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An Overview of Los Alamos Research on Soil and Water Processes in Arid and Semi-Arid Ecosystems

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Abstract

Some important research needs to improve understanding and forecasting ability on water balance and erosion in arid lands are discussed along with new approaches, using remote sensing technology, that may improve this ability. Relationships on radionuclide distribution and transport in the Los Alamos and Trinity site environs in New Mexico are described to add historical perspective to current Los Alamos and Nevada Test Site studies using the rainfall simulator. A brief description of current rainfall simulator studies is given with emphasis on applications of the resulting data.

Introduction

Some of the current environmental research at Los Alamos and Nevada Test Site emphasizes surface water hydrology and erosion, including the use of the rainfall simulator as an experimental tool. Much of that work, which involves collaboration with several organizations, is described in these workshop proceedings.

The purpose of this paper is to review the results of early DOE-sponsored research at Los Alamos to add historical perspective to the Los Alamos and Nevada Test Site studies described in these proceedings. Information needs and some newly emerging technology are also identified that may improve our understanding and ability to predict soil and water processes in arid lands.

Background

Contaminant Distribution:

In the early 1970's, the Atomic Energy Commission (now the Department of Energy) began a major research program to investigate the behavior of transuranic elements in the environment (Hanson 1980). The interest in these radionuclides arose because some of them are long lived (e.g., ^{239}Pu has a 24,000 year physical halflife) and are widely distributed in the environment as a consequence of nuclear weapons testing and disposal of wastes generated by the nuclear industry.

In support of the AEC effort, Los Alamos began studies on the distribution and transport of plutonium (and other radionuclides) in ephemeral stream channels used for liquid waste disposal at Los Alamos and in the fallout zone created by the atomic bomb test in 1945 at Trinity Site in south central New Mexico. We were especially interested in the behavior of two isotopes of plutonium, ^{238}Pu and ^{239,240}Pu, although data were also gathered on ^{137}Cs, ^{3}H and stable mercury.

The results from the Los Alamos studies (Hakonson 1975, Hakonson and Nyhan 1980, Nyhan et al. 1976), as well as those from a number of other locations (Hanson 1980), revealed that plutonium (and, in fact, several other radionuclides), deposited almost quantitatively in soils and sediments. Furthermore, the importance of soil and sediment as a reservoir for many radionuclides was often independent of the source term (i.e., weapons fallout, effluent release, accidental release, etc.) and the type of ecosystem (i.e., arid, humid, terrestrial, freshwater aquatic; Watters et al. 1983).

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At Los Alamos and Trinity Site, over 99% of the plutonium inventory was found in soils and sediments, while very small percentages were associated with the biological components of study area ecosystems (Table 1). We also found that the concentrations of plutonium in soil (pCi/g) were a strong function of soil particle size. For example, the silt-clay size fraction (<53 μm in diameter) often contained as much as a factor of 10 times higher concentration of plutonium than coarse sands (Fig. 1). With few exceptions, strong relationships between concentration and soil particle size fraction would also be expected for most other environmental pollutants in soil.

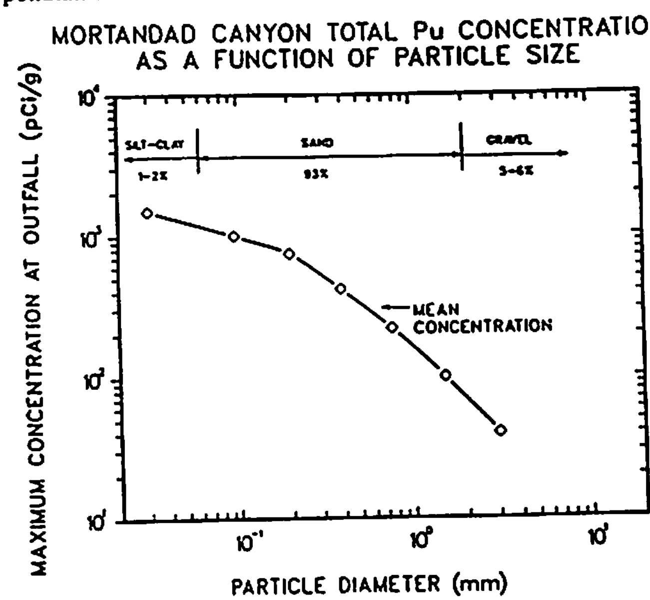

Figure 1. *Plutonium concentrations in sediment from Mortandad Canyon as a function of soil particle size fraction. Contribution of various size fractions to whole soil mass are shown as percentages (from Lane and Hakonson 1982).*

A further consideration arises from the fact that the relative contribution of a particular particle size class to the whole soil mass is variable from location to location. Consequently, while the silt clay size fraction may contain relatively high concentrations of plutonium, the total amount of plutonium in that fraction may be relatively small. For example, the silt-clay fraction of sediments from Los Alamos stream channels contained relatively little of the plutonium inventory owing to the small contribution of this size class to total sediment mass (Table 2). In contrast, at Area 21, in the Trinity fallout zone, about 75% of the plutonium inventory in whole soil was present in the silt-clay fraction, which comprises 36% of the whole soil mass.

The importance of contaminant distribution relationships in soils stems from the fact that erosion by water may selectively sort

Table 1. Mean plutonium inventory ratios for some components of Los Alamos and Trinity Site study areas in New Mexico (from Hakonson and Nyhan 1980).

	Plutonium inventory ratio[1]							
	Los Alamos				Trinity			
Component[1]	n	Mortandad Canyon	n	Acid-Pueblo Canyon	n	Area GZ	n	Area 21
Grass	24	4.1×10^{-5} (0.90)	20	5.6×10^{-4} (1.6)	13	2.0×10^{-5} (0.99)	16	1.3×10^{-4} (0.76)
Forb	16	4.8×10^{-5} (1.2)	11	1.7×10^{-4} (1.0)	17	1.7×10^{-4} (1.0)	21	3.5×10^{-5} (0.77)
Litter	—	————	—	————	5	1.6×10^{-4} (2.0)	3	1.1×10^{-4} (0.81)
Rodents	33	1.5×10^{-9} (0.77)	48	4.5×10^{-10} (0.99)	40	3.7×10^{-8} (1.7)	20	2.3×10^{-9} (0.47)
Soil	29	0.99 (0.00009)	23	0.99 (0.001)	8	0.99 (0.0003)	8	0.99 (0.0008)

[1]Inventory ratio = (pCi Pu/m^2 in component)/total pCi Pu/m^2). All plutonium values are ^{239,240}Pu except Mortandad Canyon which is ^{238}Pu; parenthetic value is coefficient of variation (CV = standard deviation/mean).

Table 2. Plutonium in the <53μm soil size fraction at Los Alamos and Trinity Site (from Hakonson and Nyham 1980).

	Los Alamos		Trinity	
	Mortan-dad	Acid-Pueblo	GZ*	Area 21
Pu Concentration (pCi/g dry wt)	1500	85	0.07	3.8
% contribution to whole soil mass	2.2	3	8.9	36
% Pu in fraction	14	7	0.78	73

*Ground zero

soil particles during all phases of erosion. Consequently, the amount of contaminant transported during an erosion event is dependent not only on the physical relationships of the contaminant with soil but also on hydrologic variables which influence the kinds and amounts of sediment that are detached, transported, and deposited in the watershed.

At Area 21 (Table 2), the preferential transport of silt-clay particles would have the potential for transporting a significant fraction of the plutonium inventory in the soil. In contrast, transport of the silt-clay fraction of stream channel alluvium in the canyons at Los Alamos would be mobilizing a soil component with a relatively small fraction of the plutonium inventory.

The complex distributional and hydrologic relationships that potentially influence the redistribution of soil and sediment associated contaminants led to the need to further characterize and begin to model runoff, erosion, and contaminant transport. At Los Alamos, transport studies were initiated in the stream channels contaminated with treated radioactive liquid effluents.

Contaminant Transport:

Los Alamos receives an average of 46 cm of precipitation per year with 75% of it falling during intense thunderstorms that occur in late summer. These short duration, high intensity storms often produce runoff in the ephemeral streams at Los Alamos, leading to the potential for downstream transport of sediment-associated radionuclides.

Rainstorm runoff at Los Alamos was first implicated in the transport of sediment associated plutonium in the mid-1940's (Kingsley 1947). In subsequent years, several studies were conducted to determine some of the relationships between rainfall, runoff, erosion, and contaminant transport (Purtymun 1974, Purtymun et al. 1966, Hakonson et al. 1976, Lane and Hakonson 1982).

Results of those studies demonstrated that snow melt and rainstorm runoff transported radionuclides attached to sediment and that the magnitude of transport was highly dependent on the hydrologic characteristics of the watershed. The dependency of concentrations of suspended sediments and plutonium in runoff on flow rate is indicated by the data from one runoff event in Mortandad Canyon (Fig. 2; Hakonson and Nyhan 1976). The nonlinearity in the curves was attributed to the relationships of flow

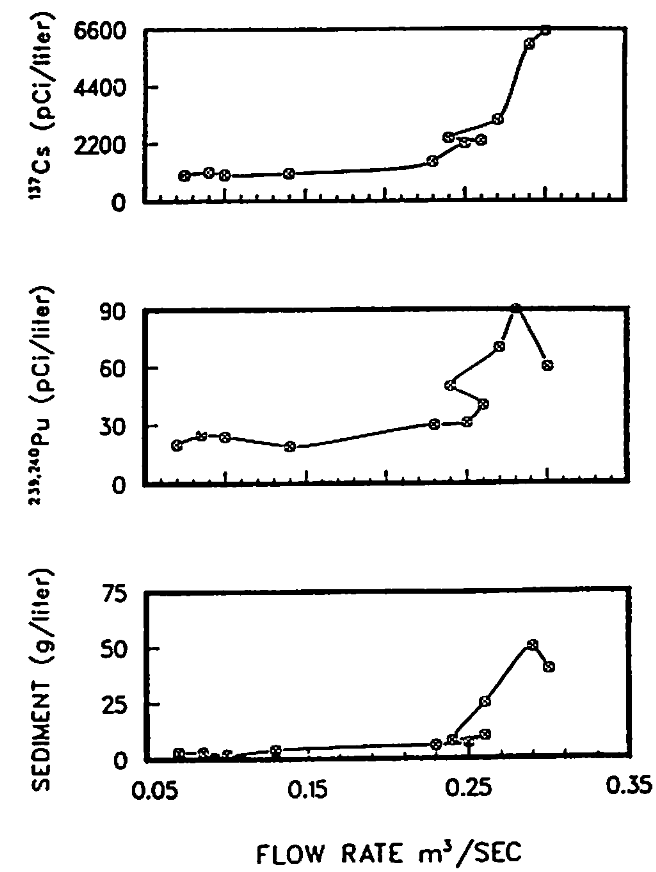

Figure 2. *Concentration of sediment and plutonium in unfiltered runoff water from Mortandad Canyon as a function of runoff flow rate (from Hakonson et al. 1976).*

rate to the particle size of suspended material. At flows less than 0.25 m^3/sec, only the silt-clay particles, which comprise less than 2% of the alluvium by weight (Table 2), were in suspension in the runoff. However, at flow rates in excess of 0.25 m^3/sec, fine to coarse sands, which contain about 85% of the plutonium inventory, were in suspension. Higher flow rates typically occur during the early phases of rainstorm runoff events at Los Alamos owing to the short duration and intense nature of local rainstorms. For the runoff event depicted in Fig. 2, we found that 80% of the sediment and 70% of the radioactivity was transported within the first half of the runoff event.

Table 3. Average (n=2) sediment yield (g/m²) from erosion plots at Nevada Test Site using rainfall simulator to apply precipitation at 60 mm/hr. Sediment yield normalized to 60 mm total precipitation input.

		Spring 1983			Fall 1983		
Location	Cover Treatment	Dry[1]	Wet	Very Wet	Dry	Wet	Very Wet
Area 11	Natural[2]	1.3	12.0	24.3	4.4	3.6	9.2
	Clipped	1.2	16.4	32.2	72.3	22.4	25.0
	Cleared	82.6	208.0	358.0	304.9	349.0	438.8

[1]Antecedent soil moisture
[2]Natural = vegetation and erosion pavement intact.
Clipped = vegetation removed.
Cleared = vegetation and erosion pavement removed.

Procedures were developed to predict runoff, sediment yield, and contaminant transport from semi-arid watersheds with alluvial stream channels (Lane et al. 1985). The procedures represent a mix of mathematical models and data from our studies to approximate the complex processes of runoff generation, stream flow-routing and hydrograph development, sediment transport and yield, particle sorting and enrichment, and transport of sediment associated contaminants.

The procedure was applied to a Los Alamos canyon system that received radioactive liquid wastes from 1942 to the present. Results suggest that runoff transport of plutonium out of the study reach was about 90% of that added to the reach during the period 1942-1980 (Fig. 3). In addition, calculated estimates of the residual inventory of plutonium in the canyon compared reasonably well (within a factor of 3) with estimates based on sediment sampling and chemical analysis (Fig. 3).

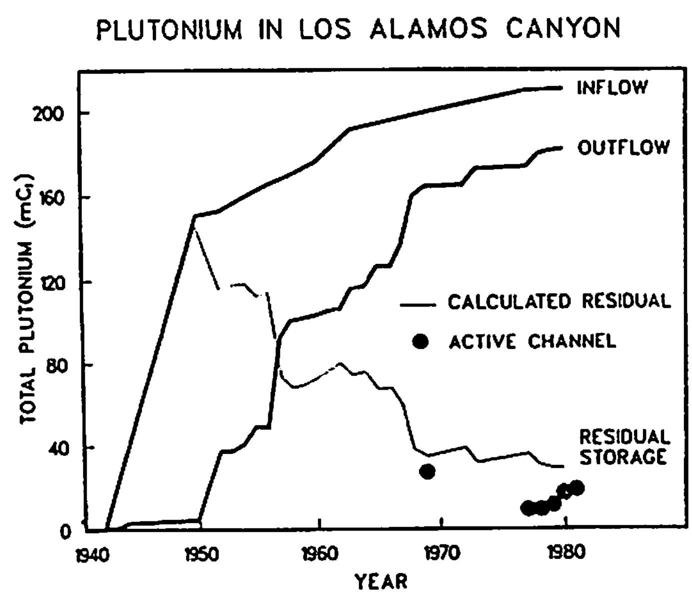

Figure 3. *Calculated and measured residual inventory of plutonium released to a canyon at Los Alamos. Data Points (solid circles) are estimated residual plutonium inventories based on sediment sampling and chemical analysis.*

Current Programs

Studies on the distribution and transport of radionuclides in Los Alamos and Trinity ecosystems demonstrated the importance of hydrologic processes in redistributing soil contaminants. In addition, complex physical, chemical and hydrologic relationships were identified that limited our ability to assess the long term fate and effects of those contaminants without better understanding of the fundamental mechanisms and relationships controlling transport. The key to resolving some of these problems lies with better understanding of the hydrology of study sites. Water is the driving force that leads to many of the environmental issues concerning land and water quality and human health and safety. Concern about non-point source pollution, radioactive and chemical waste disposal, rangeland agriculture and recovery of disturbed ecosystems all center on the need for better information and models describing surface and subsurface hydrology and erosion.

Hydrologic and erosion processes in arid and semi-arid ecosystems are highly variable in time and space and do not easily lend themselves to study under controlled field conditions. The use of the rainfall simulator in our studies of waste disposal at Los Alamos is an attempt to control some of the variables that influence the hydrologic response of waste sites. A clear understanding of the physical and biological factors controlling water balance and erosion on waste trench caps opens the opportunity to modify the cap design in ways most beneficial to insuring the long term integrity of the site. For example, models such as CREAMS (Knisel 1980), when properly calibrated for trench cap components, can be used to evaluate the benefits (i.e., reducing erosion and/or percolation) of modifying the depth and type of cap soil, the effect of changing slope and cover management practice, and the type and density of vegetation cover. During the operation and close-out phases of a waste site, a properly calibrated model can also be used to design monitoring programs and to predict long term site performance.

The rainfall simulator has proved particularly useful in evaluating the effects of animal burrowing on water balance and erosion in disturbed soil profiles. The ability to quantitatively measure the influence of pocket gopher *(Thomomys bottae)* burrowing and erosion is noteworthy on two accounts. First, pocket gophers commonly invade disturbed sites (i.e., waste burial sites) at Los Alamos leading to the potential for influencing waste site integrity and, secondly, existing water balance and erosion models do not account for the influence of burrowing activity primarily because of the lack of appropriate data.

The rainfall simulator studies at Nevada Test Site are descirbed in several workshop papers by E.M. Romney, E.H. Essington, J.R. Simanton, and R.B. Hunter. In addition to the basic research questions being addressed by the study, some of the treatments imposed on the plots simulate a cleanup operation that was conducted on a nearby area highly contaminated with plutonium (Orcutt 1982). The cleanup involved complete removal of the plant and erosion pavement cover similar to the treatment imposed on some of our erosion plots at NTS.

Erosion estimates from rainfall simulator runs (in Area 11) at NTS are presented in Table 3 to illustrate the value of simulator data in evaluating some of the consequences of a cleanup practice. Sediment yield from the undisturbed (or natural) plots, even under very wet antecedent moisture conditions, averaged less than 30 g/m² (0.3 T/ha). Removal of the plant cover had little additional effect on sediment yield from the plots. However, removal of both the plant and erosion pavement covering the ground surface increased sediment yield by a factor of about 10 to 100 over the natural plot treatment. The implication for site cleanup is that the contamination in an undisturbed site is relatively resistant to transport by erosion. A cleanup operation that involves plant and erosion pavement removal, if not 100% effective in removing the contaminant, exposes the residual contaminant to highly accelerated rates of transport from the site. Results of the cleanup operation conducted at Area 11 indicated that about 10% of the initial activity remained in the soil following treatment for plutonium removal (Orcutt 1982).

New Directions

Remote sensing capabilities are being incorporated into the NTS studies to determine the feasibility of using satellite and aircraft based imagery for parameterizing watershed scale hydrologic models. Ground based data, obtained from the rainfall simulator studies and field reconnaissance, will provide estimates of soil characteristics, soil erodibility, infiltration, runoff, and erosion. Satellite and aircraft based imagery will be used to estimate topographical features (e.g., slope, aspect, drainage network) using a digital elevation model generated from low altitude stereo pairs. Surface features of the watershed (vegetation, soil types) will be obtained from digital multispectral scanner data while surface roughness will be determined from digital Seasat radar imagery. The ground based and remote sensing data will be used to parameterize a watershed scale model, focusing on a small contaminated watershed in Area 11. The distribution of contaminant in the area downstream from the source area will be used to partially validate the modeling results.

A critical weakness in our understanding and ability to model water balance is the lack of data and methods to measure evapotranspiration. In arid sites, a very large fraction (>80%) of annual precipitation may be lost to evapotranspiration. A major problem at waste disposal sites may result from water that percolates below the root zone where it is free to interact with waste and possibly move, along with solutes, outside the waste site boundaries. Because plants play such a dominant role in the water balance, revegetation with species that maximize water use may resolve the problem of percolation into waste sites. Unfortunately, data on evapotranspiration from plant canopies as a function of species and season, that could be used in selecting an optimum cover, are generally unavailable.

Estimates of evapotranspiration from stands of vegetation by measuring profiles of water vapor, temperature and wind above the canopy; have always been difficult, especially without perturbing the profiles in the process. Recent developments in LIght Detection And Ranging (LIDAR) technology for remote monitoring of the concentration of atmosphere constituents such as water vapor, and temperature, have created an unprecedented opportunity for obtaining data on these processes by non-interfering means both at ground level and aloft. We are planning to develop and apply specific LIDAR techniques for measuring evapotranspiration (ET) over a variety of native plant canopies under well defined plant physiological conditions. Important links will be established between the flux of water vapor up to the boundary layer and both environmental variables and plant physiological states.

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Literature Cited

Hakonson, T.E. 1975. Environmental pathways of plutonium into terrestrial plants and animals. Health Phys. 29:583-588.

Hakonson, T.E., J.W. Nyhan, and W.D. Purtymun. 1976. Accumulation and transport to soil plutonium in liquid waste discharge areas at Los Alamos. *In:* Transuranium Nuclides in the Environment, STI/Pub/410, IAEA, Vienna.

Hakonson, T.E., and J.W. Nyhan. 1980. Ecological relationships of plutonium in southwest ecosytems. *In:* W.C. Hanson (ed.), p. 403-419. Transuranic Elements in the Environment, TIC-22800. U.S. Department of Energy, NTIS, Springfield, VA.

Hanson, W.C., (ed.) 1980. Transuranic elements in the environment. DOE/TIC 22800. U.S. Department of Energy, NTIS, Springfield, VA.

Kingsley, W.H. 1947. Survey of Los Alamos and Pueblo Canyons for radioactive contamination and radioassay tests run on sewer-water samples and water and soil samples taken from Los Alamos and Pueblo Canyons. Los Alamos Scientific report, LA-516.

Knisel, W.G. Jr., ed. 1980. CREAMS: a field scale model for chemicals, runoff, and erosion from agricultural management systems. U.S. Dept. of Agriculture. Conservation Research Report No. 26, Washington, D.C.

Lane, L.J., and T.E. Hakonson. 1982. Influence of particle sorting in transport of sediment associated contaminants. P. 543-557, *In:* Proc. Waste Management '82 Symp., Univ. of Arizona Press, Tucson, AZ.

Lane, L.J., W.D. Purtymun, and N.M. Becker. 1985. New estimating procedures for surface runoff, sediment yield, and contaminant transport in Los Alamos County, New Mexico. Los Alamos National Laboratory report, LA-10335-MS.

Nyhan, J.W., F.R. Miera, and R.J. Peters. 1976. Distribution of plutonium in soil particle size fractions of liquid effluent-receiving areas at Los Alamos. J. Environ. Qual. 5:50-56.

Orcutt, J.A. 1982. Cleanup and treatment (CAT) test: a land area decontamination project utilizing a vacuum method of soil removal. U.S. DOE report, DOE/NV/00410-70.

Purtymun, W.D., G.L., Johnson and E.C. John. 1966. Distribution of radioactivity in the alluvium of a liquid waste disposal area at Los Alamos, New Mexico. U.S. Geol. Survey Prof. Paper 550-D.

Purtymun, W.D. 1974. Storm runoff and transport of radionuclides in DP Canyon, Los Alamos County, New Mexico. Los Alamos Scientific Laboratory report, LA-5744.

Watters, R.L., D.N. Edgington, T.E. Hakonson, W.C. Hanson, M.H. Smith, F.W. Whicker, and R.E. Wildung. 1980. Synthesis of the research literature *In:* W.C. hanson (ed.) Transuranic Elements in the Environment, DOE/TIC-22800, U.S. Dept. of Energy, NTIS, Springfield, VA.

Watters, R.L., T.E. Hakonson, and L.J. Lane. 1983. The behavior of actinides in the environment. Radiochemica Acta 32:89-103.