MAR 31 1966

COO-1191-10

MASTER

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IN NUCLEAR SCIENCE ABSTRACTS

TERMINAL REPORT

to

U.S. ATOMIC ENERGY COMMISSION

Contract No. AT(11-1) - 1191

RADIOECOLOGY OF THE COLORADO FRONT RANGE

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PATTERN AND PROCESS OF FALLOUT DISTRIBUTION IN AN ALPINE WATERSHED

INTRODUCTION

High mountains comprise only a small percentage of the earth's total landscape. However, they are very important as contributors of water. For instance in sections of the Rocky Mountains, this type of landscape covers less than 4 percent of the area but may supply 20 percent (Schwan and Costello, 1951) or as much as 90 percent (Packer, 1957 and Johnson, 1962) of the water used for purposes of drinking or irrigation.

Very little is known about the levels and movements of natural or man-generated radioactivity in these high mountain watersheds. Although it is known that particular snowfields throughout the northern hemisphere have concentrated fission products to levels several times higher than recommended by the Public Health Department (U.S. Public Health Service, 1961) for continued use as drinking water, the reduction in radioactivity from snowfield to "tap water" is so great there is general agreement that the radioactivity does not present a hazard to municipalities utilizing the snow melt water. Specific areas of study have been reported in Norway (Bergh, et al., 1961), Austria (Reiter, 1960), Japan (Osawa, 1961), Russia (Novikov, Y. V., V. A. Liperovskii, and A. A. Polynkova, 1962), and Colorado, U.S.A. (Osburn, 1963).

Preliminary investigation in 1958 of a number of snowfield, plant and soil samples from the Boulder city watershed indicated that fallout distribution was far from uniform and that it had been concentrated to a relatively high amount in some particular ecosystems (Osburn, 1963). A study project was immediately designed to obtain detailed information on the amount, time, and manner of fallout concentration and dispersion within an area which appeared to have a relatively high amount of gross beta radioactivity - a late melting snowfield (Osburn, 1963). An expansion of this project was initiated during April of 1962, with the ultimate goal of being able to determine the gross pattern of fallout distribution for an entire 11 square mile watershed and to explain the major processes involved in the differential distribution.

Research Area Characteristics

It is very important to measure and describe characteristics of the research area in a good deal of detail since with greater detail, it becomes easier to compare one watershed more accurately with another. First, the pattern of fallout nuclide distribution can be related or correlated with a large number of parameters. Some of these parameters such as type of bedrock, surface deposits, soil type, rainfall pattern, snow pattern, and vegetation, have previously been determined in other areas and comparative maps are readily available. Thus after the fallout pattern has been worked out in detail in this particular watershed and properly related to causal factors, it may be possible to make reasonably accurate predictions concerning fallout distribution and movement in a new area, based largely on the ordinations of the various landscape units.

Location, topography and physiography

The Boulder city watershed is located about twenty-five miles west of Boulder, Colorado at $105^{\circ} 37' 30''$ W. longitude and $40^{\circ} 01' 45''$ N. latitude. This mid-latitude region has had the highest levels of worldwide nuclear fallout. In addition, the site is about 600 miles east north east of the Nevada nuclear test site and is almost directly in the path of the winds prevailing during many nuclear test events. Also the topography to windward is such that the mountain watershed region forms the lowest portion of a barrier to the easterly flow of air; consequently the region is subjected to the passage of relatively large amounts of wind only a short distance removed from the test site.

Physiographically the region appears to be representative of the Colorado Front Range Mountains at the general altitude of 10,000 feet to 13,000 feet (Figure 1). The Front Range, one of the ranges of the Southern Rocky Mountains, is the eastern most unit of the Rocky Mountains and extends from the Medicine Bow Range to the north, southward to about Pikes Peak, Colorado, a linear distance of approximately 150 miles. This mountain range is relatively narrow (about 20 to 40 miles wide) and is bounded on the east by the Great Plains Region and on the west by large inter-mountain basins or "Parks".

The specific research area occupies approximately 11 square miles and lies between the altitudes of 13,300 and 9,500 feet. The almost barren rocky continental divide, a ridge ranging between 13,500 and 12,700 feet delimits the western boundary

Figure 1. Aerial photograph showing the midwinter aspect of the high mountain watershed. This type of landscape occupies less than four percent of the states of Colorado and Wyoming, but contributes more than 20 percent of its yearly stream flow (Schwan and Costello, 1951).

Figure 1

of the watershed. Two nearly parallel tundra ridges form boundaries on the north and south and a long lateral moraine-clad ridge, supporting a dense forest of lodgepole pine (Pinus contorta) forms the eastern enclosure to the watershed.

The watershed may be variously sub-divided into a number of units. An impression of its various characteristics may be gained from inspecting figures 3, 4, 6, and 8.

The area is about 11 square miles (28.5 sq. kilometers) or 7,000 acres (2,833 hectares). The shape resembles the majority of western mountain watersheds in that it is of an ovoid or pear shape, with a single outlet located at the narrow end. According to numerical indices the form factor (ratio of the average width (1.96 miles) to the axial length (5.68 miles)) is 0.35 and the compactness coefficient (ratio of the perimeter of the watershed to the circumference of a circle whose area is equal to that of the drainage basin) is 1.35.

Elevation characteristics are quite useful in making quantitative comparisons of watersheds and are important because many associated climatic characters, such as temperature and precipitation which indirectly act on fallout distribution are altered with change in elevation. See the hypsometric curve (Figure 2).

The general orientation of the watershed is eastward, with about 15 percent of the landscape a ridgetop, about 20 percent occupied by valley floors, and of the remaining area about equally divided between northern and southern exposures. The influence of orientation is most easily observable in the rate of snowfield reduction. Only for a short period in mid-summer does exposure (orientation) fail to influence the rate of snowfield ablation. Since strong winter winds are predominantly from the west, the general easterly orientation has additional import. Snow may actually fall on the westward slope of the mountains and be transported across the divide onto the upper portions of the watershed. Thus, the upper portion of the watershed may occasionally receive snow while the remainder of the watershed may be enjoying clear weather.

Erosion by former glaciers, perennial snowfields, and various types of mass wasting contributes to the physiographic distinction of this alpine landscape. The western portion of the watershed is characterized by rugged glaciated topography. Slopes are precipitous and littered with talus, and the narrow adjacent valleys head into deep gorges and glacial cirques. On the other hand, the eastern part of

Figure 2. Area-elevation relationship of the Boulder, Colorado city watershed.

Figure 2

the watershed is of more gentle contour and bordered by wide, shallow valleys. The slopes are gradual and have distinctive rounded shapes that imply prolonged mass wasting.

Many types of mass wasting features are evident and occur on various parent rocks. Some features, such as large solifluction terraces and stone nets seem stable, even though only partly vegetated. Presently active features are mainly non-sorted circles. All stages of growth and increasing stability are conspicuous.

Seven principal types of parent rock (Figure 3) schist and gneiss, monzonite, glacial till (mostly schist and gneiss), syenite and granite, quartz-bearing monzonite, and granite occur in the watershed.

Aerially the watershed (Figures 1 and 4) presents a mosaic of vegetation types, lakes, snowfields, bare rock outcrops, and mass-wasting features. Approximately 30 percent of the area is covered with forests, 30 percent tundra, 4 percent lakes and streams, 8 percent perennial snowfields and the remainder is comprised of bare rock or substrate having less than 10 percent of its surface covered with vascular plants.

Vegetation:

The vegetation map (Figure 4) shows the distribution of the major vegetation types found in the watershed. The number of types is large because the 11 square mile area encompasses two climax regions (Alpine and Sub-alpine) and the ecotone between. As far as the alpine area is concerned all of the major tundra vegetation types which occur in the central Rocky Mountains can be found in the city watershed. This landscape presents a mosaic of stands predominantly of perennial plants of prostrate or short tussock growth habit. The patches of plants provide covers ranging from those of sparse distribution to those growing densely and completely closed. The pattern of plant communities often follows the pattern of snow accumulation, soil moisture, mass-wasting or other erosional conditions very closely.

Forest stands are largely restricted to the lower one third of the watershed. Mixed stands of Englemann spruce (Picea engelmannii) and sub-alpine fir (Abies lasiocarpa) appear to be the climax forest type and these trees probably have the greatest total coverage of any tree species. However, the lodgepole pine (Pinus contorta) dominates a high percentage of the region while deciduous trees, and shrub stands of aspen, willow, birch, and alder cover a relatively small percent of the area.

Figure 3. Distribution of principal types of bedrock in the Boulder city watershed.

Figure 3

Figure 4. Major plant community types of the Boulder City Watershed. Modified from the United States Forest Service vegetation map.

Figure 4

Finally, bogs, though covering a small portion of the watershed, are important indicator stands for fallout studies and have a significant influence on the stream-flow.

The Alpine Year:

In order to give the reader a general frame of reference, the typical animal activities and plant responses usually associated with the general climatic sequence will be outlined for an entire year.

Springtime in this Colorado high country is characterized by storms of heavy wet snows with reduced wind velocities. In April, 1921 (Leudlum, 1953) nearly seventy-six inches of snow fell in a 24 hour period, an official U.S. Weather Bureau record. The conditions (up-slope Mexico Gulf air) which accounted for this immense snowfall prevail in this area each year and sometime in March, April, or more frequently in May, one or more snowstorms of this type will deposit a deep mantle of snow over the entire area. Garnsy et al. (1961) reports that 50% of the annual precipitation in the Colorado River basin is produced by only 15% of the yearly storms. It is quite possible that a lower percentage of storms than this in the city watershed may account for an even larger proportion of the total annual precipitation.

Toward the end of spring general animal activity increases markedly. Field voles, having been restricted to a few sites by the patchy winter snow cover, have used up most of the available food, now take advantage of the extension of snow cover and under its protection move out into new territory, both for food and to find suitable sites for breeding and brooding. Strong up-drafts of air, originating over the plains region several thousands of feet below where summer-like conditions have produced a large amount of pollen and insects, transport heavy loads of pollen, insects, and other light debris into the high country where it may be deposited on snowfields. Here large sections of snowfields may be densely covered with snowfleas (Achorutes) (collembola). Presumably these organisms are feeding on the debris deposited on the snow. Representative species of nearly all of the winged orders of insects which normally are found in the high plains region have been found in the tundra above treeline. Many of these insects fall on snowbanks, become immobilized, and are easy prey for several of the early arriving alpine birds such as the horned lark (Otocoris alpestris), brown-capped rose finch (Leucosticte australis), and pipit (Anthus spinoletta).

Concurrently, with the arrival of the birds to eat the insects, predaceous hawks appear to harass.

Summer returns abruptly to the alpine region as there is a greater increase in free air temperature during June than at any other time of the year. Thus spring snow melts rapidly and the tundra soil is thoroughly irrigated. Plant dormancy is disrupted and a rapid sequence of flowering and fruiting follows. Even though the daily free air temperature may drop below freezing occasionally, sites of bare soil, which lack the insulation afforded by plants, freeze nearly every night.

June starts the nesting season of ptarmigan (Lagopus leucurus), pipets, horned larks, and rosey finches. The young of several species of small mammals, especially juvenile field voles (Microtus sp.) and white footed deer mice (Peromyscus pennsylvanicus) are beginning to appear.

Even though rain showers occur almost daily, the storms are of short duration and low intensities, which combined with high evaporation and transpiration rates and soils with high infiltration capacities, seldom produce surface water runoff.

During August, animal activity reaches a peak. Young birds, mammals, grasshoppers, and mormon crickets are rather conspicuous. Pika (Ochotona princeps) are busily harvesting hay, marmots (Marmota flaviventris) are digging bulbs, roots and feeding on above-ground plant parts, pocket gophers (Thomomys talpoides fossor) are cleaning out and elongating burrowways, and predatory animals such as the weasel, (Mustela erminea), the coyote (Canis latrans) and an occasional fox (Vulpes fulva) are taking advantage of the ample food supply.

Summer grades gently into a characteristically dry period, autumn (September and October). Sometimes several weeks may pass without a trace of precipitation. Soils become dry and frequently their moisture content drops to a level where it is no longer available to plants. Because of cloudless (though hazy) skies, days are warm but nights are cool to cold. Most plants become dormant, insect numbers decline rapidly, bands of migratory birds form in large numbers only to disappear rapidly, but small mammals such as the golden mantled ground squirrels, and chipmunks are busy all day long collecting "cotton" from willow shrubs and fireweeds for nest insulation, or caching food for the winter. Meanwhile, marmots though extremely fat, are still feeding with voracious appetites.

Predaceous birds are frequent visitors. In fact, each major group of hawks is represented in the avian fauna of the high country. The accipiters, or true hawks,

are primarily bird eaters and are best represented by the Western Goshawk (Astur atricapillus striatulus), the sharp shin (Accipiter velox), and the coopers (Accipiter cooperi).

The marsh hawk (Circus cyaneus), the only representative of harriers in the United States, commonly are seen flying a systematic pattern of search over Carex meadows where voles (Microtus pennsylvanicus or Microtus montanus) frequently abound.

The falcon, is best represented in the high country by the sparrow hawk (Falco sparverius). This compact little hawk may be seen daily hovering or perched on observation points above timberline when the grasshopper and mormon crickets begin to reach adult stages. Crop examination of these birds reveals that in August and September nearly 100% of their diet is composed of grasshoppers and crickets.

Of the buteos perhaps the western red-tailed hawk (Buteo borealis calurus) is more abundant than the Ferruigonius roughleg (Buteo regalis) or the Swainsons hawk (Buteo swainsoni). These huge hawks feed largely upon small mammals such as voles, rabbits, and ground squirrels.

Short intervals of cold snowy days usually foretell of approaching winter but winter conditions seldom are continuous until the latter days of October and occasionally may be delayed until late December. The action and sound of strong winds are the most diagnostic stamp of winter in the high country. Although winter produces little snow, that which falls is quickly moved to ravines, or to the upper forested region where the drifts may become enormous. It is this pattern of snow which exerts a heavy influence on the distributional pattern of soil moisture, plants, animals and nuclear fallout.

During the winter months (November through April), very little animal activity may be observed in the alpine region. However, shrews (Sorex), white-footed mice, pika, and pocket gophers are known to be active beneath the snow.

While no animal attempts to withstand prolonged direct exposure to the strong bitter alpine winds, occasionally on milder days some ptarmigan or rabbits (Lepus townsendii) may wander out onto the tundra regions, a raven (Corus corax sinuatus) or two may be seen winging slowly up the canyons and over the ridges, or a pika may be seen busily collecting a few plants.

The deep snow in the sub-alpine forest sends most large mammals down to lower elevations in late autumn and keeps them there until late spring - consequently the sub-alpine active vertebrate fauna consists of a few species of birds and small

mammals. Though some dusky grouse (Dendragapus obscurus obscurus) leave the area, most will stay and feed on spruce buds and blueberry leaves (when they are not snow covered). Ptarmigan seek shelter in the Krumholz region but will feed on willow buds high upon the open tundra during less severe intervals. Tracking through the forest one occasionally cuts across the trail of the snowshoe hare (Lepus americanus bairdii), pine squirrel (Tamiasciurus hudsonicus baileyi), or porcupine (Erethizon dorsatum). Clark's nutcrackers (Nucifraga columbiana), and crossbills (Loxia leucop-tera) utilize seeds from the extremely stable and abundant supply of lodgepole pine (Pinus contorta) cones, while mountain chickadees (Penthestes gambeli gambeli) endlessly search the tips of the branches for insects. Pine grosbeaks (Penicola enucleator) too are quite common winter residents.

Two species of insects, both black and wingless, a crane fly (Chionea nigra) and a scorpion fly (Boreus coloradensis) may be seen in late winter crawling over the surface of the snow. Little is known about these insects.

In a brief summary of an alpine year, autumn is mild and dry, winter is long and windy, spring is wet and snowy, and summer is short and variable.

Pathways by which fallout enters the watershed:

During the period of study, September, 1961, through August, 1964 the major vectors transmitting fallout from the atmosphere into the various landscape units of the watershed, are, in order of decreasing significance, snow, rain and turbulent or dry fallout. The relative importance of each process varied between years and will be discussed later.

Evidence that the above processes satisfactorily explain all the major pathways of incoming fallout is as follows. A series of Sphagnum moss samples were collected in the fall of 1962 and again in 1963. Field measurements and observations of the collection site demonstrated that conditions in this type of situation (a Sphagnum moss bog) were nearly ideal to determine the amount of fallout per unit area that has come down without redistribution since the introduction of nuclear fission products into the atmosphere (Bergh, et al., 1961). This is largely because the density and height of deciduous shrubs is such that the winter snowfall is well enough anchored that the site neither gains nor loses snow during periods of high winds.

The gross beta radioactivity, minus decay, increased 27,000 picocuries per square decimeter between 1 September 1962 and 1 September 1963. Incoming gross beta

radioactivity, measured in the spring snowpack was $5,880 \pm \text{pCi/square decimeter}$. Spring dust deposited $3,000 \pm \text{pCi/square decimeter}$, summer rainfall provided $11,800 \pm \text{pCi/dec}^2$, and $3,300 \pm \text{pCi/dec}^2$ were unassociated with rainfall. (Spring dust and the unassociated fallout are explained later under the heading of dry fallout). The summation of these contributions closely approximated the total amount measured in the Sphagnum moss. This agreement is interpreted as evidence that the major incoming fallout pathways have been accounted for and each is discussed below.

Snow:

Four conditions account for the relative importance of snow as a fallout vector: (1) approximately 2/3 of the annual precipitation is in the form of snow, (2) falling snow may be carried many miles by wind, thereby encountering a greater amount of fallout laden atmosphere than would a comparable amount of rain, (3) the amount of atmosphere washed free of fallout, per unit volume of water, is greater via snow than via rainfall, (4) and the time of the largest amount of snowfall is coincident with the spring break of the tropopause which enriches the lower atmosphere with fallout.

Snow distribution in the high country is extremely uneven and is largely dictated by altitude, general topography, wind force and direction, temperature and vegetation type (Figure 5).

At the end of the snow accumulation season in 1962 and 1963 snow depth was measured along a number of transects which passed through every major plant community type in the watershed. Snow depths ranged from zero inches in some areas to many feet in other parts of the watershed. The sites of greatest accumulation, late lying or perennial snowfields, were too deep to measure directly and ablation data were taken until snow melt had reduced the snowfields to depths shallow enough for probing.

Over five hundred snow samples were radio-assayed. The mean radioactivity of the snow was found to be $1.04 \pm 0.05 \text{ pCi/cm}^2/\text{inch}$ of snow for spring 1962 and 1.47 ± 0.12 for spring 1963. As indicated by the relatively high standard error of the mean in 1963, the amount of fallout in the snow was somewhat variable, even though good correlation (.72) existed between depth of snow and gross beta radioactivity. Studies conducted during the snow accumulation period had revealed that snow storm radioactivity varies widely. Levels of radioactivity appeared to be related to a

Figure 5. Typical snow pattern within the Boulder city watershed. The time of melt-out gives an indirect measure of the depth of annual accumulation.

Figure 5

number of variables such as the total amount of snow to fall, duration of the storm, origin of the air mass, time of year, amount of radioactivity in the air, steadiness of the snowfall, snow density, windiness, and amount of organic debris associated with the snow. However only one variable correlated consistently with the levels of snow radioactivity, this was the amount of incorporated debris and the average wind velocity. See Table. Thus the pattern of snow and contained debris served to superimpose a fallout pattern over the entire watershed.

Within the forests (the lower 1/3 of the research area), a snowfall altitude relationship could be established. A definite trend toward increase in snowfall with altitude was observed but varied, too, with specific forest stand types. In the higher region, (alpine tundra) snow tended to accumulate in hollows to the lee of barriers, or where the wind velocity was sufficiently reduced so that wind transport of snow was ineffectual. Wind velocity varied seasonally and with the topography. While the average monthly winter-time velocity approaches 30 miles per hour, the snow distribution pattern is undoubtedly more nearly related to winds of considerably greater intensities. During the spring, wind velocities are reduced and snow is allowed to accumulate in places where formerly it blew away. Concurrently with this reduction in wind velocities, newly fallen snow is "wetter" or more dense, again making wind removal more difficult. The effect of temperature too is quite marked in the spring, when a few hours of sunshine help form a crust over the snow which further reduces the possibility of snow redistribution by the wind.

In its response to topography, wind velocity can be accelerated, decelerated, caused to change direction, or made turbulent. Such response can be on a micro-scale, for example, being accelerated in passing between two small stones or on a macroscale, where it is forced between two mountain peaks or where a transverse ridge obstructs its flow and the wind spills over, much as water does over a dam.

Since the area's strong prevailing winds blow from the west, an east-west orientation of snow accumulation lines is imposed upon the landscape to the lee or eastward of barriers.

The density, height, phenology, and morphology of vegetation strongly influences the amount of snow to reach ground level. The alpine vegetation, regardless of its density was never tall enough to hold the amount of snow which fell upon it. Forest and shrub communities generally had sufficient height to retain snowfall, but their efficiency to trap and hold the snow varied many fold.

Snow Radioactivity - Environmental Correlations

Variable Name	Fall 1959 - Spring 1960		Fall 1960 - Spring 1961		Fall 1961 - Spring 1962	
	Means	Correlation Coefficients $\mu\mu\text{C per liter}$	Means	Correlation Coefficients $\mu\mu\text{C per liter}$	Means	Correlation Coefficients $\mu\mu\text{C per liter}$
Snow Precipitation (in gauge)	9.706	0.09333-	7.870	0.59344-	11.625	0.22940-
Snowdepth Red Snow Site	15.437	0.09923-	25.200	0.06616	18.437	0.27130-
Concentration Factor	1.145	0.10590-	19.232	0.15233-	1.696	0.14059-
Snow Stake	10.375	0.27221-	10.100	0.47816-	6.312	0.42081-
Miles of Wind	8013.437	0.35652-	9289.500	0.20813	7718.375	0.12773-
Wind (velocity miles per hour)	22.962	0.16873-	23.500	0.54701	22.05	0.05158-
MG Debris/liter	63.812	0.681843	45.400	0.73974	24.812	0.78856
PiC per liter	54.625		17.457		1678.312	
PiC per liter H ₂ O	168.000	0.05343	609.700	0.54129	3698.500	0.45882
PiC/M ³ Air	1.825	0.25422-	0.110	0.00566	9.212	0.07344
	(N = 16)		(N = 10)		(N = 16)	

Dense, mature spruce-subalpine fir stands intercepted a great deal of snow before it reached the ground but their pyramidal shape allowed snow to penetrate far down from the top of the tree where it was more difficult for the wind to blow it away and where much of it could slide on down to the ground. In direct contrast, pine stands, both Pinus flexilis and Pinus contorta, with their broadly conical or flat-topped crowns, intercepted comparatively greater amounts of snow near the top of the tree where the winds could blow it away or where it could vaporize. Deciduous trees and shrubs formed a distinctly different category in which the lack of winter leaves permitted nearly all of the snow to reach the ground level.

Though form of the trees and shrubs (along with their height and their needle or leaf persistence, arrangement, and number) played key roles in determining the amount of snow to reach ground level, density or spacing also influenced the retention of the snow at ground level. Open stands of widely spaced trees growing on wind exposed knolls, characteristic of Pinus flexilis stands, were swept free of snow during much of the year. In contrast, dense stands of spruce, alpine fir, or lodgepole pine reduced the wind velocity so that at most only minor local shifting, usually flattening of the snow mantle, occurred.

Debris in Snow:

As previously stated, strong winds frequently occur in above tree-line areas. These strong winds are able to transport relatively heavy soil particles (Healy and Fuguary, 1958). As the soil surface accumulates fallout directly via rain, snow, and dry processes, it becomes comparatively rich in fallout; consequently small amounts of surface soil increase the amount of radioactivity in the blowing snow.

A number of processes make surface soils available for erosion; but the activity of small burrowing mammals and needle ice activity (a frost phenomenon) are perhaps the two most important processes. Needle ice, found in some particular sites almost daily in the alpine country, causes crusts of soil to be shoved upward, exposing the soil to desicating winds and subsequent erosion.

Debris patterns within a snowfield depends upon the morphology of the snowfield and the manner and time of year in which it accumulates snow (Osburn, 1963). Concentrations of debris may occasionally run as high as 2 grams per liter of snow melt water, particularly during the fall of the year, when sharp increases in the average wind velocity are observed (and when dying vegetation supplements an already abundant amount of summer dust).

By approximately mid-April the melt rate exceeds the snow accumulation rate. As water percolates down into the snowfield, accumulated debris particles serve as adsorption surfaces for filtration of fallout materials from the water. The effectiveness of this snow incorporated debris in accumulating fallout was demonstrated a number of times.

Snow cores were secured from a number of snowfields and the amount of radioactivity above specific ground units was calculated. This was repeated a number of times throughout the summers of 1960, 1962, and 1963. In general, the snowfield retained nearly all of the gross beta radioactivity until the snow depth became reduced to only a few inches. The type of incorporated debris influences the retention of nuclides immensely. Sandy debris seems to adsorb only a small fraction while organic debris such as plant litter, algal cells, and the hyphae of fungus retain huge amounts of fallout nuclides.

In situations where huge amounts of snow are deposited on nearly barren, rocky substrate and (upon melting) large amounts of water are filtered by very small amounts of soil or organic materials, gross beta concentration may reach extremely high levels. Surface soil collected in 1963 from some such sites reached levels of 15,000 or more picocuries per gram. Thus, on a per square decimeter basis, this radioactivity exceeds 2 nanocuries. Occasionally minute sites (such as decaying debris-filled cracks in rocks or small erosion basins or "potholes" on rock surfaces) may reach nearly a millicurie per gram of surface litter.

Rainfall

Little data exists on the amount of rainfall which occurs in the mountains of the Colorado Front Range, particularly concerning the variability of rainfall within a single watershed. Therefore it was necessary to see how much fallout variation might be attributable to the variation in rainfall.

By using a table of random numbers and a gridded map of the watershed 50 points were selected to establish rain gauge sites. In placing the gauges in the field, an error of 200 yards radius from the selected point was allowed. It was believed that the points could not be located (by use of topography sheets of a 40 ft. contour interval and by aerial photos) with greater accuracy. Furthermore, this allowed enough subjective placement of gauges in forested stands so that they could be located in sites where the canopy appeared to be open enough not to intercept a significant amount of rainfall. As it turned out, the number of sites per

exposure (ridgetop, valley, north, and south slope) was roughly proportional to the area of each, i.e. 9 gauges on the ridgetops, 11 in the valleys and nearly 15 on each slope exposure.

One hundred number 10 cans (rain gauge) were paired at each site. One can had a small amount of oil added to keep the precipitation from evaporating. This can was used to measure the amount of rainfall. The other can, used to collect fallout, had a double layer of plastic bags inserted and no oil added. In this way the liquid sample could be washed from the plastic bag much easier and with less fear of nuclide loss or contamination of the sample than from an untreated can. A piece of $\frac{1}{4}$ " hardware cloth was bent downward about 2" and placed over the lip and down into the can. This was to keep out moths, millers, and butterflies, which according to Jarad Davis (personal communication) would result in higher estimates of fallout if they were allowed to enter the gauge. No precaution was taken to discourage birds from using the gauges as perch points, but possible contamination from this standpoint was thought to be small.

Twice during the summer the oil covered gauges were measured while the water and plastic bags from the other cans were collected and brought into the laboratory to be analyzed separately. The water was evaporated from each sample and the residue weighed, ashed, and counted for gross beta radioactivity.

In order to establish the reliability of the cans as rain gauges, a series of (10) cans were laid out in close proximity to a standard weather bureau 8" rain gauge at one ridge top station. Thus variation in rainfall inherent in the manner of measuring the precipitation was determined and found to be very small (plus or minus 0.10 inches during a two month period).

From the collected data several things resulted: the pattern and amount of rainfall distribution over the entire watershed was determined. The amount of gross beta radioactivity per liter of water, per milligram of debris, and per unit surface area was calculated.

Despite the generation of a distinct rainfall pattern from plotting the data (Figure 6) no correlation between the amount of precipitation, elevation, slope exposure, or debris associated with the rainfall proved to have statistical significance. This lack of correlation was possibly related to the influence of irregular deposition of local fallout from two nuclear tests only 600 miles to windward during the summer of 1962. Regardless, the pattern of rainfall was quite uneven

Figure 6. Map of the 1962 summer precipitation. Data are based on 50 sampling points.

Figure 6

which does substantiate previous field observations. As the amount of rainfall varied two-fold over the eleven square mile area it suggests that this irregularity could introduce significant variation in the pattern of fallout deposition.

Dry Fallout:

It has long been assumed that precipitation scavenging is responsible for nearly all delayed fallout deposition (Martell, 1959 and others). However, a number of investigators postulate that dry processes can be relatively important. Alexander (1962), suggests that as much as 30% of the fallout nuclides in some regions may be credited to dry fallout. Bergh, et al. (1961) reports that the amount of fallout in a Norwegian watershed cannot be totally accounted for by precipitation scavenging and credits turbulent deposition for making up the difference. Evidence obtained from four lines of research indicate that dry fallout may be a very important process in explaining the distribution of gross beta radioactivity in this region of the Rocky Mountains. Each line of evidence is presented separately.

In late May, 1958, several days after a heavy snowfall, a thin mantle of freshly deposited dust was observed on snowfields above timberline in the southern Rocky Mountains. Based on the average of three samples, the gross beta radioactivity deposited per unit area (9,500 picocuries/dec.²) was considerably greater than that brought in via snowfall during the entire spring months.

Again in the spring of 1963, after a series of strong south-westerly winds followed by a calm period, a film of reddish-brown dust was observed on the snowfields above timberline throughout the state of Colorado and much of Wyoming. Semi-quantitative samples of this dust were secured by placing a quadrat frame over the snow surface and scraping off the top 2-4 centimeters of snow. Samples were collected from approximately 25 regions extending from the mountains of southwestern Colorado northward into the Teton Mountains and Medicine Bow Range of Wyoming. In the alpine region of the Colorado Front Range, an average gross beta radioactivity of 5,000 piC/gram was measured (nearly 8,000 piC/dec²). Again, this level exceeded the amount reported to be deposited in Denver, Colorado, (25 miles eastward) during the full winter's precipitation.

The third line of evidence was obtained by the following experiment. In 1963 a battery of 13 large plastic containers were placed in a large clearing at 9,500 feet altitude. Each container was partly filled with distilled water. Six containers were kept open during the entire six week test period. Six of the containers were

closed during clear weather and the remaining six were closed only during periods of rainfall. Results are as follows:

1. Containers kept open for the entire test period yielded $6,970 \pm 341 \text{ piC/dec}^2$.
2. Containers open only during rainfall periods yielded $4,795 \pm 75 \text{ piC/dec}^2$.
3. Containers open only during periods of no rain yielded $1,562 \pm 71 \text{ piC/dec}^2$.

Even though this period had the most rain of any like period measured during 12 years of collecting environmental data at the site (by the University of Colorado's Institute of Arctic and Alpine Research) the dry fallout gauges had trapped approximately 28 percent of the total radioactivity to come down.

The fourth bit of evidence was secured from a single sample. During September of 1962, a small plastic gauge half-filled with distilled water was placed on the top of the Denison Laboratory building on the University of Colorado campus. After two rainless weeks, the distilled water was evaporated and the residue counted for gross beta activity. The level of radioactivity measured $2,332 \text{ piC/m}^2$, again indicating that dry fallout processes can contribute a material amount of fallout. Mechanisms of this dry fallout process are discussed below.

In the first two cases, portions of the brown dust samples were examined by Dr. Estella Leopold of the U. S. Geological Survey Paleontology Laboratories. One portion of the dust samples was treated with 5% boiling potassium hydroxide and flotated on zinc chloride solution. The organic fraction, composed entirely of pollen, was acetylated and a measured portion of it was in turn mounted on a slide with glycerine jelly. The pollen fraction contained over (1/3) of the total sample radioactivity in the first case and about (4/5) of the gross beta activity in the second instance. Taxonomic identification of the pollen indicated that it was not of local origin, but was largely produced by desert vegetation types. Many of the pollen particles were of Pinus or Quercus-Cercocarpus type genera, were adapted for long distance dispersal, presented proportionally to their weight an enormous sorption surface to encounter fallout particles, and had sections of the pollen surface containing sites which favor nuclide lodgement. Also, in the second case, the amount of time the dust remained aloft, that is, the distance it was actually transported, influenced the amount of radioactivity. The amount of gross gamma-beta radioactivity varied from $0.5 \text{ nanocuries per m}^2$ to $3.1 \text{ nanocuries per m}^2$. Composited samples from the mountains of southwestern Colorado and from the

Boulder City Watershed were sent to Hazelton Nuclear Science Corporation for nuclide determinations. The results, expressed as picocuries per gram, were as follows:

<u>Sample</u>	<u>Ce-144</u>	<u>Cs-137</u>	<u>Sr-90</u>	<u>Cs/Sr ratio</u>
S. W. Colorado	173	112	17	8.06
Boulder City Watershed	712	460	80	5.75

It would thus appear that the additional 200-300 miles of pollen transport washed considerably more nuclides from the atmosphere.

Distribution and Movement of Radioactive Fallout Materials in the Watershed Drainage System.

The pattern or arrangement of natural stream channels (drainage net) provides an indirect indication of the nature of the existing soil and surface conditions and other meaningful watershed conditions. If the basin is well drained (it is efficient) the time from precipitation contact with any point of the watershed to the outlet is shortened; hence this characteristic alone should receive considerable attention when considering pathways of fallout movement. The characteristics commonly considered in describing the drainage net are (1) order of streams, (2) length of tributaries, (3) stream density, (4) drainage density, and (5) length of overland flow. The drainage system of the Boulder city watershed when classified according to order of streams (number of bifurcations) is a very distinctive type of drainage pattern (Figure 7).

Designating all non-branching streams of the first order, one bifurcation denoted by second order and so on we find only three orders of watershed streams. The number of tributary streams of a given order per square mile of drainage basin is a function of the order of the tributaries. This drainage basin has approximately one first order stream per square mile of drainage, one second order stream per five and one half square miles and only one third order stream in the eleven square mile watershed. The first order streams drain the late-melting or perennial snowfields. The effectiveness of the first order streams in reducing the fallout concentration of the snow fields may be seen in Figure 7.

Figure 7. Down valley changes in gross beta radioactivity, early September 1962. The radioactivity of the water is expressed in picocuries per liter. The encircled numbers refer to the snowfield radioactivity while the numbers superimposed on the streams indicate the radioactivity at that point. Note the efficiency of the first order streams in reducing the amount of water radioactivity.

scale: 1:24000

1 mile

Figure 7

Because these late-lying snowfields supply approximately 95% of the late summer streamflow, their importance in fallout reduction can hardly be over-emphasized.

The length of tributaries indicates the steepness of the drainage basin as well as the degree of drainage. In general, the lengths of tributaries increase as a function of their order. Frequently, the meander distance to airline distance ratio reveals interesting information about a stream. This can be of particular significance to warming of water, amount of water lost by stream evaporation, and other conditions influencing filtration or cleansing of fallout from a stream system. The ratio of measured length to airline length of all the streams in the watershed is approximately 1.22, while that of the first order streams is 1.13. These ratio figures suggest rapid drainage, placing a greater burden on the fallout filtration mechanisms.

For this watershed the stream density is 1.4 streams per square mile and the drainage density (length of streams per unit area) is slightly larger than 1 mile per square mile area. The comparative sparseness of streams indicates that relatively little of the water is eliminated by over the surface flow.

The length of overland flow is the average distance travelled by water (if it flowed in a straight line) from the point where it fell as precipitation to the nearest point on a permanent stream channel and is obviously related to drainage density. The average length of overland flow is approximately 0.5 miles.

During the winter the surfaces of lakes and streams are frozen. This covering protects the water from fresh increments of fallout so the reservoir waters gradually decrease in radioactivity as nuclear materials decay, settling occurs and other filtration processes continue. In the spring the lakes rapidly increase in radioactivity. Most of this increase is from snow falling upon or near the ice-covered lake. This snow, because it contains seven or eight months of fallout accumulation, is much more radioactive than the lake water. The lake water activity drops rapidly when surface or nearby snow is melted and the lake begins to receive water via streams and subsurface seepage. However, several lakes are located in the higher watershed regions where the snow accumulates on adjacent barren rock, talus slides, or blockfields. These coarse materials effect little fallout filtration of passing water. The drainage basin gradient of water radioactivity during spring melting is thus characterized by a sharp down-valley decrease in water radioactivity, yet with each lake steadily increasing in radioactivity. Inlet stream radioactivity

progressively lessens until a midsummer shift in roles between the lakes and streams occurs. By late July, the lake begins to increase rather than decrease the radioactivity of the downstream water. The overall effect of the large reservoirs is to dampen the magnitude of the seasonal fluctuations of radiation level in the water released from the watershed.

Although the late-lying snowfields contain relatively high levels of fallout, they contribute little radioactivity to the lakes. Radioactivity is generally reduced rather drastically within a few inches of leaving the snow accumulation site, then is gradually reduced as the streamlet flows toward the nearest lake. The steepness of the reduction gradient depends upon the type of substrate and the distance from the snowfield to the lake. Since most perennial snowfields are situated relatively great distances from the lakes, streams draining these snowfields usually contribute much less radioactivity than that which enters associated with direct precipitation.

The effectiveness of fallout filtration processes in reducing radioactivity may be seen in Figure 8. The general mechanisms responsible for much of the reduction may be seen in the following section, a detailed study of several tundra pond ecosystems.

Figure 8. Data are expressed in gross beta radioactivity approximately 3 months after collection. The dramatic increase in radioactivity of the precipitation by resumption of atmospheric nuclear testing is quite evident in September, 1961.

Figure 8

Tundra ponds -

This study was conducted by David Jessup, a National Science Foundation summer research participant and this section is largely from his as yet unpublished data.

Ecological components of four Alpine pond basins adjacent to the Boulder city watershed were sampled weekly from June 22 to September 10, 1962 and analyzed for gross beta activity. See Tables I and II.

The most radioactive component was the snowfield $\mu\text{Ci/liter}$ of meltwater (32,800 $\mu\text{Ci/gm}$ debris, dry wt.) followed in decreasing order by algae, aquatic bryophytes, Limnephilus larva, terrestrial bryophytes, Aedes larva and pupae, Limnephilus pupae, bottom sediments, various terrestrial plants, surrounding soil, Copelatus, Pysidium, Oligochaeta worms, and tendipid larvae (0-1 $\mu\text{Ci/gm}$ dry wt.). Four components showed definite seasonal trends; caddis fly larvae (Limnephilus), pond water, and surface scum radioactivity fell markedly during the 12 weeks, whereas bottom sediment radioactivity rose slightly. Important differences existed in pond water and surface scum radioactivity of the four ponds, because of their different locations with respect to snow banks. Water radioactivity increased as the snow bank receded across the pond surface to the pond edge, but decreased after leaving the pond edge because of filtration of nuclides by surrounding soil and vegetation. Addition of nuclides via winds and precipitation compensated for the loss of radioactivity by decay, settling, adsorption, and absorption by the biota.

Mechanisms for the entrance of fallout materials into the ponds:

There are five plausible mechanisms for the entrance of fallout into alpine pond-ecosystems: (1) Direct precipitation onto the open surface of the pond, (2) runoff from surrounding areas, (3) seepage, (4) wind-blown debris and (5) melt-out of over-lying snowbanks. (1) Direct precipitation onto the open surface of the pond could be a very important source; however, the summer of 1962 was notable for its low amount of rainfall (only 3.0 inches, appreciably below the 9-year summer average of 5.7 inches). The average gross beta radioactivity of the entire summer's precipitation was approximately 1,200 picocuries/liter or 203,700 picocuries/meter² of pond surface area. Of course, evaporation could cause an increase of radioactivity of the pond water. (2) Runoff from surrounding areas was modified much as

Table 1.
Summary of Pond Characteristics

Characteristic	Van Pond	East Pond	Middle Pond	North Pond
Location	s.e. slope near crest of ridge	n. slope near base of ridge	n. slope near base of ridge	n. Slope near base of ridge
Type of basin	solifluction terrace	Glaciated depression	glaciated depression	glaciated depression
Type of drainage	seepage	open and seepage	seepage	seepage
Area	96.5 m ²	218.3 m ²	46.9 m ²	42.9 m ²
Surface-volume ratio	.69	.32	.39	.80
Date snow receded from pond	July 3	July 10	Before June 22	Before June 22
Surrounding soil - organic matter (by ignition)	36.1	65.2	65.2	65.2
Water - color	clear	clear	clear	colored (weak tea)
Water - gms residue/l	.0232	.0293	.0270	.0381
Water - % organic matter of residue (by ignition)	35.1	34.2	29.2	46.7
Water - surface temperature on Aug. 6, 1:00 PM	13 - 14°C	3 - 14°C	12 - 15°C	15 - 17°C
Water - gross beta radioactivity in picocuries - early August	12	6	8	20
Type of bottom	rock and mud	rock and mud	rock and mud	mud only
Bottom sediments - % organic matter (by ignition)	16.4	26.5	41.9	43.7
Biotic community				
Algae	present	present	present	present
Aquatic bryophytes	none	present	present	present

Characteristic	Van Pond	East Pond	Middle Pond	North Pond
Caddis flies, <u>Limnephilus</u>	present	present	present	vary rare
Midges, Tendipidinea	245/m ²	2774/m ²	2070/m ²	75/m ²
Annelid worms, Oligochaeta	6858/m ²	729/m ²	205/m ²	75/m ²
Clams, <u>Pysidium</u>	667/m ²	none	none	none
Mosquitoes, <u>Aedes</u>	rare	none	present	present
Beetles, <u>Copelatus</u>	present	present	present	rare

TABLE 2: Average concentration factors of pond components (the mean of the concentration factors measured each week). Concentration factor = $\frac{\text{uuc/gm dry wt of component}}{\text{uuc/ml of water}}$. Total number of samples for 12 weeks are given in parentheses.

Component	Van Pond	East Pond	North Pond	Middle Pond
Algae	88,637 (4)	160,491 (8)	45,597 (5)	168,393 (6)
Aquatic bryophytes		192,515 (11)	30,690 (2)	119,687 (5)
Caddis fly larvae, <u>Limnephilus</u>	54,619 (15)	28,807 (3)	5,393 (2)	22,645 (7)
Caddis fly pupae, <u>Limnephilus</u>	11,577 (3)	1,648 (4)		4,133 (7)
Midges, Tendipidinea		1,122 (2)	2,129 (1)	1,667 (1)
Annelid worms, Oligochaeta	1,997 (15)			
Clams, <u>Pysidium</u>	2,302 (9)			
Bottom sediments	2,662 (43)	11,744 (29)	1,947 (21)	6,727 (14)
Mosquitoes, <u>Aedes</u>	13,500 (3)		15,103 (4)	20,710 (8)
Beetles, <u>Copelatus</u>	1,999 (17)	3,143 (6)	1,017 (6)	3,005 (7)

previous research (Osburn, 1963) has shown; unless the water is flowing over barren rock, the fallout load is effectively removed by vegetation and soil, which acts as a physical and chemical filter. Undoubtedly the same process occurred in the ponds studied. (3) Seepage. Only dissolved materials are able to enter the pond by seepage; all particulate matter is probably absorbed by the surrounding soil and vegetation as described above. (4) Fallout particles are frequently closely associated with dust and other wind blown debris. This phenomenon may account partly for the activity of the surface scum noted at various times during the season. However, there is relatively little dust blown about in mid-summer (seldom more than 300 milligrams per liter of water was trapped in nearly 50 rain gauges distributed throughout the watershed in 1962). Thus debris contributed relatively small amounts of radioactivity to the water samples. (5) Not only does the process of eliminating plausible explanations indicate that the snow bank mechanism was by far the most important means for fallout to enter the ponds, but data also indicates it directly.

During the winter months, when the water in the ponds is frozen, snow banks accumulate in the pond basins. With the advent of warmer weather, the ice melts and the snow bank recedes back over the pond surface. As it recedes it releases debris, including dissolved and particulate fallout material directly into the water and onto the surface of the pond. The activity of the pond water thus gradually increases as the snow melts, until it attains a peak at the time the snow bank reaches the pond's edge. From that time on, most of the debris in the snow bank becomes filtered out of the meltwater before it reaches the pond. Consequently, the activity of the water decreases rapidly, because the addition of new fallout materials via wind and new precipitation is not enough to compensate for the loss of activity by decay, settling, adsorption, and absorption by the biota. The direct correlation between pond radioactivity and the surface area-volume ratios (Table 1) provided additional evidence to support the snow bank mechanism hypothesis.

Mechanisms for the removal of fallout materials from the pond water:

The radioactivity of the pond water, always much less than that of the surface scum and snow debris, decreased rapidly during the season. Certain factors must have been at work to remove nuclides from the water. Loss by seepage and outflow is not the answer, for this loss would likely have been balanced by seepage and inflow from above.

A good part of the loss must be attributed to the decay of short-lived nuclides, such as iodine-131, which is a common product of nuclear testing. Decay curves were kept for many of the snow and water samples, and the radioactivity of those samples taken during the peak of water radioactivity and counted for gross beta activity within a week after collection had decreased by 30 percent sixty days later.

The drop due to decay was not enough to account for the total drop in water radioactivity, however. The biotic community also removed some of the nuclides from the water. The primary producers of the pond, algae and moss, served especially well in this capacity. Nuclides were probably absorbed directly into the cells and bound with detritus to the plant surface (Williams and Swanson, 1958). The plankton producers were not measured directly for radioactivity, but several water samples were filtered through a number twenty plankton net before analysis, and these counted similarly to samples which had not been filtered. Thus, even though the small amount of plankton present might have had high nuclide concentration, it was not significant in comparison to the radioactivity in the water due to dissolved materials and particles or plankton small enough to pass through the net.

Caddis flies are important primary consumers in most tundra ponds. They climb over rocks and submerged sedge plants near the shore, scraping off the periphyton and constructing their cylindrical cases from cut sedge leaves and other vegetable matter. As would be expected, their radioactivity was quite high. Their rapid drop from nearly 4,000 to less than 100 picocuries per gram dry weight during the summer probably was a result of decay, decreasing availability of the nuclides, shedding of the exoskeleton during instar development, dilution by the increase in biomass as the animals grow (Pendleton and Hanson, 1958), and changing of habits (as pupation approached, the larvae began to construct their cases out of sand grains rather than vegetable matter). When pupation occurred there was another drop in activity. No adults were found. The fact that the caddis fly peak burden of radioactivity did not correspond with the peak for water radioactivity shows that these animals obtained their fallout loads somewhat independently of the condition of the pond water. This is a reasonable assertion as the caddis flies collected early in the season were found on the submerged Carex along the shore, which had already received a heavy deposit of radioactive debris from the melting

snow even though the snow was not yet completely removed from the rest of the pond.

The benthic detritus feeders, including oligochaetes, clams, and midges, as a group had low amounts of radioactivity throughout the summer. Most of the nuclides obtained by these organisms came from the bottom sediments, which were also fairly low in activity.

Occasional samples of mosquito larvae and pupae showed them to be intermediate in activity between the caddis flies and the benthic species. But the other free living species, the beetle, Copelatus, showed very low amounts of radioactivity. This beetle forms the highest trophic level in the pond, for it is supposedly exclusively carnivorous (Pennak, 1953). If caddis flies form a large part of the beetle's diet, then there must be a very high discrimination factor in the transition of nuclides from the preceding trophic level (Libby, 1957).

Thus it is seen that in the case of the ponds studied, there is a general decrease in activity from one trophic level to the next. This finding agrees with several authors (Williams and Pickering, 1961; Libby, 1957) who report a discrimination factor in the food web transfer. Other authors, however, (Ophel, 1963; Pendleton and Hanson, 1958) show that sometimes the higher trophic levels have the greatest concentration of radioactivity. Still others report both concentration and discrimination at various levels in the food chain (Minckley, et al., 1963; Ball and Hooper, 1963). There seems to be a great deal of uncertainty as to what generally takes place in the transfer of nuclides through the food web. Perhaps each situation is unique and depends on the balancing of a number of variables, such as the discrimination factor, the weight and kind of food ingested, the change in food habits as an organism matures, the types of nuclides available, the amount of nutrients available, the sources of nuclides outside the food web, and the specific nature of the organisms involved (Nelson, 1960; Davis, 1963).

One other mechanism accounted for the reduction in gross beta concentration of pond water -- adsorption by various organic and inorganic surfaces. Submerged sedge leaves, both living and dead, served as such a surface, for unwashed samples of this material showed much higher activity than washed samples. Still other fall-out particles adhered to detritus present in the snow and water and gradually sunk to the bottom. The rapid disappearance of cesium-137 from the water was probably due to this factor, as cesium-137 has been shown to be closely bound by detritus

(Williams and Swanson, 1958). This settling process added to the radioactivity of the bottom sediments at a slightly faster rate than decay and leeching removed radioactivity. Since nearly all the living organisms will eventually end up on the bottom also, it is expected that the bottom sediments will gradually increase in radioactivity over the years if fallout materials are made continuously available in the atmosphere (Williams and Swanson, 1958). This increase will probably proceed in a stairstep fashion due to the inactive period of the winter months, during which no new fallout is added. There will probably be no corresponding gradual increase in water radioactivity of the ponds, however, because each season's addition from the snowbank will be rapidly removed by the mechanisms just discussed.

The only organism found in the watershed drainage system which is in a food chain leading to man was fish (Salvelinus fontinalis and Salmo clarkii). As expected, the amount of radioactivity varied seasonally and in conjunction with a number of environmental situations. Of particular interest was a sample of about 25 brooktrout and native cutthroat caught from the same section of a particular stream in September of 1962. The flesh of the brooktrout averaged about 10.5 picocuries per gram wet weight while the flesh of the native trout averaged about 34 picocuries per gram wet weight. This would indicate, at least at this time of the year, each species was utilizing quite different sources of food. The gills of both species averaged about 25 picocuries per gram wet weight. It was anticipated that the gills would contain much higher levels of radioactivity as they present a large surface area in contact with nuclide laden water. However, some mechanism which mitigates against nuclide concentration seems to be in process. Perhaps the surface cells of the gill tissue are renewed at short intervals, or the fallout particles are continuously carried away by mucous. (Muncy, oral communication).

A detailed study of fallout distribution, conducted by Ronald Foreman, is nearing completion.

Fallout Interception and Retention Efficiencies of Alpine Vegetation

This section of the manuscript reports fallout concentrations found within three different types of alpine tundra vegetation at the end of the 1962 and 1963 growing seasons. It also attempts to relate their differential concentration to the responsible factors.

To collect the plant samples, $\frac{1}{4}$ meter² quadrat frames were placed subjectively within the three different plant communities, the plants were clipped at ground level, air dried in the laboratory, weighed, ashed, and counted for gross beta activity approximately eight months after the collection date. The amount of rainfall, amount of fallout, and length of growing season were recorded for each vegetation type. Direction of quadrat exposure was recorded for each sample.

The amount of fallout per unit area was determined by placing plastic-lined number ten cans adjacent to clipped quadrats, collecting the gauge contents twice during the summer, evaporating the water, and counting the residue in a Baird-Atomic proportional counter. Counter efficiency was established by sending a composited sample to Hazelton Nuclear Science Corporation for gross beta determination and specific nuclide analysis.

Examination of the picocuries per gram dry weight of plant material reveals distinct differences in the relative abilities of Kobresia myosuroides, Deschampsia caespitosa, Carex scopulorum communities to intercept and then retain fallout nuclides. This variation in fallout interception and retention efficiencies seems dependent not only on species and microhabitat characteristics, but also upon weather conditions, overall fallout levels, and especially the sequence of environmental events and the growth stage of plants during the summer growing season. Each of the three community types is discussed individually below. Although a number of other species occurred within the boundaries of these three community types, each community was dominated by only one plant species. As a minimum this species contributed at least 90 percent of the total clipped quadrat weight.

Kobresia myosuroides community

Kobresia plants vary from 5 to 35 centimeters in height and propagate centrifugally by developing short rhizomes. The center culms of older tussocks are commonly dead, black, broken off to a uniform level, and may be partially covered by liverwort or lichen growths. Each culm is stiff and slender and appears to have no special morphological aid for intercepting or holding fallout particles.

Kobresia plants begin growth in early spring, when the ground is nearly water-saturated, and can grow, flower, and fruit with little additional rainfall. Indeed, because of this early summer growing season, Kobresia plants intercept much of the late spring fallout. However, Kobresia's total productivity (plant yield per quadrat) is greatly influenced by the amount of summer rainfall. Also, as Kobresia cannot tolerate a winter snow cover, their distribution is limited to sites which expose them to the full force of the wind the year round. Wind thus may be an important influence whereby Kobresia plants either gain or lose fallout particles.

The overall Kobresia fallout collection efficiency was 29 percent in 1962 and only 8 percent in 1963 (Table 3). It is quite possible that this decrease in interception and retention efficiency between 1962 and 1963 was related to plant yield as this too showed a comparable decrease between years. However, when 1962 and 1963 quadrats of equivalent yields are compared, the 1963 efficiency is still reduced much less than that of 1962. Several explanations are possible. The type of fallout changed between years, the ability of Kobresia to intercept fallout changed between years, or the conditions under which the fallout was deposited and which existed afterward changed between years. The most plausible explanation contrasts weather conditions. Summer rains in 1962 were very light, only rarely greater than 10 millimeters per day, and merely moistened the vegetation without penetrating through the foliage. The total summer precipitation was less than 10 centimeters. In 1963, on the other hand, nearly 33 centimeters of rain fell during the summer, with approximately half of it coming in the month immediately prior to quadrat clipping. Average wind velocities were somewhat higher in 1962 than 1963, but wind is not postulated as having a major influence on the differential fallout accumulation.

Deschampsia caespitosa

Hairgrass (Deschampsia caespitosa) stands may be exposed to wind much of the winter, but generally snow cover is moderate to deep during the winter and spring months. Typical stands are snow free by mid-June, but some may stay covered until mid-August and occasionally remain snow-covered throughout the entire summer. Late season release from a winter snow cover tends to lessen growth compared to other stands. Thus, Hairgrass communities seem more dependent upon snow-

TABLE 3.

Vegetation Type	Year	Yield gram dry wt./m ²	Gross Beta Radioactivity		Fallout inter- ception & reten- tion efficiency	pCi/gram dry wt.	N
			in pCi intercep- ted & held per m ² vegetation	pCi/m ² fall- out during growing season			
<i>Kobresia myosuroides</i>	1962	122 ± 13	59,910 ± 6440	203,700	29.4%	501 ± 23	20
<i>Carex scopulorum</i>	1962	234 ± 27	48,419 ± 5,744	130,300	37.1%	215 ± 20	15
<i>Deschampsia caespitosa</i>	1962	190 ± 17	88,708 ± 15,467	115,400	76.8%	437 ± 37	25
<i>Kobresia myosuroides</i>	1963	64 ± 4	99,600 ± 10,800	1,216,950	8.1%	1600 ± 70	9
<i>Carex scopulorum</i>	1963	244 ± 40	212,000 ± 51,600	1,178,000	17.9%	800 ± 100	12
<i>Deschampsia caespitosa</i>	1963	176 ± 20	222,800 ± 25,600	1,069,700	20.8%	1300 ± 200	12

Comparison of Interception-retention efficiencies 1962-63

(Based on pCi/unit area)

(Based on pCi/gram dry wt.)

	(Based on pCi/unit area)			(Based on pCi/gram dry wt.)		
	1962	1963	% reduced efficiency	1962	1963	Increase factor
<i>Kobresia myosuroides</i>	29.4	8.1	72.5%	501	1600	3.20
<i>Carex scopulorum</i>	37.1	17.9	52%	215	800	3.7
<i>Deschampsia caespitosa</i>	76.8	20.8	73%	437	1300	3.0

melt water than summer rainfall, with even the best-drained sites maintaining a high soil moisture content during most of the growing season.

The dominant plant species Deschampsia caespitosa forms dense tufts which appear to be a closed canopy in mature stands. Leaves and flowering spikes are rather coarse, but do not appear to have other special characteristics such as stickiness or pubescent leaves which would favor fallout entrapment. The plants grow rapidly after snow cover removal and spread quickly, producing sturdy, but flexible and easily bent leaves. Total height varies but seldom exceeds 35-45 centimeters above timberline.

The 1962 hairgrass communities intercepted an average of 77 percent of the radioactive particles measured in the ground-level fallout gauges. The total radioactivity per $\frac{1}{4}$ meter² plot was $55,700 \pm 6,400$ picocuries. Regression analysis showed a gain of 4,000 picocuries gross beta activity for each ten-gram increase in dry weight of plant material. With few exceptions, on a comparative area basis, quadrats producing more than 60 grams of vegetation (dry weight) intercepted as much fallout as was measured in the gauges. The fact that several samples contained significantly more radioactivity than the ground gauge reading suggest that the plants almost surely gained some radioactivity via another mechanism. Perhaps it concerns filtering of fallout particles carried by the wind or uptake of nuclides from the soil.

In both 1962 and 1963, one sample of hairgrass quadrat ash counted approximately 100 times higher than any of the others. By shielding regions of the planchet, the radiation microsource was narrowed to one small point within the sample. The occurrence of such hot particles has been previously reported (Romney, 1963), although usually nearer to the Nevada test site.

In 1963 the fallout interception-retention efficiency dropped to 21 percent, similar to the reduction in the Kobresia stand. However, the dry weight yield in the hairgrass meadows approached 1962 values, thus tending to discredit community productivity changes as an explanation. Again it would appear that weather differences between the two seasons comprise the major factors explaining differential efficiencies.

Carex scopulorum community

The sedge, Carex scopulorum, grows in a wide range of habitats but forms dense stands in areas with abundant water. The most successful stands are

located at the base of late-lying snowfields. Though Carex communities can withstand winter snow cover, they are typically uncovered during most of the winter. The plants grow best when the ground is reasonably well-drained, but do tolerate standing water sites. The annual productivity of this community type may be consistently high when the site is irrigated by prolonged supplies of snow-melt water. Carex scopulorum culms are coracious with some surface hairs, but otherwise have no conspicuous fallout-collecting characteristics.

The total quadrat fallout collecting efficiency of this plant community lies between the Kobresia and Deschampsia averages. However, when equivalent weights of organic matter are compared, Carex scopulorum communities are much less efficient interceptors than other community types. Radioanalysis of hay from pika (Ochatona principis) storage piles adds another bit of evidence. Instances where the Carex comprised a major hay constituent were consistently less radioactive.

Although Carex scopulorum communities were less efficient fallout collectors in 1963 than in 1962, their efficiency reduction was much less than the other two communities. It is possible that the average fallout particle size in 1963 was smaller than in 1962, enabling the coracious leaves of the Carex to better retain fallout nuclides relative to the other two community types. More densely vegetated stands may also tend to be more efficient fallout interceptors during highly rainy periods. Lower leaves may indeed catch fallout nuclides which have blown or washed from upper leaves. And as these lower leaves are less subject to rain or wind erosional processes fallout tends to remain.

One further factor seems important. The amount of cesium-137 in the samples of all three plant types increased from 1962 to 1963. However, it increased in the Carex by a factor of nearly four, while it barely doubled in Kobresia and hairgrass. It was found that Carex can translocate cesium-137 from the leaves to overwintering buds. Evidence clearly demonstrates that in the 1962 samples a portion of the cesium-137 had been translocated from the leaves, producing a lower radiation count. Carex plants in 1963 had not progressed as far towards winter dormancy by the collection date as they had in 1962; consequently, they contained relatively more cesium-137 than they had the previous year.

Fallout radionuclide cycling in the Conifer forests:

Gross fallout cycling in forest ecosystems seems to be comparatively simple to follow. The sites of fallout concentration, their magnitude, and the mechanisms responsible for their pattern of distribution are revealed by comparing stands of lodgepole pine, limber pine, and spruce-fir. Sites of concentration may be related to portions of trees, individual trees, or to the trees acting as a group or stand unit.

In autumn, when the physiological activity of trees is low, a large number of samples were gathered from a number of spruce, fir, lodgepole pine and limber pine trees. Previous studies had revealed that windward sites tended to accumulate higher levels of gross beta activity than leeward sites so branches were systematically collected at various heights and from eight directions of each tree. Since the needles remain on the twigs a number of years and each year's growth is relatively easy to distinguish, the samples were divided into twigs and needles of several consecutive growth years.

Samples of freshly fallen, not noticeably decayed needles, were collected on the ground surface from each of the three forest community types and analyzed for radioactivity. Later, a portable beta monitor was used to measure the amount of radioactivity above and below the litter layer of several forest stands. An initial reading was made on the litter surface and a second measurement was then made after the litter and fermentation layer were removed. All in all, the levels of needle radioactivity were traced from the tree to the ground surface and into and below the fermentation layer (A_f) of each stand's soil horizon (See Tables 4 and 5).

Needles on the trees:

Several things seem evident from Tables 4 and 5. First, regardless of the tree species, the level of needle radioactivity increases from the younger to the older needles for several years, then essentially plateaus. This plateau simply reflects the position of the needles on the tree. The oldest needles appeared during the years of low atmospheric fallout; by the time heavier fallout deposits were occurring, these needles were located (because of branch growth) on the interior of the tree and thus were much less exposed to fallout.

Table 4: Gross Beta Activity of the Needles and Twigs Collected in Autumn, 1964
According to Species and Age Groups

(picocuries per gram dry weight)

<u>Year</u>	<u>Pinus flexilis</u>		<u>Pinus contorta</u>		<u>Abies lasiocarpa</u>		<u>Picea englemanni</u>	
	(limber pine)		(lodgepole pine)		(alpine fir)		(Engleman spruce)	
	Twigs	Needles	Twigs	Needles	Twigs	Needles	Twigs	Needles
1958	42	79	179	55				
1959	53	96	162	82	38	71		
1960	63	81	229	78	153	49	151	
1961	54	68	169	104	31	40	283	
1962	35	57	116	78	20	38	284	
1963	42	48	136	58	27	24	190	41
1964	30	31	64	20	17	8	62	38

Table 5: Gross Beta Activity Associated With Conifer Needles
(picocuries/gram dry wt.)

<u>Species</u>	On Tree		On Ground
	Needles	Twigs	3 yr needle fall
Limber pine	66	45	683
Lodgepole pine	68	150	619
Spruce	39	194	385
Sub alpine fir	39	47	

Comparisons of the needle radioactivity with the twig radioactivity of each species are particularly interesting. The needles of both pine species (Pinus contorta and Pinus flexilis) contained almost identical amounts of radioactivity, which were much higher than those of Englemann spruce and alpine fir, yet the twig radioactivity of the limber pine was much less than the lodgepole pine twig radioactivity. The difference is easily explained. Limber pine twigs are smooth while those of lodgepole pine are much roughened; thus the limber pine twig tends to lose fallout nuclides due to rain or wind erosion while the lodgepole pine tends to retain it. In the case of spruce and alpine fir, the needles of both species tended to have the same amount of associated radioactivity, but the amount retained by the twigs differed immensely. Again the smoothness of the twigs is apparently responsible. Fir twigs are relatively smooth, while spruce twigs are extremely roughened. The small woody projections at the base of the spruce needles (strigula) increase the surface area per unit weight of the twigs enormously, giving the twigs much higher radiation levels.

The difference in radioactivity between the needles of the pine, the spruce, and the fir trees is less readily explained. The pine needles are much longer but the needles of each tend to be somewhat cylindrical or flattened. Since all of the trees were located reasonably close to each other, they probably all experienced about the same amount of rainfall and wind. However, snow accumulation was consistently greater in spruce-fir forests than in pine forests. Field observations indicate that the clustering of pine needles allow them to hold much more snow than the smaller, less densely bunched needles of spruce and fir. Vaporization of greater quantities of snow may thus leave more radioactivity behind.

It is interesting to note that in spite of differences between the needle and twig radioactivity levels of lodgepole pine and spruce trees, when needle and twig measurements are composited on a dry weight basis, the total radioactivity compares quite closely between species. However, because the spruce needles were exposed to much more snow, it seems as if the lodgepole pine is a more efficient fallout interceptor than any of the other forest tree species.

Freshly fallen needles contained approximately eight to ten times more radioactivity than needles still on the trees, regardless of the tree species. This increase occurs for the following reasons:

TABLE 6

	Needles pCi/gram dry wt		Ground level gross beta radioactivity/dec ²	
	on tree	fresh fallen on ground	above fermen- tation layer	below fermen- tation layer
<u>Picea engelmannii</u> and <u>Abies lasiocarpa</u>	39 ± (50)*	358 ± (20)	12,240 ± (309)	8,120 ± (130)
<u>Pinus flexilis</u>	66 ± (50)*	683 ± (20)	10,460 ± (299)	4,928 ± (80)
<u>Pinus contorta</u>	68 ± (50)*	619 ± (20)	11,752 ± (194)	6,432 ± (72)

Data are expressed as mean ± one standard deviation and the number of samples in parentheses.

* n is a composite of 50 subsamples.

Needle fall

First, pine trees hold their needles much longer than fir or especially spruce. At the time of initial ground deposit, pine needles thus have accumulated much more radioactivity than spruce or fir needles. Once on the ground, needles gain radioactivity from melting snow, rainfall, and dry deposition. In general, snow-pack is heavier and longer-lasting in the spruce and fir sites than in the pine sites; consequently, the needles of the spruce and fir become compacted more densely. The small size and shape of the spruce and fir needles also aids compaction. In such snow-covered sites fungus is a primary participant in needle decay. The greater abundance of water in these high-altitude spruce-fir forest regions, even though soil temperatures are colder, hastens needle decay. In spruce-fir forests, excepting well-protected sites where deep layers of undecomposed needles can build up at the bases of large trees, more than one or two years accumulation of undecomposed needles is uncommon, whereas the general ground cover of the lodgepole pine forest usually has a three-year accumulation and the limber pine forest has a three to five year accumulation. The amounts of needles to fall in any one year are dependent upon

preceeding environmental factors, especially wind and drought. If wind velocities are low and soil moisture is abundant, needles tend to remain on the trees longer. Finally, as the needles decompose their surface area increases relative to their weight and they become more efficient for fallout entrapment.

Fermentation layer: (incorporation of nuclides into the soil)

The freshly-fallen needle group lies rather loosely on the ground surface and as it dries out quickly, it is little attacked by fungi. As the seasons pass, snow weight compresses the needles. Fresh layers of needles accumulate above them and act as a moisture-retaining mulch, and a dense web of fungal hyphae develops. Below this fermentation layer the material forms a light amorphous mass with proven efficiency in fallout nuclide retention. It is well established that peat soils act as ion exchangers with a high captive capacity (Bergh, et al., 1959). Comparative data which show the radioactivity both above and below the fermentation zone indicate that mechanisms to incorporate fallout into the soil are much more rapid in spruce-fir forests than in pine forests. Fallout nuclides are thus becoming concentrated (and will undoubtedly accumulate for a number of years) in these stands where mineral cycling is most rapid and are becoming available for root uptake by plants. The amount of plant fallout nuclide uptake via the soil has not been measured in stands such as spruce-fir forests where creeping root stock plants like Vaccinium spp. comprise the major ground cover. However, because plants such as watercress, growing in the relatively radioactive stream-side soil were found to have levels of fallout nuclide concentration much higher than could be explained by foliar deposition alone, these ground cover species are suspected of accumulating similar nuclide concentrations.

When data are expressed on the basis of a unit area of ground surface, the picture of needle radioactivity in relation to their nutrient cycling stage changes markedly. This change is due largely to the difference in annual needle fall of the various plant communities.

First, the annual needle fall was heaviest in the mature stand of spruce and fir (1,700 gms/m²), next in lodgepole pine (1,275 gms/m²), and then in limber pine (1,150 gms/m²). Quantitative comparisons cannot be made conclusively, but qualitatively these differences are readily explainable. The spruce-fir stand is generally much older, the trees are larger and their annual needle production therefore proportionally greater. The needle fall in a maturing stand of spruce and fir

can be expected to increase gradually and over a many year period. On the other hand, a lodgepole pine stand would be expected to show rapidly increasing needle production (and needle fall) for a few years, then as light penetration becomes limiting (insufficient light restricts growth of lower branches of lodgepole pine and eventually causes death) needle production would become limited to a rather narrow treetop region and the annual needle production would then stabilize at a lower level than in the spruce-fir stand.

In the case of the limber pine, the tree density is much less than in either the lodgepole pine or spruce-fir stands. Though fewer needles are produced per unit area of ground surface, two mechanisms compensate enough that the ground surface contains almost as many fresh needles as does the lodgepole pine stand. For one thing, needles are produced each year over almost the entire (ground level to treetop) periphery of the tree. Secondly, wind blows much of the ground winter snow cover away from the more open limber pine stand, leaving the needles uncompacted and with a reduced supply of water the following spring. Both conditions are unfavorable for needle decay. In fact, it takes about three to five years before the needles begin to be noticeably broken down. Thus, the "fresh fall" layer of needles on the ground surface is nearly the same in both limber and lodgepole forest stands.

Animals

Since the advent of nuclear fallout, volumes of information have been published concerning the distribution of fallout debris. Pathways of fallout contamination leading to man have been examined extensively and are reasonably well understood. In contrast to this, the concentration of fallout nuclides in wild animals has scarcely been studied. This section of the manuscript contains rather generalized radioecological information on the major vertebrate animals of the watershed.

During the fall months of 1962, 1963, and 1964 approximately 500 mammals and birds were collected. The numbers of each species collected did not reflect their proportion of the animal population of the watershed - merely the collection contained representatives of all the common vertebrates found within the study area. Most of the animals were sectioned into the following subsamples, fur or feathers, stomach, cheek pouch, crop, or gizzard content, pre-feces, cleaned-skinned body and remaining viscera. Each subsample was ashed and counted for gross beta radioactivity and expressed as picocuries per unit fresh weight.

In general, the amount of radioactivity contained in the various body components reliably reflected the food source, behavior, or habitat of the animals regardless of their taxonomic position. Relationships within and between groups often varied from year to year but a number of relationships were very consistent and a number of general categories could be readily distinguished. Predators such as the Ermine weasel and the wildcat had radioactivity concentrations of 7.5 and 6.5 picocuries per gram of flesh respectively while such grazing animals as pika (Ochotona princeps) and Microtus had concentrations of 78 and 28 picocuries per gram of flesh, respectively. The following list of birds and small mammals collected in 1963 is categorized according to their feeding habits. The gross beta radioactivity of the cleaned, skinned body (skeleton plus musculature) in picocuries per gram wet weight follows each animal named.

<u>PREDATORS AND SCAVENGERS</u>		<u>N</u>	<u>MEAN AND STANDARD DEVIATION</u>
<u>Mustela erminea</u>	Weasel	2	7.5
<u>Lynx rufus</u>	Bobcat	1	6.5
<u>Astur atricapillus striatulus</u>	Goshawk	1	7.0
<u>Pica pica hudsonia</u>	Magpie	1	7.0
<u>Falco sparverius</u>	Sparrowhawk	4	9.0 $\pm$ 4.1
<u>Bubo virginianus pallescens</u>	G. horned owl	1	4.0
<u>Corvus corax sinuatus</u>			
<u>Accipiter velox</u>	Raven	1	6.0
<u>Accipiter velox</u>	Sharpshin hawk	1	7.0
<u>SEED EATERS</u>			
<u>Tamiasciurus hudsonicus baileyi</u>	Pine squirrel	8	10.0 $\pm$ 3.6
<u>Spinus pinus pinus</u>	Pine siskin	3	11.0
<u>Spermophilus lateralis</u>	Ground squirrel	13	12.5 $\pm$ 5.0
<u>Nucifraga columbiana</u>	Clark's nutcracker	3	14.5
<u>Zonotrichia leucophrys</u>	White crowned		
<u>leucophrys</u>	sparrow	8	14.6 $\pm$ 9.3
<u>Peromyscus maniculatus</u>	White footed		
	mouse	2	15.5
<u>Eutamias quadrivittatus</u>	Chipmunks	23	15.2 $\pm$ 2.9
<u>AQUATIC INSECT</u>			
<u>Cinclus mexicanus unicolor</u>	Dipper	1	18.0
<u>Actitis macularia</u>	Spotted sandpiper	1	18.0
<u>GRAZERS</u>			
<u>Ochotona princeps</u>	Pika	27	78.0 $\pm$ 170
<u>Microtus pennsylvanicus</u>	Field vole	29	28.0 $\pm$ 10.3

INSECTIVORUS

<u>Myotis</u>	Bat	1	110.0
<u>Penthestes gambeli gambeli</u>	Chickadee	6	84.6 ± 8.9

Even though the sampling was extremely disproportionate, the observed differences were so great that it seems reasonable to accept these results as meaningful. The large standard deviation of the pika group is explained later in the text.

¹Scientific names after Miller and Kellogg (1955) for mammals and after Peterson (1941) for the birds.

In general, the radioactivity on a per gram weight basis remained the same for juvenile, sub-adult and adult animals or it tended to decrease slightly. This decrease is consistent with that noted by other researchers (Hanson, 1960). Since the body fat usually contained very low levels of nuclide accumulation it was postulated that the negative correlation between weight and picocuries per gram of radioactivity was related to a proportional increase in the amount of fat accumulated by the heavier animals.

The radioactivity of the skin and feathers of the different species of birds varied widely. Occasionally some correlation seemed to exist between the size of the bird and the picocuries per gram of skin and feathers. However, when the behavior pattern, especially that exhibited in searching for food, of each species is considered, the differences in skin radioactivity are revealed. For instance, birds that are strong active fliers and spend many hours a day in the air apparently wash out relatively large amounts of radioactivity. In fact, their skin radioactivity is very likely directly related to the amount of time (or amount of air passed through) spent in air. The following list of birds and their skin gross beta activity (piC/gram) is graded accordingly: bat (Myotis sp) (846); magpie, Pica pica hudsonia (118); goshawk, Astur atricapillus (66); pipet, Anthus spinoletta (37); sparrowhawk, Falco sparverius (31); and the great horned owl, Bubo virginianus pallescens (21). Birds which spend a large portion of their time searching among pine needles or among plants on the ground encounter and retain large amounts of fallout. Examples are red crossbill, Loxia leucoptera (250); chickadee, Penthestes gambeli gambeli (110); clark's nutcracker, Nucifraga columbiana (92); Canada jay, Perisoreus canadensis (90); Gray-headed junco, Junco caniceps (67); and the brown

capped rosy finch, Leucosticte australis (59).

Occasionally the amount of radioactivity in the flesh of some individuals of the same species was several fold above that of the average. Investigations into plausible explanations usually revealed some interesting ecological relations. In the case of the pika in 1963, four of the 27 animals collected showed relatively high body burdens of radioactivity. In each case it was found that the individual was a juvenile and that the particular colony from which the animal was collected was occupying a marginal site, usually one badly overgrazed. When the mother pika drives the juveniles from her care they must compete with the adult pika for territory-confirmed by Robert Krear (personal communication). Where the colony is over populated the young are relegated to very poor hay collecting regions. Examination of their hay piles usually show they contain relatively large amounts of a foliose lichen Parmelia conspersa. This lichen appears to be quite low in their preference as food material but it is collected to much greater extents when other types of forage are not available. These lichens present a constantly exposed surface to the atmosphere and have accumulated relatively large amounts of fallout radioactivity. As the radioactivity of the food source increases so does the body content of the pika.

In regard to pocket gophers (Thomomys talpoides) of unusually high burdens of radioactivity it was noted that both the flesh and the skin contained relatively high levels and that the individuals were usually juveniles. Upon close examination of the site from which they were trapped, two features were consistently associated. First, the number of plants with edible root systems such as Silene acaulis or Polygonum bistortoides were extremely scarce. Secondly, the clipping or grazing of above ground portions of plants had been extensive. It is theorized that juveniles driven from their mother's burrow system had been forced to occupy these less desirable areas and in turn must secure their food from above ground. Here the plant parts contained much more fallout materials and the pocket gophers in running through the vegetation accumulated fallout particles on their fur and by eating these more highly contaminated plant parts increased their burden of gross beta activity in both their flesh and fur.

Within some groups of animals the food collected in the cheek pouches or crops, within the stomachs, and within the intestinal tract, and within the flesh all had consistently high or low levels of radioactivity. This was interpreted as evidence that individuals within a particular species group had strong individualistic preferences. Additional evidence to substantiate this was gained by noting the crop

Exposure of organisms to radiation:

Every ecosystem of the watershed landscape seemed to contain some microsites of relatively high fallout concentration. Thus one would expect that organisms associated with these sites would be subjected to proportionally high dosages of irradiation. However, the intensity of this effect is modified by one of the following conditions which usually prevails:

1. Few organisms are usually present in these hotspot situations.
2. Organisms which do occupy these sites of high fallout concentration are extremely radioresistant.
3. Environmental factors tend to serve as an ameliorating mechanism when organisms are in their most radiosensitive stages. Each condition will be examined separately.

In general, sites which tend to concentrate high levels of fallout materials are locales which can support only a very few kinds of organisms. For instance, deep snow accumulation sites are the most radioactive of the entire watershed since these sites do not become snowfree until late summer and since few plants can tolerate such extensive periods of snowcover and short growing seasons, little vegetation other than highly radioresistant mosses, exists in these areas. Furthermore, few animals are found amid this scarcity of plants.

In addition to snowfield-associated areas, fermentation sites where litter is being converted to soil may have accumulated relatively large amounts of fallout. The most abundant plants in these layers of decaying litter are greatly radioresistant species like algae, fungi, and bacteria; likewise the most abundant animals are usually various species of mites which are also quite radioresistant.

Organisms also tend to be in their most radioresistant stages during periods of higher environmental radiation levels. For instance, mice, marmots, chipmunks, gophers, and ground squirrels may line their nests with fluffy plant material which, having a high ratio of surface to weight may retain a large amount of associated fallout nuclides. Yet these animals, likely born in the early summer, are older and represent a less radiosensitive age group, as well as some of the species being at the less radiosensitive hibernating stage (Godfroi, 1958).

Because they exist as seeds, are dormant or have depressed physiological activity, and show few regions of new growth, plants are generally relatively radioresistant in the winter.

During the spring, when concentration of fallout from melting snowfields is high, plants enter the most radiosensitive stages of their life history; (rate of all division increases sharply) seeds germinate, plants break dormancy, and new growth is resumed. However, their exposure to radiation is greatly reduced by particle and gamma ray absorption by the more abundant spring soil moisture. The top several inches of soil may easily contain over an inch of water that is capable of nullifying the penetration of beta and alpha particles and reducing the penetration of gamma rays immensely. Dry sites may well be subjecting organisms to more radiation than wet ones, even though the amount of radioactive material is far less in the dryer sites.

Even the small mammals, perhaps one of the most radiosensitive groups, receive less spring radiation exposure. Although nuclear debris from melting snowfields certainly could greatly contaminate the plant surfaces brushed against and eaten by small mammals, two factors seem to limit nuclide accumulation. The particles adhering to an animal's fur when it runs through contaminated vegetation may be greatly lessened due to the natural process of shedding. And, too, the spring diet of the animals would tend to shift from the old and contaminated plant food to younger, newly-developing, and less-contaminated plant foods. Many exceptions of course exist. For example, some animals may increase fallout intake burdens significantly by grooming and licking their fur. The more thoroughly the animal behavior is known, the easier it will be to predict the fallout concentration points.

Even though the advent of nuclear fallout is highly regrettable, the release of radioactive nuclides introduced a massive dose of tracer materials into natural ecosystems. If properly exploited by ecologists, these tracers can increase our knowledge of ecosystem dynamics in a way impossible by any other means or manner.

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SUPPLEMENTARY ANIMAL DATA

RADIOACTIVITY OF SOME ANIMAL SAMPLES

All animals collected 1 Sept. '63 and counted on 1 Nov. '64.

Radioactivity expressed in dpm/gram of ash.

Analysis by Hazelton Nuclear Science Laboratories, Palo Alto, Calif.

Animal & part	Gross beta	Ce-144 & Pr-144	Rn-106 & Rd-106	Cs-137	Sr-90 & Yt-90	Sb-125	Mn-54	Gross γ	* Total beta	%Fission accounted	Ash wt = % dry wt
Pika											
" body	1,531	48	104	40	603	--	--	200	795	52	6.26
" skin	1,566	182	248	137	174	18	28	686	787	50	1.71
" stomach contents											
Marmot											
" body	437	20	--	52	106	--	--	95	178	41	6.2
" skin	442	38	76	45	21	--	--	181	180	41	4.5
" stomach contents	3,352	554	360	163	290	74	118	1,854	1,559	47	2.9
Ptarmigan											
" body	642	18	76	14	194	--	--	85	302	47	6.2
" skin	1,146	162	139	54	176	20	17	434	568	50	3.4
" stomach contents											
" body organs	2,270	178	248	65	87	21	49	594	648	29	2.6

* From nuclide analysis

Distribution of Radioactivity and Weight Per Species

1962

<u>Name</u>	<u>N</u>	<u>Hide</u>		<u>Cleaned Body</u>		<u>Remainder</u>	
		<u>% Activity</u>	<u>% Weight</u>	<u>% Activity</u>	<u>% Weight</u>	<u>% Activity</u>	<u>%Weight</u>
Birds:							
White crowned sparrow	1	39.0	28.8	42.3	60.7	18.7	10.5
Junco	2	35.35	31.6	32.95	58.5	31.70	9.9
Mountain Bluebird	3	36.17	21.83	34.93	59.13	28.90	19.03
Ptarmigan	4	24.07	26.95	33.87	53.37	42.05	19.67
American pipit	2	32.80	26.2	33.75	57.30	33.45	16.5
Horned lark	1	48.2	22.5	28.1	61.0	23.7	16.5
Rosy finch	3	41.57	22.03	36.5	59.5	21.93	18.47
Animals:							
Chipmunk	3	24.77	24.63	55.10	60.60	20.13	14.73
Pine Squirrel	3	15.87	15.40	49.03	70.83	35.10	13.77
Pocket Gopher	14	18.61	20.67	50.66	57.79	30.73	21.54
White-footed mouse	9	18.33	17.24	39.92	50.89	41.74	31.87
Snowshoe Rabbit	1	17.9	17.5	22.0	34.4	60.1	48.1

Distribution of Radioactivity and Weight Per Species
1963

		Hide		Cleaned Body		Remainder	
<u>Name</u>	<u>N</u>	<u>% Activity</u>	<u>% Weight</u>	<u>% Activity</u>	<u>% Weight</u>	<u>% Activity</u>	<u>%Weight</u>
Birds:							
White crowned sparrow	8	42.06	21.21	33.04	59.54	24.9	19.25
Junco	8	48.37	23.79	41.11	63.41	10.51	12.80
Mountain Bluebird	3	36.33	24.13	29.07	58.4	34.60	17.47
Canada Jay	7	59.44	21.54	29.46	60.88	11.10	17.57
Pine Grosbeak	3	42.57	18.37	40.33	61.20	17.10	20.43
Pine Siskin	3	44.37	21.67	39.30	63.23	16.33	15.10
Ptarmigan	6	27.08	17.52	42.05	62.75	30.87	19.73
Sparrow hawk	3	39.60	22.50	43.43	59.33	16.97	18.17
Clark's Nutcracker	3	51.71	14.27	42.43	73.03	5.87	12.70
Robin	4	34.40	17.68	38.48	62.42	27.12	19.90
Woodpecker	2	35.80	18.45	47.20	72.1	17.00	9.45
Red Crossbill	1	77.5	19.2	19.1	72.7	3.4	8.10
Mtn. Chickadee	6	53.55	25.05	33.42	60.2	13.03	14.75
American pipit	3	48.27	29.97	36.80	52.77	14.93	17.27
Horned lark	2	47.90	28.10	31.50	52.55	20.60	19.35
Goshawk	1	72.7	22.7	25.4	70.7	1.9	6.6
American Magpie	1	79.5	22.6	14.2	64.3	6.3	13.1
Spotted Sandpiper	1	29.5	22.1	51.6	64.3	18.9	13.6
Wren Bewiks	1	33.5	22.1	43.0	66.1	23.5	11.8
Cassin's Finch	1	76.1	31.2	14.7	47.7	9.2	21.1
Pyrcer Ouzel	1	12.2	26.3	34.5	59.4	53.3	14.3
Rosy Finch	5	43.5	23.6	38.22	58.74	18.28	17.66
Townsend's Solitaire	1	38.8	15.6	39.1	62.1	22.1	22.3

Distribution of Radioactivity and Weight Per Species
1963

		Hide		Cleaned Body		Remainder	
<u>Name</u>	<u>N</u>	<u>% Activity</u>	<u>% Weight</u>	<u>% Activity</u>	<u>% Weight</u>	<u>% Activity</u>	<u>%Weight</u>
Animals:							
Chipmunk	23	21.70	17.05	51.15	61.21	27.15	21.74
Pine Squirrel	8	28.41	17.05	54.21	64.75	17.38	18.20
Pocket Gopher	11	13.94	20.15	48.77	50.04	37.29	29.81
Pika	27	10.33	15.12	50.57	54.63	39.27	30.24
Pack Rat	2	10.45	19.05	52.95	58.50	36.60	22.45
White-footed Mouse	2	21.2	17.0	45.15	55.0	33.65	28.0
Microtus	28	9.91	14.95	58.65	59.18	31.44	25.87
Red-backed vole	2	10.55	11.25	40.85	42.0	48.60	46.75
Bat	1	82.3	22.6	14.0	60.5	3.7	16.9
G.M. Ground Squirrel	13	16.78	17.79	51.41	57.80	31.81	24.41

Distribution of Radioactivity and Weight Per Species
1964

		Hide		Cleaned Body		Remainder	
<u>Name</u>	<u>N</u>	<u>% Activity</u>	<u>% Weight</u>	<u>% Activity</u>	<u>% Weight</u>	<u>% Activity</u>	<u>%Weight</u>
Birds:							
Mountain Bluebird	2	31.90	17.75	43.95	62.45	24.25	19.80
Canada Jay	1	14.6	14.1	40.9	66.0	44.5	19.9
Pine Grosbeak	1	14.3	10.6	68.6	74.3	17.1	15.1
Animals:							
Chipmunk	2	27.15	17.20	49.30	61.6	23.55	21.2
Pocket Gopher	5	14.94	17.32	59.28	65.54	25.78	17.14
Pika	7	12.93	15.99	59.80	67.81	27.27	16.20
White-footed mouse	16	21.79	22.51	55.67	55.73	22.54	21.76
Microtus	3	20.27	18.2	44.80	51.3	34.93	30.5
Red-backed vole	9	21.82	23.82	50.54	53.98	27.63	22.20
Common Shrew	2	14.85	24.05	54.65	46.75	30.50	29.20
Phenacomys	12	20.57	22.41	47.57	48.94	31.86	28.65

Comparisons of Several Characteristics of Field Mice:
Within and Between Various Types of Plant Communities

<u>Plant Community</u>	<u>025 White-footed Mouse</u>			<u>Correlation Coefficients</u>	
	<u>Weight</u>	<u>μpc/gram</u>	<u>N</u>	<u>μpc/sample</u> <u>μpc/gram</u>	<u>Weight</u> <u>μpc/gram</u>
01 Mature Spruce-Alpine Fir					
025 White-footed Mouse					
Totals	19.20	15.00	1		
Hide	6.01	12.00	1		
Cleaned Body	10.06	17.00	1		
Stomach Contents	0.56	18.00	1		
03 Limber Pine					
Totals	13.35	15.54	11	.68647	.02139
Hide					
Cleaned Body	14.24	21.0	1		
Stomach Contents					
07 Krumholtz					
Totals	20.8	19.0	3		
Hide					
Cleaned Body					
Stomach Contents					
09 Mature Kobresia					
Totals	13.91	14.08	12	.34387	.37163-
Hide	2.73	12.73	11	.71435	.25272
Cleaned Body	8.47	12.67	6	.55314	.50158-
Stomach Contents					
011 Gopher Garden					
Totals	12.43	15.04	26	.70242	.15995

025 White-footed Mouse (Cont'd)

<u>Plant Community</u>	<u>Weight</u>	<u>μμc/gram</u>	<u>N</u>	<u>Correlation Coefficients</u>	
				<u>μμc/sample</u> <u>μμc/gram</u>	<u>Weight</u> <u>μμc/gram</u>
013 Fellfield					
Totals	15.95	11.25	8	.77797	.38494
Hide	3.29	11.50	8	.74803	.08235
Cleaned Body	8.50	11.50	8	.84274	.48292
Stomach Contents	1.29	9.43	7	.80153	.43934
014 Geum-Sage					
Totals	14.07	11.71	7	.36738	.43126-
021 Mature Hairgrass					
Totals	17.26	13.50	10	.97161	.26128
Hide	3.49	12.00	10	.88653	.16545
023 Frost Scars					
Totals	14.67	13.89	9	.84660	.46249-
027 Sphagnum Moss Bog					
Totals	9.6	13.00	1		
Hide	3.03	8.00	1		
Cleaned Body	6.63	15.00			
033 Unknown					
Totals	17.27	11.75	4	.97905	.58718

Comparisons of Several Characteristics of Field Mice:
Within and Between Various Types of Plant Communities

037 Red Backed Vole

<u>Plant Community</u>	<u>Weight</u>	<u>μuc/gram</u>	<u>N</u>	<u>Correlation Coefficients</u>	
				<u>μuc/sample</u> <u>μuc/gram</u>	<u>Weight</u> <u>μuc/gram</u>
01 Mature Spruce-Alpine Fir					
Totals	13.03	16.83	30	.45890	.11894
Hide	2.11	16.07	30	.44104	.01741-
Cleaned Body	6.58	17.55	9	.70389	.16650-
Stomach Contents	.77375	28.75	8	.60187	.71962-
011 Gopher Garden					
Hide	2.26	14.00	1		
Stomach Contents	1.21	25.00	1		
021 Mature Hairgrass					
Totals	18.10	18.00	2		
Hide	2.42	10.0	2		

Comparisons of Several Characteristics of Field Mice:
Within and Between Various Types of Plant Communities

		<u>035 Microtus</u>			Correlation Coefficient	
<u>Plant Community</u>		<u>Weight</u>	<u>μuc/gram</u>	<u>N</u>	<u>μuc/sample</u>	<u>Weight</u>
					<u>μuc/gram</u>	<u>μuc/gram</u>
00	No vegetation					
	Totals	8.8	37.0	1		
	Hide	1.88	24.0	1		
	Cleaned Body	5.15	40.0	1		
03	Limber pine					
	Hide	3.12	28.0	1		
	Cleaned Body	9.78	45.0	1		
	Stomach Contents	1.00	33.0	1		
09	Mature Kobresia					
	Totals	19.30	10.0	1		
	Hide	2.79	10.0	1		
011	Gopher Garden					
	Totals	20.70	14.0	1		
	Hide	3.79	16.0	2		
	Cleaned Body	9.07	11.0	2		
	Stomach Contents	1.22	46.0	1		
014	Geum-Sage					
	Totals	15.8	17.0	1		
	Hide	2.59	24.0	1		
	Cleaned Body	8.11	13.0	1		
	Stomach Contents	1.33	18.0	1		
027	Sphagnum Moss Bog					
	Totals	12.10	15.5	2		
	Cleaned Body	6.94	18.5	2		

Comparisons of Several Characteristics of Field Mice:
Within and Between Various Types of Plant Communities

054 Common Shrew

<u>Plant Community</u>	<u>Weight</u>	<u>μuc/gram</u>	<u>N</u>	<u>Correlation Coefficient</u>	
				<u>μuc/sample</u> <u>μuc/gram</u>	<u>Weight</u> <u>μuc/gram</u>
01 Mature Spruce-Alpine Fir					
Totals	3.20	17.5	2		
Hide	0.915	13.0	2		
Cleaned Body	1.10	27.0	1		
Stomach Contents	0.23		1		
021 Mature Hairgrass					
Totals	3.00	21.0	2		
Hide	0.975	21.5	2		
027 Sphagnum Moss Bog					
Totals	3.9	16.5	2		
Hide	1.62	15.0	2		
Cleaned Body	2.285	18.0	2		
033 Unknown					
Totals	4.6	22.0			
Hide	0.79	14.0	1		
Cleaned Body	2.62	22.0	1		
Stomach Contents	0.26	23.0	1		

Comparisons of Several Characteristics of Field Mice:
Within and Between Various Types of Plant Communities

108 Phenacomys Pinter

<u>Plant Community</u>	<u>Weight</u>	<u>μμc/gram</u>	<u>N</u>	<u>Correlation Coefficient</u>	
				<u>μμc/sample</u> <u>μμc/gram</u>	<u>weight</u> <u>μμc/gram</u>
011 Gopher Garden					
Totals	11.70	13.00	1		
Hide	1.88	15.00	1		
Stomach Contents	1.74	22.0	1		
Cleaned Body	6.075	15.0	2		
014 Geum-Sage					
Totals	8.65	23.50	6	.47608	.13084
Hide	1.79	21.50	6	.53107	.04468
Stomach Contents	1.21	36.33	6	.95767	.31231
Cleaned Body	4.07	21.17	6	.92099	.21360-
023 Frost Scars					
Totals	10.00	26.00	2		
Hide	2.49	25.00	2		
Stomach Contents	1.04	25.50	2		
Cleaned Body	4.73	30.00	2		
024 Carex Scop.					
Totals	10.80	17.00	1		
Hide	3.85	14.00	1		
Cleaned Body	7.03	19.00	1		
033 Unknown					
Totals	10.75	21.50	2		
Hide	2.02	20.00	2		
Stomach Contents	1.30	22.00	2		
Cleaned Body	5.41	21.00	2		

NUCLIDE ANALYSES

1963 Nulcide Analyses
Activity Corrected to 11/1/64
dpm/gram ash wt.

Sample # & Kind	gross beta	gross gamma	Ce-144	Sb-125	Ru-106	Cs-137	Mn-54	Sr-90*	Total**	% gross explained	Cs/Sr ratio
1 Marmot body	437.5	94.9	10.1	ND	ND	52.2	ND	53.2	178.8	41	1
2 Marmot hide	441.9	178.9	19.2	ND	37.9	44.7	ND	10.7	169.6	39	4.2
3 Marmot stomach con.	3,956.0	1,877.6	280.2	75.1	182.3	165.4	119.8	145.1	1,575.5	40	1.1
4 Pika body	1,531.4	200.1	27.3	ND	51.9	39.7	ND	301.5	801.1	52	0.1
5 Pika Hide	1,566.0	680.9	90.3	17.9	123.0	135.6	27.4	87.0	781.5	50	1.6
6 Ptarmigan hide	1,146.1	418.5	80.6	20.1	69.3	54.1	17.0	88.0	567.0	50	.6
7 Ptarmigan body	642.6	85.8	8.8	ND	37.5	13.6	ND	97.2	300.6	47	.1
8 Ptarmigan organs	2,256.7	590.6	89.0	21.0	119.6	65.1	48.4	43.5	638.7	28	1.5
12 Carex scap	9,975.3	6,547.0	1,235.3	248.2	508.8	475.9	318.2	75	5,081	51	1.7
13 Kob.	25,244.0	8,931.0	1,933.1	262.7	743.5	811.6	610.9	1,788	10,606	42	.45
14 Hairgrass	13,103.0	6,464.0	1,281.2	193.4	544.4	588.2	380.4	478.0	5,789.2	44	1.2
15 Sphagnum mound (L.W. Bridge Bog)	8,871.0	4,316.0	631.0	145.0	487.0	780.0	175	413.5	4,163.0	47	1.9
16 Sphagnum depression	5,122.0	2,095.0	340.0	56.0	284.0	398.0	73	85	1,945.0	38	4.7
17 Sphagnum mound (Big Lake Bog)	17,640	9,721.0	1,486	365.0	1,086	1,295	451				
18 Sphagnum depression	22,369	11,429.0	1,979	448.0	1,234	1,328	534				
19 Sp-for soil	1,259	456.0	75	17	63	102	12	37	481	38	2.8
20 Kobresia soil	866	306.0	57	12	50	54	15	25	345	40	2.2
21 Imm. lodgepole pine	1,270	397.0	73	16	53	93.3	15	44	464	37	2.1
22 Aspen soil	938	288.0	62	14	41	57	13				
23 Mat. L.P. pine soil	1,240	389.0	66	13	54	88	11	49	450	36	1.8
24 Old carex	12,685	8,829.0	1,409	246	716	622	396				
25 New carex buds	3,317	2,269.0	314	ND	ND	241	130				
26 Fish guts	1,683	674.0	44	ND	208	101	36	32	705	42	3.2
27											

Sample # & Kind	gross beta	gross gamma	Ce-144	Sb-125	Ru-106	Cs-137	Mn-54	Sr-90*	Total**	% gross explained	Cs/Sr ratio
28 Fish stomach contents	3,257	4,071.0	285	ND	ND	257	300	7.86	1,143	35	32.7
29 Fish body	310	87.0	ND	ND	45	45	ND				
30 Water sample	3,570		47.4	242	541	73.7	29.9	227	1,976.4	55	0.31

* Corrected to 1-28-65

** Includes contribution by radioactive daughts

SUPPLEMENTARY SNOW DATA.

Snow Radioactivity - Environmental Correlations

Variable Name	Fall 1959 - Spring 1960		Fall 1960 - Spring 1961		Fall 1961 - Spring 1962	
	Means	Correlation Coefficients $\mu\text{C per liter}$	Means	Correlation Coefficients $\mu\text{C per liter}$	Means	Correlation Coefficients $\mu\text{C per liter}$
D-1 Snow Precipitation	9.706	0.09333-	17.870	0.59344-	11.625	0.22940-
Snowdepth Red Snow Site	15.437	0.09923-	25.200	0.06616	18.437	0.27130-
Concentration Factor	1.145	0.10590-	19.232	0.15233-	1.696	0.14059-
C-1 Snow Stake	10.375	0.27221-	10.100	0.47816-	6.312	0.42081-
Miles of Wind	8013.437	0.35652-	9289.500	0.20813	7718.375	0.12773-
MPH Wind	22.962	0.16873-	23.500	0.54701	22.05	0.05158-
MG Debris/liter	63.812	0.681843	45.400	0.73974	24.812	0.78856
$\mu\text{C per liter}$	54.625		17.457		1678.312	
$\mu\text{C per liter H}_2\text{O}$	168.000	0.05343	609.700	0.54129	3698.500	0.45882
$\mu\text{C/M}^3$ Air	1.825	0.25422-	0.110	0.00566	9.212	0.07344
	(N = 16)		(N = 10)		(N = 16)	

Snow Radioactivity - Environmental Correlations

Fall 1960 - Spring 1961

Sampling Interval	D-1 Snow Precipitation	Red Snow Site Snow Depth	Conc. Factor (a)	C-1 Snow Stake	Miles of wind	mph wind	mg debris per liter	μuc per liter	μuc per liter H ₂ O (b)	μuc per m ³ air (c)
31 October-										
20 November	6.5	36.0	11.69	6.0	12,582	26	43.0	29.90	< 730	0.10
21 November-										
30 November	0.1 (e)	0.5 (d)	10.00	0.0	7,128	30	147.3	32.43	< 1750	0.12
1 December-										
17 December	4.0	103.0	25.75	10.5	9,115	22	22.0	18.86	< 350	0.10
17 December-										
31 December	6.0	45.0	7.50	7.0	9,627	29	33.0	13.57	< 1167	0.10
1 January-										
14 January	0.1 (e)	13.0	130.00	0.0	6,828	20	49.6	11.27	< 350 (g)	0.11
14 January-										
31 January	5.0	0.5 (d)	0.20	7.0	11,238	28	117.8	25.07	< 350 (g)	0.11
1 February-										
18 February	4.5	24.0	5.33	7.0	9,400	22	8.5	14.72	< 350	0.11
18 February-										
18 March	21.0	22.0	1.05	36.0	14,365	21	13.8	13.57	< 350	0.11
19 March-										
31 March	10.0	8.0	0.80	3.0	4,696	15	19.0	15.18	< 350	0.13
1 April-										
15 April	21.5	----	----	24.0	7,916	22	----	----	< 350 (f)	0.11

- (a) Concentration factor = $\frac{\text{D-1 snow depth}}{\text{Red snow site snowfall}}$
- (b) Cheyenne, Wyoming gross beta (Laboratory measurement)
- (c) Denver, Colorado gross beta (Laboratory measurement)
- (d) trace of snow recorded

- (e) recorded as 0.0 on data sheets, 0.1 substituted
- (f) Denver, Colorado gross beta (lab. meas.)
- (g) interpolated consistent with Cheyenne, Wyoming data before 1 Jan. 1961 and after 31 Jan. 1961.

Snow Radioactivity - Environmental Correlations

Fall 1961 - Spring 1962

Sampling Interval	Snowfall (inches)	Accum. Snow Depth (in.)	Conc. * Factor	C-1 Snow Stake(in)	Miles of Wind	X mph wind	mg debris per liter	μuc per liter	μuc per liter H ₂ O **	μuc per m ³ air **
1-6 Sept	15	44	3.00	6			76	15		
6-26 Sept	34	29	0.85	6			69	1839		
26-30 Sept	6	22	3.67	1			34	1741		
30 Sept-14 Oct	8	4	0.50	0			88	4488		
14-31 Oct	6	16	2.67	6.5			26	1314		
31 Oct-18 Nov	10	48	4.80	17			11	2553		
18-30 Nov	6	3	0.50	0			59	3755		
30 Nov-16 Dec	8	5	0.62	8.5			9	1946	3200	13.1
16-31 Dec	14	42	3.00	8			6	758	3200	16.4
31 Dec-13 Jan	19	48	2.63	13	7,298	23.0	7	524	600	11.6
13-31 Jan	12	6	0.50	7+	10,940	25.0	19	976	600	13.6
31 Jan-20 Feb	14	14	1.00	2+	12,854	27.0	5	1231	350	7.5
20-28 Feb	10	5	0.50	9	3,891	20.0	3	612	1300	4.3
28 Feb-17 Mar	12	13	1.08	7	8,500	20.5	12	774	1200	7.0
17-31 Mar	3	6	2.00	8	6,975	20.5	15	1401	1200	6.8
31 Mar-6 Apr	5	7	1.40	5	2,295	15.5	13	1574	870	6.7
6-30 Apr	19	27	1.42	3+	9,695	17.0	21	1367	870	5.7

* concentration factor = $\frac{\text{accumulated snow depth}}{\text{depth of snowfall}}$

**Denver
gross beta
laboratory measurement

SPRING SNOW SURVEYS

Community Type	1962 Snow Depth			1963 Snow Depth			1964 Snow Depth		
	N	x ± s/	√N	N	x ± s/	√N	N	x ± s/	√N
Mature Spruce Fir	22	62.9 ± 5.2		241	39.5 ± 1.6		60	78.6 ± 1.0	
Immature Spruce Fir	12	35.2 ± 4.4		57	23.2 ± 1.4		66	59.7 ± 0.7	
Mature Lodgepole Pine	11	44.5 ± 2.1		9	16.3 ± 3.9		87	50.6 ± 0.7	
Immature Lodgepole Pine	--	-----		--	-----		55	42.4 ± 1.0	
Limber Pine	--	-----		45	5.8 ± 1.3		98	34.4 ± 1.2	
Sphagnum Bog	--	-----		64	15.4 ± 2.9		53	50.5 ± 1.2	
Mature Kobresia	16	18.4 ± 3.7		180	1.3 ± 0.2		--	-----	
Immature Kobresia	10	15.9 ± 4.6		27	12.0 ± 3.2		--	-----	
Fellfield	65	42.7 ± 6.3		153	0.2 ± 0.02		--	-----	
Snow-Black-Fellfield		*		144	10.5 ± 1.5		--	-----	
Buttercup-Geum-									
Sage-Sobbaldia	53	75.4 ± 10.1		261	44.3 ± 2.3		--	-----	
Mature Hairgrass	--	-----		45	67.4 ± 2.9		--	-----	
Immature Hairgrass	38	36.3 ± 3.4		98	31.7 ± 2.4		--	-----	
Carex Scopulorum	17	20.0 ± 4.8		63	29.6 ± 3.2		--	-----	
Carex Pyrenaica	11	204.8 ± 25.8		--	-----		--	-----	
Black-headed Carex	10	202.2 ± 19.6		10	188. ± 8.0		--	-----	
Geum-Sage-Parrys									
Clover	26	24.5 ± 4.1		198	10.9 ± 0.9		--	-----	
Parrys Clover	34	30.8 ± 3.5		--	-----		--	-----	
Terrace Lip	--	-----		72	32.8 ± 4.2		--	-----	
Scree, talus, crevice <u>et al.</u>	18	14.0 ± 1.6		8	41.4 ± 6.3		--	-----	
Polygon		**		189	10.1 ± 0.7		--	-----	
Gopher Garden	--	-----		45	6.6 ± 1.6		--	-----	
Gravel Mulch	--	-----		27	0.5 ± 0.0***		--	-----	
Marsh Marigold	--	-----		18	36.1 ± 2.9		--	-----	

* Included in Fellfield

** Included in scree et al.

*** All samples 1 inch of snow

SILVER LAKE SNOW COURSES

Snow INCREMENTS In Inches

	Dec-Jan	Jan-Feb	Feb-Mar	Mar-Apr	Apr-May
<u>1955-1956</u>					
Immature Spruce Fir	+ 19.7	+9.7	+1.8	-13.8	----
Lodgepole Pine	----	----	----	----	----
S-F minus Lodgepole	----	----	----	----	----
<u>1956-1957</u>					
Immature Spruce Fir	+ 16.3	+3.8	+39.4	+ 1.4	+ 14.7
Lodgepole Pine	----	-1.2	+32.8	-12.7	----
S-F minus Lodgepole	----	5.0	6.6	14.1	
<u>1957-1958</u>					
Immature Spruce Fir	+ 10.8	+3.1	+23.0	+ 13.4	----
Lodgepole Pine	+ 12.0	-0.7	+14.1	+ 1.0	----
S-F minus Lodgepole	-1.2	3.8	8.9	12.4	----
<u>1958-1959</u>					
Immature Spruce Fir	+ 17.5	+18.2	+ 2.3	+ 0.0	----
Lodgepole Pine	+ 4.3	+ 9.6	+ 9.5	-10.4	----
S-F minus Lodgepole	13.2	8.6	-7.2	10.4	----
<u>1959-1960</u>					
Immature Spruce Fir	+ 2.7	+18.7	+11.5	-7.7	-26.5
Lodgepole Pine	+ 3.3	+12.1	+ 4.6	-12.8	----
S-F minus Lodgepole	-0.6	6.6	6.9	5.1	----
<u>1960-1961</u>					
Immature Spruce Fir	+ 3.5	+12.2	+11.2	+ 6.4	-32.5
Lodgepole Pine	+1.9	+ 8.4	+ 6.9	-4.2	----
S-F minus Lodgepole	1.6	3.8	4.3	10.6	----
<u>1961-1962</u>					
Immature Spruce Fir	+17.2	+16.6	+ 1.8	-17.1	-28.4
Lodgepole Pine	+13.8	+ 9.5	+ 0.9	-15.0	----
S-F minus Lodgepole	3.4	7.1	0.9	-2.1	----
<u>1962-1963</u>					
Immature Spruce Fir	+24.5	+14.3	-6.1	-7.7	-26.2
Lodgepole Pine	+14.9	+13.5	-2.3	-18.4	----
S-F minus Lodgepole	9.6	0.8	-3.8	10.7	----
<u>1963-1964</u>					
Immature Spruce Fir	+2.2	+12.5	+ 9.3	+ 0.1	-40.6
Lodgepole Pine	+3.5	+10.0	+ 7.0	-2.8	-30.1
S-F Minus Lodgepole	-1.3	2.5	2.3	2.9	-10.5
<u>1964-1965</u>					
Immature Spruce Fir	+26.5	-6.9	+18.8	-5.2	-30.1
Lodgepole Pine	+20.4	-5.0	+12.4	-2.8	-31.2
S-F minus Lodgepole	6.1	-1.9	6.4	-2.4	1.1

GROUND SURFACE GROSS BETA RADIOACTIVITY

GROSS BETA ACTIVITY AT GROUND SURFACE FOR VARIOUS PLANT COMMUNITIES

Mic's Data

Plant Community	Constant	N	CAP Condition*	Snow Cover	Litter Layer	Penetrometer Mean	Penetrometer Std. Dev.	WMC	Wetness	Year
01 Mature Lodgepole Pine	1.00	100	1		8.75	687.10	247.57	1752.42	4.90	1964
	0.51	19	2		8.32	718.90	238.63	3386.63	4.89	1964
		17	4		9.18	803.53	266.70	1768.24	4.88	1964
	1.25	30	1		19.33			2164.27		1963
	2.00	12	1					972.00	2.00	1964
	1.00	40	1		12.05			1557.02	4.87	1964
		18	3		9.50	777.22	262.17	1099.61	4.89	1964
		14	7					918.75		1963
	1.00	56	1		8.00	846.43	259.59	2091.18	No reading	1964
	1.00	18	5					3147.75		1963
	0.51	10	2	4.6	14.40			3088.00	4.70	1964
		12	4		12.00			1870.50	4.50	1964
		12	3		12.00			1115.00	4.50	1964
	0.65	16	6		20.00			3498.00		1963
02 Immature Lodgepole	1.00	150	1		19.69	928.87	297.35	1429.08	4.95	1964
	0.49	30	2		22.70	877.33	262.33	3028.00	5.07	1964
		29	3		23.45	884.48	266.14	764.52	5.03	1964
		29	4		23.45	884.48	266.14	1041.41	5.03	1964
	1.00	46	1		4.89			2220.54		1963
	1.00	40	1		18.82			1510.12	4.87	1964
	1.00	14	1		19.50	21.75		1984.75	6.00	1964
		13	3					986.00		1963
	0.49	18	2		17.62			3031.25	4.62	1964
		12	4		11.50			2112.50	5.00	1964
	1.00	20	5		15.10			2280.15		1963
	0.49	13	6		10.38			3896.46		1963
		12	3		11.50			1288.50	5.00	1964
03 Spruce-fir	1.50	42	1		5.09	961.43	251.95	1441.83	2.83	1964
	1.25	207	1		10.94	745.75	279.23	1580.04	4.37	1964
	0.65	50	2		11.00	761.20	264.20	3309.50	4.40	1964
		40	3		13.60	780.50	260.30	985.25	4.40	1964
		36	4		14.72	798.06	268.03	1514.86	4.47	1964
		12	3		7.50			1068.50	4.00	1964

Plant Community	Constant	N	CAP Condition	Snow Cover	Litter Layer	Penetrometer Mean	Penetrometer Std. Dev.	µmc	Wetness	Year
03 Spruce-fir	1.00	15	1		20.00			3181.80		1963
	1.51	16	1	29.44	8.37			1303.94	2.81	1964
	1.25	44	1	6.82	13.61			1534.07	4.50	1964
	1.25	55	1	45.25				1938.40	No readings	1964
	0.49	10	2	5.00	9.90			2668.10	4.20	1964
		12	4		7.50			1557.00	4.00	1964
	1.00	39	5	44.82	24.61			3771.92		1963
04 Limber (9,780-9,970 ft) Limber (10,880-18,890)	1.00	100	1		13.30	851.48	272.52	1380.04	5.40	1964
	1.00	99	1		5.81	964.75	330.91	1348.01	5.18	1964
	0.49	40	2		7.97	1005.75	316.57	2611.67	5.52	1964
		19	3		16.26	1182.10	383.95	849.68	5.42	1964
		19	4		16.26	1182.10	383.95	1232.16	5.42	1964
	1.00	39	1		13.43			1667.87	5.59	1964
	1.00	19	1	17.33				1481.44		1964
	1.00	50	1					2515.42		1963
	0.49	10	2		7.60			3041.20	5.40	1964
		12	4		8.50			1814.00	6.00	1964
	0.49	14	5	30.36	17.50			2674.64		1963
		12	3		8.50			1222.50	6.00	1964
05 Aspen	1.00	49	1		15.04	716.12	215.57	1500.88	4.63	1964
	0.49	10	2		13.70	709.00	231.20	3061.20	4.50	1964
		18	3		17.12	822.50	245.00	925.00	3.75	1964
		17	4		16.43	897.14	257.43	1488.57	4.57	1964
	1.00	20	1					2190.15		1963
	1.00	36	1		12.75			2670.94		1963
	1.00	40	1		22.15			1607.60	5.00	1964
	0.49	18	2		39.12			3275.00	5.00	1964
		12	4		17.50			1604.00	5.00	1964
	0.49	17	6		2.86			4347.28		1963
		12	3		17.50			1184.00	5.00	1964

Plant Community	Constant	N	CAP Condition *	Snow Cover	Litter Layer	Penetrometer Mean	Penetrometer Std. Dev.	$\mu\mu c$	Wetness	Year
06 Mature Kobresia	1.00	73	1					2981.34	No readings	1963
	2.00	14	1					1140.36	2.00	1963
		14	1					1415.21	4.43	1963
	1.00	154	1	4.73	0.065	1652.92	417.38	1408.33	4.71	1964
	1.20	60	1	1.62		1908.67	407.07	1236.90	3.00	1964
	1.00	45	1					2163.40	No readings	1964
	0.49	42	2	3.19		1488.33	370.81	2407.57	4.48	1964
		32	6					2369.12	2.81	1963
		28	5					1466.89	3.21	1963
07 Fell Field		75	1	4.19				2394.36		1963
		274	1	1.22	0.28	1663.87	379.20	1321.67	4.65	1964
		50	2	0.08	0.50	1388.80	312.14	2357.16	4.88	1964
		15	6					2210.00		1963
08 Juncus		12	1		6.75			4361.42	1.83	1963
		32	1		6.31			3608.12	4.34	1964
		16	2		11.17			9449.33	4.50	1964
		11	3		25.00			2832.00	5.00	1964
		11	4		25.00			6306.00	5.00	1964
		27	5					7231.67		1963
		11	7					4698.00		1963
00 No vegetation (snow cover more than 8½") No vegetation		14	1	84.00				3081.25		1963
		12	2	69.00				1205.50	6.00	1964
09 Moss		12	1					1342.00		1963
		19	1	20.84				1320.74	3.42	1964
		15	2	39.60				2458.80	3.40	1964
		50	5					4629.58		1963
		13	6					3970.69	0.84615	1963
10 Primula Parryi		14	2					2059.75	2.25	1964
		81	1					2374.54		1963
		13	5					3284.67		1963
		19	1					1546.42	2.37	1964

Plant Community	Constant	N	CAP Condition *	Snow Cover	Litter Layer	Penetrometer Mean	Penetrometer Std. Dev.	WUC	Wetness	Year
11 Mature Hairgrass		20	5		14.00			1809.60	3.50	1963
		110	1		2.95			3907.25	0.64	1963
		23	1	23.22		353.48	80.57	2024.22	1.65	1964
		12	2	54.00		1725.00	458.50	3783.00	5.00	1964
		31	6		14.68			3598.29	2.26	1963
12 Calamogrostis		14	1					3779.00		1963
		13	6		23.33			4957.33		1963
13 Carex Scop		52	1		0.577			3533.79		1963
		37	1	9.00		258.65	61.84	1669.27		1964
		22	5		2.73			4290.59		1963
		13	2	18.31		676.15	142.23	1965.08	3.54	1964
14 Black-headed Carex		14	2					3631.00	4.50	1964
		19	1					2760.00		1963
		20	1					1690.60	4.30	1964
		11	6					1739.00		1963
15 Carex Pyrenaica		13	2					4156.00	3.70	1964
		28	1					5897.50		1963
		22	1					2787.54	2.50	1964
		12	3					4785.50		1964
16 Geum-Rossii		10	1					1998.00		1963
		12	1	6.50		279.17	50.83	1362.33	4.17	1964
		12	2					3123.00	4.00	1964
17 Rock		55	1					2280.25		1963
		39	2					2481.67	6.00	1964
		51	1	0.509		52.35	18.88	1249.47	5.88	1964
21 Salix		18	1		22.50			3186.00		1963
		10	1		24.00			1857.40	4.00	1964
		12	2		15.00			3568.00	4.00	1964
		11	6		60.00			1266.00		1963
22 Dryas		14	1					1846.00		1964

Plant Community	Constant	N	CAP Condition*	Snow Cover	Litter Layer	Penetrometer Mean	Penetrometer Std. Dev.	µpc	Wetness	Year
24 Pussy Toes		17	1					5443.43		1963
		11	6					2562.00		1963
25 Geum-Sibbaldia Buttercup		66	1	18.61				2173.26	0.11	1963
		112	1	20.70		1366.25	300.03	1250.97	3.99	1964
		27	2	17.70		1545.63	334.56	2184.89	4.44	1964
		12	5					1853.00	3.50	1963
		13	6					2638.67	2.33	1963
26 Sibbaldia		12	1					4622.00		1963
29 Gravel Mulch		20	1					2093.30		1963
		19	1					1626.78	4.67	1963
		87	1		0.229	1564.83	364.55	1446.23	3.54	1964
		12	2			2020.83	419.00	2067.67	4.75	1964
		29	6					2802.89	4.67	1963
		22	5					1311.00	3.50	1963
37 Immature Hairgrass		24	2	9.50		1680.00	627.00	2979.25	5.00	1964
		47	1	10.42				2808.57	0.89	1963
		31	1	16.64		867.61	241.42	1892.16	2.77	1964
		14	5					1732.07	3.00	1963
		14	6					2876.21	3.00	1963
38 Gopher Garden		40	1					1330.50		1963
		70	1	0.714		1156.88	380.06	886.11	4.16	1964
		12	2			1266.67	355.17	1328.17	4.92	1964
39 Immature Kobresia		20	1					2625.70		1963
		28	1	3.50		772.50	160.87	1401.75	4.37	1964
40 Willow Birch		40	1					2321.42		1963
41 Carex Elynaides		15	1					1648.60		1963

Plant Community	Constant	N	CAP Condition *	Snow Cover	Litter Layer	Penetrometer Mean	Penetrometer Std. Dev.	µµc	Wetness	Year
42 Bog		55	1					1221.76		1963
		42	1	4.55	0.595			902.21	1.17	1964
		32	5	5.19	3.59			1553.69		1963
		16	6					2055.25		1963
44 Pareys Clover		12	5					1822.50	3.50	1963
		12	6					2936.00	3.50	1963
		12	1					1555.50	3.50	1963
46 Buttercup		14	1	81.00				3222.50		1963
		14	1	87.00		1532.50	323.75	1091.75	5.50	1964
47 Terrace Lip	1.00	10	1	12.60		2076.00	370.60	1331.30	5.10	1964
	0.49	12	2	36.00		2195.00	357.50	2785.00	5.00	1964
48 Frost scars-center	1.00	20	1					870.95	3.20	1964
	0.57	14	2					1330.00	3.25	1964
49 Frost scars-edge	1.00	20	1					1003.90	3.85	1964
	1.51	14	2					1823.00	3.75	1964
50 Geum sage	1.00	36	1	9.06		1144.17	262.53	1522.03	4.33	1964
	0.47	10	2	5.40		991.00	266.20	2816.70	4.00	1964
	1.00	79	1	3.57	2.04	1870.89	443.19	1427.21	4.92	1964
	0.47	15	2		3.47	2027.33	492.20	2844.87	4.87	1964

Cap Conditions

1. Cap on; Al foil in cap
2. Cap off; Double window
3. Cap on; Al foil in cap; Litter removed
4. Cap off; Double window; Litter removed
5. Cap on; No Al foil in cap
6. Cap off; Single window
7. Cap on; No Al foil in cap; Litter removed
8. Cap off; Single window; Litter removed

GROSS BETA ACTIVITY AT GROUND SURFACE FOR VARIOUS PLANT COMMUNITIES

Mic's Data

Correlation Coefficients

Plant Community	N	Snow Cover $\mu\mu\text{C}$	Litter Layer $\mu\mu\text{C}$	Penetrometer Mean $\mu\mu\text{C}$	$\mu\mu\text{C}$ Wetness
01 Mature Lodgepole Pine	100		.10290	.33240	.11516-
	19		.09184-	.31133	.37334-
	17		.39007-	.01336-	.37897-
	30		.22084		
	12				
	40		.01337-		.05348
	18		.60678-	.06156-	.49345-
	14				
	56		.15210-	.12172	
	18				
	10	.43878	.25011-		.09688-
	12				
	12				
	16				
02 Immature Lodgepole	150		.20740-	.38178	.07475
	30		.55638-	.58114	.20813
	29		.59555-	.47749	.19923
	29		.51765-	.51385	.28550
	46		.13808		
	40		.37783		.10435-
	14	.69986	.33387		
	13				
	18		.09494		.54845
	12				
	20		.25647		
	13		.69196		
03 Spruce-fir	12				
	42		.01433	.01872-	.34917
	207		.26648	.23380	.00528
	50		.28071	.23936	.11731

Correlation Coefficients

Plant Community	N	Snow Cover r _{SC}	Litter Layer r _{LL}	Penetrometer Mean r _{PM}	Wetness r _W
03 Spruce-fir	40		.14639	.02406	.10043
	36		.00493-	.12943	.15965
	12				
	15				
	16	.22476	.38782-		.52043-
	44	.28068	.24971		.34461
	55	.49197			
	10	.19508-	.60154		.40608
	12				
	39	.39734	.04269		
04 Limber (9,780-9,790 ft.) Limber (10,880-10,890 ft.)	100		.06738	.29787	.12732
	99		.11548	.56735	.26576-
	40		.28850	.59470	.33388-
	19		.40266-	.52809	.07744
	19		.49873-	.50581	.16746
	39		.25000-		.27166
	19	.35283			
	50				
	10		.10996-		.59450
	12				
	14	.85879	.47156		
	12				
05 Aspen	49		.34975	.27403	.37717-
	10		.53128	.19325	.02081-
	18		.30224-	.01666	.13348
	17		.48274-	.17355	.21630
	20				
	36		.41266		
	40		.21983		
	18		.11857		
	12				
	17		.90407		
	12				

Correlation Coefficients

Plant Community	N	Snow Cover r _{SC}	Litter Layer r _{LL}	Penetrometer Mean r _{PM}	r _{WC} Wetness
06 Mature Kobresia	73				
	14				
	14				.30591
	154	.14572-	.46988-	.18841	.27631-
	60	.13521		.05227-	
	45				
	42	.03494-		.33012	.04295
	32				.40242
	28				.51051
07 Fell Field	75	.38837			
	274	.01577	.32234	.15713	.08899-
	50	.19218-	.21140	.36379	.24823-
	5				
08 Juncus	12		.93149		.08124-
	32		.36742		.24757
	16		.86027		.35334
	11				
	11				
	27				
	11				
00 No Vegetation (snow cover more than 8½")	14	.40044-			
No Vegetation	12				
09 Moss	12				
	19	.22536			.62731
	15	.86423			.66834
	50				
	13				.47897
10 Primula Parryi	14				.74485
	81				
	13				
	19				.62150

Correlation Coefficients

Plant Community	N	Snow Cover r _{SC}	Litter Layer r _{LL}	Penetrometer Mean r _{PM}	Wetness r _W
11 Mature Hairgrass	20		.82449		.36554
	110		.46379-		.51269-
	23	.67201-		.43819	.69140-
	12				
	31		.25527		.24765-
12 Calamogrostis	14				
	13				
13 Carex Scop	52		.04582-		
	37	.05210-		.15130-	.14815-
	22		.85707		
	13	.68323		.83305	.91723
14 Black-headed Carex	14				.77893
	19				
	20				.84979
	11				
15 Carex Pyrenaica	13				.80817
	28				
	22				.78243-
	12				
16 Geum-Rossii	10				
	12	.30300		.23176	.30300
	12				
17 Rock	55				
	39				
	51	.01923		.03764	.06073-
21 Salix	18		.34861-		
	10		.18838-		
	12				
	11				

Correlation Coefficients

Plant Community	N	Snow Cover $\mu\mu c$	Litter Layer $\mu\mu c$	Penetrometer Mean $\mu\mu c$	$\mu\mu c$ Wetness
22 Dryas	14				
24 Pussy Toes	17				
25 Geum-Sibbaldia Buttercup	66	.46770			.07773-
	112	.37815		.05739	.13999-
	27	.61903		.21152	.23963
	12				.98295
	13				
26 Sibbaldia	12				
29 Gravel Mulch	20				
	19				.50929
	87		.02600-	.59343-	.83919-
	12			.34660	.14167
	29				.40676
	22				
37 Immature Hairgrass	24	.39039			
	47	.29760			.61728-
	31	.24549-		.23097-	.46593-
	14				.27908
	14				.38611
38 Gopher Garden	40				
	70	.35112		.01427	.51342-
	12			.69780	.60860-
39 Immature Kobresia	20				
	28	.22250-		.01050-	.38636
40 Willow Birch	40				
41 Carex Elynaides	15				

Correlation Coefficients

Plant Community	N	Snow Cover r _{SC}	Litter Layer r _{LL}	Penetrometer Mean r _{PM}	r _{WC} Wetness
42 Bog	55				
	42	.66076	.54511		.50264
	32	.68207	.51054		
	16				
44 Pareys Clover	12				
	12				
	12				
46 Buttercup	14	.30345			
	14	.06783		.99677	.99053
47 Terrace Lip	10	.42932		.15758	.31075
	12				
48 Frost scars-center	20				.24468
	14				.90908
49 Frost scars-edge	20				.52443
	14				.88794
50 Geum sage	36	.39890			
	10	.23084			
	79	.04759	.20551	.24319	.00952
	15		.13908	.14649	.45953

CHECK LISTS

A CHECKLIST OF THE BIRDS OF THE BOULDER WATERSHED

ORDER ANSERIFORMES

FAMILY ANATIDAE (DUCK FAMILY)

Anas platyrhynchos platyrhynchos (Mallard)

Querquedula discors (Blue-Winged Teal)

Branta canadensis canadensis (Common Canada Goose)

ORDER FALCONIFORMES

FAMILY ACCIPITRIDAE

Accipiter cooperi (Cooper's Hawk)

Astur atricapillus striatulus (Western Goshawk) (3)

Accipiter velox (Sharp-Shinned Hawk) (8)

Buteo borealis calurus (Western Red-Tailed Hawk)

Buteo regalis (Ferruginous Rough-Leg)

Buteo swainsoni (Swainson's Hawk)

Aquila chrysaetos canadensis (Golden Eagle)

Circus cyaneus (Marsh Hawk)

FAMILY FALCONIDAE

Falco sparverius (Sparrow Hawk) (5)

ORDER GALLIFORMES

FAMILY TETRAONIDAE

Lagopus leucurus (White-Tailed Ptarmigan)

Dendragapus obscurus obscurus (Dusky Grouse)

ORDER COLUMBIFORMES

FAMILY COLUMBIDAE

Zenaidura macroura marginella (Western Mourning Dove)

ORDER STRIGIFORMES

FAMILY STRIGIDAE

Bubo virginianus pallescens (Western Horned Owl) (6)

ORDER CAPRIMULGIFORMES

FAMILY CAPRIMULGIDAE

Chordeiles minor henryi (Western Nighthawk)

ORDER APODIFORMES

FAMILY APODIDAE

Nephoecetes niger borealis (Black Swift)

FAMILY TROCHLIDAE

Selasphorus platycercus platycercus

ORDER PICIFORMES

FAMILY PICIDAE

Dryobates pubescens (Downy Woodpecker)

Picoides arcticus (Arctic Three-Toed Woodpecker)

Colaptes auratus luteus (Northern or Yellow-Shafted Flicker)

ORDER PASSERIFORMES

SUB-ORDER PASSERES

FAMILY FRINGILLIDAE

Spinus pinus pinus (Pine Siskin) (10)

Leucosticte australis (Brown-Capped Rosy Finch)

Pinicola enucleator montana (Rocky Mountain Pine Grosbeak)

Loxia leucoptera (White-Winged Crossbill)

Zonotrichia leucophrys leucophrys (White-Crowned Sparrow) (13)

Junco caniceps (Gray-Headed Junco)

FAMILY PARIDAE

Penthestes gambeli gambeli (Mountain Chickadee) (21)

ORDER PASSERIFORMES (CON'T)

SUBORDER PASSERES (CON'T)

FAMILY CORVIDAE

Cyanocitta stelleri (Steller's Jay)

Corvus corax sinuatus (American Raven)

Nucifraga columbiana (Clark's Nutcracker)

Pica pica hudsonia (American Magpie)

Perisoreus canadensis (Canada Jay)

FAMILY ALAUDIDAE

Otocoris alpestris (Horned Lark)

FAMILY MOTACILLIDAE

Anthus spinoletta (American Pipit)

FAMILY TURDIDAE

Myadestes townsendi (Townsend's Solitaire)

Turdus migratorius propinquus (Western Robin)

Sialia currucoides (Mountain Bluebird)

FAMILY CINCLIDAE

Cinclus mexicanus unicolor (Dipper or Water Ouzel) (16)

FAMILY CETHIIDAE

Certhia familiaris montana (Rocky Mountain Creeper)

FAMILY SYLVIIDAE

Regulus satrapa olivaceus (Western Golden-Crowned Kinglet)

Corthylio calendula cineraceus (Western Ruby-Crowned Kinglet)

FAMILY BOMBYCILLIDAE

Bombycilla garrula pallidiceps (Bohemian Waxwing)

FAMILY PARULIDAE

Dendroica auduboni auduboni (Audubon's Warbler)

REFERENCES USED:

1. Peterson, Roger T., "A Field Guide to Western Birds," Houghton Mifflin, Co. 1941 (GENERA AND SPECIES)
2. Van Tyne, Josselyn and Andrew J. Berger, "Fundamentals of Ornithology," John Wiley & Sons, 1961 (ORDERS AND FAMILIES)

BOULDER COUNTY, COLORADO

ORDER INSECTIVORA

FAMILY SORICIDAE (SHREWS)

Sorex cinereus Common or Masked Shrew

Sorex vagrans Vagrant Shrew

*Sorex palustris Water Shrew

Sorex merriami Merriam's Shrew

ORDER CARNIVORA

FAMILY URSIDAE (BEARS)

Ursus americanus Black Bear

FAMILY MUSTELIDAE (WEASELS, SKUNKS, AND ALLIES)

* Martes americana origines Marten

Mustela erminea Ermine (1)

* Mustela vison Mink

* Mephitis mephitis Striped Skunk

FAMILY CANIDAE (FOXES, WOLVES, AND DOGS)

Vulpes fulva Red Fox

Canis latrans Coyote

FAMILY FELIDAE (CATS)

Felis concolor Mountain Lion (Cougar)

Lynx rufus Bobcat

ORDER RODENTIA

FAMILY SCIURIDAE (MARMOTS, SQUIRRELS, AND CHIPMUNKS)

Marmota flaviventris luteola Yellow-bellied Marmot

* Spermophilus lateralis Golden-mantled Ground Squirrel (11)

* Eutamias quadrivittatus Colorado Chipmunk (15)

* Tamiasciurus hudsonicus baileyi Pine Squirrel (9)

FAMILY GEOMYIDAE

Thomomys talpoides fossor Mt. Pocket Gopher

ORDER RODENTIA (CON'T)

FAMILY CASTORIDAE (BEAVER)

* Castor canadensis Beaver

FAMILY CRICETIDAE

Peromyscus maniculatus Long-tailed White-footed Deermouse (14)

Microtus montanus Gray Meadow Mouse

Microtus pennsylvanicus Meadow Mouse (Vole) (19)

Microtus longicaudus Long-tailed Vole

Phenacomys intermedius intermedius "Phenacomys" Heather Vole

Neotoma cinerea crolestes Bushy-tailed Woodrat

* Neotoma mexicana (?) Mexican Woodrat

* Clethrionomys gapperi galei Gapper's Western Red-backed Mouse (Vole)

FAMILY ZAPODIDAE

Zapus princeps Western Woodland Junping Mouse

FAMILY ERETHIZONTIDAE

* Erethizon dorsatum Porcupine

ORDER LAGOMORPHA

FAMILY OCHOTONIDAE (PIKA)

Ochotona princeps Pika (Cony) (18)

FAMILY LEPORIDAE (RABBITS AND HARES)

* Sylvilagus nuttallii pinetis Mountain Cottontail Rabbit

Lepus americanus bairdii Varying Hare (Snowshoe Hare)

Lepus townsendii campanius White-tailed Jackrabbit

ORDER ARTIODACTYLA

FAMILY CERVIDAE (DEER AND ELK)

Cervus canadensis Elk (Wapiti)

Odocoileus hemionus Mule Deer

FAMILY BOVIDAE

Ovis canadensis Bighorn Mountain Sheep

ORDER CHIROPTERA

FAMILY VESPERTILIONIDAE

Myotis sp. Little Brown Bat (20)

* SUB-ALPINE ONLY!

SUPPLEMENTARY DRY FALLOUT DATA

Dry Fallout and Rainfall Study

Conversion of cpm/dec² to picocuries/dec²

(cpm)(4.3 counter eff.)(3.7 decay correction) ÷ (2.2 convert Dpm to picocuries)

Sample A

$$(917)(4.3)(3.7) \div 2.2 = 6,970 \text{ } \mu\mu\text{c/dec}^2$$

$$6,970 \text{ } \mu\mu\text{c/dec}^2 \div 7.15 = 950 \text{ } \mu\mu\text{c/dec}^2/\text{inch of ppt.}$$

Sample B

$$(216)(4.3)(3.7) \div 2.2 = 1,562 \text{ } \mu\mu\text{c/dec}^2$$

$$1,562 \text{ } \mu\mu\text{c/dec}^2 \div 7.15 = 218 \text{ } \mu\mu\text{c/dec}^2/\text{inch of ppt.}$$

Sample C

$$(663)(4.3)(3.7) \div 2.2 = 4,795 \text{ } \mu\mu\text{c/dec}^2$$

$$4,795 \text{ } \mu\mu\text{c/dec}^2 \div 7.15 = 671 \text{ } \mu\mu\text{c/dec}^2/\text{inch of ppt.}$$

28.4% of the total radioactivity due to dry fallout.

Dry Fallout and Rainfall Study
Summer 1963 (20 July - 1 September 1963)

Sample No.	Description	Planchet No.	CPM/Sample	CPM/Gram	CPM/Sq. Dec.	Std. error of mean	CPM/Sq. Ft.
A	Composite of six buckets which remained uncovered at all times; sample contained four readably noticeable but small insects which resembled small (i.e. 1-2mm long) beetles. These insects were <u>not</u> removed from the sample.	2-136	28349.6	14642.6	691.79		6426.73
		2-184	38432.6	19850.5	937.84		8712.50
		2-184	38144.5	19701.7	930.81		8647.19
		2-185	40676.0	21009.2	992.58		9221.07
		2-185	41478.3	21423.6	1012.16		9402.95
		2-230	38384.9	19825.9	936.67		8701.69
		Average	37577.7	19408.9	916.95 ± 47.17		8518.7 ±
B	Composite of six buckets which remained uncovered when it was not raining but were covered when it was raining; the sample contained one small moth (i.e. 12-15mm long) and two very small beetles (i.e. 0.5-1.0mm long). These insects were not removed from the sample.	2-135	6882.9	5024.0	167.96		1560.32
		2-182	9594.2	7003.1	234.12		2174.96
		2-182	8824.0	6440.9	215.32		2000.36
		2-183	9310.9	6796.3	227.21		2110.74
		2-183	9337.2	6815.5	227.85		2116.70
		2-229	9114.7	6653.1	222.42		2066.26
		Average	8843.9	6455.4	215.8 ± 9.86		1946.55 ±
C	Composite of six buckets which remained uncovered when it was raining but were covered when it was not raining.	2-134	25249.7	10788.2	616.15		5724.00
		2-180	27487.1	11744.1	670.74		6231.21
		2-180	27489.6	11745.2	670.81		6231.77
		2-181	28316.9	12098.7	690.99		6419.32
		2-181	27273.8	11653.0	665.54		6182.85
		2-228	27121.8	11588.0	661.83		6148.39
		Average	27156.5	11602.8	662.6 ± 10.34		6156.2 ±

SPHAGNUM DATA

1962 - Sphagnum Bogs
Gross Beta Radioactivity 1 dec²

	<u>N</u>	<u>Mean</u>	<u>Std. Dev.</u>	<u>Std. Error of The Mean</u>
<u>Big Lake Bog</u>				
1. Dry wt./dec ² Mounds	20	12.345	2.455	0.548
2. Ash wt./dec ²		0.7965		
3. $\mu\mu\text{c/gm. dry wt}$	20	628.95	164.18	36.71
4. $\mu\mu\text{c/gm. ash wt.}$		9398.43		
5. $\mu\mu\text{c/dec}^2$	20	7485.85	1401.41	313.37
7. $\mu\text{c/meter}^2$	20	0.748585	0.140141	0.031337
<u>Bog NNW of Watershed Gate (Weir Bog)</u>				
1. Dry wt. 1 dec ² Mounds	19	9.936	2.228	0.511
Depressions	14	19.197	6.259	1.672
2. Ash wt./dec ² Mounds		0.7355		
Depressions		5.38		
3. $\mu\mu\text{c/gm. dry wt.}$ Mounds	19	712.63	164.785	37.803
Depressions	14	559.357	453.31	121.141
4. $\mu\mu\text{c/gm. ash wt.}$ Mounds		9336.29		
Depressions		1630.47		
5. $\mu\mu\text{c/dec}^2$ Mounds	19	6866.84	1386.82	318.15
Depressions	14	8771.93	4318.566	1154.08
7. $\mu\text{c/meter}^2$ Mounds	19	0.686684	0.138682	0.031815
Depressions	14	0.877193	0.431857	0.115408

1962 - Sphagnum Bogs
Gross Beta Radioactivity 1 dec²

	<u>N</u>	<u>Mean</u>	<u>Std. Dev.</u>	<u>Std. Error of The Mean</u>
<u>Bog Just East of Upper Watershed Snow Course</u>				
1. Dry wt./dec ²				
Mounds	19	11.22	2.558	0.586
Depressions	14	40.06	16.301	4.356
2. Ash wt./dec ²				
Mounds		0.6943		
Depressions		12.30		
3. $\mu\text{c/gm. dry wt.}$				
Mounds	19	582.737	199.06	45.666
Depressions	14	555.00	345.95	92.450
4. $\mu\text{c/gm. ash wt.}$				
Mounds		8919.01		
Depressions		1454.25		
5. $\mu\text{c/dec}^2$				
Mounds	19	6192.47	1312.35	301.066
Depressions	14	17887.28	5190.034	1386.967
7. $\mu\text{c/meter}^2$				
Mounds	19	0.619247	0.131235	0.030107
Depressions	14	1.788728	0.519003	0.138697
<u>Bog North of Lower Albion Creek (Long Bow)</u>				
1. Dry wt./dec ²				
Mounds	24	11.56	3.135	0.639
Depressions	20	48.69	13.95	3.119
2. Ash wt./dec ²				
Mounds		1.16		
Depressions		14.81		
3. $\mu\text{c/gm. dry wt.}$				
Mounds	24	641.08	198.90	40.60
Depressions	20	147.10	52.14	11.659
4. $\mu\text{c/gm. ash wt.}$				
Mounds	24	6049.57		
Depressions	20	473.83		
5. $\mu\text{c/dec}^2$				
Mounds	24	7017.50	1545.196	315.41
Depressions	20	6961.90	2490.068	556.81
7. $\mu\text{c/meter}^2$				
Mounds	24	0.701750	0.154519	0.031541
Depressions	20	0.696190	0.249007	0.055681

Sphagnum Bogs
October 1963

	<u>Mean</u>	<u>Standard Deviation</u>	<u>No. of Samples</u>	<u>Standard error of the mean</u>
<u>1st Watershed Bridge</u>				
1. Dry weight/dec. ²				
Mounds	23.27	3.4842	10	1.1015
Depressions	33.55	9.8712	10	3.1208
Total	28.413	8.93	20	1.9964
2. Ash weight/dec. ²				
Mounds	2.737	1.1532	10	0.3646
Depressions	6.732	3.2317	10	1.0217
Total	4.735	3.127	20	0.6991
3. $\mu\mu\text{c/gm. dry wt.}$				
Mounds	1312.	260.14	10	82.24
Depressions	907.	288.64	10	91.26
Total	1110.	338.66	20	75.71
4. $\mu\mu\text{c/gm. ash wt.}$				
Mounds	12287.	4121.53	10	1303.04
Depressions	5015.	2214.00	10	699.97
Total	8651.	4927.86	20	1101.69
5. $\mu\mu\text{c/dec.}^2$				
Mounds	30297	6401	10	2023.71
Depressions	28747	6102	10	1929.18
Total	29522	6138	20	1372.23
7. $\mu\text{c/meter}^2$				
Mounds	3.029698	0.640056	10	0.202357
Depressions	2.874670	0.610161	10	0.192905
Total	2.952184	0.613791	20	0.137221

1963	<u>Mean</u>	<u>Standard Deviation</u>	<u>No. of Samples</u>	<u>Standard error of the mean</u>
<u>Big Bog Lake</u>				
1. Dry weight/dec. ²				
Mounds	16.407	4.898	10	1.5485
Depressions	14.089	5.875	10	1.8574
Total	15.248	5.397	20	1.2066
2. Ash weight/dec. ²				
Mounds	1.339	0.4404	10	0.1392
Depressions	1.6114	0.7885	10	0.2493
Total	1.4752	0.6371	20	0.1424
3. $\mu\mu$ /gm. dry wt.				
Mounds	1999	594.26	10	187.88
Depressions	3179	864.29	10	273.25
Total	2589	942.12	20	210.62
4. $\mu\mu$ /gm. Ash wt.				
Mounds	25440	6543.33	10	2068.61
Depressions	28432	7765.96	10	2455.25
Total	26936	7155.58	20	1599.73
5. $\mu\mu$ /dec. ²				
Mounds	31010	7073.72	10	2236.40
Depressions	41534	9394.52	10	2970.13
Total	36272	9728.96	20	2175.04
7. μ /meter ²				
Mounds	3.131018	0.678592	10	0.214540
Depressions	4.153376	0.939472	10	0.297019
Total	3.642197	0.954601	20	0.213414

1963	<u>Mean</u>	<u>Standard Deviation</u>	<u>No. of Samples</u>	<u>Standard error of the Mean</u>
<u>Deer Bog</u>				
1. Dry weight/dec. ²				
Mounds	9.274	5.545	5	2.4798
Depressions	15.36	4.195	5	1.8760
Total	12.317	5.637	10	1.7822
2. Ash weight/dec. ²				
Mounds	1.262	0.335	5	0.1498
Depressions	3.00	0.8927	5	0.3992
Total	2.1315	1.104	10	0.3490
3. $\mu\text{c/gm. dry wt.}$				
Mounds	3331.0	2788.46	5	1247.02
Depressions	1234.0	148.72	5	66.51
Total	2283.0	2164.93	10	684.45
4. $\mu\text{c/gm. ash wt.}$				
Mounds	18992	5461.52	5	2442.43
Depressions	6453	929.03	5	415.47
Total	12723	7570.51	10	2393.46
5. $\mu\text{c/dec.}^2$				
Mounds	23364	6585.74	5	2945.19
Depressions	18784	4120.18	5	1842.57
Total	21074	5713.84	10	1806.46
7. $\mu\text{c/meter}^2$				
Mounds	2.336424	0.658547	5	0.294506
Depressions	1.878452	0.380460	5	0.170144
Total	2.107438	0.571383	10	0.180645

Series 02

October, 1964

	<u>N</u>	<u>Mean</u>	<u>Std. Dev.</u>	<u>Std. Error of The Mean</u>
<u>Wier Bog</u>				
1. Dry wt./dec ² Mounds	14	27.87	11.95	3.19
2. Ash wt./dec ² Mounds	14	3.524		
3. $\mu\mu\text{c/gm. dry wt.}$ Mounds	14	729.93	354.19	94.70
4. $\mu\mu\text{c/gm. ash wt.}$ Mounds		4926.24		
5. $\mu\mu\text{c/dec}^2$ Mounds	14	17360.07	5984.11	1600.03
7. $\mu\text{c/meter}^2$ Mounds	14	1.73601	0.598411	0.160002
<u>Lower Watershed Bridge</u>				
<u>Annual Bog Sampling Area (Long Bog)</u>				
1. Dry wt./dec ² Mounds	10	16.37	6.70	2.118
Depressions	10	54.09	24.39	7.711
2. Ash wt./dec ² Mounds	10	1.21		
Depressions	10	12.71	4.35	1.375
3. $\mu\mu\text{c/gm. dry wt.}$ Mounds	10	891.8	371.88-	117.57
Depressions	10	538.5	592.68	187.38
4. $\mu\mu\text{c/gm. ash wt.}$ Mounds		10982.73		
Depressions		1863.42		
5. $\mu\mu\text{c/dec}^2$ Mounds	10	13289.10	4172.87	1319.28
Depressions	10	23684.10	24156.23	7637.13
7. $\mu\text{c/meter}^2$ Mounds	10	1.32891	0.417287	0.131927
Depressions	10	2.36841	2.415623	0.763712

Mounds and Depressions Together
Summer 1964

Series 031

	<u>N</u>	<u>Mean</u>	<u>Std. Dev.</u>	<u>Std. Error of The Mean</u>
<u>Deer Bog</u>				
1. Dry wt./dec ²	79	7.42	0.6280	0.1985
2. Ash wt./dec ²		0.6450	0.0010	0.0316
3. $\mu\mu\text{c/gm. dry wt.}$		1502.60	186.84	59.07
4. $\mu\mu\text{c/gm. ash wt.}$		17189.24		
5. $\mu\mu\text{c/dec}^2$		<u>11087.06</u>		
7. $\mu\text{c/meter}^2$		1.108706		
<u>Big Lake</u>				
1. Dry wt./dec ²	53	8.09	0.6944	0.2195
2. Ash wt./dec ²		0.6570	0.0940	0.0297
3. $\mu\mu\text{c/gm. dry wt.}$		1417.10	148.90	47.07
4. $\mu\mu\text{c/gm ash wt.}$		17420.00		
5. $\mu\mu\text{c/dec}^2$		<u>11444.94</u>		
7. $\mu\text{c/meter}^2$		1.14449		
<u>Tulee's Bog</u>				
1. Dry wt./dec ²	113	7.545	0.6904	0.2182
2. Ash wt./dec ²		0.6537	0.0775	0.0245
3. $\mu\mu\text{c/gm dry wt.}$		1412.20	140.03	44.27
4. $\mu\mu\text{c/gm. ash wt.}$		16375.54		
5. $\mu\mu\text{c/dec}^2$		<u>10704.69</u>		
7. $\mu\text{c/meter}^2$		1.070469		

Mounds and Depressions Together
Summer 1964

Series 031

	<u>N</u>	<u>Mean</u>	<u>Std. Dev.</u>	<u>Std. Error of The Mean</u>
<u>Albian Bog</u>				
1. Dry wt./dec ²	57	7.204	0.7416	0.2344
2. Ash wt./dec ²		0.6616	0.0794	0.0251
3. $\mu\mu\text{c/gm. dry wt.}$		1785.70	293.70	92.85
4. $\mu\mu\text{c/gm ash wt.}$		19370.90		
5. $\mu\mu\text{c/dec}^2$		<u>12815.79</u>		
7. $\mu\text{c/meter}^2$		1.281579		
<u>Sister Bog</u>				
1. Dry wt./dec ²	57	6.459	0.9498	0.3002
2. Ash wt./dec ²		0.6693	0.1233	0.0389
3. $\mu\mu\text{c/gm. dry wt.}$		1602.70	266.28	84.186
4. $\mu\mu\text{c/gm. ash wt.}$		15208.35		
5. $\mu\mu\text{c/dec}^2$		<u>10178.95</u>		
7. $\mu\text{c/meter}^2$		1.017895		
<u>Wier Bog</u>				
1. Dry wt./dec ²	82	9.44	2.0322	0.6424
2. Ash wt./dec ²	(missing an ash reading)			
3. $\mu\mu\text{c/gm. dry wt.}$		1316.90	371.33	117.40
4. $\mu\mu\text{c/gm ash wt.}$				
5. $\mu\mu\text{c/dec}^2$		<u>12105.67</u>		
7. $\mu\text{c/meter}^2$		1.210567		

Mounds and Depressions Together

Summer 1964

Series 031

	<u>N</u>	<u>Mean</u>	<u>Std. Dev.</u>	<u>Std. Error of the Mean</u>
<u>Long Bog</u>				
1. Dry wt./dec. ²	85	6.567	0.5142	0.1625
2. Ash wt./dec. ²	(ash reading missing)			
3. $\mu\mu\text{c/gm. dry wt.}$		1577.00	731.91	231.40
4. $\mu\mu\text{c/gm. ash wt.}$				
5. $\mu\mu\text{c/dec.}^2$		<u>10,452.56</u>		
7. $\mu\text{c/meter}^2$		1.045256		
		<u>MEAN</u>		
Average $\mu\mu\text{c/dec.}^2$		11,255.66		
	<u>STD. DEV.</u>		<u>STD. ERROR</u>	
	942.39		<u>OF THE MEAN</u>	
			356.16	

Gross Beta Activity per dec² Instrument Efficiency Comparison

	Probe	Effic. 1	Effic. 2	Lab Instrument	Hazleton
<u>Deer Bog</u>					
Sample No. 3					(4.3)
7	1294	4.77	20.52	6176.28	26,558
8	1026.58	5.08	21.83	5213.02	22,416
9	884.70	3.64	15.63	3216.51	13,831
10	1151.77	6.41	27.56	7383.49	31,749
14	1043.27	4.14	17.81	4321.09	18,581
17	934.77	3.24	12.49	3029.30	13,026
18	1243.58	4.61	19.84	5738.14	24,674
19	517.46	8.42	36.21	4357.91	18,739
20	717.77	6.12	26.33	4395.81	18,902
Mean	979.32	5.16	22.02	4870.17	20,942
Std. Dev.	249.39	1.605	7.132	1405.60	6,044
Std. Error	83.13	0.535	2.38	468.53	2,015
<u>Mounds</u>					
Mean	977.78	4.97	21.38	5497.32	23,638.5
Std. Dev.	174.73	1.1384	4.906	1761.51	7,571.52
Std. Error	87.36	0.5692	2.453	880.755	3,785.76
<u>Depressions</u>					
Mean	891.37	5.31	22.54	4368.45	18,784.0
Std. Dev.	282.38	2.03	9.108	958.185	4,120.18
Std. Error	126.288	0.907	4.073	428.526	1,842.656
<u>Big Bog Lake</u>					
1	1310.45	5.22	22.43	6835.79	29,393.89
2	1152.73	4.69	20.17	5406.41	23,247.55
3	1260.45	5.78	24.85	7284.58	31,323.7
4	1260.45	4.56	19.61	5747.07	24,712.42
5	1527.27	4.85	20.85	7404.28	31,838.41
6	1318.64	6.57	28.27	8669.87	37,280.43
7	1560.91	6.54	28.13	10212.31	43,912.95
8	1585.91	5.69	24.49	9030.59	38,831.55
9	1210.00	4.97	21.39	6019.42	25,883.50
10	1193.64	4.61	19.84	5506.28	23,677
11	968.18	11.32	48.69	10963.00	47,140.92
12	1160.00	10.08	43.36	11697.71	50,300.14
13	1093.18	8.90	38.29	9734.22	41,857.15
14	1310.45	9.59	41.24	12567.05	54,038.32
15	1010.00	5.70	24.53	5762.46	24,778.60
16	1469.09	4.41	18.94	6472.26	27,830.72
17	1060.00	8.80	37.84	9329.23	40,115.67
18	1243.64	8.65	37.19	10755.60	46,249.10
19	1644.09	6.48	27.86	10652.32	45,804.99
20	993.18	8.72	37.48	8656.27	37,221.96

Gross Beta Activity per dec² Instrument Efficiency Comparisons

	Probe	Effic. 1	Effic. 2	Lab Instrument	Hazelton
<u>Big Bog Lake cont'd</u>					
Mean	1266.61	6.80	29.27	8435.00	36,272.00
Std. Dev.	202.93	2.152	9.245	2262.46	9,729.00
Std. Error	45.37	0.48	2.066	505.80	2,175.00
<u>Mounds</u>					
Mean	1338.04	5.35	23.00	7211.66	30,410.14
Std. Dev.	160.446	0.7615	3.278	1645.38	6,728.90
Std. Error	50.726	0.2407	1.036	520.196	2,127.379
<u>Depressions</u>					
Mean	2149.18	8.26	35.54	9659.01	41,533.76
Std. Dev.	223.286	2.109	3.942	2185.17	9,394.72
Std. Error	70.593	0.667	1.246	690.854	2,970.193
<u>Watershed Bridge</u>					
1	1042.49	4.68	20.08	4869.91	20,940.63
2	1155.45	4.48	19.24	5168.22	22,223.33
3	992.21	8.60	37.02	8541.80	36,729.74
4	916.77	8.68	37.30	7952.51	34,195.81
5	1067.64	6.46	27.78	6899.05	29,665.93
6	1356.61	4.68	20.12	6346.31	27,289.14
7	1199.56	5.20	22.36	6239.18	26,828.47
8	986.02	9.86	42.42	9726.59	41,824.34
9	1268.40	5.64	24.26	7158.61	30,782.01
10	1092.79	6.92	29.74	7555.92	32,490.44
11	634.40	12.44	53.54	7898.28	33,962.61
12	1017.36	7.04	30.24	7152.97	30,757.79
13	540.00	6.14	26.44	3320.53	14,278.27
14	716.02	8.54	36.72	6115.50	26,296.64
15	540.00	15.42	66.28	8323.71	35,791.95
16	1205.74	5.64	24.28	6811.17	29,288.02
17	973.25	5.90	25.36	5737.90	24,672.98
18	1029.72	6.40	27.52	6588.09	28,328.80
19	1054.86	7.04	30.28	7427.32	31,937.48
20	766.31	9.76	41.96	7477.31	32,152.43
Mean	977.78	7.48	32.14	6865.55	29,522.00
Std. Dev.	231.11	2.772	11.93	1427.36	6,138.00
Std. Error	51.67	0.62	2.66	319.11	1,372.23
<u>Mounds</u>					
Mean	1161.79	4.767	23.18	6235.90	26,814.37
Std. Dev.	123.784	1.971	3.491	940.44	4,043.85
Std. Error	43.77	0.6969	1.2344	332.54	1,429.93
<u>Depressions</u>					
Mean	855.11	8.28	37.62	7285.30	31,326.81
Std. Dev.	203.64	3.747	12.943	1573.52	6,766.14
Std. Error	58.787	1.082	3.736	454.25	1,953.27

SOILS DATA

SOILS DATA - Summary By Stand Type and Depth in Inches

Stand Type and Depth		PWP*	Field Capacity	Organic Matter	Soil x 1mm	Soil x 1mm & x 300	Soil x 300 mesh
Gravel Mulch	0-½	8.7 ± 1.1 (20)	25.3 ± 2.4 (10)	9.6 ± 1.1 (10)			
	½-2	7.0 ± 0.9 (12)	26.6 ± 1.7 (10)	7.5 ± 1.0 (5)			
	5-7	2.0 ± 1.1 (4)	12.0 ± 2.9 (2)	3.5 ± --- (1)			
	11-13	2.3 ± 0.2 (3)	15.6 ± 0.3 (2)	5.7 ± --- (1)			
Aspen	0-½	11.7 ± 3.2 (6)	67.0 ± 22.7 (6)	30.6 ± 12.4 (4)			
	½-2	9.0 ± 1.6 (6)	55.9 ± 17.7 (6)	10.1 ± 3.3 (4)			
	5-7	2.5 ± 0.3 (4)	26.7 ± 3.9 (4)	3.6 ± 0.4 (2)			
	11-13	1.8 ± 0.3 (4)	20.2 ± 0.2 (2)	1.9 ± --- (1)			
Limber I	0-½	8.3 ± 2.1 (9)	46.9 ± 24.4 (10)	16.2 ± 10.8 (5)			
	½-2	10.2 ± 5.75(10)	20.2 ± 8.6 (10)	7.1 ± 4.5 (5)			
	5-7	3.5 ± 0.7 (4)	8.4 ± 0.6 (2)	9.8 ± 7.1 (2)			
	11-13	1.6 ± 0.5 (4)	5.1 ± 0.2 (2)	1.4 ± 0.3 (2)			
Limber II	0-½	28.6 ± 7.1 (10)	84.7 ± 17.6 (10)	23.5 ± 8.1 (5)			
	½-2	14.4 ± 3.9 (10)	51.1 ± 13.3 (10)	12.7 ± 5.2 (5)			
	5-7	4.4 ± 1.4 (4)	10.0 ± 1.0 (4)	1.7 ± 0.1 (2)			
	11-13	3.5 ± 0.5 (4)	6.5 ± 0.8 (4)	1.6 ± 0.1 (2)			
Fell Field	0-½	27.6 ± 2.2 (10)	58.4 ± 6.2 (10)	25.9 ± 2.1 (5)			
	½-2	23.4 ± 2.6 (10)	63.7 ± 6.6 (10)	19.6 ± 3.5 (6)			
	5-7	12.4 ± 1.3 (5)	49.2 ± 0.2 (2)	12.4 ± --- (1)			
	11-13	16.0 ± 6.0 (2)	32.9 ± 0.8 (2)	8.4 ± --- (1)			
Carex Scop.	0-½	88.3 ± 6.9 (10)	266.4 ± 12.2 (10)	55.0 ± 3.6 (5)			
	½-2	56.5 ± 3.5 (10)	229.3 ± 18.7 (10)	47.8 ± 3.5 (5)			
	5-7	58.1 ± 3.2 (10)	196.2 ± 5.5 (10)	42.1 ± 1.9 (5)			
	11-13	29.1 ± 2.9 (10)	76.2 ± 4.7 (10)	17.7 ± 1.6 (5)			
Lodgepole I	0-½	17.9 ± 2.8 (10)	140.2 ± 27.1 (8)	23.0 ± 6.6 (4)			
	½-2	7.3 ± 1.2 (10)	6.6 ± 1.0 (8)	7.9 ± 1.2 (4)			
Lodgepole II	0-½	12.1 ± 2.1 (10)	43.0 ± 7.4 (10)	18.2 ± 6.1 (5)			
	½-2	3.4 ± 0.5 (10)	21.8 ± 2.4 (10)	4.7 ± 1.3 (5)			
	5-7	2.0 ± 0.4 (4)	10.0 ± 1.1 (2)	2.9 ± --- (1)			
	11-13	1.5 ± 0.2 (4)	22.6 ± 6.1 (2)	2.2 ± --- (1)			

Stand Type and Depth		FWP*	Field Capacity	Organic Matter	Soil x 1mm	Soil x 1mm & x 300 mesh	Soil x 300 mesh
Spruce Fir I	0- $\frac{1}{2}$	17.7 $\pm$ 4.8 (12)	120.9 $\pm$ 18.4 (10)	44.2 $\pm$ 10.9 (6)			
	$\frac{1}{2}$ -2	9.5 $\pm$ 3.6 (10)	45.4 $\pm$ 10.1 (10)	20.0 $\pm$ 10.6 (5)			
	5-7	3.1 $\pm$ 0.4 (5)	13.3 $\pm$ 2.2 (4)	3.4 $\pm$ 1.6 (2)			
	11-13	3.7 $\pm$ 0.8 (5)	12.7 $\pm$ 1.9 (5)	11.5 $\pm$ 9.2 (2)			
Spruce Fir II	0- $\frac{1}{2}$	126.4 $\pm$ 13.4 (8)	242.1 $\pm$ 29.2 (8)	62.2 $\pm$ 11.2 (4)			
	$\frac{1}{2}$ -2	75.7 $\pm$ 11.5 (8)	153.9 $\pm$ 26.3 (8)	50.0 $\pm$ 10.2 (4)			
Spruce Fir III	0- $\frac{1}{2}$	71.4 $\pm$ 13.3 (8)	113.0 $\pm$ 17.0 (8)	56.2 $\pm$ 6.8 (4)			
	$\frac{1}{2}$ -2	30.7 $\pm$ 14.9 (8)	55.6 $\pm$ 15.0 (8)	31.1 $\pm$ 16.2 (4)			
SF Udoty I	0- $\frac{1}{2}$	10.5 $\pm$ 4.7 (10)	67.0 $\pm$ 22.6 (10)	13.7 $\pm$ 5.6 (5)			
	$\frac{1}{2}$ -2	1.1 $\pm$ 0.2 (10)	19.2 $\pm$ 1.7 (10)	4.3 $\pm$ 0.3 (5)			
	5-7	1.3 $\pm$ 0.2 (4)	23.2 $\pm$ 2.8 (4)	4.8 $\pm$ 2.0 (2)			
	11-13	5.2 $\pm$ 0.6 (4)	19.1 $\pm$ 5.0 (4)	4.6 $\pm$ 1.6 (2)			
SF Udoty II	0- $\frac{1}{2}$	23.0 $\pm$ 5.5 (8)	66.4 $\pm$ 9.2 (8)	18.4 $\pm$ 5.1 (4)			
	$\frac{1}{2}$ -2	8.5 $\pm$ 1.5 (8)	34.3 $\pm$ 4.7 (8)	7.2 $\pm$ 2.5 (4)			
Pea Soils	0- $\frac{1}{2}$	10.8 $\pm$ 0.8 (8)	27.3 $\pm$ 3.5 (8)	10.4 $\pm$ 2.5 (7)			
	$\frac{1}{2}$ -2	12.2 $\pm$ 1.8 (8)	27.5 $\pm$ 2.7 (8)	8.7 $\pm$ 1.1 (7)			
	5-7	14.5 $\pm$ 2.4 (8)	41.5 $\pm$ 4.5 (8)	10.0 $\pm$ 1.6 (7)			
Geum-Sib	0- $\frac{1}{2}$	10.7 $\pm$ 1.9 (10)	27.7 $\pm$ 3.5 (10)	11.9 $\pm$ 1.7 (8)			
	$\frac{1}{2}$ -2	7.7 $\pm$ 0.8 (10)	16.9 $\pm$ 1.9 (10)	11.0 $\pm$ 1.1 (4)			
	5-7	7.4 $\pm$ 0.5 (3)	29.6 $\pm$ 0.4 (2)	9.4 $\pm$ --- (1)			
	11-13	8.3 $\pm$ 0.7 (3)	29.9 $\pm$ 1.4 (2)	10.9 $\pm$ --- (1)			
O-1 Seed	0- $\frac{1}{2}$	74.9 $\pm$ 5.9 (10)	147.7 $\pm$ 11.1 (10)	51.0 $\pm$ 3.6 (5)			
	$\frac{1}{2}$ -2	61.5 $\pm$ 5.1 (10)	181.2 $\pm$ 5.1 (10)	41.8 $\pm$ 3.2 (5)			
Hairgrass	0- $\frac{1}{2}$	41.3 $\pm$ 3.7 (10)	110.2 $\pm$ 6.5 (10)	28.5 $\pm$ 2.9 (5)			
	$\frac{1}{2}$ -2	21.3 $\pm$ 1.4 (10)	67.1 $\pm$ 4.1 (10)	16.7 $\pm$ 1.3 (5)			
	5-7	13.4 $\pm$ 0.6 (10)	45.9 $\pm$ 2.1 (10)	11.9 $\pm$ 0.5 (5)			
	11-13	7.2 $\pm$ 0.5 (10)	21.1 $\pm$ 3.3 (10)	6.3 $\pm$ 0.4 (5)			

* FWP is an abbreviation for permanent wilting percentage and data are expressed as means, plus or minus standard error of the mean, and the number following and enclosed in brackets is N or the number of samples percentage.

Soil Samples (Nuclide Analyses)
dpm gram ash wt.
Collected in September 1963, Counted 1 November 1964
Hazelton Nuclear Science Laboratories

Sample (soil 0-24)	Gross Beta	Ce144 Pr144	Ru106 Rd106	Cs137	Sr90 Yt90	Sb125	Mn54	Total beta fission explained	% Fission	Cs/Sr Ratio
Spruce-fir	1,259	152	126	103	75	18	13	487	38.7	2.75
Mature lodgepole pine	1,244	134	109	89	97	16	11	456	36.6	1.84
Immature lodgepole pine	1,270	146	107	94	89	17	16	469	36.9	2.11
Aspen	938	126	82	57		14	14	293*	31.2*	
Kobresia	866	115	100	55	50	13	16	349	40.3	2.20
Sphagnum moss #1 (mounds)	12,163	1,263	976	780	827	146	176	4,168	34.4	1.89
Sphagnum (depression) #1	11,853	680	568	399	169	56	74	1,946	16.4	4.72
#2 Sphagnum mounds	20,287	2,974	2,174	1,296		365	451	7,260*	35.8*	
#2 Sphagnum (depression)	33,330	3,960	2,470	1,329		449	534	8,742*	26.2*	

* Without Sr90 Readings

ATTACHMENT I

FALLOUT MATERIALS
IN SEVERAL COLORADO ALPINE PONDS

David M. Jessup

Fallout in Tundra Ponds

INTRODUCTION

The distribution of radioactive fallout materials in ecosystems has received attention only recently (Caldecott and Snyder, 1960; and Schultz and Klement, 1963). One such ecosystem, located in the Colorado Alpine Tundra area, has been under study for several years by the University of Colorado's Institute of Arctic and Alpine Research (Osburn, 1963). The Alpine Region, although small in size, is important as a water source and as a grazing and recreational area. A knowledge of the fallout distribution in this ecosystem is of primary importance.

The purpose of the present study was to supply some detailed information about a small segment of that total complex--the Alpine pond. The various components of several such ponds were sampled weekly and counted for gross beta activity. Any trends in the rise and fall of radioactivity through the summer and any differences in concentration of nuclides by the various components were related to other variables determined in the course of the study. These variables included the location of ponds with respect to snow banks, the precipitation, the nature of the area surrounding the ponds, and the physical, chemical, and biological characteristics of the ponds themselves.

MATERIALS AND METHODS

Four ponds on Nivot Ridge, about 20 miles west of Boulder, Colorado, were selected for study. From each pond area the following components were sampled each week: (i) components outside the pond: snowbank, surrounding soil, major terrestrial plants, which included alpine willow (Salix sp.), rose crown (Sedum rhodanthum), marsh marigold (Caltha leptosepala), hairgrass (Deschampsia caespitosa), Parry's primrose (Primula parryi), an emergent sedge (Carex scopulorum), and various terrestrial bryophytes;¹ (ii) inanimate components within the pond: pond water, bottom sediments, and scum on the water surface; (iii) animate components within the pond: plankton, various species of algae, aquatic bryophytes, caddis flies (Limnephilus), dytiscid beetles (Copelatus), seed clams (Pisidium), various midges (Tendipedidae), mosquitoes (Aedes), and oligochaete worms.²

Each component required a different sampling method. The top 4 cm. of snow surface was sampled with a metal cylinder having a cross-sectional area of 1 dm². Surrounding vegetation and soil were removed at 10 to 15 locations

around the edges of the ponds. The foliage was merely plucked by hand, and the soil was taken from the ground in small cores to a depth of 6 in., the top 2 in. of plant material and litter being discarded or counted separately for the sake of uniformity. The pond water was collected in 4-liter jugs. The samples were taken 6 in. below the surface, care being taken not to stir up any bottom debris that might contaminate the sample. Each jug was filled with water taken from numerous locations in the pond, 4 to 8 liters being taken from each pond on each date. The uppermost 4 cm of bottom sediments were collected from 5 to 15 locations in each pond and then composited to make one to three large samples. The pond surfaces usually were covered with a thin scum of dust, pollen, and other debris blown in by the wind or released by melting snow. When possible, this scum was sampled by skimming the surface with a paper cup.³

Aquatic bryophytes were hand picked from several locations and combined into a single sample. Substrate algae were collected with a glass tube and rubber suction bulb. (The material actually counted for radioactivity should probably be called periphyton rather than algae.) Benthic oligochaetes, clams and midges were collected with a modified shovel that sampled $1/25\text{m}^2$ of bottom surface. The mud was strained through several grades of wire screening to separate the organisms, which were preserved in alcohol. Free-swimming forms were collected by hand or with a dip net and also preserved in alcohol. Plankton samples were taken with No. 20 silk bolting cloth. There was never sufficient plankton material to use for radio-analysis, but this deficiency was overcome in part by analyzing both filtered and unfiltered water samples.

In the laboratory the samples were either evaporated or dried in an oven, then transferred wholly or in part to small stainless steel planchets for gross beta determination. (Foliage was washed in a weak detergent to remove surface debris before drying.) The material in the planchets was then weighed, ashed, and reweighed before counting. All calculations were made on a dry weight basis.

In all, about 1200 planchets were prepared from the various components of the pond ecosystem. Except for a few cases, these planchets were counted for radioactivity from four to five days after the sample was collected in the field. Certain planchets were counted at later intervals to determine decay curves.

All counts were made on a Baird-Atomic end window model 821B, proportional flow counter and a model 132 scaler. The methods of determining efficiency of the scaler are similar to those used by Osburn (1963).

Only two samples were analyzed for specific nuclide content. One was the debris from a snow bank and the second was a composite of all the debris concentrated from the water samples of one pond during the summer. These analyses were made by the Eberline Instrument Company, Santa Fe, New Mexico.

LOCATION AND DESCRIPTION OF PONDS

The four ponds chosen for study are located near the treelimit region of Niwot Ridge, at an altitude of 11,200 ft. Niwot Ridge (105°35' W, 40°3' N) is a substantial edifice extending eastward from the continental divide for approximately 6 miles. The first pond, named Van Pond, is located near the crest of the middle portion of this ridge on a southeast-facing slope. The other three ponds, named North, East, and Middle Isabelle Ponds, are together at a point further west at the base of the north-facing slope of the ridge. At this point the ridge is considerably steeper and higher than further east, such that the ponds are about 1200 ft. below the ridge crest, at the bottom of a steep talus slope.

Van Pond (Figs. 1 and 3) is strictly a seepage pond, having no inlet or outlet. Its basin is formed by one of the numerous solifluction terraces on this part of the ridge. Because of the unusually low amount of precipitation during the 1962 summer, Van Pond was reduced to about half its normal volume on August 27 and was completely dry by September 11.

In contrast, the Isabelle Ponds (Figs. 2 and 3) remained full throughout the season, being well supplied by a late lying snowbank to the south. The basin containing this snow bank and its ponds is a rather large, glaciated depression at the base of the ridge. (Neldner and Pennak, 1955, described a similar basin near Trail Ridge Road.) East Pond, the largest of the three, has a tiny inlet stream about five feet long and two inches deep at its southern end. Water slowly flows out of the pond through a series of sedge hummocks on the northwest shore. Middle and North Ponds are strictly seepage ponds.

Further differences in the four ponds are summarized in Table 1. Note especially the surface-volume relationships, the time schedule for snow bank melt out, and the type of biotic community found in each. These data, while

not all quantified, show that the ponds differ with respect to several important variables. These differences help explain some of the results set forth in the next section.

The striking characteristics of North Pond deserve further comment here. The north end of the Isabelle basin is covered by a dense growth of waist-high willow bushes, making approach to the two small ponds, especially North Pond, extremely difficult. The location of North Pond, in relation to these bushes and to the direction of the prevailing wind makes it probable that it receives the greatest accumulation of dead willow leaves, which are shed each fall. (Schmitz, 1959, described two alpine ponds similarly surrounded by willows.) North Pond also has the longest open season of the three ponds, enabling willow leaves and other organic matter to accumulate for a longer period of time. It is hypothesized that this excessive accumulation has filled up North Pond at an accelerated rate, making it the shallowest of the three ponds and the only one with an all-mud bottom. This explanation would account for the high organic content of the water and the bottom sediments, which would in turn partially explain the impoverished biotic community and other differences shown in Table 1.

RESULTS

Only four components showed definite trends in the rise and fall of radioactivity through time (Figs. 4-8). These were water, surface scum, caddis flies, and, to a lesser degree, bottom sediments. The other components showed fluctuations which fell within the range of two standard deviations and thus could not be called trends. The relative order of magnitude of these latter components, however, was valid and significant.

In Van Pond (Figs. 4-5), the following differences in magnitude were important: (i) the excessive amount of radioactivity present in the pond water and the surrounding soil and vegetation; (ii) the relatively high activity of ground bryophytes as compared to other surrounding plants, including Carex scopulorum; (iii) the relatively high activity of algae-periphyton and caddis flies as compared to other pond organisms of different trophic* levels; and (iv) the similarity in activity of most pond organisms to that of the bottom sediments. Also significant were the following trends during the summer:

*The manner in which trophic levels are used follows Odum, 1953.

(i) the surface scum on the pond was very radioactive during the first part of the season (comparable to the snow bank activity), then dropped to very low amounts later; (ii) the pond water reached a peak of activity on July 3, then dropped off rapidly during the middle part of the season (except for one fluctuation), and finally rose again on August 27; (iii) radioactivity in caddis fly larvae decreased at a rapid rate throughout the season, with a sharp loss accompanying pupation; and (iv) the activity of the bottom sediments, in contrast to most other components, failed to drop and may have risen slightly during the summer.

The orders of magnitude of radioactivity for the components of the Isabelle Ponds were similar to those of Van Pond, although there were some minor differences in actual activity. Basic seasonal trends were also similar, except for those that will be noted in subsequent paragraphs. The additional components of aquatic bryophytes, mosquitoes, and midges, none of which were present in quantity in Van Pond, were sampled from the Isabelle Ponds. These components had activities comparable to those of the Van Pond algae-periphyton, caddis fly pupae, and oligochaetes, respectively. Table 2 points out these similar relationships by listing the average concentration factors⁵ of the components of all four ponds. Since the water of North Pond had the highest activity, the concentration factors of its components were reduced, even though they were similar in specific amount to the other ponds.

The trends in water radioactivity of the four ponds were different in several significant ways (Fig. 6). North Pond, the most radioactive of the four, had already reached a peak of activity when sampling began. Middle Pond also showed its highest activity on the first sampling date. East Pond, on the other hand, was most radioactive on July 10, and Van Pond, as previously mentioned, had its peak a week earlier. None of the Isabelle Ponds showed an upturn on August 27, as did Van Pond, but they did increase slightly on September 10 (Van Pond was dry by then).

Other significant differences were shown by the surface scum activity of the four ponds (Fig. 7). For East and Van Ponds, the scum activity at the first of the season was very high, comparable to that of the respective snow banks, but then fell off markedly. For the other two ponds, the activity of the surface scum also decreased during the season, but it was not as high initially.

In contrast to water and surface scum, the activity of the bottom sediments appeared to rise in all ponds during the course of the season. When concentration factors instead of actual amounts are plotted (Fig. 8), this trend becomes even more apparent.

The results of the two nuclide analyses showed that over 90 percent of the activity in the tundra snowbanks was due to the nuclides strontium-90 (0.7%), cesium-137 (0.9%), cerium-144 and praseodymium-144 (92.7%), and their daughter products. However, only about 20 percent of the total water activity of Van Pond was due to these nuclides, cesium-137 being reduced to insignificant amounts--strontium 90-(3.4%), cesium-137 (0.03%), and cerium-144 and praseodymium-144 (24.5%). Although this one sample proves little, it indicates that some mechanism might exist for rapidly removing cesium-137 from the water or preventing it from getting there in the first place. It also raises the possibility that naturally occurring isotopes might contribute significantly to water activity.

DISCUSSION

Mechanisms for the entrance of fallout materials into the pond water:

Most fallout is originally brought to earth in precipitation (Davis, 1963). Of this fallout, there are five plausible mechanisms for its entrance into the alpine pond ecosystem: (i) direct precipitation onto the open surface of the pond, (ii) runoff from surrounding areas, (iii) seepage, (iv) wind-blown debris, and (v) the snowbank mechanism.

1) Direct precipitation onto the open surface of the pond. This mechanism could be a significant source during summer wet periods. The 1962 summer, however, was notable for its low amount of rainfall (only 3.0 inches instead of the 9-year average of 5.7 inches), so that direct precipitation was probably not too important in this case. There was, however, a sizable snowstorm on September 7 before the last collection date, which probably accounted for the slight upturn in activity of the Isabelle Ponds on September 10. A local shower also might explain the fluctuation shown in Van Pond on July 17. (The increase in activity of Van Pond on August 27 was probably not due to precipitation, but to the concentration of debris resulting from the evaporation of the pond.)

2) Runoff from surrounding areas. Since most precipitation in the tundra is in the form of snow, this factor is not important except in the spring and summer. Moreover, Osburn (1963) has shown that most meltwater from Tundra areas has its fallout load effectively removed by vegetation and soil, which acts as a physical and chemical filter. Undoubtedly the same process occurred in the ponds studied, as they were surrounded by extensive sedge mats which filtered virtually all runoff. The plants and soil of these sedge mats, especially the bryophytes, retained a good deal of radioactivity, as shown by Fig. 4. Spotty sampling of unwashed vegetation and the top layer of soil litter showed that this filtration mechanism was even greater than Fig. 4 indicates. In this connection it is hypothesized that a pond at the base of a talus or sheer rock slope free of surrounding vegetation would accumulate much more fallout than the ponds studied.

3) Seepage. Only dissolved materials can enter the pond in this manner; all particulate matter is probably absorbed by the surrounding soil and vegetation in the manner already described.

4) Windblown debris. When fallout particles are deposited as litter on soil and plant surfaces by the melting snow, they can dry out and be blown onto the pond surface by the strong tundra winds. This phenomenon may account partly for the activity of the surface scum noted at various times during the season, but probably is not too significant in terms of total radioactivity.

5) The snowbank mechanism. The data indicate that this mechanism is by far the most important means for fallout to enter the ponds. During the winter months, when the water in the ponds is frozen solid, snowbanks usually accumulate in the pond basins. Winter observations on Nivot Ridge have shown that these snowbanks cover all the ponds studied. With the coming of warmer weather, the ice melts and the snowbank recedes back over the pond surface. As it recedes it releases debris, including dissolved and particulate fallout material, directly into the water and onto the surface of the pond. The activity of the pond water thus gradually increases as the snow melts, until it attains a peak at the time the snowbank reaches the pond's edge. From that time on, most of the debris in the snowbank becomes filtered out of the meltwater before it reaches the pond. Consequently, the activity of the water decreases rapidly, because the addition of new fallout materials via wind and new precipitation is not enough to compensate for the decrease of radio activity by decay, settling, adsorption, and absorption by the biota.

This snowbank mechanism hypothesis is substantiated by two sets of data. Fig. 6 shows that the peak of activity for East Pond and Van Pond correlated exactly with the data that the snow bank had reached the edge of these ponds. For North Pond, which was completely snow free on the first collection date, the activity peak apparently occurred earlier. Although collection from Middle Pond did not start till later, there is no indication that it did not behave similarly to North Pond. Fig. 7 shows that the surface scum activity on East and Van Pond was at first similar to that of the snowbanks that extended over their surfaces. This activity soon dropped when the snow receded from the pond margin. The fact that snow free North and Middle Ponds had only moderate surface scum activity early in the season tends to substantiate the hypothesis of the snowbank mechanism of fallout release.

The differences in the water radioactivity of the four ponds, particularly the greater activity of North Pond (Fig. 6) is most easily explained by referring to the map and noting the surface area - volume relationship. According to the snowbank mechanism hypothesis, the actual amount of fallout materials released by the snow is in part a function of the surface area of the pond; that is, ponds with equal areas will receive similar amounts of fallout from the same amount of snow. But a deeper pond would tend to dilute this amount more than a shallow pond, so that the activity per unit volume would be less for the deeper pond. North Pond is on the average only half as deep as Middle Pond, explaining in part the difference in activity. North Pond's lack of biological activity, which in other situations serves to remove radioactivity from the water, probably also contributes to that pond's greater nuclide content.

Mechanisms for the removal of fallout materials from the pond water:

The activity of the pond water, even at its peak, was much less than that of the surface scum and snow debris, and even this activity decreased rapidly during the season. Certain factors must have been at work to remove nuclides from the water. Loss by seepage and outflow is not the answer, for this loss would have been balanced by seepage and inflow from above.

A good part of the loss must be attributed to the decay of short-lived isotopes, such as iodine-131, which is a common product of nuclear testing. Decay curves were kept for many of the snow and water samples, and the activity of those samples taken during the peak of water activity had decreased by 30% 60 days later.

The drop due to decay was not enough to account for the total drop in water activity, however. The biotic community also removed some of the nuclides from the water. The primary producers of the pond, algae and moss, served especially well in this capacity. Nuclides were probably absorbed directly into the cells and bound with detritus to the plant surface (Williams and Swanson, 1958). The plankton producers were not measured directly for radioactivity. But several water samples were filtered through a number twenty plankton net before analysis, and these counted similarly to samples which had not been filtered. Thus, even though the small amount of plankton present might have had high activity, it was not significant in comparison to the activity in the water due to dissolved materials and particles and plankton small enough to pass through the net.

Caddis flies are important primary consumers in most tundra ponds. They clamber over the rocks and submerged sedge plants near the shore, scraping off the periphyton and constructing their cylindrical cases from cut sedge leaves and other vegetable matter. As would be expected, their activity was quite high. The rapid drop shown in Fig. 5 was probably a result of decay, decreasing availability of the nuclides, shedding of the exoskeleton during instar development, dilution by the increase in biomass as the animals grew (Pendleton and Hanson, 1958), and changing of habits (as pupation approached, the larvae began to construct their cases out of sand grains rather than vegetable matter). When pupation occurred there was another drop in activity. No adults were found. The fact that the caddis fly peak of activity in Van Pond did not correspond with the peak for water activity shows that these animals obtained their fallout loads somewhat independently of the condition of the pond water. This is a reasonable assertion when it is noticed that the caddis flies collected early in the season were found on the submerged Carex along the shore, which had already received a heavy deposit of radioactive debris from the melting snow even though the snow was not yet completely removed from the rest of the pond.

The benthic detritus feeders, including oligochaetes, clams and midges, as a group had low amounts of radioactivity throughout the summer. Most of the nuclides obtained by these organisms came from the bottom sediments, which were also fairly low in activity. The counts fluctuated around background levels, and this lowness of activity, coupled with the small number and weight of the samples, accounts for the variability shown in Fig. 5.

Occasional samples of mosquito larvae and pupae showed them to be intermediate in activity between the caddis flies and the benthic species. But the other free living species, the beetle, Copelatus, showed very low amounts of activity. This beetle forms the highest trophic level in the pond, for it is supposedly exclusively carnivorous (Pennak, 1953). If caddis flies form a large part of the beetle's diet, then there must be a very high discrimination factor in the transition of nuclides from the preceding trophic level (Libby, 1957).

Thus it is seen that in the case of the ponds studied, there is a general decrease in activity from one trophic level to the next. This finding agrees with several authors (Williams and Pickering, 1961; Libby, 1957) who report a discrimination factor in the food web transfer. Other authors, however, (Ophel, 1963; Pendleton and Hanson, 1958) show that sometimes the higher trophic levels have the greatest concentration of radioactivity. Still others report both concentration and discrimination at various levels in the food chain (Minckley, et al, 1963; Ball and Hooper, 1963). There seems to be a great deal of uncertainty as to what generally takes place in the transfer of nuclides through the food web. Perhaps each situation is unique and depends on the balancing of a number of variables, such as the discrimination factor, the weight and kind of food ingested, the change in food habits as an organism matures, the types of nuclides available, the amount of nutrients available, the sources of nuclides outside the food web, and the specific nature of the organisms involved (Townsend, 1960; Nelson, 1960; Davis, 1963; and Nat. Acad. Sci. Publ., 1957).

One other mechanism accounted for the reduction in activity of the pond water--adsorption by various organic and inorganic surfaces. Submerged sedge leaves, both living and dead, served as such a surface, for unwashed samples of this material showed much higher activity than washed samples. Still other fallout particles adhered to detritus present in the snow and water and gradually sunk to the bottom. The rapid disappearance of cesium-137 from the water was probably due to this factor, as cesium-137 has been shown to be closely bound by detritus (Williams and Swanson, 1958). Fig. 8 shows that this settling process added to the activity of the bottom sediments at a slightly faster rate than decay and leeching removed activity. Since nearly all the living organisms will eventually end up on the bottom also, it is

expected that the bottom sediments will gradually increase in activity over the years if fallout materials are made continuously available in the atmosphere (Williams and Swanson, 1953). This increase will probably proceed in a stairstep fashion due to the inactive period of the winter months, during which no new fallout is added. There will probably be no corresponding gradual increase in water activity of the ponds, however, because each season's addition from the snowbank will be rapidly removed by the mechanisms just discussed.

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TABLE 1: Summary of Pond Characteristics

Characteristic	Van Pond	East Pond	Middle Pond	North Pond
Location	s.e. slope near crest of ridge	n. slope near base of ridge	n. slope near base of ridge	n. slope near base of ridge
Type of basin	solifluction terrace	glaciated depression	glaciated depression	glaciated depression
Type of drainage	seepage	open and seepage	seepage	seepage
Area	96.5 m ²	218.3 m ²	46.9 m ²	42.9 m ²
Surface-volume ratio	.69	.32	.39	.80
Date snow receded from pond	July 3	July 10	Before June 22	Before June 22
Surrounding soil-- % organic matter (by ignition)	36.1	65.2	65.2	65.2
Water--color	clear	clear	clear	colored (weak tea)
Water--gms residue/l	.0232	.0293	.0270	.0381
Water--% organic matter of residue (by ignition)	35.1	34.2	29.2	46.7

TABLE 1: Summary of Pond Characteristics (continued)

Characteristic	Van Pond	East Pond	Middle Pond	North Pond
Water--surface temperature on Aug. 6, 1:00 PM	13 - 14°C	3 - 14°C	12 - 15°C	15 - 17°C
Type of bottom	rock and mud	rock and mud	rock and mud	mud only
Bottom sediments-- % organic matter (by ignition)	16.4	26.5	41.9	43.7
Biotic community				
Algae	present	present	present	present
Aquatic bryophytes	none	present	present	present
Caddis flies, <u>Limnephilus</u>	present	present	present	very rare
Midges, Tendipidinea	245/m ²	2774/m ²	2070/m ²	75/m ²
Annelid worms, Oligochaeta	6858/m ²	729/m ²	205/m ²	75/m ²
Clams, <u>Pisidium</u>	667/m ²	none	none	none
Mosquitoes, <u>Aedes</u>	rare	none	present	present
Beetles, <u>Copelatus</u>	present	present	present	rare

TABLE 2: Average concentration factors of pond components (the mean of the concentration factors measured each week). Concentration factor = uuc/gm dry wt of component divided by uuc/ml of water. Total number of samples for 12 weeks are given in parentheses.

Component	Van Pond	East Pond	North Pond	Middle Pond
Algae	88,637 (4)	160,491 (8)	45,597 (5)	168,393 (6)
Aquatic bryophytes		192,515 (11)	30,690 (2)	119,687 (5)
Caddis fly larvae, <u>Limnephilus</u>	54,619 (15)	28,807 (3)	5,393 (2)	22,645 (7)
Caddis fly pupae, <u>Limnephilus</u>	11,577 (3)	1,648 (4)		4,113 (7)
Midges, Tendipidinea		1,122 (2)	2,129 (1)	1,667 (1)
Annelid worms, Oligochaeta	1,997 (15)			
Clams, <u>Pisidium</u>	2,302 (9)			
Bottom sediments	2,662 (43)	11,744 (29)	1,947 (21)	6,727 (14)
Mosquitoes, <u>Aedes</u>	13,500 (3)		15,103 (4)	20,710 (8)
Beetles, <u>Copelatus</u>	1,999 (17)	3,143 (6)	1,017 (6)	3,005 (7)

TITLES FOR FIGURES

- Figure 1. Van Pond from the northeast..
- Figure 2. East Isabelle Pond from the southwest, showing position of snowbank on June 22.
- Figure 3. Morphology of ponds. Dashed lines show extent of snowbanks on dates given.
- Figure 4. Gross beta activity of Van Pond components. Each point represents the mean of the number of samples shown above by a small numeral. SD refers to average standard deviation, or the mean of the SD's taken each week.
- Figure 5. Gross beta activity of Van Pond components. Each point represents the mean of the number of samples shown above by a small numeral. SD refers to average standard deviation, or the mean of the SD's taken each week.
- Figure 6. Gross beta activity of pond water.
- Figure 7. Gross beta activity of surface scum.
- Figure 8. Concentration factors of bottom sediments. (Concentration factor = $\text{uuc/gm dry wt of component divided by uuc/ml of water.}$)

SMALL MAMMAL POPULATIONS AND ECOLOGICAL
VARIATIONS IN AN ALPINE WATERSHED

ATTACHMENT II

to

U. S. Atomic Energy Commission
Contract No. AT (11 - 1) - 1191

RADIOECOLOGY OF THE COLORADO FRONT RANGE

William S. Osburn, Principal Investigator

Submitted by
Horace F. Quick

POPULATIONS OF SMALL MAMMALS IN THE BOULDER CITY WATERSHED

Estimates of the numbers of small mammals in various plant communities were desired in adjunct to a project conducted by William S. Osburn to describe the pattern and process of radioactive fallout in a domestic water source, the Boulder City Watershed, Boulder, Colorado.

Among other objectives, it was desired to ascertain estimates of the rates of body-return to soil (population turn-over) insofar as the translocation of radioactive nuclides through mammal bodies might be evaluated, and to facilitate the tracing of radioactive elements through food chains.

A more detailed description of this area, which has been studied intensively by staff and associates of the Institute of Arctic and Alpine Research, is given in "Ecosystems of the East Slope of the Front Range in Colorado" by Marr (1961), but for the purpose of this project 20 plant communities were recognized in which small mammal population estimates were made.

This paper deals only with the population ecology of small mammals in the watershed and adjacent areas in the summer of 1964. Estimates of populations were made from a sampling effort of approximately 30,434 trap nights during which 826 small mammals were trapped. Two hundred and two plots were sampled in 20 plant communities, prorated according to the ratio of the areas of each type to the 6,000 acre watershed.

The sampling design was based on a composite of designs employed by Burt (1940), Calhoun (1950), Davis (1956), Stickel (1954), Williams (1955), and others, that was modified so that direct estimates of densities could be ascertained (Quick, 1954, 1955, 1956) in terms of number of animals per acre. The unit area of sampling was one acre in the form of a square, approximately 209 feet on each side. Over the unit sample area, a grid of 25 stations in five rows of five stations each, were placed at about 40 foot intervals. Two snap traps were placed near each station, within a radius of three feet and baited with a mixture of oatmeal, peanut butter and bacon grease. Traps were tended daily, rebaited frequently and left in place for three days except in a few cases when the trapping period was extended because of hail, snow, or for experimental reasons.

The original design of the experiment was maintained on 170 one acre plots through the first 25,500 trap nights. Then, to allow for the spatial limitations imposed by small plant communities, 24 one quarter acre plots were sampled using the same trap spacing. On eight plots time extensions were employed to test the

functioning of "rapid area exhaustion" which was an essential premise of the scheme. No area was trapped twice and no plot was ever set closer than the dimension of a plot from its nearest neighbor.

The Sampling Philosophy Employed:

The idea of the sampling scheme was to obtain direct density estimates in terms of number of animals per acre in various plant communities. Since the acre is the most familiar land measurement unit and an acre is also an adequate habitat unit for mice, voles, and shrews, this area was used as the sampling unit. The trap spacing employed was based on home range studies, in particular by Burt, Stickle and Williams, and intends to provide a trap station for each potential home range on the one acre sample unit, as might be occupied by a rodent or shrew. The scheme assumes, based on previous studies, that an area of one acre is large enough to support more than one small mammal, and proceeds to test the level of occupation. Previous experience (Quick, 1953) has shown that at times populations are so high that 3 traps must be maintained at each station especially during the fall peak population period. But, beginning in the spring with the lower, over-wintering populations, three traps per station are rarely required. Therefore, only two traps were set at each station during the first (spring) sampling period. In no case were 2 animals caught at a single station during this period, but two traps were maintained to assure having at least one functional. Since the trap itself is the essential, primary sampling unit, it must be meticulously maintained. A missing trap means a missing record, positive or negative as concerns mammal populations, and so intensive search was made for all missing traps.

The system implies that an exhaustion of the resident population on the sample area can be accomplished before the vacuum created by the removal of an occupant can be re-occupied by an immigrant from an adjacent area. The performance of most of the traps followed a rather consistent pattern, the largest catches taken on the first night at stations random over the plot, with dwindling catches on subsequent nights and tending to appear in peripheral traps. Thus, each plot is subjected to a sudden impact of population reduction with 150 trap nights in three successive nights. The period of sampling has been derived from Burt's live trapping experiments that indicate that most resident animals are taken in three nights of trapping. Each trap station has a circle of influence equal to an average home range, which if occupied, should be revealed within the 3 day sampling period.

In any kind of trapping system it must always be acknowledged that an un-trappable part of the population might escape detection. Therefore, only minimum reliable estimates of populations can be made. That is, an animal trapped is positive evidence of his presence at that point and at a specific time, but there is no measure of animals that might have escaped trapping.

From knowledge of reproduction patterns (Kalela, 1956) the design of a population sampling method must anticipate changes resulting from births and deaths of members of the population. In order to perceive the occurrence of these events, the uteri of females and the testes of males were examined and measured, as well as total length, tail length, hind foot, ear length and weight to one tenth gram.

The incidence of foeti and placental scars, classified according to size and freshness, were recorded to provide a description of the local reproduction phenology, for example, clues as to the occurrence of seasonal population increases.

Finally, this experimental design recognizes from many other studies that it is not possible to make an instantaneous population estimate. Therefore, either a seasonal average must be stated or some datum such as over-wintering population level, or fall-peak population level must be used to express an average population level for a given period. This arises not only from the elemental fact that populations are always changing but equally from the standpoint of the pure impossibility of extracting samples that represent instantaneous conditions.

This investigation attempts to quantify in absolute terms of density, the current (1964) status of small mammal populations that lived as a faunistic complex in a given area, by tracing seasonal changes and searching for such intrinsic indicators of change as variations in pregnancy rates, age ratios and litter sizes as means of interpreting the changes that were observed.

Distribution of Sampling Effort:

Work capability was estimated from the available labor force and the number of days that could be spent afield. The crew consisted of four full-time members and several occasional helpers. A target of 30,000 trap nights was set, based on the estimate of work capability with regard for the sampling procedure, and the work season, which extended from June 7 to October 9, 1964.

Within the calendar limits of the field work, three periods of populations status were visualized similar to those encountered by Kalela in his studies of red back voles in Finland. These could be described as "over-wintering" levels, "first reproduction period" levels, "second reproduction period" levels, and possibly even a third, either of which latter two periods might also be regarded as "fall peak" population levels. The sampling effort was categorically divided into three periods, June 1 to July 15, July 16 to August 15, and August 16 to September 15. Obviously natural phenomena do not start and stop with calendar precision but it was anticipated to adjust these periods, in the analysis of the data, according to the population phenology observed from the examination of uteri and seasonal weight changes in the animals that were collected.

The over-all quota of 200 plots was ultimately met, but some variations in distribution of sampling effort became necessary because of lack of manpower and discovery of the desirability to concentrate more effort on some plant communities and less on others.

Description of Areas Sampled:

Sample plots that were located in timber types were, at least optically, uniform and posed no visible problem insofar as homogeneity of the sampling unit was concerned. Plots were situated so that the surrounding area of at least another plot dimension consisted of the same plant community or habitat.

In the tundra, however, it was often difficult to find areas that were sufficiently homogeneous within the bounds of the sample unit, and even more difficult to find such areas adequately buffered by similar surroundings. This resulted in the need for a habitat classification that is somewhat more specific than that which is useful to the plant ecologist. To accommodate this problem the tundra area of the Boulder watershed has been classified into five Mosaic types and two patterned ground types. Some micro-habitats may be missing from the following list of types sampled, but most likely are embraced within one or another of the larger sampling units listed.

Description of Plant Communities Sampled:

Hay meadow	<u>Carex</u> , <u>Juncus</u> , <u>Alium</u> , mixed grasses; mowed annually.
Aspen I	Dry site; Aspen dominant, 50% or more crown cover, ground cover mixed herbaceous, spring aspect <u>Arnica-Thermopsis</u> ; fall aspect, grasses and mixed herbs.

Aspen II	Wet site; Aspen dominant, 50% or more crown cover; ground cover; alder-willow-spruce-fir; <u>Calamagrostis</u> .
Limber pine	Crown dominant, 50% or more; boulder cover 30% or more; very old stands, some more than 400 years old; ground cover; very sparse, Juniper, grasses, Lupine.
Lodgepole pine	Essentially pure stands; barren floor covered with accumulation of needle litter.
Spruce-Fir	Crowns dominant; pole, mature or over-mature stands; two sites distinguishable, flat and slope; ground cover; <u>Vaccinium</u> , on slopes; grasses and sedges on flats that are pools in spring aspect.
Bog I	Willow-Birch <u>Sphagnum</u> hummocks interspersed with sedges and grasses.
Bog II	<u>Carex aquatilis</u> , often 100% cover over areas of 1/4 acre.
Limber pine-spruce fir understory	This type probably will be a spruce-fir climax. Ground cover; <u>Vaccinium</u> .
Lodgepole pine-spruce fir understory	Probably spruce-fir climax. Ground cover; <u>Vaccinium</u> .
Limber pine burn	Dead standing snags, fallen snags. Spruce-fir reproduction. Willow and fireweed often appear in clumps.
Krumholz	Spruce-fir clumps not exceeding 50% of area; often willow clumps are associated; 50% or more in some mosaic type.
Mosaic I	"Gopher garden"; 50% or more of ground surface is soil, gravel, rock, resulting from intense gopher activity; <u>Hymenoxys</u> , <u>Artemesia</u> , <u>Achillea</u> , <u>Chrysopsis</u> , <u>Agropyron</u> . A tundra type occurring at altitudes of 11,000 to more than 12,000 in this region.
Mosaic II	A tundra type; sometimes called "fell field" dominated by cushion plants; windswept and snow-free; often 30% to 50% bare soil, gravel and rock; <u>Silene acaulis</u> prominent; <u>Dryas</u> , <u>Arenaria</u> , <u>Eritrichium</u> .

- Mosaic III A tundra type; alpine meadow type with spring and fall aspects differing; 80% or more cover of Geum and associates in spring aspect with Trisetum and Carex more apparent in fall aspect.
- Mosaic IV A tundra type; pure stands of Kobresia.
- Mosaic V A tundra type; a mosaic of turf banks and basins; solifluction terraces which are well drained are covered with cushion plants, Klamia, Dryas, Vaccinium, and Deschampsia; while the wet, poorly drained basins are dominated by Caltha and small mounds of Calamagrostis.
- Patterned Ground I Fine gravel pans (frost scars) formed by "needle ice" action, surrounded by larger rock compression ridges. Trisetum, Geum, Dryas, Carex, Kobresia dominate in the more stable spaces between frost scars. Polygons of rock may be found but not in crater-like patterns as in Patterned Ground II.
- Patterned Ground II Polygon rock net and rock-stripe phenomena formed of large boulders moved into formation by frost action; craters sometimes 5 feet deep. Interspaces vegetated with Trisetum, Geum, Carex elynoides and others.
- Tree-line wet meadow Open areas surrounded by large trees, usually spruce; plant cover of Caltha, Carex, willow and grasses; solifluction terraces common.

Primary Analysis of Data:

The six species of small mammals that were collected (Appendix I), insofar as taxonomic status is concerned, are considered to belong each to a single species. Some color variation was observed in Peromyscus, that seemed related to habitat type but not enough to warrant the expectation of more than one species. Similarly specimens of Sorex occasionally were taken that had variations in color but this seemed more related to age than to specific variations. Several different species of Sorex have been recorded from this region, but not specifically from the watershed area in which there is some foundation for expecting topotypes to be of one species. Watershrew,

Notiosorex, have been taken by others in this area but for reasons not understood, none were taken this season, despite the effort at wide coverage and intensive trapping of all obvious habitats. The nomenclature used here is taken from "Mammals of North America," Hall and Kelson (1959).

In Table I the nature of the results of primary analysis show several categories of population phenomena for each of the six species of small mammals collected. Probably the most significant information is that of "Average density in occupied types." This value expresses density with reference to distribution, allowing for areas in this same habitat that were not occupied. In contrast to this, "Average density on occupied plots" is a measure of density without reference to distribution. However, this value serves importantly to identify niche affinity and acknowledges the animal itself as the informant of its own most favored habitat.

It would be expected that at higher population levels the spread of a species into other niches, adjacent to optimum ones, would make perception of this ecologic relationship more difficult. It is believed from other population studies in this region (Reid, 1963) that the general population level is moderate; that is, somewhere between high peaks and low ebbs.

First Period of Sampling:

During the first sampling period (Table I) the objective was to obtain an estimate of over-wintering populations to which subsequent seasonal increases during the summer favorable period could be compared. To some extent this objective was accomplished, especially in habitats at higher altitudes, but the over-all average of animals trapped during this period showed that at least one new generation had been added (Table IV) during the period of June 7 to July 28. In general, the early season catches consisted of adult animals, many of the females gravid. Some females had, by this period, already given birth to a first litter as shown by placental scars. In the summary section of this table the ratios of young (non-breeding) to breeding adults permits the estimate of what proportion of first period catches were over-wintering adults. About 69% of the Peromyscus taken during the first period, being adult at this early part of the season, probably represent the over-wintering population. Applying this ratio to the estimate of densities of Peromyscus (6% of 1.18 Peromyscus per acre) yields the parameter of over-wintering Peromyscus density at about 0.81 per acre. The same procedure applied to

TABLE I. POPULATIONS OF SMALL MAMMALS IN THE BOULDER CITY WATERSHED
RELIABLE MINIMUM ESTIMATES
DURING THREE SAMPLING PERIODS

FIRST PERIOD: June 7 to July 28, 1964; 100 Plots.

	PEROMYSCUS	CLETHRIONOMYS	SOREX	MICROTUS	PHENACOMYS	ZAPUS
Greatest Density per acre	7	4	6	3	2	3
Least Density where sps. occurred	1	1	1	1	1	2
Average Density on Occupied Plots	2.04	1.80	2.83	1.83	1.21	2.60
Average Density in Occupied Types	1.18	0.53	0.89	0.31	0.31	1.03
Freq. of Occurrence on Plots Sampled	56%	15%	12%	6%	14%	5%
Freq. of Occurrence in Types Sampled	94%	50%	38%	31%	31%	19%

SECOND PERIOD: August 3 to September 9, 1964; 68 Plots.

Greatest Density per acre	14	7	14	3	5	1
Least Density where sps. occurred	1	1	1	1	1	1
Average Density on Occupied Plots	3.50	2.00	2.93	1.60	1.57	1.00
Average Density in Occupied Types	2.97	1.31	1.14	0.28	0.54	0.50
Freq. of Occurrence on Plots Sampled	80.9%	47.0%	22.0%	7.4%	20.6%	1.5%
Freq. of Occurrence in Types Sampled	38%	71%	64%	36%	57%	7%

THIRD PERIOD: September 17 to October 9, 1964: 34 plots.

Greatest Density per acre	12	31	9	8	2	0
Least Density where sps. occurred	1	2	1	1	2	0
Average Density on Occupied Plots	4.55	11.71	3.45	2.33	2.00	0
Average Density in Occupied Types	3.64	6.31	2.53	1.40	0.55	0
Freq. of Occurrence on Plots Sampled	58.8%	20.6%	32.3%	17.6%	8.8%	0
Freq. of Occurrence in Types Sampled	67%	33%	44%	33%	33%	0

TABLE II. POPULATION ESTIMATES: MID-SUMMER (AUGUST).
AVERAGE NUMBER OF MAMMALS PER ACRE

<u>TYPE</u>	<u>PEROMYSCUS</u>	<u>CLETHRIONOMYS</u>	<u>SOREX</u>	<u>MICROTUS</u>	<u>PHENACOMYS</u>	<u>ZAPUS</u>	<u>AVERAGE DENSITY SMALL MAMMALS BY TYPE</u>
HAY MEADOW	0	0	0.50	0	0	0	0.50
ASPEN-DRY	4.70	1.10	0.10	0	0.20	0	6.10
ASPEN-WET	1.50	1.00	11.50	0	0	1.00	15.00
LIMBER PINE	2.16	0.50	0.16	0	0	0	2.82
LODGEPOLE	1.33	3.33	0	0	0	0	4.66
SPRUCE FIR	1.00	2.33	2.00	0.50	0.33	0	6.16
BOG/BIRCH WILLOW	NOT SAMPLED THIS PERIOD						
BOG/CAREX	NOT SAMPLED THIS PERIOD						
LIMBER PINE Spruce-Fir	1.29	1.43	1.00	0.14	0	0	3.86
LODGEPOLE Spruce-Fir	2.33	2.00	0.33	0	0	0	4.66
LIMBER PINE BURN	7.25	1.25	0.50	0.25	0.25	0	9.50
KRUMHOLZ	2.00	1.00	0	0	0.50	0	3.50
MOSAIC I	5.83	0.16	0	0.33	0.16	0	6.43
MOSAIC II	NOT SAMPLED THIS PERIOD						
MOSAIC III	2.50	0	0.33	0.16	2.00	0	4.99
MOSAIC IV	NOT SAMPLED THIS PERIOD						
MOSAIC V	0	0	0	0	0	0	0
PATTERNED GROUND I	1.0	0	0	0	0.50	0	1.50
PATTERNED Ground II	3.00	0	0	0	0.33	0	3.33
ALPINE MEAD. TIMBERLINE	2.66	0	0	0	0	0	2.66

AVERAGE DENSITY OF MAMMALS BY SPECIES
IN TYPES IN WHICH THEY OCCURRED

2.97 1.31 1.14 0.28 0.54 0.50

TABLE III. OPTIMUM HABITAT AS INDICATED BY HIGHEST AVERAGE DENSITY IN TYPE

First Sampling Period: June 7 to July 23, 1964.

SPECIES	OPTIMUM HABITAT	GREATEST DENSITY	AVERAGE DENSITY
Peromyscus	Aspen (dry types)	7	3.43
Clethrionomys	Spruce-Fir	4	2.17
Sorex	Bog/Birch-Willow and Aspen (<u>wet</u> types)	6	4.67
Microtus	Mosaic V and Krumholz	3	1.33*
Phenacomys	Mosaic II	2	0.71*
Zapus	Bog/Birch-Willow	3	2.67*

Second Sampling Period: August 3 to Sept. 10, 1964.

Peromyscus	Aspen (dry types) and Limber pine burn	14	7.25
Clethrionomys	Spruce-Fir and Lodgepole/S-F	7	3.33
Sorex	Aspen (<u>wet</u> types)	14	11.50
Microtus	Mosaic I	3	0.33*
Phenacomys	Mosaic III	5	2.00
Zapus	Bog/Birch-Willow	1	0.50*

Third Sampling Period: Sept. 17 to Oct. 9, 1964.

Peromyscus	Patterned Ground	12	8.00
Clethrionomys	Spruce-Fir	31	15.40
Sorex	Aspen (<u>wet</u> types) Spruce-Fir	9	5.00
Microtus	Bog/Birch-Willow	8	1.67*
Phenacomys	Mosaic V	2	0.67*
Zapus	--	--	-- *

*Populations too
sparse to permit
high-confidence
estimates.

TABLE IV. REPRODUCTION PATTERNS

PEROMYSCUS

SAMPLING PERIOD	CONDITION OF UTERI				
	Clear	Embryos	Embryos & Scars	Scars 1 set	Scars 2 sets
June 7-July 28	31%	41%	10%	14%	3%
Aug. 3-Sept. 10	39%	19%	5%	31%	6%
Sept. 17-Oct. 9	69%	0	4%	27%	0

CLETHRIONOMYS

June 7-July 28	40%	40%	20%	0	0
Aug. 3-Sept. 10	30%	70%	0	0	0
Sept. 17-Oct. 9	68%	22%	17%	12%	0

SUMMARY INTO TWO CLASSES

PEROMYSCUS

	Non-Breeding Young		Breeding Adults (and Sub-Adults)
July 28	31%		69%
Sept. 10	39%		61%
Oct. 9	69%		31%

CLETHRIONOMYS

July 28	40%		60%
Sept. 10	30%		70%
Oct. 9	68%		32%

Clethrionomys yields an estimate of about 0.32 animals per acre, as a threshold or over-wintering population. Not enough information was obtained about the other species to derive a more refined estimate of this population level than that given in Table I.

Summarized, the principal objective of First Period sampling was to obtain an estimate of over-wintering population levels, to which maximum population levels achieved later in the summer, could be compared. The difference provides a measure of the cycle of animal bodies in the ecosystem.

It would, of course, be more logical to obtain an estimate of the rate of body-return in the ecosystem by following the summer population build-up with over-wintering population estimates during the next spring. However, these objectives had to be accomplished during one summer field season.

Second Period of Sampling:

The pattern of reproduction (Table IV) observed by examining the uteri of female animals indicated that the timing of the field work was behind schedule all summer long. These data could be adjusted to conform to the observed reproduction pattern but the presentation is based on the original concept of the sampling design, the objective of which was to obtain the First Period sample from all of the plant communities. Coverage of all plant communities could not be accomplished by July 15 and resulted in delays through the rest of the experiment.

Second Period reproduction patterns Table IV, August 3 - September 10, show that this is the period during which the age structure begins to shift from predominantly adult to predominantly young of the year. During August and early September there is an increase in the proportion of females with multiple sets of placental scars and a decrease in the number actually pregnant, as compared to first Period reproduction patterns.

Some females bearing embryos and scars during this period actually were members of the juvenile cohort born during the First Sampling period and indicates the approach to the period of maximum recruitment when the fullest force of reproductive power gives the population a surge of increase that results in a shuffle for suitable habitat niches in which to winter over.

During the second period, sampling effort was reduced to 68 plots and some environments sampled in the first period were not covered in the second.

The four habitats not covered, were generally not inhabited by Peromyscus and not at all by Clethrionomys at the levels attained during the summer of 1964. Therefore, this omission in sampling does not distort average population estimates of Peromyscus and Clethrionomys but it does alter estimates of Microtus and Zapus. Sorex and Phenacomys populations conformed in pattern quite closely to the more abundant Peromyscus and Clethrionomys, in regard to seasonal increase rates, changes in occurrences in types sampled and on plots sampled.

The results of this more or less geometric increase established population levels that were in general 300 to 400 percent higher than over-wintering populations. For example, the average density of Peromyscus increased from 0.81 animals per acre to 2.97 and Clethrionomys from 0.32 to 1.31. The increase in shrew population was indicated to be in the order of 20% and Phenacomys increased about 80% between first period and second period estimates. These and Microtus and Zapus population variations cannot be compared as well because of lack of information about reproduction phenology.

Third Period Sampling:

Sometime during September there was a major shift in population structure with the ratio of young to breeding adult being directly inverted to the ratio of the first period. In the two-class summary for the species of Peromyscus and Clethrionomys the patterns are shown to have been very similar. At some point in the spring, there probably were no young at all (allowing for the possibility of late winter breeding), and at some point in the fall there were no over-wintering adults (1963 cohorts) at all. Therefore, within the third sampling period there was a complete turnover of population probably indicated by the absence of animals displaying two sets of placental scars, thus signifying the loss of old adult or even some of the first period females that had matured this summer. In fact, the complete turnover of population might even have occurred in the latter part of the second sampling period, sometime during early September.

This viewpoint is corroborated by the change in weight and total length ratios, also. That is, largest animals taken in first period were larger than the biggest taken in the third period. These observations, to be sure, must be based upon the assumption that the samples adequately represent the character of the populations, for the reason that no other foundations are available.

Populations of Peromyscus and Clethrionomys, nevertheless, increased again, despite the loss of some of the older females. This is possible by virtue of the recruitment of early-season young to the adult class, having matured in 25 to 30 days after birth, and attained the status of sexually mature but young adults. This component of the population can actually exceed the parent population as was shown by the over-all average of about 5 young per litter.

Increases in populations of Clethrionomys were in the order of 500% from an average of 1.31 per acre to 6.31 per acre in all types occupied. There appeared to be a general lag in the reproduction pattern of Clethrionomys which occurred later in the season than that of Peromyscus. This observation might be induced by the sampling or from the fact that Peromyscus ranges through more plant communities (altitudinal) and therefore has a wider spread of reproduction phenology or from both.

Populations of Peromyscus increased in the third period but seemed to have reached a stabilization before Clethrionomys. Reduction of breeding adults appeared to begin in September while this class among Clethrionomys was still on the increase.

The estimate of 3.64 Peromyscus per acre during the fall-peak period represents an increase of about 300% over average spring populations and in the order of about 400% greater than over-wintering populations.

Increases in Sorex and Microtus populations were at about the same rates as Peromyscus and Clethrionomys but Phenacomys and Zapus populations were not high enough to provide sufficient data for density determinations.

The columns "Frequency of occurrence on plots sampled" and "Frequency of occurrence in types sampled" are probably important measures of population ecology, relating changes in population levels to environments. In this study, there was not enough man power to allow sampling levels in the second and third periods comparable to the first in which 100 plots throughout all 20 environments were sampled.

Mid-summer Population Estimates:

Probably the most easily appreciated of population estimates are those pertaining to mid-summer which are neither the lowest as in the early spring nor highest as in the fall-peak period. While these should not be construed to represent average seasonal nor average annual populations they do approach

closely the average summer population. For the reason that progressive changes take place in population growth a form of running average would have to be used to express true average populations and to obtain data that would yield this kind of information would require much more man power than is usually available for such studies.

Table II presents the averages of population for the six species of small mammals in 16 habitat types. Averages for all species by type are given as well as averages by species in all types. The later value represents the ratio of the six species to each other as they occurred in the entire watershed during midsummer. Peromyscus was the most ubiquitous having been found from the lowest to the very highest elevations, as well as in all types except Mosaic V. This type is a wet type with no large rock within it, the habitat requirement seeming to be either brush, windfall or boulders in which shelter is easily found. Clethrionomys was not as widely distributed ecologically and except in a very few instances was limited in altitudinal distribution by the occurrence of spruce-fir cover, even if only as a small component of aspen, limberpine or other types. Sorex has as wide a distribution in the watershed as Peromyscus, and although the most abundant mammal in any given type, 11.5 per acre in Aspen II, was not at as high a general population level as that attained by Peromyscus.

Optimum habitats of each of the six mammals were recognized by highest average density calculations determined by comparing densities in each of the 20 plant communities. Table III indicates optimum habitat for each of the three sampling periods. Peromyscus demonstrated two optima, one at the lowest altitudinal level in the watershed, in Aspen, and the other at the highest in Patterned Ground II. Differences in density values, it is believed, reflect differences in sampling, no Aspen I having been sampled in the third period. The densities of 7.25 per acre in Aspen I in the second period and 8.0 in Patterned Ground in the third are in a close agreement and are believed to represent average late summer and fall densities. Peromyscus occurred in all types at all altitudes but were sparse in coniferous timber types. Clethrionomys demonstrated a consistent preference for Spruce-Fir through all three periods. The average densities shown indicate rather clearly the geometric pattern of population increase in this type. The average density of 15.4 is among the highest measured but does not exceed estimates made by other workers in other places. One plot in dense spruce-fir forest yielded 31 animals per acre which is probably an unusual concentration.

Sorex demonstrated a reasonable consistency of preference for Aspen II, wet types, most of which had rills of running water or boggy ground in them. During the late part of the summer shrews were found in equal density in Spruce-Fir types, particularly those on flats in which there had been small pools of standing water in the spring. Birch-Willow bogs were also well populated with shrews during this season. Viewed in the light of the present study, the optimum habitat for shrews is a wet area. However, shrews were seen on rock talus at elevations of more than 12,800 feet and caught on plots at an elevation of about 12,400 feet. They are reported as being present on 14,000 foot peaks in Colorado.

Microtus were found mostly in high alpine types. Although greatest densities during the three sampling periods occurred in three different types, certain aspects of plots in these different types were similar. Wetness, but not saturation, of at least a part of the plot, and association with some shrub or small trees, usually willow, seemed to be a common characteristic of plots on which Microtus were taken. Though winter nests of Microtus and Phenacomys probably cannot be distinguished as both are made of cuttings of sedge and grass, a number of these nests were found in the bottom of gullies, basins under solifluction terraces, and in low wet spots adjacent to "gopher gardens." (See photo)

Phenacomys were most abundant in the tundra types but two were caught in aspen stands at about 10,000 feet elevation. Although greatest densities and highest average densities occurred in the same type for a given sampling period, this was not consistent through all sampling periods. That is, three different Mosaics appear as optimum each in a different period. The difficulty of classifying the tundra habitats has already been mentioned and these difficulties probably enter into the discrepancy regarding the recognition of optimum habitat of Phenacomys. The visual impression obtained by the observation of nests, cuttings, tunnels and galleries in turf banks, is that Phenacomys finds it most favored habitat in the mosaics with solifluction terraces that provide elevated areas to which the animals can retreat during wet periods when basins are flooded. Banks of Geum-Bistort-Trisetum in juxtaposition with basins of Carex and grasses seemed to be favored at the population levels attained in 1964.

Zapus appeared mainly in Birch-Willow bogs and in Aspen stands with swards of Calamagrostis in wet areas. They were more clearly confined to specific plant communities than any of the other five species during this study period. Populations in the watershed area seemed confined to the lower level birch-willow bogs, but several Zapus were caught in open spruce bogs, where there was considerable water and tall grass.

THE CYCLE OF ANIMAL BODIES IN AN ECOSYSTEM:

The continuum of the population process renders any instantaneous estimate of the rate of body-return to the soil impossible, but qualified estimates can be based on running averages of populations if reliable periodic censuses can be obtained. A considerable obstacle to this procedure is caused by the dynamic character of population phenomena, especially those composed of animals that have short life spans. In the birth-death process the death phase is concealed from any sampling device that depends on the action of live animals. Information about reproduction rates which represent accruals to the population, combined with "instantaneous" population estimates provide a qualified basis for estimating biomass. "Instantaneous" estimates in such a case must refer to short-term average densities such as obtained during the three periods of sampling in this study. Even these, however, are too broad to give more than a rough estimate. (Diagram illustrates a schematic pattern of this problem.)

A contingent factor that enters into this problem is that of body weight. Those organisms that survive increase in weight through most of the life span and those that die represent a spread of weight classes correlated with age at death. Eventually, of course, all die, so the latter statement applies, the first statement only serving as a perspective on sampling a live population.

The assumption employed here is that the geometric mean of a series of "instantaneous" estimates of densities represents the annual productivity of an over-wintering population. The animals thus born have an average weight related to mean life span which also may be determined as a weighted mean, since at least three age-weight classes can be observed and measured.

Estimate of Mean Density:

<u>Peromyscus</u>	$\sqrt[3]{1.18 \times 2.97 \times 3.64} = 2.337$ per acre
<u>Clethrionomys</u>	$\sqrt[3]{0.53 \times 1.31 \times 6.31} = 1.636$ per acre
<u>Sorex</u>	$\sqrt[3]{0.89 \times 1.14 \times 2.53} = 1.369$ per acre
<u>Microtus</u>	$\sqrt[3]{0.31 \times 0.28 \times 1.40} = 0.495$ per acre
<u>Phenacomys</u>	$\sqrt[3]{0.31 \times 0.54 \times 0.55} = 0.452$ per acre
<u>Zapus</u>	(Insufficient data)

These series of density estimates from Table I represent "instantaneous" averages obtained for each of the three sampling periods. The order of increase observed among Peromyscus, Clethrionomys and Sorex conformed reasonably to the pattern of reproduction observed by autopsy of these same animals which provided the basic density estimates. All represent an approximation to Malthusian or geometric increase.

The "slump" shown in the second period by Microtus could actually have occurred but is not likely. It probably is attributable to inadequate sampling of Microtus habitat combined with population levels that were too low to detect. Among Phenacomys, while there is a gradual increase in density estimates, the progression does not match the observed reproduction rates (autopsy of specimens) but can be explained partly by high mortality or inadequate sampling. There was inadequate sampling of optimum Zapus habitat, because sampling effort was concentrated on the larger plant communities in the watershed.

Estimate of Mean Weight:

All of the six small mammals collected exhibited a rather clearcut size-weight relationship, size being determined by the standard total length measurement and weight in grams. Three classes were readily determined and intermediate ones were measurable but seemed to serve no further purpose than could be derived from the three-class assortment of data. These classes were derived by first classifying the specimens according to the condition of reproduction organs. The classification was more clear-cut among females than males because of the visible conditions of uteri. The first class was definitely established as a juvenile class by the complete absence of uterine blood, scars or foeti. A second group classified as sub-adult was based on the combination of size-weight and breeding status, the animals carrying first litters or showing one set of placental scars. The adult group consisted of larger animals with evidence of two or more litters of young having been produced or in some stage of production. Classification of males was more difficult and greater reliance was placed on size relationship including size of testes.

Snap-trap sampling provides an instantaneous sample but the validity of an average weight statement depends upon a proper factoring of the frequency of each age-weight class at an instant in the population cycle. In addition, differences between the sexes of a given species, as well as separate consideration of each species is required. The average weights of three age-weight groups, for each sex, of six species are given in the following table.

Table V. Average weight of age groups by sex and species

Age Group	Weight in grams					
	I		II		III	
	Male	Female	Male	Female	Male	Female
<u>Peromyscus</u>	13.5	13.09	19.2	20.5	28.0	27.1
<u>Clethrionomys</u>	15.7	14.7	23.1	23.9	26.3	31.2
<u>Sorex</u>	3.4	3.2	4.8	5.0	6.8	6.7
<u>Microtus</u>	15.9	13.6	21.4	22.5	29.7	33.4
<u>Phenacomys</u>	14.6	15.2	22.3	25.2	32.0	35.0
<u>Zapus</u>	19.5*	19.7*	22.6*	20.9*	28.5*	28.0*

*Only one specimen in each of these classes.

Weights given are almost certainly minimum weights inasmuch as some loss of body fluids likely occurred between trapping and weighing. The generally heavier weight of females in the sub-adult and adult classes represents pregnancy. Juvenile males were found to be heavier, which fits a pattern common among mammals.

Some indication of the frequency of each of these age-weight classes can be derived from Table IV for Peromyscus and Clethrionomys but not yet analyzed for the other species. Mid-summer or second sampling period conditions indicated that roughly 39% of Peromyscus were juvenile, the balance in breeding condition distributed through at least two age-weight classes. During the same period the proportion of Clethrionomys juveniles was somewhat lower, indicating a lag in the population cycle. Later, the two patterns became practically identical, perhaps in response to the over-ruling control of environment, closing the period of reproduction.

The net annual return of animals in occupied habitat in terms of individual animals does not represent animals of equal body weight (see preceding paragraphs). Since the shifts of age groups from early season to late season population levels are inverse to the shifts in weight groups, the direct product of these means cannot be used. The larger portion of summer population actually belongs to the lighter weight classes. There are also shifts in sex ratios, but detailed consideration of these variables are not warranted in this trial.

Following, is an example of correction for age-weight class shift in population structure.

Table VI. Population Composition: Density per Acre by Age Classes in Suitable Habitat

	Juvenile	Sub-Adult	Adult	Mean Summer Density
<u>Peromyscus</u>	0.911	0.445	0.981	2.337
<u>Clethrionomys</u>	0.491	1.145*		1.636

*Breakdown of classes not observed until later in season

Table VII. Average Weight in Grams by Age Classes, Sexes Combined

	I	II	III
	Juvenile	Sub-Adult	Adult
<u>Peromyscus</u>	13.29	19.85	27.55
<u>Clethrionomys</u>	15.20	23.50	28.75
<u>Sorex</u>	3.30	4.90	6.75
<u>Microtus</u>	19.75	21.95	31.05
<u>Phenacomys</u>	14.90	23.75	33.50
<u>Zapus</u>	19.60	21.75	28.25

This procedure assumes that the mean summer density is a measure of annual productivity and that an over-wintering population would be reserved from the difference between mean summer population and maximum summer population. Such a viewpoint allows flexibility to account for year-to-year variations in winter survival and annual productivity and also accounts for a perennial breeding reserve above which a "mean summer density" can be considered as annual productivity.

Following this reasoning, the rate of body return for Peromyscus could be calculated as,

$$(0.911 \times 13.29) \div (0.445 \times 19.85) \div (0.981 \times 27.55) = 48.016 \text{ grams/acre,}$$
 which is the sum of the products of mean summer density by age classes and average weight for each age class. Inasmuch as these methods do not measure "running losses" that occur from juvenile mortality (and other) these estimates may be increased as much as 100% (see Conclusions).

Other Perspectives on the Problem:

A viewpoint that is perhaps more in keeping with the ideas of animal husbandry regards the difference between breeding stock and maximum herd size as the annual productivity. Following this perspective the rate of body return to the soil can be estimated as the net mortality between maximum summer populations and over-wintering populations. Net mortality would include, in the case of wild small mammals, all of the over-wintering adults, which die in early summer, as shown in the turn-over of the age classes, Table IV, of course, unlike domestic livestock. This class is the heaviest weight class and as in the former procedure variations in weight with age must be considered.

Table VIII. A Preliminary Method of Estimating Net Seasonal Mortality

	Over-wintering Density Per Acre*	Maximum Summer Density Per Acre*	Net Mortality Per Acre*
<u>Peromyscus</u>	0.81	3.64	2.83
<u>Clethrionomys</u>	0.32	6.31	5.99

*in suitable habitat.

Since this latter procedure is based on late-season population estimates (in contrast to the former procedure in which mean summer populations were used) the age ratio pattern for the latter part of the summer seems to best represent the character of the population at the time specified. This can be applied to the balance after deduction of that part of the late season population that will become over-wintering adults. Thus, for Peromyscus, a net mortality of 2.83 less an over-wintering population of 0.81 leaves a population of 2.02 which is 69% juvenile and 31% sub-adult (Table IV, Summary into Two Classes).

Then, the weight of Peromyscus bodies returned to the soil is, $(69\% \times 2.02) \times 13.29 + (31\% \times 2.02) \times 19.85 + (0.81 \times 27.55) = 53.265$ grams per acre per year (1964).

Conclusion:

The foregoing are trials of hypotheses derived from a basic population study, to experiment with methods of measuring the rate of cycle of small mammal bodies in a natural environment. To do this, it is necessary to proceed

through problems, which in themselves are in need of further experimentation. These, in particular, relate to methods of obtaining definitive population estimates and correlating them to measured environments.

Since these methods do not provide for measuring the part of a small mammal population that dies before it can be sampled, this factor needs be considered by other means, as yet not worked out. There is an indication that as many as 40% to 50% of mice born do not survive juvenile stages. If this is so, then the above estimates can be increased nearly 100%.

The greatest need, if these problems are to be "solved", is for continuing research through several years, in a given location, with standardized and consistent sampling methods, so that year to year comparisons can be made. The research approach must have two independent phases to be correlated later. One must pursue quantitative studies of animal populations and the other must define the environment in which the animals live.

Finally, it must be re-emphasized that the results of this work pertain to population conditions in 1964. This and other studies make it clear that variations of rodent populations are sometimes drastic, even within one calendar year. This study also demonstrates that niche affinities are a function of population levels and that the idea of a population reservoir in an optimum environment as an essential premise of population genetics and race survival.

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APPENDIX I

IDENTIFICATION OF SMALL MAMMALS WITH ANNOTATIONS

FAMILY SORICIDAE

Sorex merriami. The specimens taken in the summer of 1964 appeared to be of this species. Other shrews (cinereus and vagrans) are reported from this region. Watershrews, Sorex palustris, have been collected in the immediate vicinity of the Watershed but so far as can be determined not from within the area of this study.

FAMILY CRICETIDAE

Peromyscus maniculatus, Long tailed white footed deermouse. This mouse is probably of one sub-species, maniculatus, in the eleven square mile area of the Watershed. It was the most ubiquitous of the small mammals during the summer of 1964, with what appeared to be a continuous distribution through all habitat types. Color variations occur probably as much related to age as to habitat.

Microtus montanus, Gray meadow mouse. The specimens examined appeared to be of one species. Two other species are said to occur in this region.

Phenacomys intermedius, Heather vole. Listed in Mammals of North America, Hall and Kelson, 1959, as the only species in this region.

Clethrionomys gapperi, Red-backed mouse or vole. This vole is currently regarded as being of the sub-species galei.

FAMILY ZAPODIDAE

Zapus princeps, Western woodland jumping mouse. Jumping mice were found only in the lowest areas of the watershed during the summer of 1964 and therefore did not enter significantly into this study. However, on a few sample plots in Birch-Willow Bogs, populations were abundant.

APPENDIX II

Some characteristics of the population cycle observed in the summer of 1964.

Peromyscus:

1. None of the females less than 16.5 grams total weight had bred, regardless of the season in which they were caught.
2. No animal was caught later than August 15 that weighed more than 25.7 grams. This marks the period of turn-over when young of the year replace over-wintering adults.
3. Sixty percent of all females trapped which weighed more than 25 grams were caught by June 30. These are part of the over-wintering population.
4. Of all juvenile females trapped 37% were caught after June 30. Of all juvenile males trapped about 90% were caught after June 30.
5. The first period of recruitment is represented by the first sub-adult group that appears in sampling. Seventy-five percent of these were breeders at time of capture.
6. There is a distinct shift of age composition that is inverse in the fall to that of the spring population.
7. Fifty percent of the sub-adult males trapped were caught before August 5. These were born before July 1 and represent the first period of recruitment. Forty percent of the sub-adult females trapped were caught before August 5. The ten percent differential probably represents biased sampling differential mortality or uneven sex ratio at birth.
8. Highest populations are found in areas with good escape cover at ground surface but not high crown densities. Open aspen and limber pine stands and areas of large boulders in the tundra areas, had most dense populations.

APPENDIX III

DESCRIPTION OF ILLUSTRATIONS

- Plate No. 1. Mosaic V. Turf-bank terrace and basin. A tundra type on Niwot Ridge. July, 1964.
- Plate No. 2. Mouse-made galleries in turf-bank of solifluction terrace shown in Plate No. 1. These appear to be used especially during periods of high run-off that flood the basins, such as summer hail or rain storms as well as in spring when snow-melt begins.
- Plate No. 3. Mouse nest in basin shown in Plate No. 1. Nests appear to be used in winter only, under snow before spring run-off begins.
- Plate No. 4. Krumholz type, near upper limit of dwarfed trees. Site near plots 65, 66, 67, in saddle north and east of Timberline Van.
- Plate No. 5. Limber pine burn. Site of plot No. 133 about one mile east of Kiwi Van, north of road. Ten Peromyscus, one shrew and one chipmunk were trapped on this plot during the peak population in mid-August.
- Plate No. 6. Limber pine burn, plot No. 143 above "Elk's Roost". Two Peromyscus caught at same station (one juvenile and one adult), a rare occurrence during the summer of 1964.
- Plate No. 7. Alpine meadow at bottom of "The Trough". Site of plot No. 137.
- Plate No. 8. Mouse nest appears old and unused in summer. The blades of sedge and grass are arranged in a criss-cross pattern that tends to weave the mass together. Nests can be distinguished from accumulations of run-off debris by the woven pattern as well as by position, such as in the fork of a stick as shown. Plot No. 138.
- Plate No. 9. Nest in small basin in Krumholz on plot No. 194, old mill site near Albion. Note pencil for scale.

- Plate No. 10. Girdling by mice during winter took place under snow cover. Leader killed but lower branches still alive. Plot No. 137, tree-line meadow.
- Plate No. 11. Plot No. 141, Krumholz. Corner station showing traps in place and small spruce completely girdled and killed.
- Plate No. 12. Plot No. 100, location of 12,000th trap-night. Patterned Ground II, Nivot Ridge, July 23, 1964.
- Plate No. 13. Plot No. 161, Mosaic III. Flat saddle between Kiowa and Albion peaks. Phenacomys and Sorex taken here.
- Plate No. 14. House nest, probably Phenacomys, in turf bank on plot No. 161, saddle between Kiowa and Albion peaks. Note pencil for scale. Ceum, Carex and Caltha dominant.
- Plate No. 15. Plot No. 165, Patterned Ground I, in saddle between Kiowa and Albion peaks. Altitude about 12,300 feet.
- Plate No. 16. Near plot No. 156. Fresh clippings of sedge probably indicate the beginning of nest building in the fall. Sept. 8, 1964. Mosaic V, in basin, Caltha-Carex cover.
- Plate No. 17. Plot No. 190, Krumholz, at edge of cirque, above Roberts Snowfield. Trap dragged about eight feet by Peromyscus that had been caught by tail.
- Plate No. 18. Same trap as in Plate No. 17 showing how mouse took refuge in rock crevice. Large boulder, rock stripe and patterned ground seem to be favorite habitat of Peromyscus.
- Plate No. 19. Plot No. 170, meadow near Island Lake. Road divides meadow type; left, Deschampsia, right, Carex. Microtus taken in Deschampsia and Sorex in Carex on this particular plot.
- Plate No. 20. Plot No. 168, Patterned Ground II, site of 25,000th trap-night; south slope of Kiowa, elevation about 12,600 feet. Population of Peromyscus on this plot attained a density of eight per acre in September.