reaches water, it may foster nitrogen limited algal associations.

17. Oxygen demand of fresh cow dung in water at 18°C was higher than older deer dung or old cow dung during the first five days, but after initial exposure of a few days, the oxygen demand rates of dung of all ages was similar, and the demand of organic litter (leaves and needles) was only slightly less. For the most part, oxygen demand of organic matter in all forms, treated separately, was about the same after it had aged in water for several days.

Mixtures of fresh cow dung and soil generated an oxygen demand five times that of any of the materials treated separately at higher oxygen levels. Similar mixtures of dung and pine needles had slightly reduced oxidation rates. At lower oxygen levels and smaller fractions of fresh dung, the demand rate was reduced greatly. Because most of the organic matter entering streams and reservoirs in our study areas could be explained by concentrations in the soils alone, stimulation of oxidation caused by a smaller fraction of dung organic matter in the soil could increase oxidation rates disproportionately above what they would be if soil alone was eroded. These results need to be augmented and clarified with further studies of interactions between fresh and old dung, soils, and litter examined for a variety of soil conditions.

18. The amounts of orthophosphate generated by dung and watershed materials were related to the oxidation rate and to the lowest level of oxygen reached in the tests, suggesting the importance of decomposition and, possibly, a changed redox potential. The relative contribution from changes in redox potential was not assessed. Most

phosphorus moved into the water within 16 days and rate of mobilization declined later. Mixtures of soil and a small fraction of cow dung generated up to two times the phosphorus expected from mobilization out of the two materials alone. Mobilization from mixtures of fresh cow dung and pine needles were depressed by up to three times. More research on interactive effects of dung and watershed materials (particularly the interaction with old dung) from a variety of sites is needed to estimate the general impact of mixing on nutrient availability for primary producers in downstream environments.

19. Enough data exists from these and other studies to develop a preliminary set of reference tables from which the relative impact of dung mobilization on oxygen concentration and phosphorus generation may be estimated for hypolimnia in small reservoirs. A series of such tables are developed in the discussion with the caveat of more intense study of coefficients. The reference tables, and models used to construct the tables, are based on data of varying accuracy and precision. The reference tables illustrate relationships between or among: (1) forage availability, stocking schedules, and dung deposition rate; (2) ground cover and fraction of plant production in suitable forage; (3) dung mobilization and soil mobilization; (4) dung deposition and the amount of dung nutrient deposited; (5) timing of rainfall and grazing; (6) the amounts of nutrient eroded with soil and the fraction eroded as dung material from the watershed; (7) erosion rates of soil and dung materials and the oxygen demand exerted in a hypolimnion; and (8) phosphorus loading into a reservoir and the potential availability of phosphorus for plant uptake.

These models can serve as a preliminary base for further research clarification.

20. Preliminary assessment indicates that under advised and exploitive grazing schedules, the effect of dung on oxygen and nutrient dynamics is likely to be greatest where more fresh dung is eroded into downstream reaches, generally at the highest elevations. At lower elevations, the amounts of nutrient eroded from watersheds is predicted to be high enough to deoxygenate hypolimnia without livestock being present. The small effect of ungulates in the lowest elevations appear to be inconsequential even if they were allowed to severely overgraze. Overgrazing in southern New Mexico would contribute mostly to deteriorated water quality in reservoirs located at higher elevations.

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APPENDIX TABLES AND FIGURES

Table A-1. Comparison of samples (mg/liter) processed by the New Mexico Environmental Improvement Division (EID) and the Water and Soils Testing Laboratory (WSTL) at New Mexico State University. Samples were collected separately but simultaneously during runoff events at Sixteen-Springs Canyon.

Date	Watershed	Time	Phosphorus		Total Kjeldahl		Ammonia Nitrogen		Nitrite-Nitrate Nitrogen	
			Persulfate	Hydrolizable	EID	WSTL	EID	WSTL	EID	WSTL
8-8-79	1	1316	1.03	0.88	8.04	9.65	0.17	0.17	0.14	0.15
8-8-79	10	1335	1.02	0.29	6.78	9.73	0.20	0.17	0.07	0.13
8-8-79	11	1338	0.92	0.78	8.09	5.52	0.36	0.17	0.06	0.12
8-8-79	8	1341	1.45	1.10	8.47	10.65	0.12	0.20	0.08	0.15
8-8-79	9	1355	1.98	0.75	10.64	6.74	0.25	0.30	0.08	0.14
8-10-79	2	1440	1.51	0.45	16.02	7.22	0.23	0.22	0.22	0.02
8-10-79	6	1450	--	1.31	7.55	6.48	0.22	0.23	0.15	0.18
8-10-79	11	1500	1.39	0.40	9.11	8.19	0.06	0.19	0.17	0.09
8-10-79	9	1501	2.25	1.10	11.78	3.42	0.05	0.20	0.19	0.20
8-10-79	10	1505	1.23	0.44	3.64	5.58	0.35	0.20	0.35	0.18
8-10-79	8	1521	1.63	1.38	7.55	7.20	0.04	0.23	0.15	0.20
Mean			1.44	0.80	8.88	7.30	0.19	0.21	0.15	0.16
Standard Deviation			±0.42	±0.38	±3.15	±2.13	±0.11	±0.04	±0.08	±0.05

Table A-2. Ratio of hydrolizable phosphorus and persulfate-digested phosphorus determined in runoff from infiltrometer studies in three plant formations of south-central New Mexico.

	Mean ± S.D.	n
Ponderosa Pine	0.72±0.23	20
Pinyon-Juniper	0.38±0.20	26
Desert Grasses	0.62±0.11	26
Mean	0.57	

Table A-3. Comparisons of phosphorus concentrations measured as orthophosphate, total hydrolizable phosphorus, and total persulfate phosphorus (mg kg^{-1}).

Source of Material	n	1 Orthophosphate Phosphorus	1–2 Polyphosphate Phosphorus (some organic)	2 Total Hydrolizable Phosphorus	2–3 Estimated Residual Phosphorus	3 Total Persulfate Phosphorus	Ratio of Hydrolizable to Persulfate
Soil							
Watersheds at Sixteen Springs Canyon							
Upper Slopes	2	0.24	17.76	18.0	30.7	48.7	0.37
Lower Slopes	2	0.12	13.71	13.9	15.4	29.3	0.47
Creosote	2	1.39	129.41	130.8	195.7	326.5	0.40
Desert Grass	2	0.01	6.39	6.4	11.6	18.0	0.36
Pinyon–Juniper	2	0.18	37.92	38.1	9.8	47.9	0.80
Ponderosa Pine	2	1.09	114.31	115.4	30.0	145.4	0.79
Mixed–Conifer	2	0.91	103.29	104.2	44.6	148.8	0.70
Dung							
Old Cow Dung	3	17.20	168.80	186.0	47.3	233.3	0.80
Old Deer Dung	3	32.60	185.20	217.8	68.3	286.1	0.76
Litter							
Mixed–Conifer	2	12.00	130.40	142.4	91.8	234.2	0.61
Ponderosa Pine	2	10.00	80.50	90.5	126.5	217.0	0.41
							mean ratio = 0.61

Table B-4. Rain-gauge measurements of precipitation (mm) in monitored watersheds of Sixteen-Springs Canyon (Lincoln National Forest). A dash indicates not checked and totals were estimated only for watershed with complete records. An asterisk indicates that the total may have been slightly underestimated by measurement before total completion.

Date	Drainage									
	1	2	3	4&5	6	7	8	9	11	12
7/24/79	1	1	1	1	0	0	0	0	7	0
7/26/79	1	1	2	1	1	1	2	3	3	3
7/27/79	1	1	1	1	1	1	1	1	1	1
7/30/79	6	8	11	8	5	8	12	12	13	17
8/1/79	1	1	1	1	1	1	1	1	1	1
8/2/79	2	--	--	--	--	--	--	13	--	--
8/5/79	8	18	18	18	13	20	16	3	12	13
8/7/79	32	36	41	29	34	45	56	57	60	53
8/8/79	17	6	6	--	--	--	27	32	30	28
8/9/79	13	0	0	0	0	0	0	0	0	0
8/10/79	--	42	--	--	43	--	46	51	48	45
8/11/79	27	25	43	40	36	55	55	56	51	53
8/12/79	4	4	4	5	4	8	7	5	4	4
8/13/79	70	65	51*	--	--	64	62	56	50*	51*
Total	--	208	--	--	--	--	285	290	280	269
Estimated Rainfall Erosivity (R)		95.8					134.7	140.1	128.7	126.8

Table B-5. Precipitation (cm) estimated for monitored runoff events in watersheds of Sixteen Springs Canyon (Lincoln National Forest).

Station	DATE 8-2-79	8-8-79	8-10-79	8-13-79
1		1.7		7.0
2			4.2	6.5
3				5.1
4				
6			4.3	
8		2.7	4.6	6.4
9	1.3	3.2	5.1	6.2
10[1]		3.0	4.8	5.6
11		2.8	4.5	5.0[2]
12				5.1[2]
Mean	1.3	2.5	4.5	5.9

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[1] Estimated from mean of adjacent watersheds.

[2] Underestimated slightly; last measured just before rain ceased.

Table B-6. Estimated Rainfall Erosivity Index for summer storms that occurred in watersheds of Sixteen Springs Canyon in July-August 1979. Estimates for watershed 10 were made by averaging measurements made in adjacent watersheds.

Date	2	8	9	10	11	12
August 13	35.0	33.5	30.2	28.6	27.0	27.4
August 11	13.4	29.7	30.2	28.9	27.6	28.5
August 10	15.9	17.4	19.3	18.7	18.2	17.0
August 8	2.2	10.2	12.1	12.0	11.3	10.6
August 7	19.3	30.2	33.7	33.1	32.4	28.5
August 2-5	5.3	7.0	7.7	6.2	4.8	5.3
July 30	4.3	6.4	6.9	7.0	7.0	9.1
TOTAL	95.8	134.7	140.1	134.8	128.7	126.8

Table B-7. Estimated maximum rainfall erosivity in single storm events occurring in different plant formations of southern New Mexico based on mean weather records of 20 years or more for 24-h rain accumulation and the calculated relationship between durations and intensity of rain (from U.S.W.S.).

Plant Community	Number of Sites	Typical Annual Precipitation (mm)	Mean Maximum Recorded Precipitation in 24 h (mm)	Calculated Maximum Precipitation Per 30 Minutes (Intensity) (mm)	Mean Maximum Storm Erosivity Index R	"Typical" Annual Erosivity Index (All Storms In a Year)
Creosote	10	150-250	78.2±21.3	62.4	15.3	20
Desert Grass	4	250-350	90.9±29.5	72.6	18.4	40
Pinyon-Juniper	7	350-450	87.1±19.6	69.6	17.3	60
Ponderosa Pine	6	450-550	76.2±25.4	60.9	14.9	80
Mixed-Conifer	3	550-650	91.9±5.8	73.4	18.6	100

Table B-8. Mean numbers of rainfalls at weather stations arranged by elevation and plant formation from July 1 - September 30, 1978-1981.

Station	Elevation	Plant Formation	Mean Number of Storms			
			2.5-12.7mm	12.7-25.4mm	Over 25.4mm	Total
Oregrande	4175	Creosote	4.75	1.33	0.41	6.49
Alamogordo	4350	Creosote	5.61	1.72	0.53	7.86
Carrizozo	5438	Desert Grass	4.67	1.08	0.33	6.08
Elk	5700	Pinyon-Juniper	6.94	2.55	1.27	10.76
Capitan	6475	Pinyon-Juniper	7.16	2.25	0.58	9.99
Corona	6500	Pinyon-Juniper	5.61	1.30	0.25	7.16
Grand Quivera	6600	Pinyon-Juniper	5.33	2.08	0.42	7.83
Ruidoso	6852	Ponderosa Pine	8.08	2.75	0.58	11.41
Cloudcroft	8827	Mixed-Conifer	9.55	2.77	1.11	13.43

Table C-9. Percentage of total residue occurring in volatile solids, phosphorus, and nitrogen in dung exposed for varying lengths of time under clear and opaque canopies from January 26 to February 27, 1980 in the creosote community at Las Cruces, New Mexico.

	Phosphorus	Nitrogen	Volatile Solids
Initial	0.123±0.025	2.02±0.25	78.48±0.94
1 Day			
Sun	0.115±0.007	2.61±0.212	77.95±4.87
Shade	0.125±0.049	2.74±0.891	78.75±0.64
4 Days			
Sun	0.245±0.021	2.81±0.947	79.1±0.29
Shade	0.200±0.014	2.22±1.364	81.6±1.20
8 Days			
Sun	0.235±0.021	2.34±1.48	79.1±0.29
Shade	0.265±0.021	2.12±1.08	78.7±0.07
16 Days			
Sun	0.250±0.042	3.22±0.36	79.5±0.92
Shade	0.315±0.106	2.09±2.31	78.7±0.29
32 Days			
Sun	0.370±0.071	1.84±0.03	76.9±1.06
Shade	0.155±0.210	0.75±0.38	77.8±0.85

Table C-10. Material retained (percent of initial dung content) in cow dung exposed under clear and opaque plastic canopies during September 1980 in creosote community at Las Cruces, New Mexico.

Exposure Time	Total Weight	Water Weight	Dry Weight	Hydrolizable Phosphorus Weight	Nitrogen Weight	Volatile Solids Weight
1 Day						
Light	70.8±2.8	64.9±1.9	91.7±6.1	92.0±3.3	57.5±12.0	93.0±7.1
Shade	82.6±0.1	80.0±0.8	92.3±1.8	109.0±19.8	43.5±12.0	91.5±0.7
2 Days						
Light	55.0±4.2	47.3±4.6	82.5±2.8	74.0±9.9	52.5±4.9	82.0±5.7
Shade	62.0±1.4	54.5±4.0	84.6±8.1	88.0±27.6	40.5±0.7	85.0±9.9
6 Days						
Light	38.0±2.1	26.5±2.5	78.6±0.8	109.0±33.3	51.0±1.4	79.0±5.7
Shade	47.9±0.2	36.8±0.7	87.2±3.3	104.0±26.2	38.5±3.5	87.5±4.9
12 Days						
Light	26.7±1.6	12.1±2.2	78.7±0.2	28.0±2.8	42.5±2.1	78.5±0.7
Shade	37.0±1.8	23.5±2.1	84.6±0.6	111.0±15.6	40.0±11.3	82.0±5.7

Table C-11. Changes in concentration of nutrient material (percent) in dung of different ages as a consequence of artificial rain in January 1980 in the creosote community at Las Cruces, New Mexico (mean ± standard deviation).

	Phosphorus		Nitrogen		Volatile Solids	
Age/Light	Before	After	Before	After	Before	After
0 Days						
Light	0.13±0.02	0.13±0.09	1.86±0.00	3.20±0.09	77.9±0.78	81.0±0.28
Shade	0.11±0.03	0.18±0.04	2.17±0.39	3.35±0.23	79.1±0.71	81.2±3.04
1 Day						
Light	0.11±0.01	0.21±0.01	2.61±0.21	3.50±0.20	78.0±4.87	79.9±0.07
Shade	0.12±0.05	0.21±0.03	2.74±0.89	3.30±0.66	78.7±0.71	79.1±0.85
4 Days						
Light	0.25±0.02	0.22±0.03	2.81±0.94	1.12±0.04	79.1±0.28	79.7±0.63
Shade	0.20±0.01	0.31±0.00	2.22±1.36	3.44±0.10	81.6±1.20	81.5±1.69
8 Days						
Light	0.23±0.02	0.19±0.01	2.34±1.47	1.79±1.19	79.1±0.28	79.0±1.27
Shade	0.26±0.02	0.27±0.09	2.12±1.07	2.33±1.73	78.7±0.07	79.3±0.85
16 Days						
Light	0.25±0.04	0.22±0.08	3.48±--	2.45±0.74	79.4±0.84	77.5±1.69
Shade	0.22±0.23	0.23±0.01	2.09±2.31	1.34±1.06	78.7±0.28	80.0±0.57
32 Days						
Light	0.25±0.23	0.37±0.11	1.84±0.02	0.75±0.34	76.1±--	78.4±1.18
Shade	0.21±0.15	0.35±0.00	0.75±0.38	0.95±0.74	77.8±0.84	78.3±0.63

Table C-12. Percent phosphorus, nitrogen, and volatile solids in dung of different ages before and after exposure to artificial rain (1.8–2.6 cm) equivalent to Rainfall Erosivities between 5.4 and 7.9. Dung pats were exposed to weather but protected from natural rain under clear and opaque canopies in September 1980 in the creosote community at Las Cruces, New Mexico (mean ± standard deviation).

Age and Light Condition	Hydrolizable Phosphorus		Non-Gaseous Nitrogen		Total Volatile Solids	
	Before	After	Before	After	Before	After
0 Days						
Light	0.16±0.01	0.17±0.00	1.51±0.38	3.05±0.45	71.80±0.28	71.35±0.35
Shade	0.16±0.01	0.19±0.01	2.27±0.55	2.44±1.40	71.85±0.50	70.75±1.20
1 Day						
Light	0.16±0.02	0.15±0.04	1.00±0.01	0.85±0.04	72.65±0.64	73.60±0.71
Shade	0.19±0.04	0.27±0.04	1.03±0.07	1.20±0.05	71.45±1.63	73.00±0.28
3 Days						
Light	0.18±0.03	0.17±0.01	1.03±0.09	0.92±0.13	71.40±2.40	71.95±2.05
Shade	0.16±0.04	0.14±0.08	1.08±0.18	0.94±0.07	72.25±0.64	73.65±2.05
6 Days						
Light	0.22±0.08	0.18±0.08	1.08±0.17	0.84±0.47	70.52±2.28	73.30±1.27
Shade	0.19±0.06	0.17±0.01	0.99±0.18	1.00±0.09	71.95±1.63	73.70±2.12
12 Days						
Light	0.06±0.01	0.16±0.02	0.87±0.07	0.50±0.28	71.42±0.73	73.90±0.42
Shade	0.21±0.04	0.29±0.10	1.05±0.06	0.78±0.25	69.50±3.54	71.75±2.90

Table C-13. Estimated percentage of volatile solids and nitrogen in dung of different ages in full sun and shade based on observed changes in concentration (Tables 2 and 5) measured in the creosote community at Las Cruces, New Mexico. Phosphorus is assumed to remain constant.

	Volatile Solids		Nitrogen	
	Sun	Shade	Sun	Shade
8 Hours	0.75	0.76	3.0	4.0
1 Day	0.70	0.70	1.4	2.3
2 Days	0.67	0.67	1.2	2.0
1 Week	0.66	0.66	1.1	1.5
1 Month	0.65	0.65	1.0	1.2
6 Months	0.65	0.65	0.8	0.9
1 Year	0.65	0.65	0.8	0.8

Table C-14. Dung deposit sizes estimated from collections in ponderosa pine and pinyon-juniper sites at the Sixteen Springs Canyon watersheds, April 20, 1980.

	Number of Deposits	Mean Weight/Deposit (g) (Mean ± Stan. Dev.)
Cow		
Old Dung	10	112.0
Old Dung	9	202.0
9-Mo. Old Dung (measured age)	2	214.5
9-Mo. Old Dung (measured age)	2	173.5
Mean Dung Size		175.5±45.7
Mule Deer		
Old	1 (127 pellets)	36.0
Old	1 (93 pellets)	22.5
Old	1 (162 pellets)	44.0
Old	1 (147 pellets)	19.0
Old	1 (96 pellets)	22.0
Recent (moist)	1 (148 pellets)	36.0
Mean Dung Size		29.9±10.1

Table D-15. Total number of dung deposits of large mammals counted and percentage of total composition in watersheds at Sixteen Springs Canyon (Lincoln National Forest).

Taxa	July (transects 1-5)		August (transects 1&4)		July (transects 1&4)	
	Number	Percent	Number	Percent	Number	Percent
Deer	1557	81.4	84	55.6	567	78.8
Cow	263	13.7	46	30.4	110	15.2
Other[1]	93	4.9	21	13.9	43	6.0
	1913		151		720	

[1] Elk, horse, coyote.

Table D-16. Percent fresh (moist exterior and interior), recent (moist interior), and old (dry interior) dung in the watersheds of Sixteen Springs Canyon (Lincoln National Forest) in July and August 1979.

	Deer			Cow			Other		
Watershed	Fresh	Recent	Old	Fresh	Recent	Old	Fresh	Recent	Old
1 July	2.3	2.3	95.4	0.0	0.0	100.0	--	--	--
August	0.0	18.7	81.2	0.0	12.5	87.5			100.0
2 July	0.0	2.9	97.1	0.0	0.0	100.0			
August	0.0	11.1	88.9	0.0	25.0	75.0			
3 July	0.6	3.9	96.3	0.0	10.0	90.0	0.0	0.0	100.0
August	0.0	0.0	100.0	--	--	--			100.0
4 July		8.5	91.2			100.0	--	--	--
August	0.0	25.0	75.0	0.0	100.0	0.0			
5 July	2.9	20.1	76.0	12.5	0.0	87.5			100.0
August	0.0	22.2	77.7	--	--	--	--	--	--
6 July	0.4	1.8	87.7	11.1	0.0	88.9			100.0
August	12.5	18.7	80.0	0.0	50.0	50.0			
7 July	0.0	5.2	94.7	0.0	0.0	100.0	--	--	--
August	0.0	0.0	100.0	--	--	--	--	--	--
8 July	0.0	1.3	98.7	0.0	0.0	100.0			100.0
August	0.0	0.0	100.0	--	--	--	--	--	--
9 July	0.8	5.4	93.7	0.0	0.0	100.0	0.0	0.0	100.0
August	0.0	0.0	100.0	25.0	25.0	50.0	--	--	--

Table D-16. Continued.

Watershed	Deer			Cow			Other		
	Fresh	Recent	Old	Fresh	Recent	Old	Fresh	Recent	Old
10 July	0.0	5.0	95.0	0.0	0.0	100.0	0.0	40.0	60.0
August	0.0	0.0	100.0	20.0	0.0	80.0	--	--	--
11 July		2.2	97.8			100.0			100.0
August	--	--	--	0.0	0.0	100.0	--	--	--
12 July	0.0	0.0	100.0		10.4	89.6	0.0	0.0	100.0
August	0.0	0.0	100.0	14.3	0.0	85.7	0.0	0.0	100.0
Mean Percentage									
July	0.6	4.9	94.5	1.9	1.7	96.3	0.0	8.0	92.0
August	1.1	8.7	90.1	5.4	19.3	75.3	0.0	0.0	100.0

Table D-17. Dung deposits (no. ha^{-1}) in watersheds of Sixteen Springs Canyon in Lincoln National Forest near Cloudcroft, New Mexico in July 1979 before significant (greater than 1 mm) summer storms.

Watershed/ Species		Transect					Mean #/ha in Watershed	Total # in Watershed	Estimated Weight of All Deposits (kg/ha)	
		1 Lowest Elevation	2	3	4 Highest Elevation	5				
1	Cow	746.3	79.8	104.9	309.7	678.0	303.4	7,720.2	47.0	61.8
	Deer	663.3	937.9	230.8	123.9	169.4	494.4	11,766.2	14.8	
2	Cow	334.4	0.0	161.0	19.5	69.8	88.9	2,098.4	13.8	26.1
	Deer	557.4	279.3	257.6	389.5	558.1	409.0	9,652.6	12.3	
3	Cow	68.5	91.3	0.0	41.2	22.1	54.7	2,017.5	8.5	35.2
	Deer	228.2	479.2	919.6	989.9	905.3	891.2	32,885.2	26.7	
4	Cow	70.8	21.2	80.1	0.0	85.0	20.1	528.6	3.1	18.9
	Deer	460.3	849.9	465.5	313.1	651.7	527.6	13,876.9	15.8	
5	Cow	0.0	0.0	85.0	0.0	364.5	43.3	1,182.5	6.7	51.1
	Deer	1,360.1	722.5	913.7	1,338.7	10,328.1	1,478.1	40,351.4	44.4	
6	Cow	85.0	44.0	30.4	0.0	0.0	30.6	1,355.7	4.7	27.2
	Deer	573.7	395.1	698.2	1,244.7	828.7	751.4	33,289.0	22.5	
7	Cow	53.1	125.0	94.5	40.5	0.0	54.7	2,062.7	8.5	21.5
	Deer	159.4	325.0	566.7	364.3	498.2	399.8	15,073.7	13.0	
8	Cow	53.1	11.5	230.7	79.7	13.7	78.9	5,870.2	12.2	24.3
	Deer	79.7	264.2	291.4	929.7	521.0	404.7	30,108.4	12.1	
9	Cow	478.1	357.9	53.1	12.5	29.6	128.1	10,445.0	19.9	44.0
	Deer	159.4	626.3	354.2	750.0	1,413.5	803.1	65,532.9	24.1	
10	Cow	175.0	111.8	141.7	75.0	0.0	105.4	4,815.1	16.3	24.9
	Deer	125.0	246.0	60.7	400.0	759.0	287.4	13,134.2	8.6	
11	Cow	0.0	67.1	81.0	25.0	0.0	38.6	1,502.7	7.0	13.7
	Deer	150.0	44.7	121.4	100.0	850.0	222.1	8,640.3	6.7	
12	Cow	425.1	246.0	283.3	250.0	340.1	358.7	10,690.6	55.6	59.9
	Deer	189.0	77.3	141.7	85.0	425.2	142.0	4,231.7	4.3	

Table D-18. Change in number of dung deposits in 12 watersheds of Sixteen Springs Canyon (Lincoln National Forest) from July to August following major summer storm events with a mean Rainfall Erosivity Index of 125.2±17.3.

		1		4		Loss from July to August		Percentage Loss from July to August	
Watershed		July	August	July	August	1	4	1	4
1	Cow	746.3	331.7	309.7	123.9	-414.6	-185.8	55.5	60.0
	Deer	663.3	110.6	123.9	371.6	-552.7	-428.8	83.3	77.6
2	Cow	334.4	111.4	19.5	38.9	-223.0	+19.4	66.7	49.9
	Deer	557.4	111.4	389.5	116.8	-446.0	-272.7	80.0	70.0
3	Cow	68.5	0.0	41.2	0.0	-68.5	-41.2	100.0	100.0
	Deer	228.2	22.8	989.9	82.4	-205.4	-907.5	90.0	91.7
4	Cow	70.8	35.4	0.0	0.0	-35.4	--	50.0	--
	Deer	460.3	106.2	313.1	22.4	-354.1	-290.7	76.9	92.3
5	Cow	0.0	0.0	0.0	0.0	--	--	--	--
	Deer	1360.1	56.7	1338.9	156.6	-1303.4	-1182.3	95.8	88.3
6	Cow	85.0	85.0	0.0	0.0	0.0	0.0	0.0	--
	Deer	573.7	21.2	1244.9	227.6	-552.5	-1017.3	96.3	81.7
7	Cow	53.1	0.0	40.5	0.0	-53.1	-40.5	100.0	100.0
	Deer	159.4	26.6	364.3	20.2	-132.8	-344.1	83.3	94.5
8	Cow	53.1	0.0	79.7	0.0	-53.1	-79.7	100.0	100.0
	Deer	79.7	13.3	929.7	26.6	-66.4	-903.1	83.3	97.1
9	Cow	478.1	185.9	12.5	12.5	-292.2	0.0	61.1	0.0
	Deer	159.4	0.0	750.0	137.5	-159.4	-612.5	100.0	81.7
10	Cow	175.0	100.0	75.0	23.6	-75.0	-51.4	42.8	68.5
	Deer	125.0	25.0	400.0	188.9	-100.0	-211.1	80.0	52.7
11	Cow	25.0	0.0	0.0	25.0	25.0	25.0	100.0	100.0
	Deer	0.0	150.0	0.0	100.0	-150.0	-100.0	100.0	100.0
12	Cow	188.9	425.1	75.0	250.0	236.2	-175.0	55.6	70.0
	Deer	0.0	189.0	0.0	85.0	-189.0	-85.0	100.0	100.0
Mean ± Standard Deviation									
	Cow							66.5±31.6	72.0±33.5
	Deer							89.1±8.9	85.6±13.9

Table D-19. Estimated amounts of nutrients in dung (g/ha) in watersheds of Sixteen Springs Canyon Lincoln National Forest) in July and decline following major summer storms with a mean Rainfall Erosivity Index of 125.2.

Watershed	Total Hydrolizable Phosphorus	Amount of Decline	Total Nitrogen	Amount of Decline	Total Organic Matter	Amount of Decline	Percent Decline
1 Cow	47.0	27.2	1,034.0	597.6	33,652.0	19,451.0	57.8
Deer	11.8	9.5	266.4	214.5	10,626.0	8,553.0	80.5
Total	58.8	36.7	1,060.4	512.1	44,278.0	28,004.0	
2 Cow	13.8	8.1	303.6	177.9	9,880.0	5,760.0	58.3
Deer	9.8	7.3	221.4	166.1	8,832.0	6,623.0	75.0
Total	23.6	15.4	525.0	344.0	18,711.0	12,383.0	
3 Cow	8.5	8.5	107.0	187.0	6,089.0	6,089.0	100.0
Deer	21.4	19.4	480.6	436.4	17,358.0	15,761.1	90.8
Total	29.9	27.9	667.6	623.4	25,206.0	23,447.0	
4 Cow	8.1	1.6	68.2	34.1	2,219.0	1,110.0	50.0
Deer	12.6	10.7	347.6	294.1	11,313.0	9,571.0	84.6
Total	15.7	12.3	415.8	328.2	13,532.0	10,681.0	
5 Cow	0.0	--	0.0	--	0.0	--	--
Deer	35.5	32.7	804.6	741.0	31,790.0	29,279.0	92.1
Total	35.5	32.7	804.6	741.0	31,790.0	29,279.0	
6 Cow	4.7	0.0	103.6	0.0	3,365.0	0.0	0.0
Deer	18.0	16.1	405.0	360.5	16,110.0	14,338.0	89.0
Total	22.7	16.1	508.6	360.5	19,475.0	14,338.0	
7 Cow	8.5	8.5	18.7	18.7	6,086.0	6,086.0	100.0
Deer	10.4	9.3	234.0	208.0	9,308.0	8,338.2	88.9
Total	18.9	17.8	252.7	226.7	15,394.0	14,424.2	

Table D-19. Continued.

Watershed		Total Hydrolizable Phosphorus	Amount of Decline	Total Nitrogen	Amount of Decline	Total Organic Matter	Amount of Decline	Percent Decline
8	Cow	12.2	12.2	268.8	268.8	8,753.2	8,753.2	100.0
	Deer	9.7	9.0	218.5	202.5	10,536.6	9.767.4	92.7
	Total	21.9	21.9	487.3	471.3	19,189.8	18,520.6	
9	Cow	19.9	6.7	436.7	133.2	14,218.6	4,336.7	30.5
	Deer	19.3	18.1	436.0	396.3	20,907.7	19,005.1	90.1
	Total	39.2	24.8	872.7	529.5	35,126.3	23,341.8	
10	Cow	16.4	9.1	359.3	200.1	11,697.2	6,515.2	55.7
	Deer	6.9	4.6	156.0	103.4	7,481.3	4,960.1	66.3
	Total	23.3	13.7	515.3	303.5	19,178.5	11,475.4	
11	Cow	7.0	7.0	1,541.0	154.0	5,012.0	5,012.0	100.0
	Deer	5.4	5.4	120.6	120.6	4,797.0	4,797.0	100.0
	Total	12.4	12.4	1,661.6	274.6	9,809.0	9,809.0	
12	Cow	55.6	34.9	1,223.2	768.2	39,809.0	25,000.0	62.8
	Deer	3.4	3.4	77.4	77.4	3,078.0	3,078.0	100.0
	Total	59.0	38.3	1,300.7	845.6	42,887.0	28,078.0	

Table D-20. Dung artificially set in June 1981 in plant formations of south-central New Mexico on low (8-15 percent), moderate (20-30 percent), and high (30-50 percent) slopes and checked for movement and disappearance.

Date Checked	Location	Fraction of Dung Deposits Moved		Fraction of Deposits Gone		Slope
		Deer	Cow	Deer	Cow	
7/15/81	Desert Grasses	0%	0%	5%	0%	low
7/15/81	Desert Grasses	0%	0%	5%	0%	moderate
7/15/81	Desert Grasses	0%	0%	5%	0%	high
7/15/81	Mixed-Conifer	20%	0%	12%	0%	low
7/15/81	Mixed-Conifer	80%	0%	30%	0%	moderate
7/15/81	Mixed-Conifer	100%	0%	24%	0%	high
7/15/81	Ponderosa Pine	0%	0%	17%	0%	low
7/15/81	Ponderosa Pine	80%	0%	33%	0%	moderate
7/15/81	Ponderosa Pine	100%	0%	52%	0%	high
7/15/81	Pinyon-Juniper	100%	0%	56%	0%	low
7/15/81	Pinyon-Juniper	100%	0%	58%	0%	moderate
7/15/81	Pinyon-Juniper	100%	20%	78%	0%	high
10/27/81	Desert Grasses	100%	0%	46%	0%	low
10/27/81	Desert Grasses	100%	0%	42%	0%	moderate
10/27/81	Desert Grasses	100%	0%	10%	0%	high
10/27/81	Mixed-Conifer	100%	100%	33%	0%	low
10/27/81	Mixed-Conifer	100%	100%	46%	20%	moderate
10/27/81	Mixed-Conifer	100%	100%	54%	0%	high
10/27/81	Ponderosa Pine	100%	0%	50%	0%	low
10/27/81	Ponderosa Pine	100%	0%	50%	0%	moderate
10/27/81	Ponderosa Pine	100%	80%	91%	0%	high
10/27/81	Pinyon-Juniper	100%	0%	97%	0%	low
10/27/81	Pinyon-Juniper	100%	0%	66%	0%	moderate
10/27/81	Pinyon-Juniper	100%	20%	99%	0%	high

Table D-21. Dung set out in June 1980 and checked at dates indicated in plant formations of south-central New Mexico on low (10-15 percent), moderate (20-30 percent), and high (35-50 percent) slope.

Date	Location Weir and Biome	Fraction of Dung Moved		Fraction of Dung Gone		Slope
		Deer	Cow	Deer	Cow	
1/5/81	#3 Pinyon-Juniper	100%	0%	20%	0%	low
1/5/81	#3 Pinyon-Juniper	100%	0%	20%	0%	moderate
1/5/81	#3 Pinyon-Juniper	100%	0%	20%	0%	high
6/25/81	#3 Pinyon-Juniper	100%	40%	55%	20%	low
6/25/81	#3 Pinyon-Juniper	100%	20%	38%	0%	moderate
6/25/81	#3 Pinyon-Juniper	100%	60%	44%	0%	high
1/5/81	#4 Pinyon-Juniper	100%	20%	10%	0%	low
1/5/81	#4 Pinyon-Juniper	100%	20%	38%	0%	moderate
1/5/81	#4 Pinyon-Juniper	100%	0%	28%	0%	high
6/25/81	#4 Pinyon-Juniper	100%	80%	64%	45%	low
6/25/81	#4 Pinyon-Juniper	100%	60%	52%	20%	moderate
6/25/81	#4 Pinyon-Juniper	100%	20%	54%	0%	high
1/5/81	#2 Mixed-Conifer	100%	75%	35%	0%	low
1/5/81	#2 Mixed-Conifer	100%	80%	24%	0%	moderate
1/5/81	#2 Mixed-Conifer	100%	20%	20%	0%	high
6/25/81	#2 Mixed-Conifer	100%	100%	92%	60%	low
6/25/81	#2 Mixed-Conifer	100%	100%	62%	50%	moderate
6/25/81	#2 Mixed-Conifer	100%	100%	71%	48%	high

Table D-21. Continued.

Date	Location Weir and Biome	Fraction of Dung Moved		Fraction of Dung Gone		Slope
		Deer	Cow	Deer	Cow	
1/5/81	#1 Mixed-Conifer	100%	40%	40%	20%	low
1/5/81	#1 Mixed-Conifer	80%	80%	57%	40%	moderate
1/5/81	#1 Mixed-Conifer	100%	50%	70%	20%	high
6/25/81	#1 Mixed-Conifer	100%	100%	62%	30%	low
6/25/81	#1 Mixed-Conifer	100%	100%	74%	60%	moderate
6/25/81	#1 Mixed-Conifer	100%	100%	94%	75%	high

Table D-22. Mean distance (meters) of dung deposits from the main drainage channels of watersheds in Sixteen Springs Canyon compared to the mean distances halfway between the channel and the watershed perimeter along the transect.

		Transect										Transect Mean	
		1		2		3		4		5			
Watershed Number		Manure Distance	Halfway to Perimeter	Manure Distance	Halfway to Perimeter	Manure Distance	Halfway to Perimeter	Manure Distance	Halfway to Perimeter	Manure Distance	Halfway to Perimeter	Manure Distance	Halfway to Perimeter
1	deer	45	45	60	63	51	60	37	40	33	15	45.2	44.6
	cow	70		70		161		114		39		90.8	
2	deer	56	22	31	31	55	39	57	64	41	54	48.0	42.0
	cow	18		--		39		61		52		42.5	
3	deer	49	55	61	55	127	58	123	61	77	57	87.4	57.2
	cow	46		65		--		150		83		86.0	
4	deer	33	35	46	47	34	62	46	56	41	44	40.0	48.8
	cow	56		--		48		--		11		38.3	
5	deer	38	44	29	59	57	59	53	59	47	10	44.8	46.2
	cow	--		43		70		--		38		50.3	
6	deer	70	59	102	85	76	82	100	82	132	56	96.0	72.8
	cow	50		125		122		--		--		99.0	
7	deer	35	47	61	50	54	52	81	62	131	85	72.4	59.2
	cow	41		45		53		39		--		44.5	
8	deer	54	94	54	109	130	103	45	94	48	91	78.2	98.2
	cow	80		62		96		51		102		66.2	
9	deer	54	47	53	56	125	71	92	100	110	126	105.6	80.0
	cow	50		66		181		60		171		86.8	
10	deer	132	50	79	50	75	59	36	53	19	49	52.2	52.2
	cow	71		105		68		36		--		68.2	
11	deer	35	50	50	56	79	62	74	50	33	41	54.2	51.8
	cow	--		43		29		79		--		50.3	
12	deer	25	26	31	32	46	44	69	50	34	15	41.0	33.4
	cow	20		47		54		51		19		38.2	
Mean ± Standard Deviation													
	deer											60.4±28.3	57.2±18.2
	cow											63.4±22.4	

Table D-23. Summary of hydrolizable phosphorus measurements in experimental analyses of vertical movements of phosphorus.

Sample Number and Type	Upper 1 cm of Soil Profile mg P Kg^{-1}	Middle 2-3 cm of Soil Profile mg P Kg^{-1}	Bottom 4-5 cm of Soil Profile mg P Kg^{-1}	Dung Samples mg P Kg^{-1}
1 No Dung (N)	2.45	4.71	2.69	
2 With Dung (D)	4.58	5.40	3.30	6.95
3 N	3.69	2.78	2.51	
4 D	3.48	2.69	2.85	6.06
5 N	3.78	5.70	2.51	
6 D	2.54	2.78	3.69	2.22
7 N	2.37	2.94	3.03	
8 D	3.03	2.37	2.69	5.12
9 N	2.54	2.51	2.45	
10 D	3.58	2.94	4.23	4.8[illegible]
11 N	3.90	2.49	3.30	
12 D	2.51	3.11	3.58	3.58
13 N	2.78	2.88	2.51	
14 D	2.15	2.56	3.21	5.25
15 N	1.86	2.69	3.03	
16 D	2.78	2.60	3.93	4.35
No Dung	2.92±0.76	3.34±1.19	2.75±0.32	
Dung	3.08±0.77	3.06±0.97	3.43±0.53	

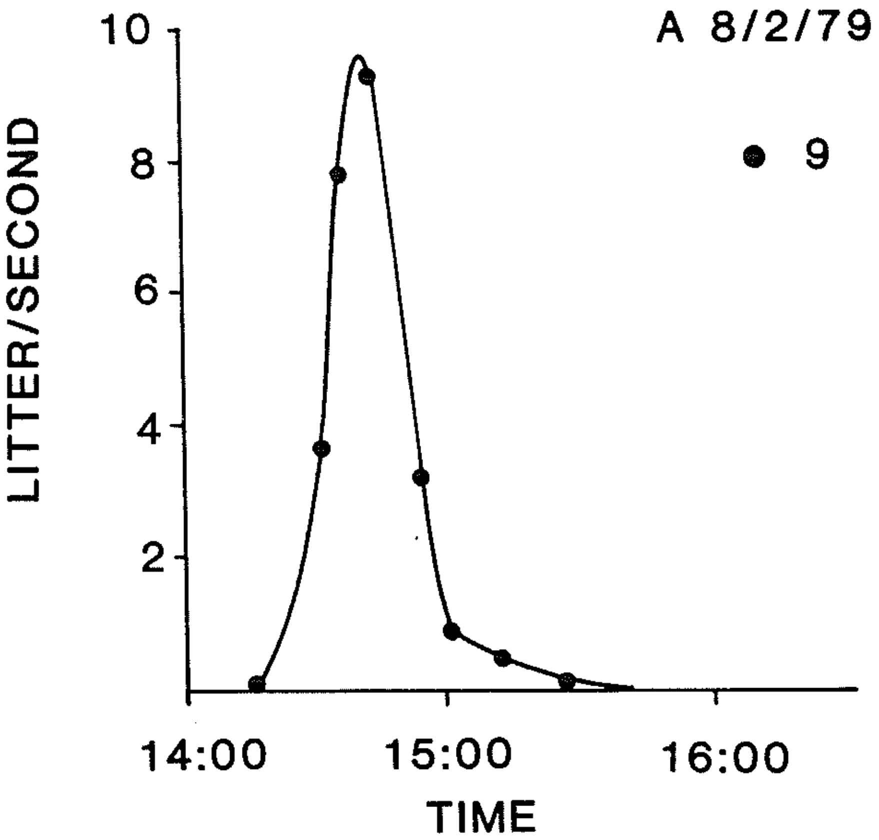

Figure E-1. Discharge curve for watershed No. 9 at Sixteen Springs Canyon on August 2, 1979.

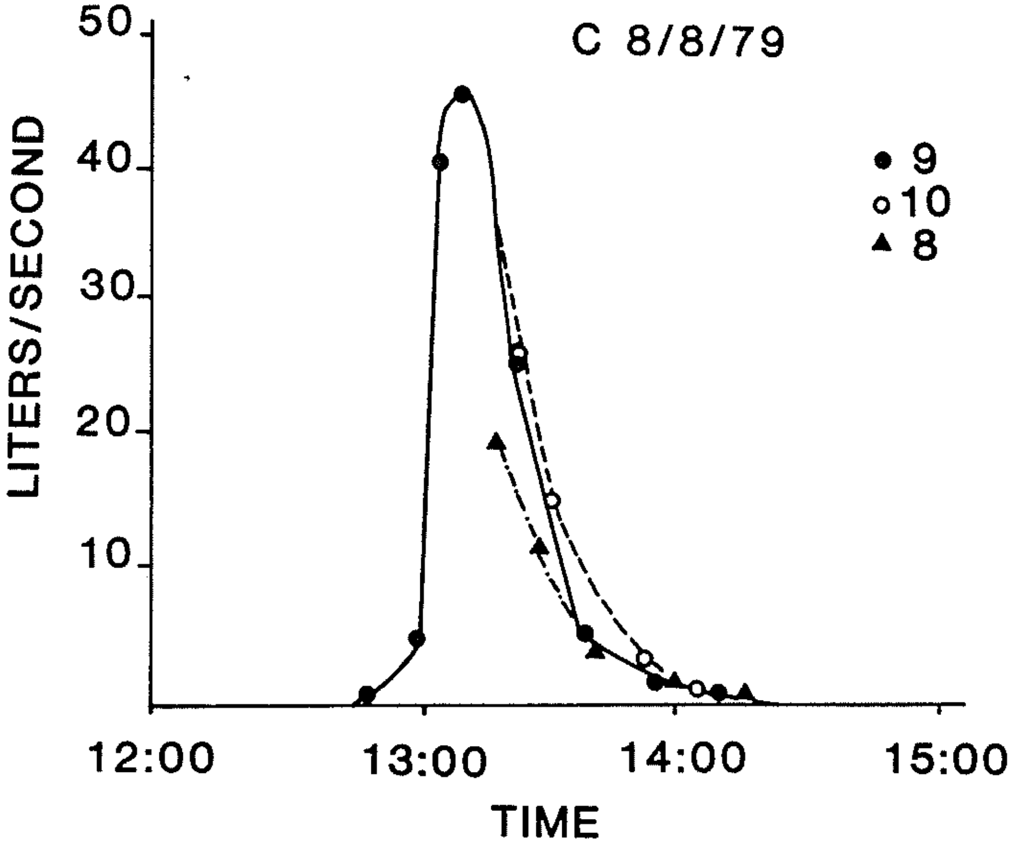

Figure E-2. Discharge curves for watersheds 8, 9, and 10 at Sixteen Springs Canyon on August 8, 1979.

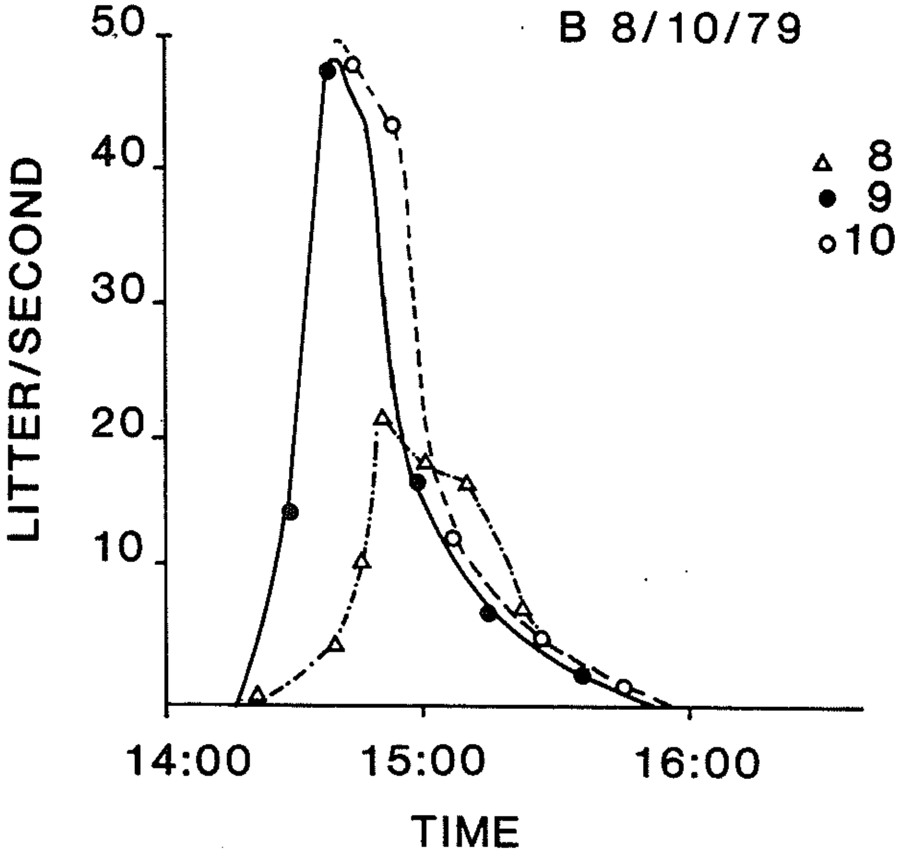

Figure E-3. Discharge curves for watersheds 8, 9, and 10 at Sixteen Springs Canyon on August 10, 1979.

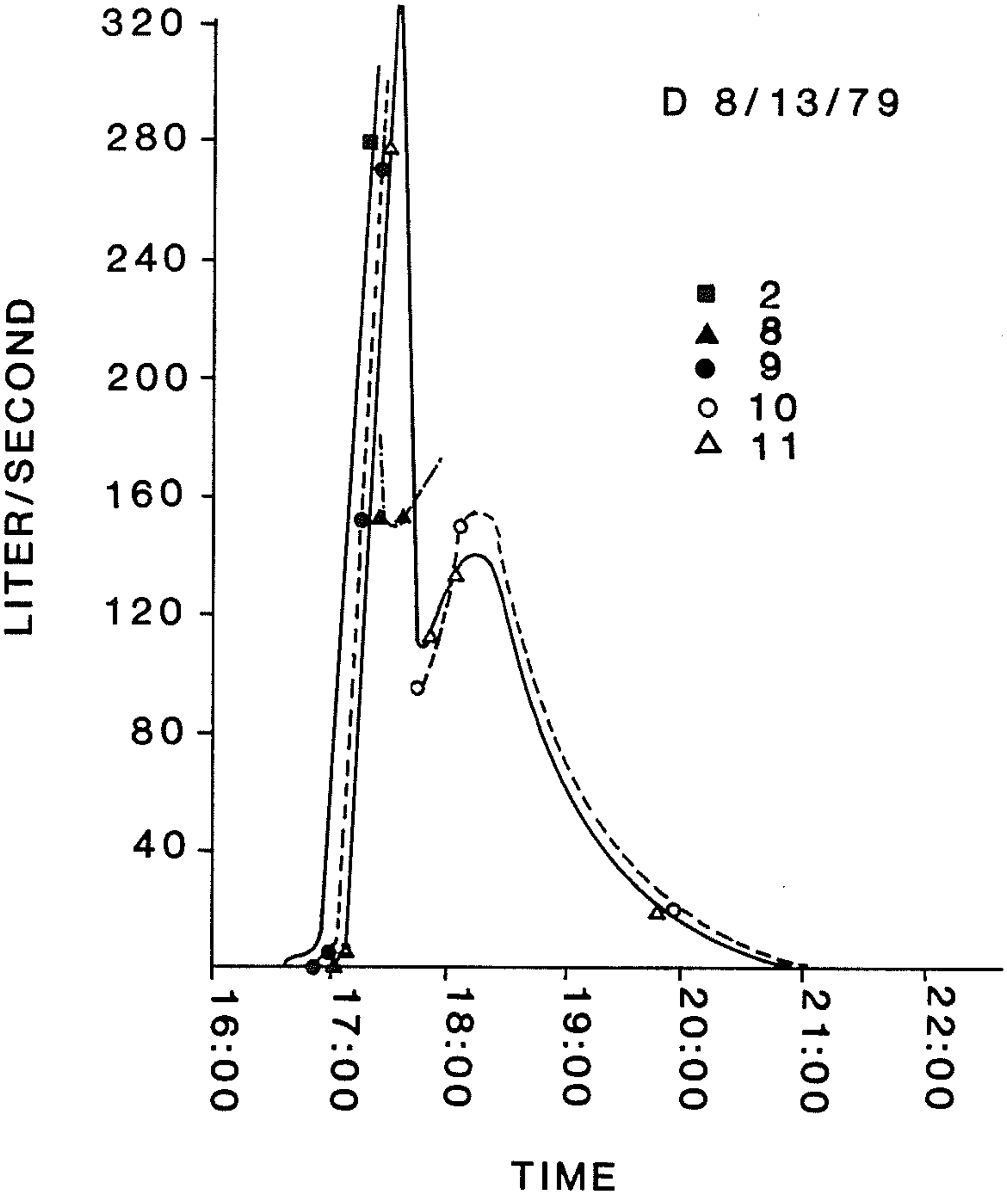

Figure E-4. Discharge curves for watersheds 2, 8, 9, 10, and 11 at Sixteen Springs Canyon on August 13, 1979.

Table E-24. Total estimated precipitation input (m^3ha^{-1}), total discharge (m^3ha^{-1}), and net percentage overland flow per hectare of watersheds monitored during storm events in Sixteen Springs Canyon (Lincoln National Forest).[1]

Watershed		DATE 8-2-79	8-8-79	8-10-79	8-13-79
2.	Rain	--	--	--	620
	Overland Flow	--	--	--	15.7
	% Overland Flow	--	--	--	2.5
4.	Rain	--	--	--	620
	Overland Flow	--	--	--	14.1
	% Overland Flow	--	--	--	2.3
8.	Rain	--	250	450	590
	Overland Flow	--	0.52	0.44	21.3
	% Overland Flow	--	0.21	0.10	3.6
9.	Rain	130	250	450	590
	Overland Flow	0.59	0.66	0.83	19.5
	% Overland Flow	0.45	0.26	0.18	3.3
10.	Rain	--	250	450	590
	Overland Flow	--	1.48	1.75	28.3
	% Overland Flow	--	0.59	0.39	4.8
11.	Rain	--	250	450	590
	Overland Flow	--	0.34	0.81	27.8
	% Overland Flow	--	0.14	0.18	4.7
12.	Rain	--	--	--	590
	Overland Flow	--	--	--	12.3
	% Overland Flow	--	--	--	2.1

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[1] All watersheds discharged on 8-13-79 but only the watersheds reported could be monitored under conditions encountered in that storm. On other dates only those watersheds measured produced a discharge.

Table E-25. Correlations between discharge and nutrient concentration for the period of declining discharge from the discharge peak to the end of flow in watersheds of Sixteen Springs Canyon (Lincoln National Forest). Number in parentheses indicates number of observations.

Station		DATE			
		8-2-79	8-8-79	8-10-79	8-13-79
8	Phosphorus		-0.89 (5)	-0.95 (3)	-0.53 (4)
	Nitrogen		-0.23	-0.99	-0.53
	Volatile Solids		+0.97	-0.59	-0.43
	Fixed solids		-0.97	-0.99	-0.57
9	Phosphorus	-0.34 (4)	-0.03 (4)	-0.99 (4)	-0.06 (4)
	Nitrogen	-0.76	-0.97	-0.96	-0.14
	Volatile solids	+0.72	-0.89	-0.95	-0.21
	Fixed solids	+0.85	-0.95	-0.99	-0.30
10	Phosphorus		-0.24 (4)	-0.99 (4)	--
	Nitrogen		-0.94	-0.86	--
	Volatile solids		-0.99	-0.88	--
	Fixed solids		-0.99	-0.98	--

Table E-26. Mean percentages of nutrients and volatile solids discharged from whole watersheds at Sixteen-Springs Canyon (see Table 1 for watershed descriptions) and from simulated rains on plots (0.84 m^2) in similar environments (ponderosa pine).

	Hydrolizable Phosphorus	Non-Gaseous Nitrogen	Volatile Solids
Watershed	.01	.13	13.2
Infiltrometer	.04	.07	17.6

Table F-27. Summary of infiltrometer studies relating to plot hydrology in the creosote community, south-central New Mexico, August 18, 1982.

Sample Number	Artificial Rain/ 30 min (cm)		Rain Total Time (fraction of hour)		Erosivity Index		Total Rain (cm)		Total Runoff (cm)		Fraction That Runs Off		Time to Runoff (fraction of hour)
	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung	
1A	10.9		.20		10.41		2.18		1.39		.74		0.06
1B		10.9		.20		10.41		2.18		1.61		.74	0.06
2A		10.9		.20		10.41		2.18		0.69		.32	0.05
2B	10.9		.20		10.41		2.18		1.27		.58		0.05
3A	10.9		.20		10.41		2.18		0.85		.27		0.03
3B		10.9		.20		10.41		2.18		1.29		.59	0.03
4A		10.9		.20		10.41		2.18		0.83		.38	0.04
4B	10.9		.20		10.41		2.18		0.93		.43		0.06
5A	10.9		.20		10.41		2.18		0.77		.35		0.05
5B		10.9		.20		10.41		2.18		1.21		.56	0.03
6A		10.9		.20		10.41		2.18		0.90		.41	0.04
6B	10.9		.20		10.41		2.18		1.11		.69		0.03
7A	10.9		.20		10.41		2.18		0.46		.21		0.03
7B		10.9		.20		10.41		2.18		0.47		.22	0.03
8A		10.9		.20		10.41		2.18		0.53		.24	0.03
8B	10.9		.20		10.41		2.18		1.52		.70		0.02
9A	10.9		.20		10.41		2.18		1.26		.58		0.04
9B		10.9		.20		10.41		2.18		1.93		.89	0.02
10A		10.9		.20		10.41		2.18		1.34		.45	0.01
10B	10.9		.20		10.41		2.18		0.98		.45		0.02
11A	10.9		.20		10.41		2.18		1.02		.47		0.03
11B		10.9		.20		10.41		2.18		1.12		.51	0.03
12A		10.9		.20		10.41		2.18		1.26		.55	0.02
12B	10.9		.20		10.41		2.18		1.83		.84		0.02

Table F-28. Summary of plot characteristics and material in runoff (mg l^{-1}) from infiltrometer studies in creosote of south-central New Mexico, August 18, 1981.

Sample Number	Percent Vegetation Cover		Percent Slope		Total Volatile Solids		Total Phosphorus		Total Nitrogen		Total Solids	
	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung
1A	2.1		31		3058		40.31		20.85		9563	
1B		4.2		31		2834		6.60		2.73		22991
2A		8.0		47		1270		17.73		1.31		8004
2B	1.2		52		2032		33.15		100.33		15138	
3A	0.8		7		3638		30.94		138.55		13498	
3B		10.8		21		1548		4.26		115.32		11094
4A		5.0		25		1560		4.81		22.41		11022
4B	4.2		41		3310		39.34		9.30		8779	
5A	5.0		26		3819		46.28		32.34		10533	
5B		3.3		33		1307		4.36		2.29		8615
6A		8.6		16		1296		1.62		1.35		7272
6B	8.0		11		3286		49.61		21.09		9501	
7A	34.2		11		1582		7.41		13.34		10285	
7B		28.3		50		1730		5.73		55.69		13987
8A		21.3		11		2608		10.44		14.09		23023
oB	20.0		21		6364		59.28		12.16		34960	
9A	13.3		27		4687		20.54		25.20		16380	
9B		15.0		23		4786		12.74		12.73		33582
10A		25.0		26		3538		4.42		2.41		26049
10B	20.8		31		3998		15.48		6.86		28655	
11A	21.7		32		6446		39.78		181.56		17544	
11B		20.3		42		3674		9.97		97.44		24505
12A		14.2		37		2923		4.78		25.20		24041
12B	19.2		27		4465		29.09		61.31		25108	

Table F-29. Summary of runoff (mg per unit of Rainfall Erosivity) for organic matter and nutrient from plots in creosote communities exposed to simulated rain.

Sample Number	Total Volatile Solids		Total Phosphorus		Total Nitrogen		Total Solids	
	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung
1A	294		3.87		2.00		438	
1B		272		0.63		0.26		2209
2A		122		1.70		0.13		769
2B	195		3.18		9.63		1454	
3A	350		2.97		13.31		1297	
3B		149		0.41		11.08		1066
4A		150		0.46		2.15		1059
4B	318		3.80		0.89		843	
5A	367		4.45		3.11		1012	
5B		126		0.42		0.22		828
6A		125		0.16		0.13		699
6B	316		4.77		2.03		913	
7A	152		0.71		1.28		980	
7B		166		0.55		5.35		1344
8A		251		1.00		1.35		2212
8B	611		5.69		1.17		3358	
9A	450		1.97		2.42		1574	
9B		460		1.22		1.22		3226
10A		340		0.43		0.23		2502
10B	384		1.49		0.67		2753	
11A	619		3.82		17.44		1685	
11B		353		0.96		9.36		2354
12A		281		0.46		2.42		2309
12B	429		2.79		5.89		2412	
	350±172	232±111	3.67±2.03	0.73±0.40	4.98±5.54	2.82±3.78	1560±869	1623±846

Table F-30. Summary of infiltrometer studies relating to plot hydrology in desert grass of Sacramento Mountains, south-central New Mexico, June 24-25.

Sample Number	Artificial Rain/ 30 min (cm)		Rain Total Time (fraction of hour)		Erosivity Index		Total Rain (cm)		Total Runoff (cm)		Fraction That Runs Off		Time to Runoff (fraction of hour)
	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung	
1A	8.7		.20		8.31		1.74		0.66		.38		0.06
1B		8.7		.20		8.31		1.74		0.58		.33	0.06
2A		10.9		.20		10.41		2.18		1.35		.62	0.03
2B	10.9		.20		10.41		2.18		1.31		.60		0.03
3A	10.9		.20		10.41		2.18		1.38		.63		0.03
3B		10.9		.20		10.41		2.18		1.13		.52	0.03
4A		10.9		.20		10.41		2.18		0.86		.39	0.06
4B	10.9		.20		10.41		2.18		0.94		.43		0.06
5A	10.9		.20		10.41		2.18		1.19		.55		0.07
5B		10.9		.20		10.41		2.18		1.27		.58	0.04
6A		10.9		.20		10.41		2.18		1.33		.61	0.03
6B	10.9		.20		10.41		2.18		1.19		.55		0.03
7A	10.9		.20		10.41		2.18		0.56		.26		0.06
7B		10.9		.20		10.41		2.18		0.83		.38	0.04
8A		10.9		.20		10.41		2.18		0.78		.36	0.03
8B	10.9		.20		10.41		2.18		0.91		.42		0.04
9A	10.9		.20		10.41		2.18		1.28		.59		0.02
9B		10.9		.20		10.41		2.18		0.73		.33	0.03
10A		10.9		.20		10.41		2.18		0.67		.31	0.04
10B	10.9		.20		10.41		2.18		0.93		.43		0.03
11A	10.9		.20		10.41		2.18		1.08		.50		0.01
11B		10.9		.20		10.41		2.18		1.71		.78	0.01
12A		10.9		.20		10.41		2.18		1.14		.52	0.03
12B	10.9		.20		10.41		2.18		1.62		.74		0.03

Table F-31. Summary of plot characteristics and material in runoff (mg l^{-1}) from infiltrometer studies in desert grasses of Sacramento Mountains, June 24-25, 1981.

Sample Number	Slope Percent		Vegetation Percent		Total Volatile Solids		Total Phosphorus		Total Nitrogen		Total Solids	
	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung
1A	24.0		10		3214		32.67		17.75		16018	
1B		26.0		10		1578		7.25		3.94		15474
2A		11.7		20		2052		16.20		11.75		36936
2B	10.0		25		8751		88.42		56.46		33274	
3A	6.8		15		16422		155.94		95.77		54096	
3B		9.8		10		2305		13.56		3.50		25176
4A		8.0		25		5435		18.49		9.29		29549
4B	7.0		10		6646		60.16		41.55		17108	
5A	13.0		25		12495		107.10		63.98		56763	
5B		7.8		15		3912		26.03		7.49		57302
6A		7.4		5		3086		25.93		8.65		51213
6B	11.5		15		9282		98.77		66.64		34510	
7A	39.3		10		2531		10.08		9.74		13484	
7B		31.6		15		2357		17.84		10.29		27489
8A		23.4		10		2839		22.23		9.44		39218
8B	22.8		20		4441		23.66		12.10		32141	
9A	25.9		20		5683		35.84		19.71		43724	
9B		11.2		20		1489		8.40		3.72		10920
10A		16.9		15		2144		12.73		4.29		15624
10B	17.7		20		4352		21.86		1.30		16852	
11A	8.0		5		2894		28.65		13.39		28209	
11B		8.0		5		5814		54.72		23.09		53762
12A		11.1		20		3238		29.64		7.98		30552
12B	13.1		10		7906		55.08		29.97		48924	

Table F-32. Summary of runoff (mg per unit of Rainfall Erosivity) for organic matter and nutrients from plots in desert grass communities exposed to simulated rain.

Sample Number	Total Volatile Solids		Total Phosphorus		Total Nitrogen		Total Solids	
	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung
1A	387		3.93		2.14		1928	
1B		190		0.87		0.47		1862
2A		197		1.56		1.13		3548
2B	841		8.49		5.42		3196	
3A	1578		14.98		9.20		5196	
3B		221		1.30		0.34		2418
4A		522		1.78		0.89		2838
4B	638		5.78		3.99		1643	
5A	1200		10.28		6.15		5453	
5B		376		2.50		0.72		5505
6A		297		2.49		0.83		4920
6B	892		9.49		6.40		3315	
7A	243		0.97		0.94		1295	
7B		226		1.71		0.99		2641
8A		273		2.14		0.91		3767
8B	427		2.27		1.16		3088	
9A	546		3.44		1.89		4200	
9B		143		0.81		0.36		1049
10A		206		1.22		0.41		1501
10B	418		2.10		-0.13		1619	
11A	278		2.75		1.29		2710	
11B		559		5.26		2.21		5165
12A		311		2.85		0.77		2935
12B	760		5.29		2.88		4700	
	621±430	293±132	5.81±4.19	2.04±1.20	3.44±2.80	0.83±0.50	3195±1438	3095±1575

Table F-33. Summary of infiltrometer studies relating to plot hydrology in pinyon-juniper communities of Sacramento Mountains, south-central New Mexico, June 19-20, 1981.

Sample Number	Artificial Rain/ 30 min (cm)		Rain Total Time (fraction of hour)		Erosivity Index		Total Rain (cm)		Total Runoff (cm)		Fraction That Runs Off		Time to Runoff (fraction of hour)
	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung	
1A	10.9		.20		10.41		2.18		0.83		.38		0.08
1B		10.9		.20		10.41		2.18		0.92		.42	0.08
2A		10.9		.20		10.41		2.18		0.57		.26	0.08
2B	10.9		.20		10.41		2.18		0.88		.40		0.09
3A	10.9		.20		10.41		2.18		0.48		.22		0.07
3B		10.9		.20		10.41		2.18		1.04		.48	0.07
4A		9.8		.20		9.35		1.96		0.83		.42	0.07
4B	9.8		.20		9.35		1.96		0.77		.39		0.08
5A	9.8		.30		14.03		2.94		0.64		.22		0.13
5B		6.5		.30		9.31		1.95		0.75		.38	0.13
6A		10.9		.20		10.41		2.18		0.60		.28	0.08
6B	10.0		.20		10.41		2.18		0.40		.18		0.08
7A	10.9		.20		10.41		2.18		0.70		.32		0.04
7B		10.9		.20		10.41		2.18		0.34		.16	0.08
8A		10.9		.20		10.41		2.18		0.81		.38	0.05
8B	10.9		.20		10.41		2.18		0.71		.33		0.06
9A	10.9		.20		10.41		2.18		1.16		.53		0.07
9B		10.9		.20		10.41		2.18		0.08		.04	0.25
10A		10.9		.20		10.41		2.18		0.60		.28	0.07
10B	10.9		.20		10.41		2.18		0.68		.31		0.07
11A	10.9		.20		10.41		2.18		1.25		.57		0.03
11B		10.9		.20		10.41		2.18		0.20		.09	0.13
12A		10.9		.20		10.41		2.18		1.17		.54	0.05
12B	10.9		.20		10.41		2.18		0.63		.29		0.05
13A	10.9		.20		10.41		2.18		0.89		.41		0.04
13B		10.9		.20		10.41		2.18		0.50		.23	0.09

Table F-34. Summary of plot characteristics and material runoff (mg l^{-1}) from infiltrometer studies in pinyon-juniper of south-central New Mexico, June 19 and 20, 1981.

Sample Number	Percent Vegetation Cover		Percent Slope		Total Volatile Solids		Total Phosphorus		Total Nitrogen		Total Solids	
	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung
1A	5.2		35		5751		2.65		4.48		17264	
1B		5.2		40		5557		10.94		10.40		19430
2A		9.2		30		1870		1.43		7.64		10738
2B	3.1		50		6794		7.48		5.14		18462	
3A	21.8		40		2899		7.30		21.93		10522	
3B		19.8		25		4014		4.99		33.59		36525
4A		14.2		45		3752		3.32		23.48		25332
4B	17.7		20		3111		13.09		19.25		13675	
5A	9.2		95		1753		5.25		1.08		3648	
5B		7.3		35		2850		2.85		16.80		16200
6A		9.2		80		1416		1.56		0.18		7116
6B	9.3		65		2240		6.00		11.20		5728	
7A	10.0		40		2380		8.12		19.39		10164	
7B		11.7		50		904		1.33		3.54		6120
8A		2.5		45		1037		1.70		7.61		5038
8B	3.1		55		7270		66.74		60.49		13433	
9A	5.0		65		2506		11.60		5.57		6032	
9B		3.3		95		49		0.15		-1.65		134
10A		3.1		75		828		1.32		2.04		5316
10B	10.4		45		3618		10.81		21.08		12838	
11A	24.2		42		9200		17.12		52.12		39850	
11B		2.3		70		196		0.58		-1.56		1080
12A		2.2		52		5125		8.31		35.68		37440
12B	3.1		47		3100		56.70		69.30		11264	
13A	2.3		60		5162		36.92		34.18		29975	
13B		17.5		70		1470		11.50		18.20		9400

Table F-35. Summary of runoff (mg per unit of Rainfall Erosivity) for organic matter and nutrient from plots in pinyon-juniper exposed to simulated rain.

Sample Number	Total Volatile Solids		Total Phosphorus		Total Nitrogen		Total Solids	
	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung
1A	360		0.25		0.43		1658	
1B		534		1.05		1.00		1867
2A		180		0.14		0.73		1032
2B	653		0.72		0.50		1773	
3A	279		0.69		2.11		1011	
3B		386		0.48		3.23		3509
4A		401		0.36		2.51		2709
4B	2		1.40		2.06		1463	
5A	125		0.37		0.08		260	
5B		203		0.20		1.20		1155
6A		136		0.15		0.02		684
6B	215		0.58		1.08		550	
7A	229		0.78		1.86		976	
7B		87		0.13		0.34		588
8A		100		0.16		0.73		484
8B	698		6.41		5.81		1290	
9A	241		1.11		0.53		579	
9B		5		0.01		-0.16		13
10A		80		0.13		0.20		511
10B	348		1.04		2.02		1233	
11A	884		1.65		5.00		3828	
11B		19		0.06		-0.15		104
12A		492		0.80		3.43		3597
12B	298		5.45		6.66		1082	
13A	496		3.55		3.28		2879	
13B		141		1.10		1.75		903
	384±252	213±187	1.84±2.00	0.31±0.38	2.41±2.16	1.14±1.23	1429±977	1319±1223

Table F-36. Summary of infiltrometer studies relating to plot hydrology in ponderosa pine communities, south-central New Mexico, June 18-19, 1981.

Sample Number	Artificial Rain/ 30 min (cm)		Rain Total Time (fraction of hour)		Erosivity Index		Total Rain (cm)		Total Runoff (cm)		Fraction That Runs Off		Time to Runoff (fraction of hour)
	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung	
1A	10.9		.20		10.41		2.18		0.69		.32		.066
1B		10.9		.20		10.41		2.18		0.15		.07	.117
2A		10.9		.20		10.41		2.18		0.29		.13	.085
2B	10.9		.20		10.41		2.18		0.30		.14		.085
3A	10.9		.20		10.41		2.18		0.39		.18		.072
3B		10.9		.20		10.41		2.18		0.62		.28	.072
4A		10.9		.20		10.41		2.18		0.58		.27	.072
4B	10.9		.20		10.41		2.18		0.71		.33		.069
5A	10.9		.20		10.41		2.18		1.08		.50		.072
5B		10.9		.20		10.41		2.18		0.09		.04	.138
6A		10.9		.20		10.41		2.18		0.37		.17	.083
6B	10.9		.20		10.41		2.18		0.68		.31		.083
7A	10.9		.37		19.26		4.03		0.16		.04		.166
7B		10.9		.37		19.26		4.03		0.02		.01	.206
8A		10.9		.20		10.41		2.18		0.18		.08	.133
8B	10.9		.20		10.41		2.18		0.10		.05		.100
9A	10.9		.40		20.82		4.36		0.09		.02		.283
9B		9.8		.40		18.71		4.36		0.04		.01	.350
10A		10.9		.30		15.61		3.27		0.06		.02	.166
10B	10.9		.30		15.61		3.27		0.06		.02		.183

Table F-37. Summary of plot characteristics and material in runoff (mg l^{-1}) from infiltrometer studies in ponderosa pine of south-central New Mexico, June 18-19, 1981.

Sample Number	Percent Vegetation Cover		Percent Slope		Total Volatile Solids		Total Phosphorus		Total Nitrogen		Total Solids	
	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung
1A	9.2		70		1794		14.10		17.80		3146	
1B		3.8		80		156		1.05		-2.02		429
2A		17.5		100		220		1.40		-4.61		635
2B	18.3		90		1188		3.30		4.08		4770	
3A	10.0		90		1778		13.85		10.88		2699	
3B		14.2		90		2604		5.58		-4.65		5084
4A		19.8		80		789		12.76		5.51		4733
4B	14.6		65		2641		33.37		10.65		14569	
5A	10.8		55		3197		31.86		32.07		14472	
5B		6.7		85		862		4.90		0.00		3881
6A		7.9		90		340		5.00		-4.32		1517
6B	12.1		75		3427		33.32		21.01		8486	
7A	5.0		92		124		1.84		-0.58		650	
7B		10.0		99		24		0.17		0.02		97
8A		15.8		98		172		0.56		-0.90		774
8B	19.2		100		188		1.15		-0.41		462	
9A	16.7		100		63		0.68		-1.11		223	
9B		18.3		100		23		0.09		-0.42		94
10A		10.0		100		56		0.23		-0.81		259
10B	15.8		100		113		0.54		0.76		209	

Table F-38. Summary of runoff (mg per unit of Rainfall Erosivity) for organic matter and nutrient from plots in ponderosa pine communities exposed to simulated rain.

Sample Number	Total Volatile Solids		Total Phosphorus		Total Nitrogen		Total Solids	
	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung
1A	172		1.36		1.71		302	
1B		15		0.10		-0.19		41
2A		21		0.14		-0.44		61
2B	114		0.32		0.39		458	
3A	171		1.33		1.05		259	
3B		250		0.54		-0.45		488
4A		76		1.23		0.53		455
4B	254		3.21		1.02		1400	
5A	307		3.06		3.08		1390	
5B		83		0.47		0.00		373
6A		33		0.48		-0.41		146
6B	329		3.20		2.02		815	
7A	6		0.10		-0.03		34	
7B		1		0.01		0.00		5
8A		17		0.05		-0.09		74
8B	18		0.11		-0.04		44	
9A	3		0.06		-0.05		11	
9B		1		0.00		-0.02		5
10A		4		0.02		-0.05		17
10B	7		0.03		0.05		13	
	138±128	50±76	1.27±1.38	0.30±0.39	0.92±1.07	-0.11±0.29	473±547	166±194

Table F-39. Summary of infiltrometer studies relating to plot hydrology in mixed-conifer community, south-central New Mexico, August 7, 1980.

Sample Number	Artificial Rain/ 30 min (cm)		Rain Total Time (fraction of hour)		Erosivity Index		Total Rain (cm)		Total Runoff (cm)		Fraction That Runs Off		Time to Runoff (fraction of hour)
	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung	
1	8.43		.16		6.31		2.72		0.44		.16		0.08
2		8.43		.14		5.54		2.44		0.15		.06	0.07
3	8.16		.10		3.79		1.63		0.18		.11		0.06
4		8.16		.10		3.79		1.63		0.15		.09	0.06
5	4.89		.31		6.62		3.05		0.03		.01		0.06
6		4.89		.31		6.62		3.05		0.06		.02	0.06
7	8.70		.17		6.94		2.90		0.29		.10		0.06
8		8.70		.17		6.94		2.90		0.52		.18	0.06
9	8.70		.17		6.94		2.87		0.43		.15		0.06
10		8.70		.17		6.94		2.87		0.20		.07	0.06
11	8.04		.18		6.72		2.95		0.21		.07		0.06
12		8.04		.18		6.72		2.95		0.30		.11	0.06
13	7.95		.17		6.28		2.65		0.40		.15		0.06
14		7.95		.17		6.28		2.65		0.15		.06	0.06
15	8.70		.12		4.89		2.03		0.22		.11		0.06
16		8.70		.12		4.89		2.03		0.26		.13	0.06
17	8.70		.12		4.89		2.03		0.32		.16		0.06
18		8.70		.12		4.89		2.03		0.28		.14	0.06
19	8.70		.11		4.48		2.32		0.32		.14		0.06
20		8.70		.11		4.48		2.32		0.23		.10	0.06
21	8.70		.14		5.71		2.46		0.39		.16		0.06
22		8.70		.14		5.71		2.46		0.42		.17	0.06
23	8.70		.14		5.71		2.46		0.54		.22		0.06
24		8.70		.14		5.71		2.46		0.27		.11	0.06

Table F-40. Summary of plot characteristics and material in runoff (mg l^{-1}) from infiltrometer studies in mixed-conifer of south-central New Mexico, August 7, 1981.

Sample Number	Percent Vegetation Cover		Percent Slope		Total Volatile Solids		Total Phosphorus		Total Nitrogen		Total Solids	
	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung
1	13.4		80		3062		12.8		119.6		12804	
2		11.6		80		309		4.8		47.8		3567
3	17.2		80		626		0.6		65.5		4018	
4		11.0		80		48		4.1		28.8		1893
5	2.0		80		136		0.5		5.9		661	
6		2.0		80		56		0.9		6.7		821
7	14.0		80		2320		2.2		55.7		3758	
8		16.2		80		1238		11.3		82.2		12750
9	14.4		80		4257		11.4		215.4		17320	
10		17.1		80		208		3.8		20.8		3752
11	34.1		80		2184		12.9		84.2		6418	
12		35.4		80		2988		0.5		51.3		9774
13	33.8		80		2048		9.7		11.6		8104	
14		31.7		80		474		2.8		18.0		2586
15	7.2		80		611		5.8		37.6		5232	
16		10.9		80		1024		3.4		52.8		7270
17	6.9		80		1779		2.4		86.1		9869	
18		13.2		80		258		1.1		37.8		4312
19	30.8		80		4122		15.5		143.7		13158	
20		32.0		80		271		2.7		28.3		2397
21	9.8		80		11399		13.6		44.9		10210	
22		15.1		80		3545		12.1		89.5		14700
23	7.4		80		12452		12.9		111.8		5692	
24		8.2		80		3035		7.0		33.8		7906

Table F-41. Summary of runoff (mg per unit of Rainfall Erosivity) for organic matter and nutrient from plots in mixed-conifer communities exposed to simulated rain.

Sample Number	Total Volatile Solids		Total Phosphorus		Total Nitrogen		Total Solids	
	Dung	No Dung	Dung	No Dung	Dung	No Dung	Dung	No Dung
1	485		2.0		19.6		2029	
2		56		0.9		8.6		644
3	165		0.2		17.3		1060	
4		13		1.1		7.6		500
5	21		0.1		0.9		99	
6		8		0.1		1.0		124
7	334		0.3		8.0		542	
8		178		1.6		11.8		1837
9	613		1.6		31.0		2496	
10		30		0.6		3.0		541
11	325		1.9		12.5		955	
12		444		0.1		7.6		1455
13	326		1.6		1.9		1291	
14		75		0.5		2.9		412
15	125		1.2		7.7		1070	
16		209		0.7		10.8		1487
17	364		0.5		17.6		2018	
18		52		0.2		7.7		882
19	920		3.5		32.1		2937	
20		61		0.6		6.3		535
21	1996		2.4		7.9		1788	
22		620		2.1		15.7		2574
23	2180		2.3		19.6		997	
24		531		1.2		5.9		1385
	562±592	181±220	1.5±1.1	0.8±0.6	14.6±10.1	10.7±8.6	1272±896	1031±719

Table G-42. Soil and vegetation characteristics of areas studied with natural and simulated rains.

	Percent Vegetation Cover				Soil				
	Bare Area	Ground Cover	Shrub	Tree	Silt and Very Fine Sand 0.1 mm	Very Fine Sand 0.1-2.0mm	Structure	Permeability	Percent Volatile Solids
Infiltrometer Studies									
Creosote	86.5	13.5	10.0	0.0	32.7	15.0	medium coarse granular	slow	1.7
Desert Grass	85.9	14.1	20.0	0.0	22.4	17.0	coarse granular	slow to moderate	2.7
Pinyon-Juniper	49.3	50.7	10.0	25.0	71.6	8.2	granular	moderate	7.3
Ponderosa Pine	16.3	83.7	25.0	50.0	73.8	8.8	fine granular	moderate	14.1
Mixed-Conifer (meadow)	20.0	80.0	0.0	0.0	76.0	5.4	coarse granular blocky	moderate to rapid	15.9
Natural Runoff									
Upper Slope	43.0	57.0	20.0	25.0	66.1	3.5	granular	moderate	5.7
Lower Slope	9.0	91.0	25.0	75.0	66.1	21.0	granular	moderate	8.7