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ECOLOGY OF THE 200 AREA PLATEAU WASTE MANAGEMENT ENVIRONS: A STATUS REPORT

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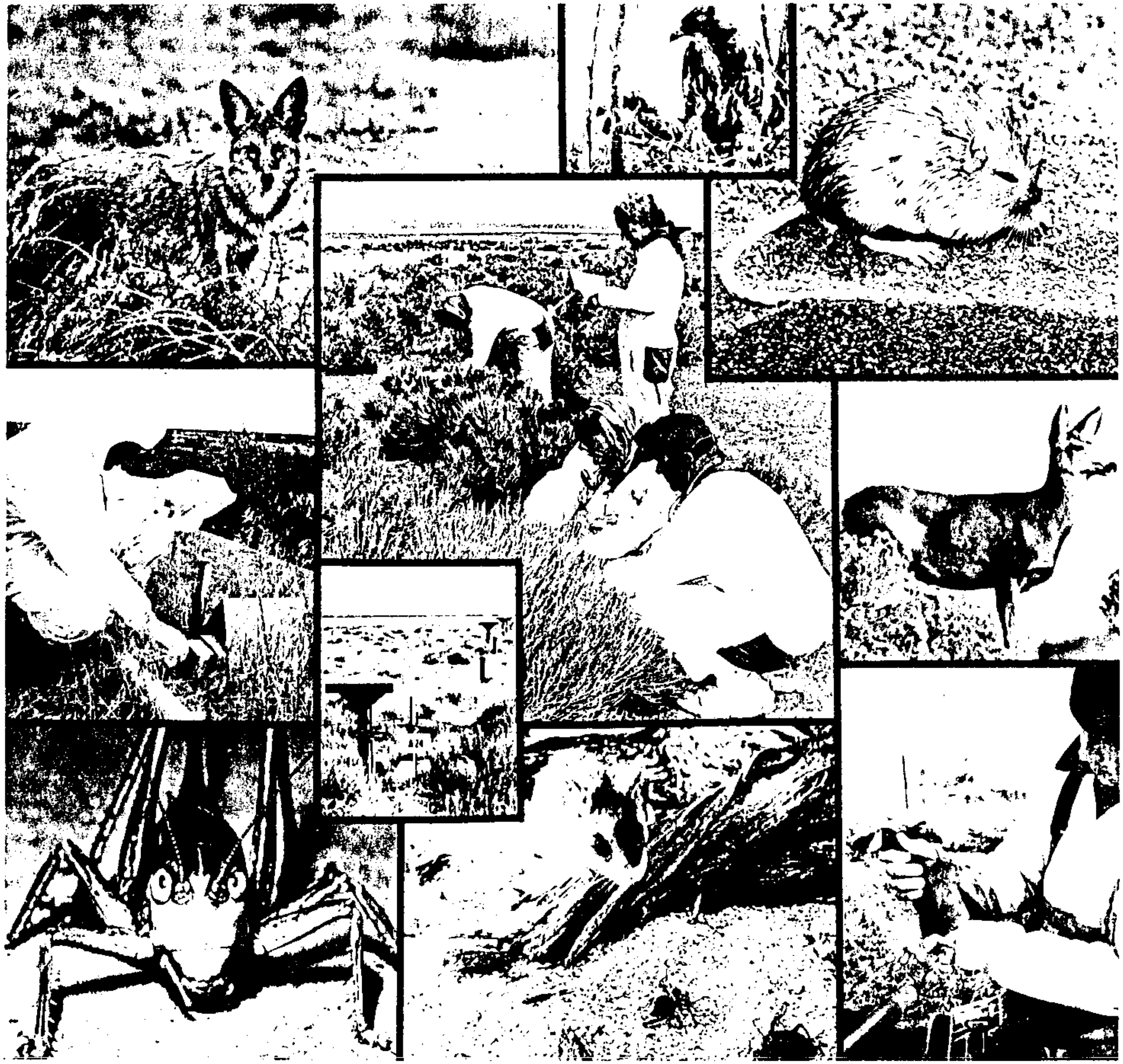

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ACKNOWLEDGEMENTS

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In developing our concepts, we have drawn extensively on the data base, design paradigms and professional experience of staff associated with the ROWMA program and its predecessor programs funded by the Division of Biomedical and Environmental Sciences of the Department of Energy. Numerous meetings have been held also with RHO staff, RHO's outside consultants and PNL's ecology staff in order to develop a comprehensive ecological capability to deal with biotic transport problems. We wish also to thank the following individuals (RHO) for their interest and participation which contributed to the success of this effort: R. D. Fox, V. A. Uresk, K. R. Price, M. N. Legatski and H. L. Maxfield.

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SUMMARY

The Rockwell Hanford Operations (RHO)-supported ecological studies are designed to clarify ecosystem structure and functioning as pertaining to the management of radioactive waste control areas. To date, emphasis has been placed on characterizing the abiotic and biotic components of these areas. Future emphasis will include energy and mineral cycling mechanisms, radionuclide transport by biota and modeling of ecosystem functioning, thereby integrating past characterization and future ecological transport studies for application to waste management operations.

This document summarizes past ecological work on the 200 Area plateau, assesses the present data base, and projects future research needs for the RHO-sponsored biotic transport program. Past and projected research needs are identified in terms of six research categories:

- Characterization
- Biotic production
- Transfer process
- Radionuclide transport
- Environmental assessment
- Management modeling

Research tasks scheduled for particular categories are identified on a 5 year milestone chart with task interrelationships illustrated in a flow diagram.

This report is organized so that readers with specific interest should have little difficulty in locating detailed information (i.e., endangered species, risk to man). Others may wish to read the abstracts provided at the beginning of each chapter rather than concentrating on detailed research reports. A general understanding of research emphasis through time, planned milestones and task interactions can be grasped from Figures IX-1 through IX-11.

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CHAPTER I. INTRODUCTION

V. A. Uresk and L. E. Rogers

A general description of ecosystem functioning introduces the need for comprehensive ecological studies as part of the overall waste management operations on the 200 Area plateau. A history of waste management operations and location of 200 Area facilities is provided.

PURPOSE OF STATUS REPORT

Ecological studies have been conducted on the Hanford Reservation for over 30 years. Much of the earlier work represented an initial effort in understanding aquatic and terrestrial systems associated with the Hanford Reservation. The purpose of this report is to provide a framework for integrating past studies with the present biotic transport investigation of the 200 Area plateau. The intent is to show how present studies have built on past work and where "holes" presently exist in the data base. Hopefully, this approach will provide an overall view as to where we are now in terms of compiling an adequate data base for waste management operation decisions and provide perspective as to how particular tasks fit into the overall program. Studies concerning the impact of radiation dose on deer mouse populations or the diets of grasshoppers may seem esoteric when considered independently, but are essential when viewed as a small part of a complete program.

NEED FOR ECOLOGICAL STUDIES

The term ecosystem was introduced by Tansley (1935) and refers to the natural interaction of organisms and their environment. Ecosystem level studies received little attention until recent years when various disturbances began to appear in natural systems as a result of environmental degradation. This visible degradation led to the passage of the National Environmental Policy Act (NEPA) of 1969.

An ecosystem may be defined to include the entire world (biosphere) or be limited to a single pond, decaying stump, or water puddle with its temporary plant and animal inhabitants. All ecosystems are generally recognized as having certain attributes. These include an abiotic (nonliving) component, a producer (green plant) component, a consumer component, and a decomposer component. The interaction of these components is illustrated in Figure I-1. The abiotic component represents the basic ecosystem building blocks--providing materials (minerals and water) and energy (sunlight) for protoplasm synthesis.

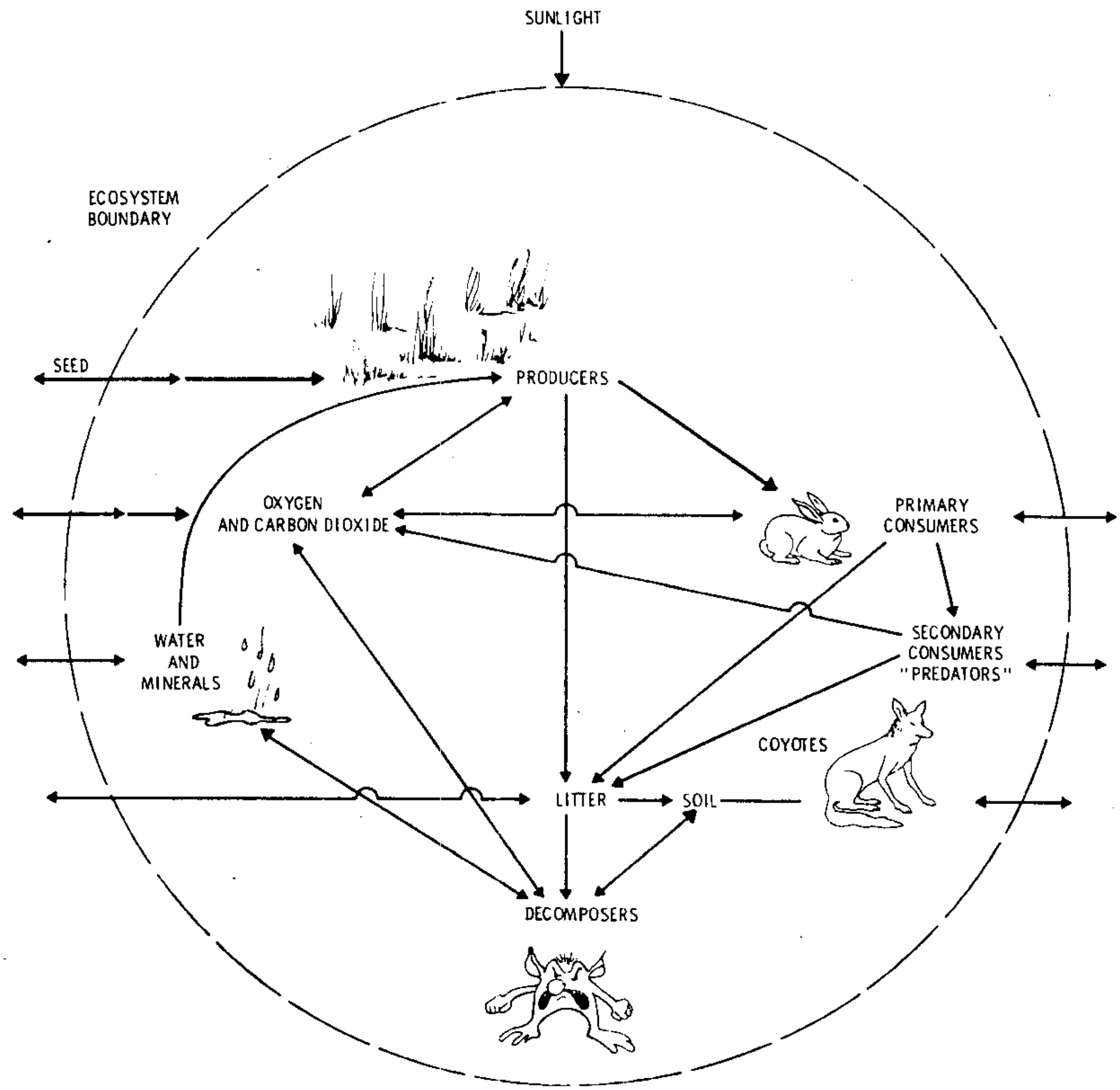

FIGURE I-1. Functional 200 Area Plateau Ecosystem. Arrows represent flow of materials. Arrows crossing ecosystem boundary represent transport into or out of the system.

The green plants represent the first step in ecosystem organization. They are the only component capable of converting solar energy into organic materials. Plants always serve as the basis for food chains leading to the consumer component. The consumers include herbivores, omnivores, carnivores, and parasites. Their role in ecosystem regulation is not well understood. They are, in theory, not an essential component in that ecosystem processes will continue in their absence, but they represent a major mechanism for physically transporting materials within and between ecosystems.

The decomposers are an essential, although an inconspicuous, ecosystem component. Comprised largely of fungi and bacteria which live on dead organic matter, they serve to prevent the buildup of organic remains. Without their presence, the litter layer would function as a nutrient sink, trapping minerals needed for succeeding generations of plant growth.

Here, we are considering the environs of the radioactive waste management areas of the 200 Area plateau to represent the ecosystem of interest. A detailed outline of ecological studies is presented later in this report, but all are designed to either: 1) acquire basic ecological data--i.e, species inventory, abundance, biomass; 2) determine transfer patterns in terms of mineral, and water cycling or the exchange of energy within the system; or 3) to reach some practical conclusions concerning a recommended program for ecosystem stabilization and management of radioactive waste storage areas.

Grasslands, in general, have been poorly studied until recent years. The International Biological Program initiated Grassland Biome Studies over a 5-year period, terminating in 1975. The Arid Lands Ecology (ALE) Reserve represented the shrub-steppe grasslands in this effort. Detailed studies of the 200 Area plateau ecosystem will permit an evaluation of similarities with the ALE studies concerning ecosystem functioning.

Specific study objectives are also prompted by the need to understand how radioactive waste management operation activities affect ecosystem functioning. Some of these objectives have been detailed in the recently issued Hanford Environmental Impact Statement, particularly the need to conduct comprehensive studies of the effect of the deposition of radionuclides in plants and animals.

In summary, knowledge concerning the structure and functioning of the 200 Area plateau will provide the data base, permitting the development of scientifically sound management processes.

LOCATION OF WASTE MANAGEMENT FACILITIES

The Hanford Reservation occupies a 570 square mile tract of land in southcentral Washington and is bound on the north and east by the Columbia River and to the west by the crest of Rattlesnake hills (Figure I-2).

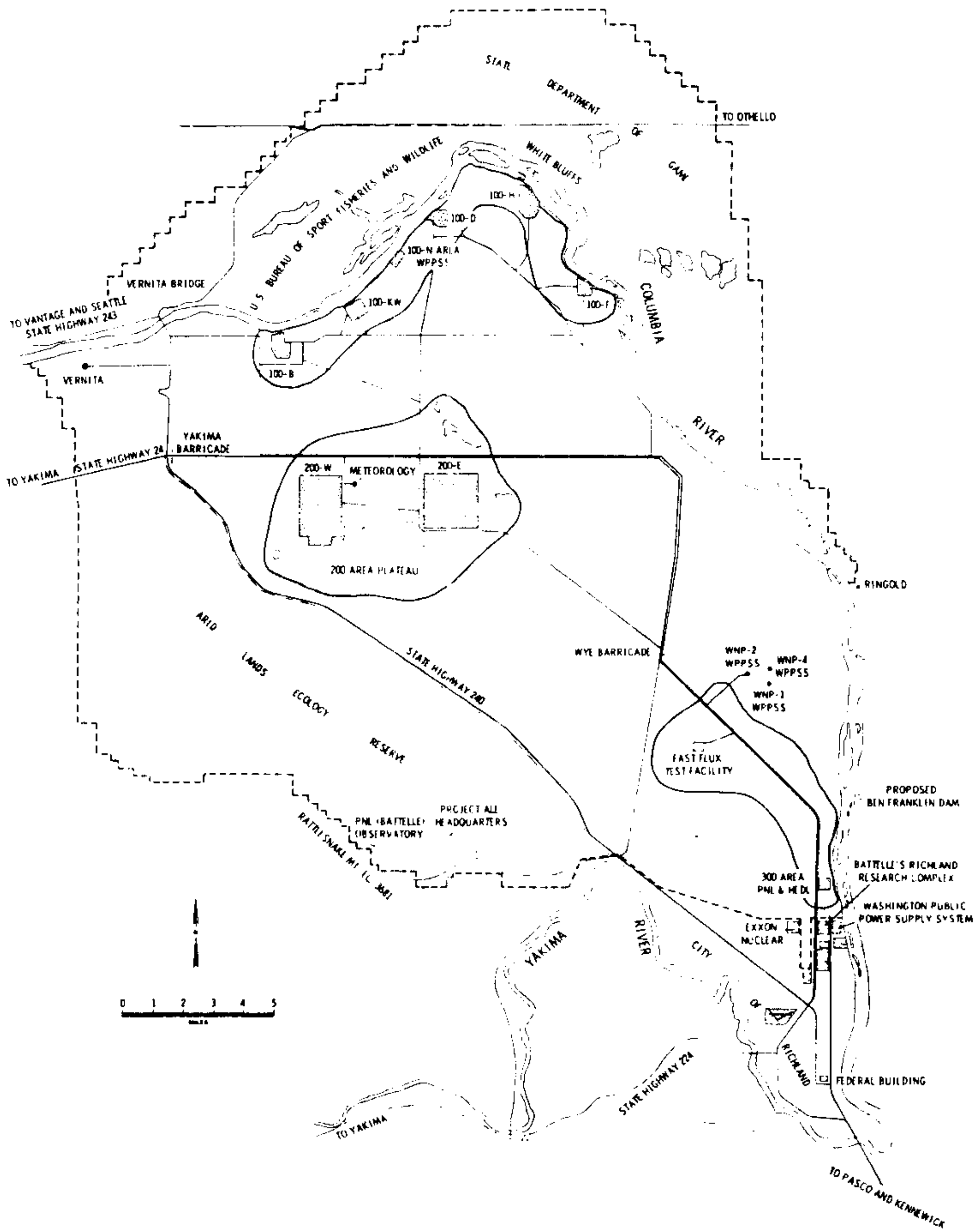

FIGURE I-2. Hanford Reservation, Department of Energy

The operating areas are identified by numbers. The 100 Areas border directly on the Columbia River and consist of nine plutonium production reactor sites. The single reactor remaining in operation, N Reactor, is operated by United Nuclear Industries. The 200 Areas are located in the middle of the Reservation on a plateau about 7 miles from reactor areas and 25 miles from Richland, Washington. Here, RHO operates the fuel reprocessing and plutonium production facilities and manages the radioactive wastes generated at Hanford during 30 years of operation. The 300 Area is located 1 mile north of Richland. United Nuclear Industries fabricates the fuel elements used at N Reactor in this area. Westinghouse and Battelle operate research and development laboratories located in the 300 Area. The 400 Area is located about 8 miles north of Richland and is the site of the FFTF construction managed by Westinghouse.

The remaining land is designated as the 600 Area and is not related to the generation or storage of radioactive wastes. The ALE Reserve is located within the 600 Area and comprises a 120 square mile tract of land set aside exclusively for ecology research. Also included within the 600 Area is 86,000 acres of land north of the Columbia River which has been designated as a wildlife refuge and recreation area by the U. S. Bureau of Sport Fisheries and Wildlife and the Washington State Department of Game.

HISTORY OF WASTE MANAGEMENT FACILITIES

In 1943, the U. S. Army Corps of Engineers selected Hanford as the location for construction of graphite moderated Fermi reactors and chemical separation facilities. These were used for the production and purification of plutonium for possible use in nuclear weapons. Hanford was selected due to an abundant water supply for reactor coolant, isolation from high density population centers and the availability of electricity from hydroelectric dams.

Actual construction started on three reactor facilities and three chemical processing plants in March 1943. The first reactor began operating 18 months later and plutonium was available 4 months after startup. Three reactor areas (100-B, 100-D, 100-F) were completed between 1942 and 1944. Production capacity was expanded between 1948 and 1963 with the addition of 6 more reactors (H, C, DR, KE, KW, and N). In 1964, a Presidential decision was made to begin closing down the older reactors. At present, only the N Reactor is in operation.

N Reactor, completed in 1963, is a dual-purpose reactor operating to provide plutonium for military purposes and the by-product, steam, for electrical power generation. Unlike the other reactors in which river water circulated once through the reactor before release back to the river, the N Reactor uses a recirculating water coolant which absorbs heat used to produce steam for electrical power generation. The cooling water from N Reactor, which is eventually released to the river, contains no radioactivity from operation of the nuclear reactor.

The original three fuel separation plants (T Plant, B Plant and U Plant), begun in 1943, were designed to use a bismuth phosphate method of processing irradiated fuels. T Plant, completed in 1944, operated until 1956 using the bismuth phosphate process. It is currently used for equipment decontamination. Completed in 1945, B Plant operated until 1952 using the bismuth phosphate process. In 1969, it was converted to a waste fractionization plant. Presently it functions in the recovery of cesium-137 and strontium-90 from high-level liquid wastes for encapsulation and storage. The strontium and cesium are converted to solid strontium fluoride and cesium chloride which are then doubly encapsulated in metal cylinders and placed in retrievable water-cooled storage.

U Plant was also designed to use the bismuth phosphate process, but it was never used for that purpose. After start up of Redox Plant, it was converted to recover uranium from stored radioactive wastes. From 1952 until 1958 wastes were mined from storage tanks for uranium recovery at U Plant. The adjacent uranium oxide plant makes powdered uranium oxide by calcining uranyl nitrate hexahydrate (UNH) solutions from Purex for offsite shipment.

The Redox Plant, completed in 1951, operated until 1967 using the reduction-oxidation process for fuel separation which succeeded the bismuth phosphate process and preceded the Purex process.

The Purex Plant, completed in 1955, eventually took over the fuel separation operations from the Redox Plant. It has been held in standby since 1972. When operating, the plant processes irradiated uranium fuels from N Reactor to recover plutonium, neptunium, and uranium. A product of the process, plutonium nitrate solution, is transferred to Z Plant for further treatment. The uranium product UNH is transferred to U Plant for conversion to uranium oxide.

Z Plant, completed in 1949, serves as the site for plutonium laboratory and finishing operations, including the processing of plutonium scrap and the preparation of plutonium products. The plutonium nitrate product from the scrap processing and from Purex is converted to either plutonium oxide or metal buttons. The recovered americium is sold for commercial purposes.

DuPont was the original contractor selected to operate the Hanford Project in 1943. In 1946, General Electric assumed responsibility for operating the plant when DuPont left. General Electric was replaced in 1965, by a number of contractors responsible for different aspects of plant operation. The current prime operating contractors are listed below.

- Rockwell Hanford Operations (RHO) is responsible for fuel reprocessing, plutonium production, radioactive waste management and site supportive services. Prior to July 1977, Atlantic Richfield Hanford Company (ARHCO) was responsible for these operations.

- Battelle-Northwest (BNW) is responsible for operating the Pacific Northwest Laboratories, a research and development facility involved in a wide variety of physical and biological sciences programs.
- United Nuclear Industries (UNI) is responsible for operating N Reactor and the associated nuclear fuel fabrication facilities.
- Westinghouse Hanford Company operates the Hanford Engineering Development Laboratories (HEDL) and is involved in advanced reactor development. Westinghouse also manages construction of the Fast Flux Test Facility (FFTF) which will support the Liquid Metal Fast Breeder Reactor Program.

WASTE MANAGEMENT IN THE 200 AREAS

Uranium fuel elements manufactured by United Nuclear Industries in the 300 Area are transferred a distance of about 25 miles to N Reactor (100 Areas), the only reactor remaining in operation today. There, the fuel elements are irradiated to produce both plutonium-239 and the by-product steam for electrical power generators. Following discharge from the reactor, the irradiated fuel elements are held in interim water-cooled storage to permit decay of the radioisotopes for a minimum of 6 months. The fuel elements are then transported by rail in water-cooled, heavily shielded casks to the fuel reprocessing site in the 200 Area. The Purex Plant, currently on standby since 1972, operates as the fuel separation facility.

At the Purex Plant, solvent extraction and ion exchange of the fuel elements, dissolved in nitric acid solution, serve to recover the products. The recovered plutonium and uranium-containing solutions are transferred to Z and U plants, respectively, for further processing. The recovered fission products, strontium and cesium, are encapsulated in metal cylinders at B Plant and held in retrievable water-cooled storage. Radioactive wastes stored in the 200 Areas are generated during most of these operations. Historically, Hanford has produced gaseous wastes, stored solid wastes, stored liquid wastes and releasable liquid wastes.

Gaseous Wastes

Gaseous wastes discharged from roof vents and stacks of reprocessing and waste handling facilities may be in either a gaseous or entrained particulate form. The particulate contaminants are removed by a series of multiple filters of sand, fiber glass or other media. Process chemicals and radioactive contaminants in gaseous effluents are removed by routing the gases through iodine absorbers, ammonia scrubbers, NO_x absorbers or HF scrubbers. The contaminant concentrations are monitored at discharge points and maintained within limits for release to the atmosphere.

Solid Wastes

Since 1944, more than 6 million cubic feet of solid wastes have been buried within the 200 Areas. These wastes have been buried in 19 sites using more than 171 acres of land. Prior to 1968 all waste buried in the 200 Areas was generated as a result of the fuel reprocessing operations. After 1968, the waste generated by the 300 Area operations was also sent to the 200 Areas for burial. Wastes from the reactor operations in the 100 Area have been sent to the 200 Area for burial since 1973.

Solid stored wastes may be either dry or industrial waste. Dry waste consists of items such as laboratory supplies, tools and clothing which are packaged in cardboard, wood or metal containers for burial. Industrial waste consists primarily of large items, such as failed equipment, and is packaged in metal or concrete containers for burial. Transuranic bearing waste has been packaged and stored separately since 1970 in a fashion to allow retrieval for a 20-year period. Extremely large items of failed processing equipment that are highly radioactive are placed on railroad flatcars and stored in underground tunnels.

The approximate inventories of disposed solid waste in the 200 Area burial grounds through September 1976 are shown below.

Radionuclide	Quantity
U	6×10^8 g
^{239}Pu	4×10^5 g
^{90}Sr	5×10^4 Ci
^{106}Ru	2×10^3 Ci
^{137}Cs	5×10^4 Ci
Other Radioactive Material	5×10^5 Ci

Stored Liquid Waste

High level liquid wastes from chemical processing of irradiated reactor fuels have been stored in underground tanks since reactor startup in 1944. The complex of present and planned (funded) tanks totals 168 ranging in capacity from 50,000 to 1,000,000 gallons. Single wall tanks comprise 149 of the total while double wall tanks make up 19 of the total. The tanks are constructed of reinforced concrete with a carbon steel liner on the bottom and side walls. The double wall tanks are built with a primary containment steel liner and a surrounding liner to the fill line (Figure I-3).

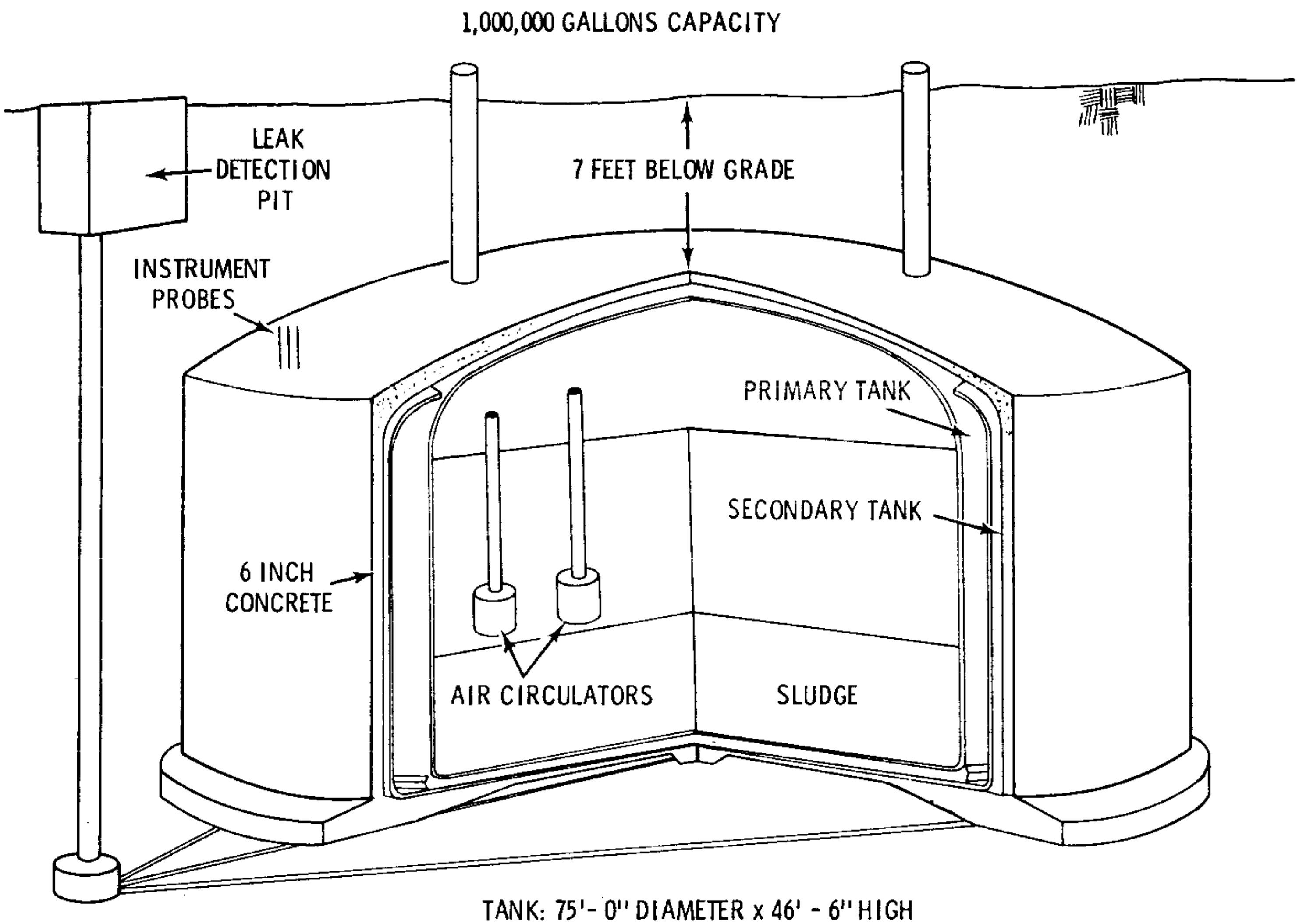

FIGURE I-3. New Boiling Waste Tank

The earliest tanks were built for low-heat wastes. These tanks are vented to the atmosphere primarily through air-cooled reflux condensers. Later, tanks were built to contain wastes with high heat generation or "boiling wastes" with features to allow self-concentraton of the wastes. These tanks are not vented to the atmosphere. More recently-built double wall tanks contain leak detection equipment between the two steel walls.

Storage of high-level liquid wastes in the underground tanks is considered an interim storage mode. Consequently, various alternatives for reducing the volume and mobility of stored liquid wastes are being explored. Currently, three vacuum evaporator-crystallizer facilities are in place serving to evaporate the tank liquids to a "salt cake" product. This nearly liquid-free material is then placed back into the underground tanks. This "salt cake" will be stored on an interim basis in underground tanks until a method for terminally immobilizing the wastes has been selected.

Releasable Liquid Waste

Chemical processing of irradiated fuels generates large quantities of aqueous wastes which have the potential of containing radioactivity. This waste water is released either to the natural soil column (cribs) or to the environment (ponds or ditches) depending on the radionuclide concentration.

Liquid effluents are termed either "intermediate level" or "low level", depending on the activity concentration. Liquid effluents containing radionuclide concentrations from 5×10^{-5} µCi/ml to 1 µCi/ml are considered intermediate level. Low level wastes are those with activity concentrations of less than 5×10^{-5} µCi/ml.

Intermediate level wastes result primarily from process and steam condensates and high level waste tank condensates. Historically, intermediate level wastes were discharged to the soil column via underground structures called "cribs." Since project startup, a total of 177 cribs have been constructed. Currently 12 cribs are receiving liquid wastes. The use of cribs and the disposal of radioactive materials to soil have been markedly curtailed over the last several years due to decreased fuel reprocessing and improved waste treatment facilities.

No new cribs are scheduled for construction and no need for these facilities is foreseen. If new processing facilities are constructed, the wastes will be recycled, concentrated and stored as high level wastes.

Cribs were constructed by a variety of methods. One method consisted of digging a ditch 20 feet deep and up to 1400 feet long, backfilling with rock and covering with plastic sheeting and soil (Figure I-4). A pipe running the length of the crib served to distribute the liquid uniformly along the crib length. The released liquid percolated slowly through the soil column which served as an ion exchange column, absorbing most of the radionuclides within a few tens of feet of the release point. Tritium, technetium and

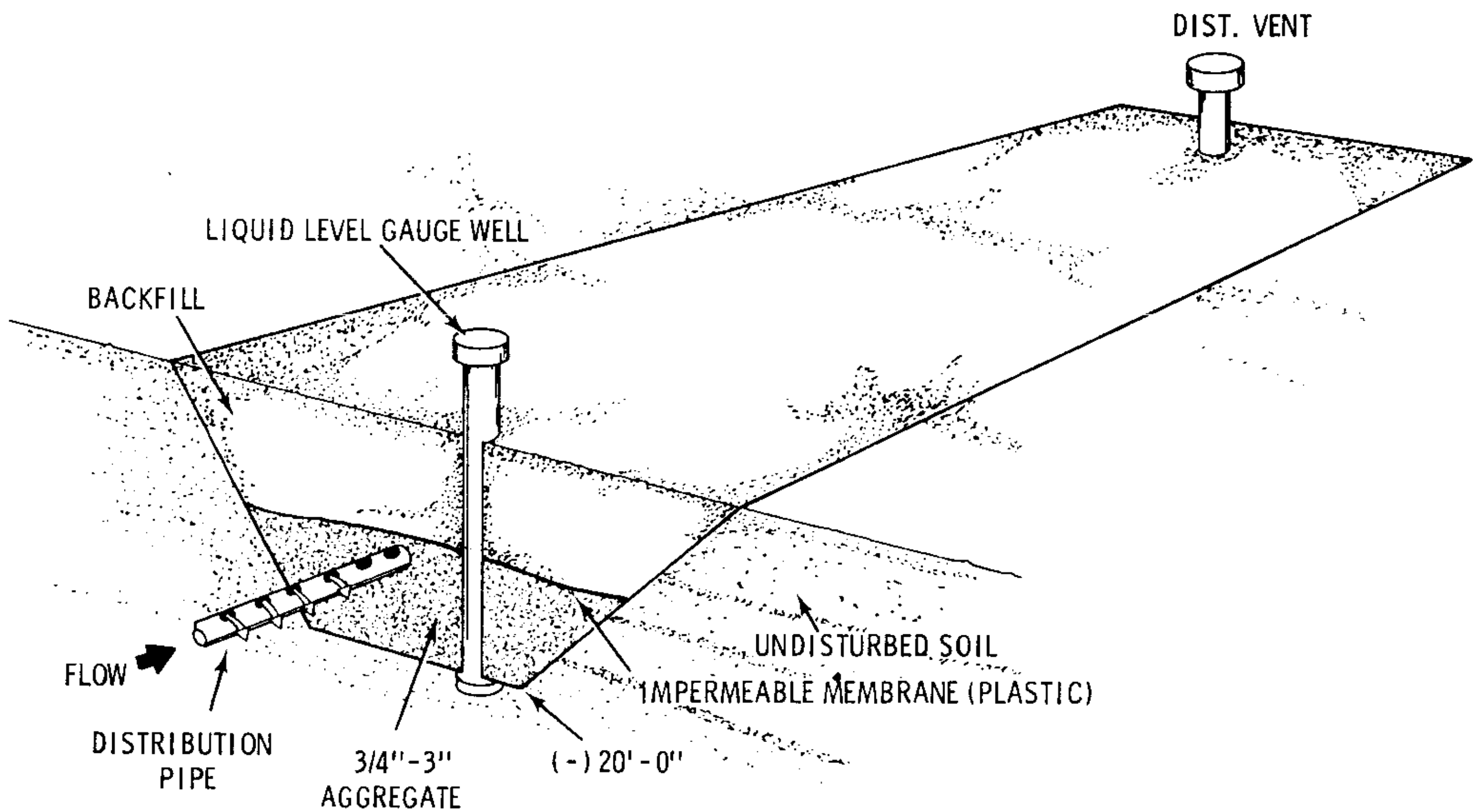

FIGURE I-4. Disposal Crib

some forms of ruthenium are only slightly absorbed by the soil and may enter the groundwater below the crib. Cesium, strontium, and plutonium are held tightly by the soil with essentially all of it held within a few tens of feet of the release point.

Low level waste released for surface impoundment consists primarily of cooling water and normally contains no radionuclides. This aqueous waste may rarely contain contamination as a result of equipment or process failures and is discharged to open ponds and ditches for evaporation or percolation through the soil column. More than 145 billion gallons of low level wastes have been discharged to 30 surface ponds and ditches in the 200 Areas since the project began. Over 360 acres of land have been used for this purpose with about 180 acres still in use.

Today, five ponds are still used for receiving low level wastes and include U, T, B, S-19, and Gable Mountain ponds. The discharge of radioactive materials to these ponds primarily occurred by accidental releases due to equipment failure and are sorbed tightly by the soil beneath the pond except tritium and ruthenium.

In those cases where ponds and ditches are no longer used, the contaminated sediments have been buried in place and the soil surface stabilized through revegetation methods. The estimated radioactive material inventories in 200 Area cribs, ponds, and ditches at the end of September 1976 are shown below.

Radionuclide	Quantity 200 Areas
Beta	1×10^5 Ci
^{90}Sr	3×10^4 Ci
^{106}Ru	2×10^2 Ci
^{137}Cs	3×10^4 Ci
^{60}Co	$<6 \times 10^1$ Ci
^{233}U	$<1 \times 10^3$ g
U	1×10^8 g
^{239}Pu	2×10^5 g

PRESENT ECOLOGICAL STUDY SITES

A map showing the relationship of the 200 Area plateau to the radioactive waste management areas is shown in Figure I-2. Ecological investigations generally require intensive studies and for this reason it was necessary to select representative sites within the 200 Area plateau (Table I-1). Terrestrial ecology studies have focused on sites located near the REDOX Pond Area, B-C Cribs, and 216-A-24 Crib; aquatic studies have focused on the U-Pond and Gable Mountain Pond areas. The general location of these sites is shown in Figure I-5.

Some studies are of a more wide ranging nature and not restricted to a particular study site. These include the raptor (birds of prey), coyote, deer and general wildlife census studies. Terrestrial study areas located off the 200 Area plateau but with application to waste management studies include ROWMA (Radioecology of Waste Management Areas) study sites located near the Washington Public Power Supply System's power reactor installation, 300 Area burial grounds, the ALE Reserve, and Columbia River studies (Table I-2).

TABLE I-1. Study Areas of the 200 Area Plateau Ecosystem

Study Area	Tasks
Redox Pond (Two reps)	1) Plant ecology 2) Ground-dwelling invertebrates 3) Root distribution studies
B-C Cribs (Two reps)	1) Small mammal population ecology 2) Ground-dwelling invertebrates 3) Grasshopper dynamics and food habits 4) Plant ecology 5) Shrub inhabiting insects 6) Diets of black-tailed hares 7) Distribution of radioactive jackrabbit pellets 8) Deer diet studies
216-A-24 Crib	1) Radionuclide distribution in biota (invertebrates, small mammals, plants) 2) Root distribution studies
B Pond	1) Waterfowl, raptor and perching bird studies 2) Deer diet studies 3) Distribution and fate of radio-active wastes in the aquatic system
Gable Mountain Pond	1) Waterfowl raptor and perching bird studies 2) Biotic and abiotic studies of the pond 3) Deer diet studies
West Pond	1) Waterfowl, raptor and perching bird studies 2) Distribution and fate of radio-active wastes in the aquatic system
U Pond	1) Limnological characterization and isotopic distribution 2) Ecological behavior of plutonium and americium 3) Waterfowl, raptor and perching bird studies 4) Radiation exposure of small free-living mamals

TABLE I-1. Study Areas of the 200 Area Plateau Ecosystem (Continued)

Study Area	Tasks
Disposal Sites (216-S-4, 216-A-6, 216-A-9, 218-E-8, 218-E-2, 216-B-6 216-B-36, 216-U-12, 216-S-22, 216-S-9, 216-Z-7, 218-W-3, 218-W-9)	1) Plant ecology studies 2) Soil texture and chemistry
Revegetation Study Site	1) Revegetation studies 2) Biobarrier studies
General 200 Area Plateau	1) Raptor studies 2) Coyote ecology studies 3) Wildlife census studies
Ditches (Z-19, B-3, A-29, S-19)	1) Fate and distribution of radioactive wastes

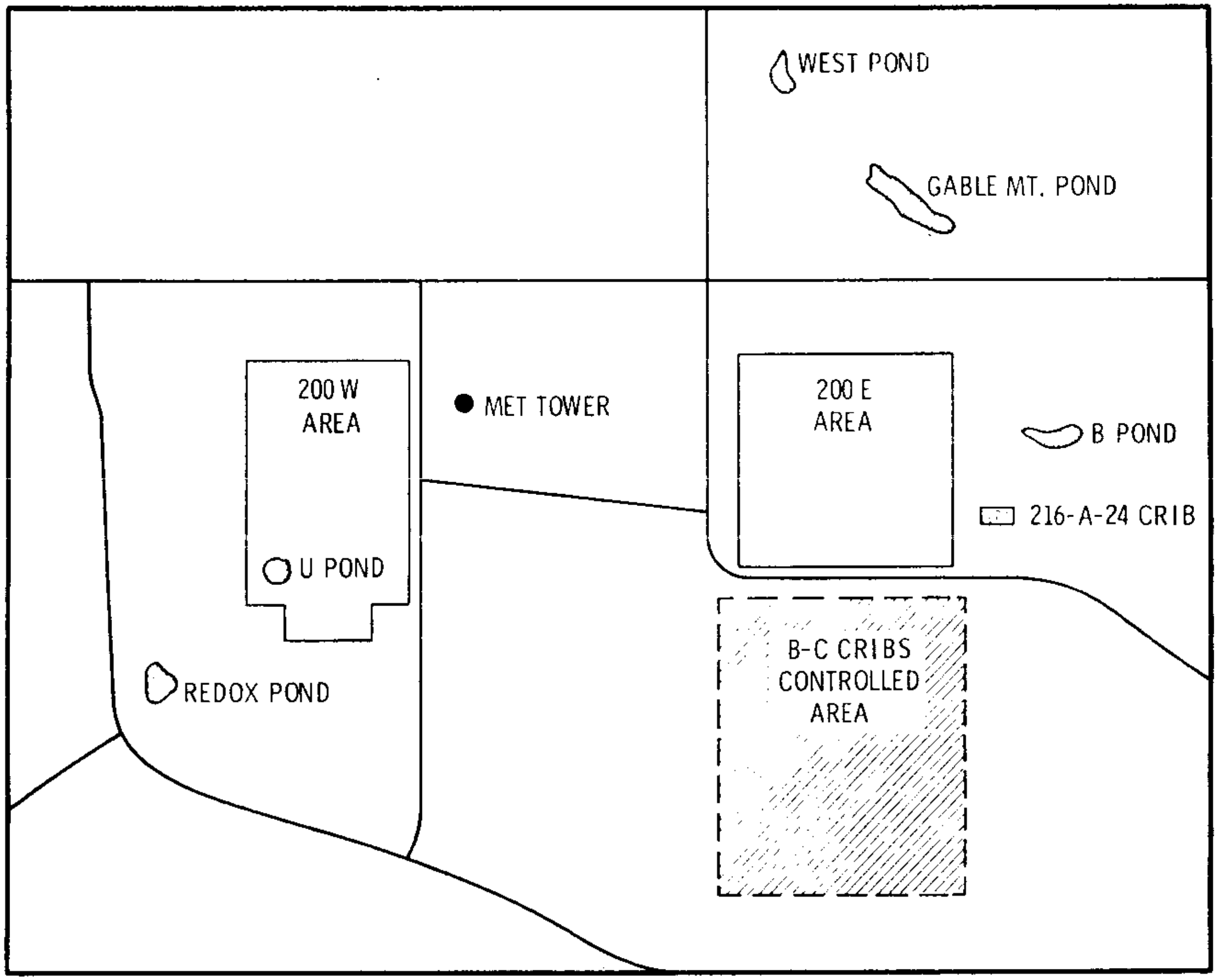

FIGURE I-5. Location of Specific Ecological Study Sites and Associated Facilities of the 200 Area Plateau Ecosystem

TABLE I-2. Related Study Areas

Study Area	Tasks
ALE Control Plot (Control for B-C Crib and Redox Pond Study Sites)	1) Plant ecology 2) Ground-dwelling and shrub inhabiting invertebrates 3) Small mammal population dynamics
ROWMA Study Plots	1) Plant ecology 2) Small mammal population dynamics 3) Reptile and lizard population dynamics 4) Shrub inhabiting invertebrates
Washington Public Power Supply System Baseline Ecology Studies	1) Plant ecology 2) Small mammal population dynamics
300 Area Burial Ground Studies	1) Plant ecology 2) Harvester ant abundance studies 3) Radiation exposure of small free living mammals
ALE Reserve	1) Plant ecology 2) Small mammal ecology 3) Insect ecology 4) Transuranic weathering in vegetation 5) Cattle studies
Columbia River Aquatic Studies	1) Biology and ecology of river organism 2) Thermal and chemical effects of reactor effluent discharges 3) Radioactivity releases from reactor operations

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CHAPTER II. ABIOTIC COMPONENTS

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The climatic regime of the 200 Area plateau consists of cold winters, hot summers and low precipitation amounts. Properties of surface soils and physiochemical properties of ponds and ditches are described.

CLIMATE

The climate of the Hanford waste management zones is the driest and hottest in the Pacific Northwest. Climatological measurements of air temperature, relative humidity, precipitation, and wind have been monitored at the meteorological station located near the 200 W Area since the early 1940's. The data are available as monthly summaries and will not be discussed here.

The aridity of the waste management zones and vicinity is due to the rain shadow cast by the Cascade Mountain Range that lies between the Pacific Ocean and the waste management area. The annual precipitation averages slightly less than 7 inches with the bulk of precipitation falling in autumn and winter months. Summers are characteristically dry. The coldest month of the year is January and the hottest months are July and August.

The low precipitation, especially during the summer months, and the cold temperatures during winter are the two factors believed to be the most significant contributors to the low biological productivity and poor species diversity associated with terrestrial plant communities.

Although the climate of the area is not regarded as windy, as compared to other places in the United States, strong winds can be expected in every month and are capable of resuspending soil particles. Dust storms can result.

SOIL

The land in the waste management zones is mostly or nearly level. The soil is highly porous and rainfall and snow-melt percolate easily into the soil surface. The landscape is unusual in that it lacks well-defined gullies or channels that mark surface water flows in other landscapes. This is indicative of the scarcity of precipitation and the porosity of the soil.

The surface 100-200 mm of soil profile are usually fine grain sediments with gravel content increasing with soil depth. The gravels are variable in size and are primarily well rounded pebbles, cobbles, and sometimes boulders. The depth of the root zone is generally regarded as 3 meters or less. The biologically active portions of the mineral soil are those particles less than 2 mm in diameter. The soil is fine grained with most of the particle sizes falling into the sand and silt sized fractions (Table II-1). As in other arid regions the organic matter content of the soil is mostly confined to the surface soil and even here the content is low. The pH of the soil is near neutral at the surface and increases to about 8.5 at a meter or so in depth. There are no harmful amounts of salt or sodium present in the root zone. Clearly water (precipitation) and available nitrogen are the important factors limiting primary productivity in the waste management zones. With irrigation and fertilization, crop plants could be profitably raised on most parts of the waste management areas.

TABLE II-1. Properties of Surface Soils Common to B-C Cribs and Former Redox Pond Environs (Cline, et al., 1975)

Soil	B-C Cribs			Redox		
Depth (dm)	% Sand	% Silt	% Clay	% Sand	% Silt	% Clay
0-1	55	43	2	63	36	1
1-2	64	35	1	60	38	2
2-3	71	28	1	62	37	1
3-4	68	31	1	57	42	1
4-5	55	44	1	58	41	1
5-6	51	47	2	62	37	1

PONDS AND DITCHES

Physicochemical data are available (Emery 1977) to tentatively describe annual ranges for ponds and ditches located on the 200 Area plateau or in nearby areas. These include U-Pond, B-Pond, Gable Pond, West Pond, Z-19 Ditch, B-3 Ditch, and A-29 Ditch.

Ranges of physicochemical characteristics for ponds and ditches are shown in Tables II-2 and II-3. Gable, B-, and U-Ponds differ widely in physical dimensions, retention times, and sedimentation properties, but are generally similar in chemistry (Table II-2). An exception to this is the unusually high concentrations of nitrogen in B-Pond. West Pond shows extreme variation from the other ponds due to the long-term accumulation of dissolved and suspended materials through evaporative concentration. This is readily evident from alkalinity and conductivity data (Table II-2). West Pond received sanitary wastes during the early development of Hanford, probably accounting for their high nitrogen and phosphorus concentrations. The ditches are generally similar in physicochemical characteristics except B-3 Ditch, which is relatively higher in nitrogen but lower in phosphorus concentrations (Table II-3).

TABLE II-2. Physical Description and Annual Ranges of Physicochemical Parameters for 200 Area Plateau of Pond System (Emery, 1977)

	Gable Pond	B-Pond	U-Pond	West Pond
Surface Area (m^2)	287,337	149,159	56,658	77,808
Surface Area (Acres)	71.0	36.9	14.0	19.2
Volume (m^3)	431,000	233,246	22,700	31,123
Mean Depth (m)	1.5	1.6	0.4	0.4
Retention Time (hr)	379	252	40	-
Temperature (°C)	0 - 25.3	0 - 25.0	0 - 28.4	0 - 25.5
Insolation Range (Langley's)	20 - 253	20 - 253	20 - 253	20 - 253
Seston (mg/ℓ)	0.59 - 60.15	0.29 - 214	2.13 -76.5	2.61 - 27.5
Sedimentation ($mg/cm^2 \cdot day$)	1.43 - 6.76	0.21 - 2.76	0.34 - 1.01	5.12 - 26.8
pH	7.85 - 8.75	7.0 - 9.0	7.0 - 9.5	9.7 - 10.0
Alkalinity (mg/ℓ $CaCO_3$)	48.9 - 73.0	48.4 - 71.4	74.0 - 132.0	6,764 - 13,177
Dissolved Oxygen (mg/ℓ)	7.9 - 12.7	8.1 - 13.8	9.0 - 13.0	8.0 - 13.8
Hardness (mg/ℓ $CaCO_3$)	50.49 - 80.59	51.46 - 85.48	39.0 - 62.14	112.6 - 145.7
Conductivity (μmhos/cm @ 25°C)	1118 - 1662	1189 - 1590	1000 - 2500	151,111 - 333,333
Total NO_3 - NO_2 (mg/ℓ)	0.035 - 0.330	0.062 - 6.10	<0.100 - 0.295	-
Total NH_3 (mg/ℓ)	0.143 - 0.640	<0.100 - 5.30	<0.100 - 0.360	1.95 - 3.50
Ortho P (mg/ℓ)	<0.01	<0.010 - 0.205	0.032 - 0.128	1.80 - 2.60
Total P (mg/ℓ)	0.025 - 0.075	0.010 - 0.081	0.088 - 0.158	1.85 - 2.70
Total Si (mg/ℓ)	0.520 - 1.53	0.400 - 2.45	0.390 - 0.840	<0.100 - 1.10

TABLE II-3. Physical Description and Annual Ranges of Physicochemical Parameters for 200 Area Plateau Ditches (Emery, 1977)

	Z-19*	A-29	B-3
Length (m)	885	1325	1200
Flow (m^3/min.)	0.48 - 7.6	1.709 - 2.034	6.177 - 10.845
Temperature Range (°C)	10.5 - 24.6	13.4 - 27.0	10.0 - 25.5
Insolation Range (Langley's)	20 - 253	20 - 253	20 - 253
Seston (mg/ℓ)	0.04 - 7.60	0.21 - 0.684	0.11 - 3.92
pH	6.5 - 7.9	7.4 - 8.1	6.95 - 8.00
Alkalinity (mg/ℓ $CaCO_3$)	55 - 87	45.91 - 69.26	48.94 - 65.46
Dissolved Oxygen (mg/ℓ)	7.8 - 11.2	7.8 - 10.5	8.0 - 12.1
Hardness (mg/ℓ $CaCO_3$)	-	54.38 - 70.88	58.26 - 80.59
Conductivity (μmhos/cm @ 25°C)	-	1151 - 1423	1040 - 2017
Total NO_3 - NO_2 (mg/ℓ)	0.004 - 0.450	0.029 - 0.910	1.20 - 6.40
Total NH_3 (mg/ℓ)	≤0 - 100	<0.100 - 4.40	<0.100 - 4.40
Ortho P (mg/ℓ)	0.070 - 0.110	<0.010 - 0.590	<0.010 - 0.032
Total P (mg/ℓ)	0.080 - 0.120	0.022 - 0.720	0.024 - 0.084
Total Si (mg/ℓ)	1.80 - 8.40	0.600 - 3.15	1.30 - 2.90

*No discharge to Z-19 ditch since March 1976.

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CHAPTER III. BIOTIC COMPONENTS

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Representative plant communities are described. The major community is dominated by sagebrush/cheatgrass-sandberg blue grass. Mammal, bird and insect species inhabiting the 200 Area plateau are representative of surrounding regions. Prairie falcons are the only species present possibly threatened with extinction. They do not nest on the plateau but probably forage over the area.

Biotic communities and ecosystems are both usually named for the characteristic plant species present. The term shrub-steppe distinguishes the region from the true steppe lands of Asia. The shrub-steppe ecosystem contains several distinct ecological communities but all with common distinguishing features; the vegetation is adapted to tolerate semi-arid conditions. The community structure is short, consisting of grasses, forbs, and shrubs with few trees, except along waterways.

REPRESENTATIVE PLANT COMMUNITIES

There are nine plant communities on the Hanford Reservation which are presented in Figure III-1. These are briefly described as follows: 1) Sagebrush/bluebunch wheatgrass community is confined to the slopes of Rattlesnake Hills at elevations exceeding 900 feet. Within this community, big sagebrush is the dominant shrub with bluebunch wheatgrass, a perennial, dominating the understory; 2) Sagebrush-bitterbrush/cheatgrass-sandberg bluegrass type occupies a large area with its apex near the 100 F reactor site. It extends to within the confines of the Army Loop Road and east to the 300 Area and Horn Rapids Bend, Yakima River. The important shrubs are big sagebrush, bitterbrush and rabbitbrush. The herbaceous understory is generally sparse, dominated by cheatgrass and sandberg bluegrass. 3) The vegetation type between the two is sagebrush/cheatgrass-sandberg-bluegrass. This plant community is one of the larger areas of the Hanford Reservation and of the 200 Area plateau. The important shrubs are big sagebrush, and rabbitbrush, while the understory is primarily comprised of cheatgrass and sandberg bluegrass. 4) Located to the north of the sagebrush/cheatgrass-sandberg blue grass is the cheatgrass community. This community is primarily located on abandoned agricultural areas where wildfires have occurred, and in areas where construction activities have been present. The dominant species are cheatgrass and Jim Hill mustard. This community occupies the northern portion of the Hanford Reservation to the Columbia River. 5) The riparian

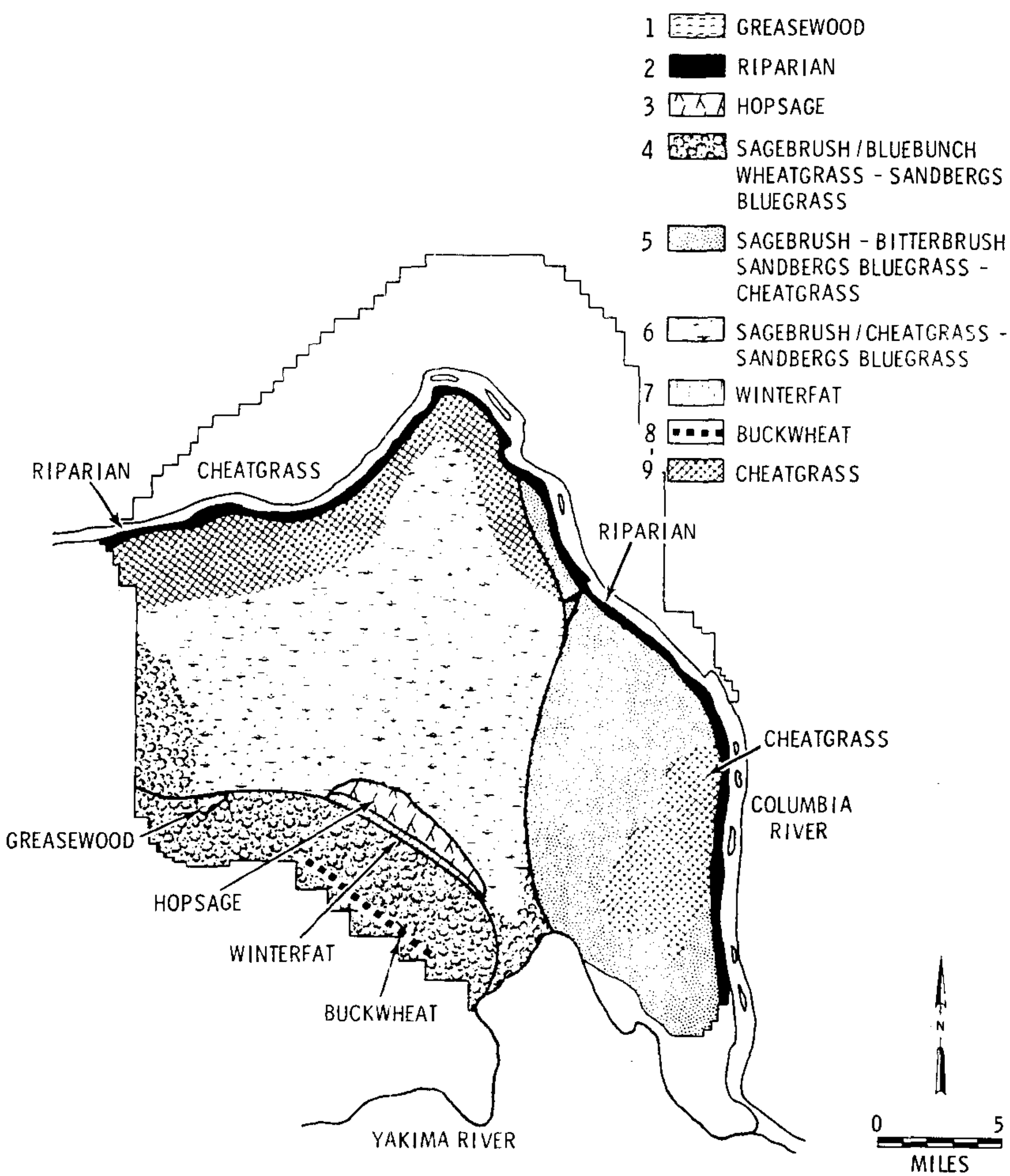

FIGURE III-1. Major Vegetation Types of the Hanford Reservation habitats are found along the Columbia River and inhabiting the areas along ponds and ditches. Common plants include blade cottonwood and willows with cattails and bulrushes. Other plant communities include: 6) greasewood, 7) spiny hopsage, and 8) winterfat at lower elevations. At higher elevations on ridge crests are the 9) thyme buckwheat communities. These communities are located on the ALE Reserve where they occupy about 100 acres.

A preliminary list of plants occurring on the 200 Area plateau was compiled by Price and Rickard (1973). A total of 92 species was identified from this area (Appendix A). Additional species are identified by Cline, et al. (1975). In general, most species that are characteristic of the Hanford Reservation inhabit the 200 Areas but some are restricted to specialized habitats provided by the waste storage sites. These species lists need to be up-dated since it is impractical to list all species due to seasonal variation and changes in management practices.

Community Structure

The structure of the 200 Area plateau ecosystem has been determined by climatic influences, fire and man's past activities. The annual vegetative yiel and cover for major vegetative components of the 200 Area plateau is shown below (adapted from Cline et al., 1975).

	Cover (%)	Yield (g/m^2)
Annual Grasses	22	25
Perennial Grasses	3	4
Perennial Forbs	2	<1
Annual Forbs	11	11
Shrubs	23	39[1]

Clearly, perennial grasses contribute little to either cover or total yield in the sagebrush community. The productivity of the understory species is relatively low. However, with sagebrush the total phytomass productivity is approximately 80 g/m^2.

The distribution of sagebrush heights is shown in Figure III-2 averaging about 1 meter in height. The occurrence of sagebrush and other shrubs modifies wind patterns near the soil surface. A hummocky microtopography caused by wind erosion exists between sagebrush plants. Most of the soil-blow from these areas builds up under the individual sagebrush plants. With a sparse understory cover some erosion occurs in these areas.

[1] Uresk, personal communication.

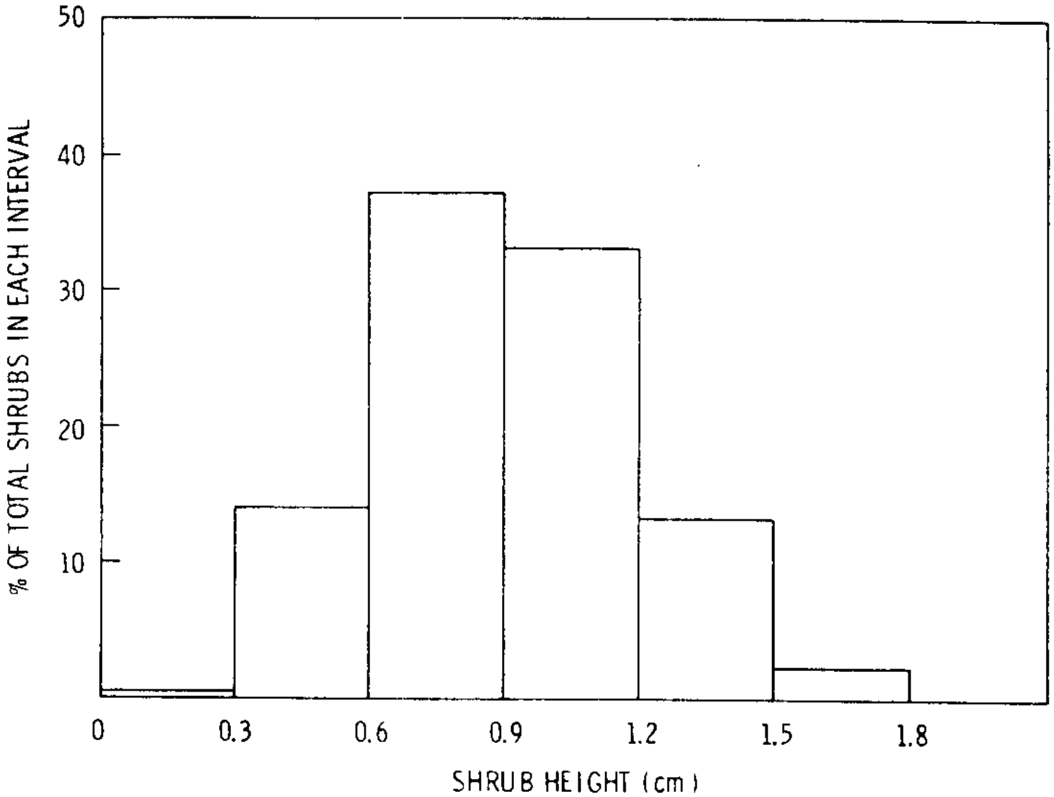

FIGURE III-2. Shrub Height (Live Sagebrush) Distribution (adapted from Cline, et al., 1975)

Wildfire

Wildfire has been a common occurrence within the steppe region on the Hanford Reservation. Fire can be detrimental to a plant community as reflected in a reduction of growth or reproductive vigor or it may improve the quantity or quality of plants by eliminating fire-sensitive species and releasing nutrients residing in accumulated litter. Knowledge of fire behavior is essential and is one area where little information is currently available (Stoddart et al., 1975). Fire will respond to three general elements: 1) Weather. Precipitation, air temperature, relative humidity and wind velocity are the major weather variables affecting fires. It is generally understood that the fire danger is high when the relative humidity is below 25% and the temperature is above 27°C. This type of information is extremely important to know during the dry and hot seasons that occur on the Hanford Reservation so that management procedures can be developed to prevent burning of critical areas, e.g. B-C Crib. 2) Topography. Roughness of the land surface influences weather generally, and causes day-to-day variation in weather patterns. This influences fire behavior. The Hanford Reservation is subject to wildfires for approximately 6 months nearly every year. 3) Fuel. The third major element that controls fire behavior is fuel. Fuels have several characteristics such as volume, continuity, and compactness. Small materials (cheatgrass) with a high ratio of surface area to volume burn readily. Grass leaves ignite quickly while plants like sagebrush are less flammable. Dense stands of shrubs are less flammable than grasses but a mixture of both is highly flammable (Stoddart et al., 1975). Fires that occur in areas of shrubs are generally very hot fires, since more fuel is available for burning.

Plant Succession

Plant succession is an orderly process of community change. It is a process whereby early invading plant species are replaced with time. Studies with cheatgrass, a dominant plant on the Hanford Reservation, on old abandoned agricultural fields have shown little change in species diversity over time. Plant succession apparently proceeds very slowly in this semi-arid region with cheatgrass retaining dominance over long time periods. Both Jim-Hill mustard and Russian thistle have extremely efficient seed dispersal mechanisms, permitting their initial dominance where soil plowing has occurred. As time passes and cheatgrass establishes a seed base it attains dominance. Cheatgrass is an introduced annual that successfully invades disturbed areas and is highly competitive for moisture and nutrients with other plants. Once established, it effectively prevents reestablishment by most native species. Plant succession is of significant interest for burial ground sites but is highly dependent upon the soil properties.

Canopy cover (Uresk, personal communication) of four waste sites is presented in Table III-1. The 216-B-36 trench is one of the oldest (1954) of the seven, and major differences are increases in cheatgrass. Russian thistle cover is highest on the more recent burial grounds. Total cover is very low on these burial sites which is a reflection of soil characteristics. Canopy cover values were highest for the older sites. Stoniness of the soil was determined using a soil penetrometer (Table III-2). These soils are very stony and favor growth of plants such as Russian thistle and Jim Hill mustard which are deep-rooting plants. These sites are not favorable for cheatgrass and other early winter annuals, the shallow rooting plants.

MAMMALS

A total of 27 mammal species (not including bats) is known to occupy the Hanford Reservation (Rickard et al., 1974). Most are small, inconspicuous, nocturnal creatures and accurate estimates of population densities, home range, and movement patterns have not been made. A total of 12 bat species have either been observed within the Hanford confines or have a high probability of occurring here. These are listed in Table III-3 along with other mammal species.

TABLE III-1. Summary of Canopy Cover (% ± SE) by Plant Species for Disposal Sites in 200 East and 200 West Areas During September 9-15, 1976 (Uresk, Personal Communication)

Plant Taxa	218-E-8	218-E-2	216-A-9	216-A-6	216-B-36	216-S-22	216-S-4
	Disposal Sites						
	200 East Area					200 West Area	
	1958-1959	1945-1953	1956-1969	1945-1970	1954-1954	1957-1967	1953-1956
Annual Grasses							
Bromus tectorum	66.99 ± 12.6	59.8 ± 7.3	49.1 ± 15.4	0.05 ± 0.05	72.0 ± 3.9	41.22 ± 6.4	63.8 ± 2.6
Festuca octoflora	0.0	0.0	0.08 ± 0.08	0.0	0.0	0.0	0.0
Perennial Grasses							
Poa sandbergii	2.0 ± 1.3	0.8 ± 0.2	1.9 ± 0.9	0.0	1.1 ± 0.5	0.0	2.9
Forbs							
Eriogonum niveum							
Salsola kali	1.8 ± 1.1	16.9 ± 2.2	24.2 ± 1.3	44.6 ± 0.3	12.8 ± 4.4	21.8 ± 0.5	0.06 ± 0.06
Sisymbrium altissimum	8.2 ± 1.9	7.6 ± 0.8	1.0 ± 0.9	0.03 ± 0.03	7.9 ± 1.7	1.0 ± 0.5	0.05 ± 0.05
Descurainia pinnata	0.2 ± 0.2	0.0	0.0	0.0	0.0	0.0	0.0
Cryptantha circumsicissa	0.03 ± 0.03	0.0	0.0	0.0	0.0	0.5 ± 0.4	0.0
Aster canescens	0.0	0.8 ± 0	2.7 ± 1.7	0.0	0.0	0.1 ± 0.1	0.0
Aster sp.	0.0	0.0	0.03 ± 0.03	0.0	0.0	0.0	0.0
Lactuca serriola	0.0	0.0	0.0	0.0	0.2 ± 0.1	0.0	0.0
Epilobium sp.	0.0	0.2 ± 0.2	0.03 ± 0.03	0.0	0.4 ± 0.4	0.0	0.0
Amsinckia sp.	0.0	0.03 ± 0.03	0.0	0.0	0.0	0.0	0.0
Shrubs							
Chrysothamnus nauseosus	0.0	0.0	0.0	0.0	0.0	0.0	33.2 ± 6.7
Total Ground Cover[a]	57.1 ± 7.3	68.9 ± 6.7	54.4 ± 12.2	44.6 ± 0.3	79.0 ± 2.8	57.7 ± 6.9	71.5 ± 4.9

[a] Estimated as a total and not summed by species.

TABLE III-2. Stoniness of Soil Expressed in Terms of cm Soil Depth, on Seven Disposal Sites (Uresk, Personal Communication)

Site	$\bar{x}$ ± SE	Range
218-E-8	10.9 + 0.8	2.0 - 36.0
218-E-2	6.7 + 0.3	2.0 - 15.5
216-A-9	5.3 + 0.3	1.5 - 18.0
216-A-6	4.6 + 0.3	1.5 - 19.5
216-B-36	6.4 + 0.4	0.0 - 17.0
216-S-22	21.9 + 1.6	3.5 - 86.0
216-S-4	11.2 + 0.8	2.5 - 280

Small Mammals

A characterization study of small mammals inhabiting the 200 Area plateau, near the B-C Cribs and in a nearby control area has been made (Hedlund and Rogers, 1976). This study used the live trapping technique coupled with mark-release-recapture estimating procedures to assess the small mammal population. Five species were captured during the 20-month study.

These include:

- Great Basin pocket mouse
- Deer mouse
- Northern grasshopper mouse
- Sagebrush vole
- Western harvest mouse

Townsend ground squirrels and pocket gophers are also known to inhabit the 200 Area plateau, but none were encountered during this study. The percentage composition of individuals trapped during the study is shown in Table III-4. The Great Basin pocket mouse is clearly the dominant small mammal in both areas. Estimated density and biomass values for Great Basin pocket mouse populations inhabiting the 200 Area plateau and a nearby control area are shown in Table III-5. Peak density occurred in March 1975 on the B-C Cribs plot with 47 individuals/ha as compared to a peak of 41/ha which occurred in October 1974 on the control plot. Detailed discussions of abundance, home range, and life cycle of pocket mice are included in Hedlund and Rogers (1976). O'Farrell et al. (1975) published results of a long-term study of pocket mice populations inhabiting a nearby shrub-steppe region on the ALE Reserve. Small mammal populations inhabiting riparian areas around waste ponds exhibit a different composition than for dryland areas as indicated by a current study (Gano, personal communication).

TABLE III-3. Mammals of the Hanford Reservation

Scientific Name	Common Name
Sorex vagrans	Vagrant shrew
Lepus californicus	Black-tailed hare
Lepus townsendia	White-tailed hare
Sylvilagus nuttallii	Nuttall cottontail
Citellus townsendii	Townsend ground squirrel
Thomomys talpoides	Northern pocket gopher
Perognathus parvus	Great Basin pocket mouse
Castor canadensis	Beaver
Reithrodontomys megalotis	Western harvest mouse
Peromyscus maniculatus	Deer mouse
Onychomys leucogaster	Northern grasshopper mouse
Neotoma cinerea	Bushy-tailed wood rat
Lagurus curtatus	Sagebrush vole
Microtus montanus	Montane meadow mouse
Ondatra zibethica	Muskrat
Rattus norvegicus	Norway rat
Mus musculus	House mouse
Erethizon dorsatum	Porcupine
Canis latrans	Coyote
Procyon lotor	Racoon
Mustela vision	Mink
Mustela frenata	Long-tailed weasel
Taxidea taxus	Badger
Mephitis mephitis	Striped skunk
Lynx rufus	Bobcat
Odocoileus hemionus	Mule deer
Cervus canadensis	Elk
Myotis lucifugus	Little brown myotis bat
Myotis thysanodes	Fringed myotis bat
Myotis californicus	California myotis bat
Myotis subulatus	Small-footed myotis bat
Myotis volans	Hairy-winged myotis bat
Myotis erotis	Long-eared myotis bat
Lasiurus cinereus	Hoary bat
Lasionycteris noctivagano	Silvery-haired bat
Eptesicus fuscus	Big brown bat
Pipistrellus hesperus	Western pipistrelle bat
Antrozous pallidus	Pallid bat
Plecotus townsendii	Lump-nosed bat

	Meadow	Forest
	--------%--------	
Deer mouse	42	50
House mouse	36	34
Pocket mouse	16	9
Harvest mouse	6	7

The presence of a pond clearly results in changes to the species composition of small mammals inhabiting the surrounding area. Comparison of the above data with Table III-4 shows that deer mice, house mice, and harvest mice are all more abundant within riparian as compared to dryland areas. Bats are known to forage over pond sites but no attempts have been made to census their populations.

TABLE III-4. Percent Composition of Small Mammal Populations Inhabiting B-C Cribs and Control Areas

Species[1]	Control	B-C Cribs
	---------%-----------	
Deer mouse	3	6
Grasshopper mouse	1	1
Sagebrush vole	0	4
Western harvest mouse	4	0
Pocket mouse	96	93

[1]Species names provided in Table III-3.

TABLE III-5. Estimated Density Size and Biomass Values for Great Basin Pocket Mice Population (Hedlund and Rogers, 1976)

Date	Control Plot		B-C Crib Plot	
	Biomass[2]	Density[1]	Biomass[2]	Density[1]
3 May 74	315	18	54	7
23 May 74	318	18	124	7
21 Jun 74	211	19	122	8
12 Jul 74	286	21	210	13
15 Aug 74	380	28	246	20
13 Sep 74	503	36	345	24
10 Oct 74	591	41	431	29
27 Feb 75	85	14	60	28
20 Mar 75	485	26	309	47
24 Apr 75	683	42	501	34
30 May 75	505	29	402	22
26 Jun 75	396	27	457	30
1 Aug 75	463	32	541	34
28 Aug 75	500	40	535	37
26 Sep 75	535	37	457	40

[1]Density expressed as the number of animals per ha.
[2]Biomass expressed as g/ha wet weight.

Medium-Sized Mammals

Muskrats also occur in the riparian areas. They live in ponds and ditches on the 200 Area plateau, but their numbers have never been estimated. Muskrats are edible but are not commonly taken for that purpose in this region.

Beavers occupy habitats similar to muskrats but require large water areas and an abundance of trees. None are known to occupy the plateau region, but they do occur in the Columbia River backwaters and occasionally migrate long distances over dry land.

Porcupines have been observed in riparian habitat near U-Pond and in Snively Canyon. Their population size has not been estimated, although few probably remain year-round due to the paucity of food materials.

Jackrabbits are the only mammal species that have been documented as dispersal agents for radioactive materials away from a burial site. During the late 1950's or early 60's burrowing animals exposed the radioactive salts buried in the B-C Cribs. Jackrabbits were apparently attracted to the salts which created a salt lick for native wildlife. This resulted in the distribution of "hot" fecal pellets and urine spots over distances up to 1.6 km from the cribs. The distribution of pellets has been well documented (O'Farrell et al., 1973). A diet analysis (Uresk et al., 1975) showed that black-tailed hares were selective in plants eaten. A comparison of recent pellets with old, radioactive pellets showed that they were eating about the same kinds of food items now as compared to when they were consuming the radioactive salts. Concentrations of black-tailed hares have been noted in the vicinity of the B-C Cribs area in the past, but very little has been documented concerning past or present population densities.

Cottontail rabbits also occur on the 200 Area plateau but are sighted less frequently than jackrabbits, indicating that they are probably less abundant. However, actual density data has not been gathered. Pocket gophers are found throughout the Hanford Reservation but have only been noted as abundant on the abandoned agriculture fields in the Rattlesnake Hills. Their burrowing and soil mining habits make them of interest as potential inhabitants of waste burial sites. Little is known concerning soil and food plant requirements for their maintenance on the Hanford Reservation.

Coyotes are the most important mammalian predator on the Reservation. They roam over large areas and consume a variety of prey including mice, cottontails, jackrabbits, birds, snakes, lizards, and insects. They also scavenge along roadways and consume some vegetable materials. While coyotes are abundant on the 200 Area plateau, they probably number less than 1 per 5 square miles. A study concerning movement patterns of coyotes is nearing completion as a doctoral thesis (Springer, 1977). Another study concerning food habits of coyotes at Hanford is also near completion (Stoel, 1976).

Badgers occur in low numbers on the 200 Area plateau. They dig conspicuous burrows, 20-25 cm in diameter, in pursuit of their prey, ground-squirrels and other rodents. A badger is believed to be the agent responsible for uncovering buried waste in the B-C Cribs area. They are powerful animals and because of their digging ability would be difficult to exclude from waste burial sites.

Raccoons are associated with riparian areas where they prey on fish, crayfish, birds, and other biota. They are extremely agile and would be difficult to exclude from ponds and ditch areas. Acutal numbers present are not known, but the population appears to be low.

Large Mammals

Mule deer are abundant within certain habitats, especially along the Columbia River, near Gable Mountain, and in Snively Canyon. They are not abundant on the 200 Area plateau but do use the pond areas for watering and feeding on the riparian vegetation. A study is currently underway to identify food habits of deer inhabiting the B-C Cribs vicinity, B-Pond, and Gable Mountain Pond areas. The mule deer is the most far-ranging of terrestrial game species occupying the 200 Area plateau. Long-term deer tagging studies (Hedlund, 1975) have shown them to move as much as 70 miles away from the Hanford Reservation. Clearly, additional information is needed concerning their abundance, movement patterns, food habits, and habitat utilization.

A small herd of elk has recently become established on the Hanford Reservation (Rickard et al., 1977). These animals primarily occur in the more isolated regions of the Rattlesnake Hills, but their tracks have been observed along the eastern edge of the ALE Reserve--not far removed from the 200 Area plateau. Their range may eventually include most of the Reservation should the herd continue to expand. A small feral horse herd has also become established at Hanford. They appear to remain along the Columbia River but could use the ponds as watering sources in the future. Little is known about their movements, food habits or herd size.

SHRUB-STEPPE BIRDS

Birds are a conspicuous element of shrub-steppe ecosystems in the Pacific Northwest. Only recently have attempts been made to integrate data on habitat selection, foraging behavior, and population ecology, aspects of most concern to waste management at Hanford, especially shallow burial of low level wastes. The previous lack of scientific interest in these communities may have been due, in part, to the rather simple nature of these communities, which generally contains few avian species. However, this attribute coupled with structural simplicity of the shrub-grass community may make ecological and behavioral relationships more detectable and amenable to study than more complex habitats such as forests.

Birds generally found in the Pacific Northwest shrub-steppe are listed in Table III-6 for comparison with a steppe or grassland region. Twenty-seven species (permanent and spring residents) regularly breed in this habitat, but only three species occur in numbers sufficiently large to be consistently included in standard area censuses (usually 10 to 40 ha., depending on the study). Several more species may be intermittently recorded such that the average number of species per plot in sagebrush and/or bunchgrass rises to six.

The low number of species present limits the complexity of bird communities and is quite likely a result of several factors. Most certainly the extremities of climate here impose checks on birds. Hot, dry summers require physiological and/or behavioral mechanisms for thermoregulation and maintenance of water balance. The very cold winters and occasional persistent snow cover require a different set of thermoregulatory abilities, and restrict

TABLE III-6. Species List of Birds Associated Either Directly or Peripherally with the Pacific Northwest Steppe. Habitat preferences are shown, along with crude estimates of abundance.

Status	Species[a]	Steppe	Shrub Steppe
Permanent Residents	Marsh Hawk	+	+
	Red-tailed Hawk	+	+
	Sharp-tailed Grouse	-	-
	Sage Grouse	-	-
	Chukar	+	+
	Ring-necked Pheasant	-	-
	Gray Partridge	-	-
	Short-eared Owl	-	-
	Horned Lark	++	+
	Black-billed Magpie	+	++
	Common Raven	+	+
	Common Crow	-	+
	Western Meadowlark	+	++
	California Quail	+	+
Summer Residents	Prairie Falcon	-	-
	Long-billed Curlew	+	
	Mourning Dove	+	+
	Burrowing Owl	+	+
	Swainson's Hawk	+	+
	Common Nighthawk	+	+
	Barn Swallow	-	+
	Sage Thrasher		+
	Loggerhead Shrike	-	+
	Grasshopper Sparrow	-	
	Vesper Sparrow	+	
	Lark Sparrow	-	-
	Black-throated Sparrow		-
	Sage Sparrow		++
	Brewer's Sparrow		+
Winter Residents	Rough-legged Hawk	+	+
	Northern Shrike	-	-
	Bald Eagle	-	-

[a] Scientific names of all birds mentioned in tables or text are listed in Appendix I.

Abundance Key: Abundant ++
Common +
Uncommon -
Absent

TABLE III-6. Species List of Birds Associated Either Directly or Peripherally with the Pacific Northwest Steepe. Habitat preferences are shown, along with crude estimates of abundance. (Continued)

Status	Species[a]	Steppe	Shrub Steppe
Migrants	Ferruginous Hawk	-	-
	Golden Eagle	-	-
	Merlin (Pigeon Hawk)		-
	Sandhill Crane	-	-
	Common Flicker (Red-shafted)		-
	Mountain Bluebird		+
	House Finch		-
	American Goldfinch	-	-
	Savannah Sparrow	+	+
	Dark-eyed Junco (Oregon and slate-colored)		+
	White-crowed Sparrow	+	++
	Song Sparrow		++
Peripherals	American Kestrel (Sparrow Hawk)	+	+
	California Quail	-	+
	Killdeer	-	
	California Gull		-
	Ring-billed Gull		-
	Great Horned Owl		-
	Long-eared Owl		-
	Eastern Kingbird	-	+
	Western Kingbird	-	+
	Ash-throated Flycatcher		-
	Say's Phoebe	-	-
	Cliff Swallow	++	
	Bank Swallow	+	
	Rough-winged Swallow	+	-
	Rock Wren	-	+
	Northern Oriole (Bullock's)	-	+
	Lazuli Bunting		-

[a]Scientific names of all birds mentioned in tables or text are listed in Appendix I.

Abundance Key: Abundant ++
Common +
Uncommon -
Absent

the amount of food available to permanent and winter resident species. The simplicity of the vegetation structure contributes to a reduction in bird species numbers and diversities.

A summary of the community attributes of bird populations censused on various plots in the spring of 1974 on the ALE Reserve appears in Table III-7. One of the salient features of this table is the very low number of species (1-3) present together on any plot, and the high degree of species dominance. The dominant species were horned larks and sage sparrows. Few quantitative data are available from winter populations of birds on the ALE Reserve. Most species listed as permanent or winter residents in Table III-6 may generally be found in the area on any given winter day. Generally, horned larks and magpies are the most numerous species this time of year. Migrant horned larks may often be seen in flocks early or late in the year, but are usually not present from mid-November to mid-February.

TABLE III-7. Summary of Bird Populations Censused on the ALE Reserve, 1974 (Rotenberry, in press)

Month	Number of Species[1]	Density (Individual/Km^2)	Total Biomass (gm/ha)
Mar	3	204.9	87.9
Mar	2	106.6	43.7
Mar	3	213.8	73.2
Mar	1	109.1	34.0
Apr/May	3	239.5	87.9
Apr/May	3	204.4	94.2
Apr/May	3	191.1	76.8
Apr/May	1	120.9	37.7
Apr/May	3	269.4	112.2
Apr/May	2	94.6	28.3
Apr/May	2	170.7	80.5
Apr/May	3	223.4	99.4

[1] Species are horned lark, meadow lark, sage sparrow.

BIRDS OF THE 200 AREA PLATEAU

An overall census of 200 Area plateau birds has not been conducted, however, birds associated with waste ponds on the 200 Area plateau were studied over a 29 month period (Fitzner and Rickard, 1975). A checklist of birds utilizing these ponds is included in Table III-8. Perching birds and other small birds not strongly oriented to the aquatic habitat were attracted to U-pond which had the best developed tree-shrub community development during the course of this study. Shore birds were observed at all ponds but were most abundant at West Lake which had little shoreline vegetation. The greatest abundance of birds occurred during autumn migration when waterfowl were present--these are discussed separately.

WATERFOWL

Gable Mountain Pond is the largest of three coolant water discharge ponds in the waste management areas. The others being U-pond and B-pond. By virtue of its relatively large size, 28 hectares, and vegetational development, Gable Mountain pond is intensively used by migrant and breeding waterfowl. Gable Mountain is characterized by year-round use although Fall is the season with the highest waterfowl population (Fitzner and Rickard, 1975).

Ducks

Two general kinds of ducks use Gable Mountain Pond, puddle ducks and diving ducks. The most abundant of the puddle ducks are Mallards, Wigeons, Gadwalls and Pintails with fewer Shoveler and Teal (Figure III-3). As a group the diving ducks are more abundant than puddle ducks. Ringnecked ducks and Scaup are the most abundant species with generally fewer numbers of Bufflehead, Ruddy, Redhead, Canvasback and Goldeneye (Figure III-4).

Gable Mountain Pond is not a first class duck producer although a few broods of Mallards, Teal and Ruddy ducks are produced each year. The major duck use is as a rest and forage stop during Fall and Spring migration. As a group the diving ducks are probably more dependent upon plants for food than are the puddle ducks.

Other Waterfowl

The American Coot is the most abundant waterfowl using Gable Mountain Pond (Figure III-5). Populations are most dense during autumn migration but a substantial number of birds do nest in the cattail and bulrush plant communities that have become established during the 20-year history of the pond. The Pied-billed Grebe is probably the most abundant breeding bird other than the Coot (Figure III-6). However, unlike the Coot the pied-billed grebe is seldom killed as food for people.

TABLE III-8. Birds Associated with 200 Area Plateau Waste Ponds

ORDER PODICIPEDIFORMES

Family Podicipedidae

Horned Grebe *Podiceps auritus*

Eared Grebe *Podiceps caspicus*

Western Grebe *Aechmophorus occidentalis*

Pied-billed Grebe *Podilymbus podiceps*

ORDER CICONIIFORMES

Family Ardeidae

Great Blue Heron *Ardea herodias*

Black-crowned Night Heron *Nycticorax nycticorax*

American Bittern *Botaurus lentiginosus*

ORDER ANSERIFORMES

Family Anatidae

Whistling Swan *Olor columbianus*

Canada Goose *Branta canadensis*

Mallard *Anas platyrhynchos*

Gadwall *Anas strepera*

Pintail *Anas acuta*

Green-winged Teal *Anas carolinensis*

Blue-winged Teal *Anas discors*

Cinnamon Teal *Anas cyanoptera*

American Wigeon *Mareca americana*

Shoveler *Spatula clypeata*

Redhead *Aythya americana*

Ring-necked Duck *Aythya collaris*

Canvasback *Aythya valisineria*

Greater Scaup *Aythya marila*

Lesser Scaup *Aythya affinis*

TABLE III-8. (continued)

Common Goldeneye *Bucephala clangula*
Barrows Goldeneye *Bucephala islandica*
Bufflehead *Bucephala albeola*
Old Squaw *Clangula hyemalis*
Ruddy Duck *Oxyura jamaicensis*
Hooded Merganser *Lophodytes cucullatus*
Common Merganser *Mergus merganser*

ORDER FALCONIFORMES

Family Accipitridae

Sharp-shinned Hawk *Accipiter striatus*
Red-tailed Hawk *Buteo jamaicensis*
Swainson's Hawk *Buteo swainsoni*
Golden Eagle *Aquila chrysaetos*
Marsh Hawk *Circus cyaneus*

Family Falconidae

Sparrow Hawk *Falco sparverius*

ORDER GALLIFORMES

Family Phasianidae

California Quail *Lophortyx californicus*
Ring-necked Pheasant *Phasianus colchicus*
Chukar *Alectoris graeca*

ORDER GRUIFORMES

Family Gruidae

Sandhill Crane *Grus canadensis*

Family Rallidae

Sora *Porzana carolina*
American Coot *Fulica americana*

TABLE III-8. (continued)

ORDER CHARADRIIFORMES

Family Charadriidae

Killdeer *Charadrius vociferus*

Family Scolopacidae

Common Snipe *Capella gallinago*

Long-billed Curlew *Numenius americanus*

Spotted Sandpiper *Actitis macularia*

Greater Yellowlegs *Totanus melanoleucus*

Lesser Yellowlegs *Totanus flavipes*

Pectoral Sandpiper *Erolia melanotos*

Least Sandpiper *Erolia minutilla*

Dunlin *Erolia alpina*

Long-billed Dowitcher *Limnodromus scolopaceus*

Western Sandpiper *Ereunetes mauri*

Sanderling *Crocethia alba*

Family Recurvirostridae

American Avocet *Recurvirostra americana*

Family Phalaropodidae

Wilson's Phalarope *Steganopus tricolor*

Northern Phalarope *Lobipes lobatus*

Family Laridae

California Gull *Larus californicus*

Ring-billed Gull *Larus delawarensis*

Bonaparte's Gull *Larus philadelphia*

ORDER COLUMBIFORMES

Family Columbidae

Rock Dove *Columba livia*

Mourning Dove *Zenaidura macroura*

TABLE III-8. (continued)

ORDER STRIGIFORMES

Family Strigidae

Great Horned Owl *Bubo virginianus*

Burrowing Owl *Speotyto cunicularia*

ORDER CAPRIMULGIFORMES

Family Caprimulgidae

Common Nighthawk *Chordeiles minor*

ORDER CORACIIFORMES

Family Alcedinidae

Belted Kingfisher *Megaceryle alcyon*

ORDER PICIFORMES

Family Picidae

Red-shafted Flicker *Colaptes cafer*

Lewis' Woodpecker *Asyndesmus lewis*

Hairy Woodpecker *Dendrocopos villosus*

Downy Woodpecker *Dendrocopos pubescens*

ORDER PASSERIFORMES

Family Tyrannidae

Eastern Kingbird *Tyrannus tyrannus*

Western Kingbird *Tyrannus verticalis*

Ash-throated Flycatcher *Myiarchus cinerascens*

Say's Phoebe *Sayornis saya*

Western Wood Peewee *Contopus sordidulus*

Family Alaudidae

Horned Lark *Eremophila alpestris*

Family Hirundinidae

Barn Swallow *Hirundo rustica*

Cliff Swallow *Petrochelidon pyrrhonota*

TABLE III-8. (continued)

PASSERIFORMES (contd)

Family Corvidae

Black-billed Magpie *Pica pica*

Common Raven *Corvus corax*

Common Crow *Corvus brachyrhynchos*

Family Sittidae

Red-breasted Nuthatch *Sitta canadensis*

Family Troglodytidae

Winter Wren *Troglodytes troglodytes*

Long-billed Marsh Wren *Telmatodytes palustris*

Canon Wren *Catherpes mexicanus*

Family Mimidae

Mockingbird *Mimus polyglottos*

Sage Thrasher *Oreoscoptes montanus*

Family Turdidae

Robin *Turdus migratorius*

Varied Thrush *Ixoreus naevius*

Hermit Thrush *Hylocichla guttata*

Western Bluebird *Sialia mexicana*

Townsend's Solitaire *Myadestes townsendi*

Family Sylviidae

Golden-crowned Kinglet *Regulus satrapa*

Ruby-crowned Kinglet *Regulus calendula*

Family Motacillidae

Water Pipit *Anthus spinoletta*

Family Laniidae

Loggerhead Shrike *Lanius ludovicianus*

Family Sturnidae

Starling *Sturnus vulgaris*

TABLE III-8. (continued)

PASSERIFORMES (contd)

Family Vireonidae

Hutton's Vireo *Vireo huttoni*

Red-eyed Vireo *Vireo olivaceus*

Warbling Vireo *Vireo gilvus*

Family Parulidae

Orange-crowned Warbler *Vermivora celata*

Nashville Warbler *Vermivora ruficapilla*

Yellow Warbler *Dendroica petechia*

Myrtle Warbler *Dendroica coronata*

Audubon's Warbler *Dendroica auduboni*

Townsend's Warbler *Dendroica townsendi*

MacGillivray's Warbler *Oporornis tolmiei*

Wilson's Warbler *Wilsonia pusilla*

Family Ploceidae

House Sparrow *Passer domesticus*

Family Icteridae

Western Meadowlark *Sturnella neglecta*

Yellow-headed Blackbird *Xanthocephalus xanthocephalus*

Red-winged Blackbird *Agelaius phoeniceus*

Bullock's Oriole *Icterus bullockii*

Brewer's Blackbird *Euphagus cyanocephalus*

Brown-headed Cowbird *Molothrus ater*

Family Thraupidae

Western Tanager *Piranga ludoviciana*

Family Fringillidae

House Finch *Carpodacus mexicanus*

American Goldfinch *Spinus tristis*

TABLE III-8. (continued)

PASSERIFORMES (contd)

Rufous-sided Towhee *Pipilo erythrophthalmus*
Savannah Sparrow *Passerculus sandwichensis*
Lark Sparrow *Chondestes grammacus*
Sage Sparrow *Amphispiza belli*
Oregon Junco *Junco oreganus*
Tree Sparrow *Spizella arborea*
White-crowned Sparrow *Zonotrichia leucophrys*
Golden-crowned Sparrow *Zonotrichia atricapilla*
Swamp Sparrow *Melospiza georgiana*
Song Sparrow *Melospiza melodia*

The following taxonomic changes listed in the "Thirty-second supplement to the American Ornithologists' Union checklist of North American Birds" Auk 90: 411-419 (1973) are applicable to the avifauna listed above.

Anas carolinensis is considered a subspecies of *A. crecca* and becomes *A. crecca carolinensis*
Mareca americana becomes *Anas americana*
Spatula clypeata becomes *Anas clypeata*
Alectoris graeca becomes *Alectoris chukar*
Totanus melanoleucus becomes *Tringa flavipes*
Erolia minutilla becomes *Calidris minutilla*
Erolia melanotus becomes *Calidris melanotus*
Zenaidura macroura becomes *Zenaida macroura*
Colaptes cafer becomes *Colaptes auratus*
Dendroica auduboni becomes *Dendroica coronata*
Icterus bullocki becomes *Icterus galbula*
Junco oreganus becomes *Junco hyemalis*

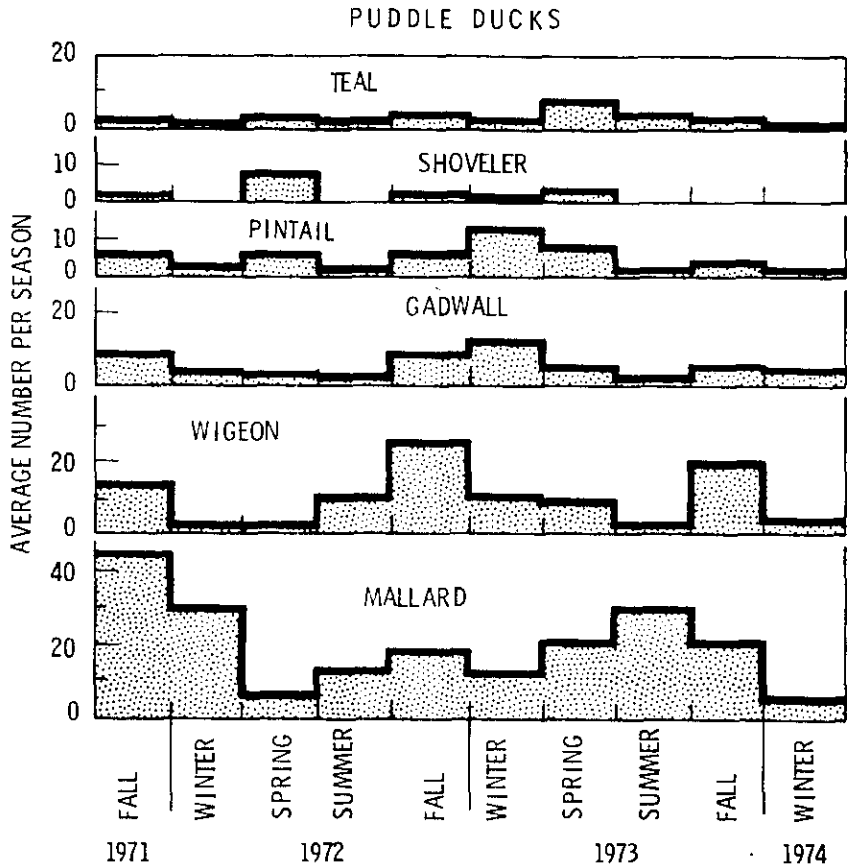

FIGURE III-3. Seasonal Distribution of Puddle Ducks at Gable Mountain Pond

The Canada goose is abundant at Gable Mountain especially during Fall and Winter months (Figure III-6). The Canada goose does not nest at Gable Mountain Pond and is seldom seen in spring and summer months. The Canada goose probably derives little forage from the pond itself and instead forages on green plant material growing in the adjacent terrestrial landscape or travels to cultivated fields beyond the boundaries of the Hanford Reservation.

The Common Merganser is a migrant species of fish-eating duck that is most abundant during autumn. It is probably attracted to Gable Mountain Pond by the presence of its fish population.

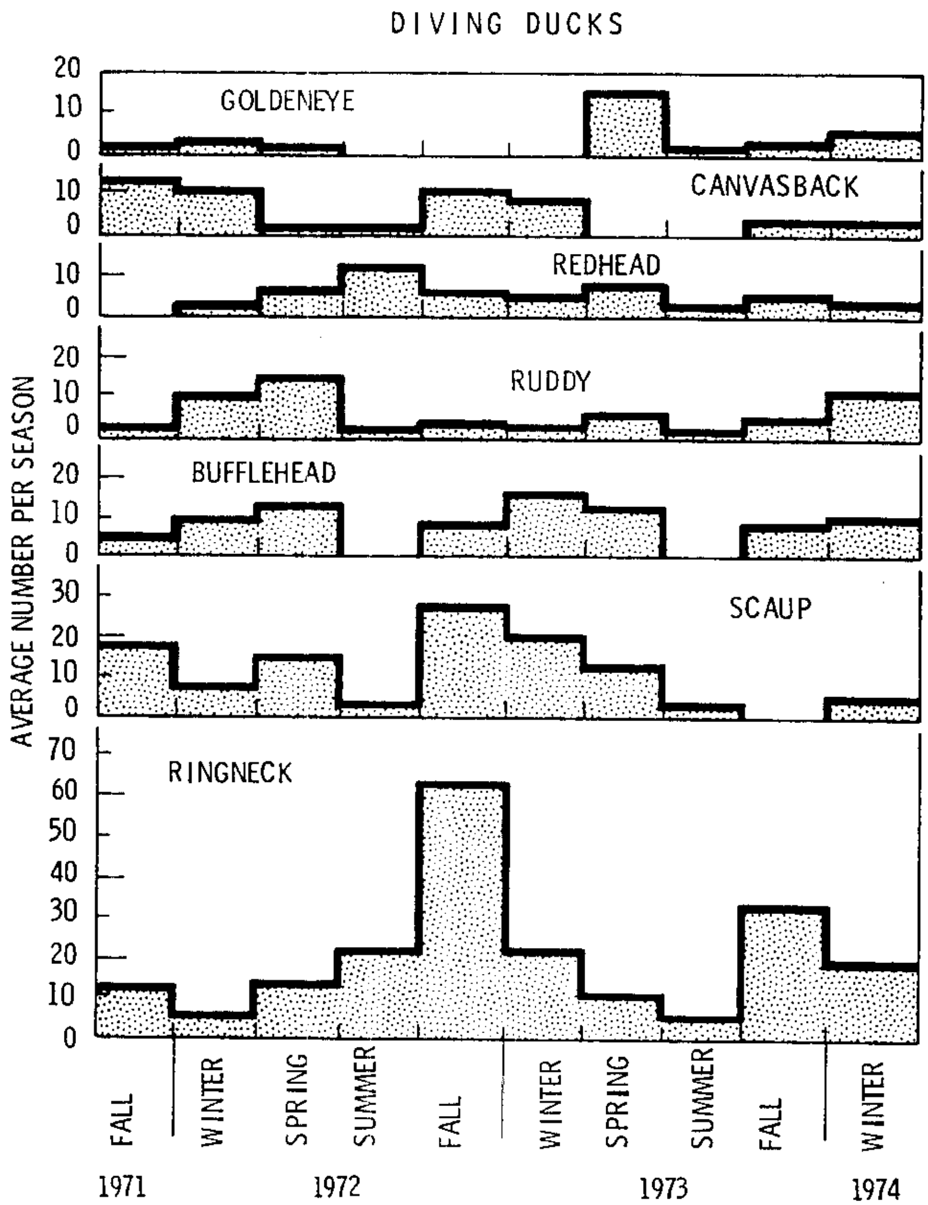

FIGURE III-4. Seasonal Distribution of Diving Ducks at Gable Mountain Pond

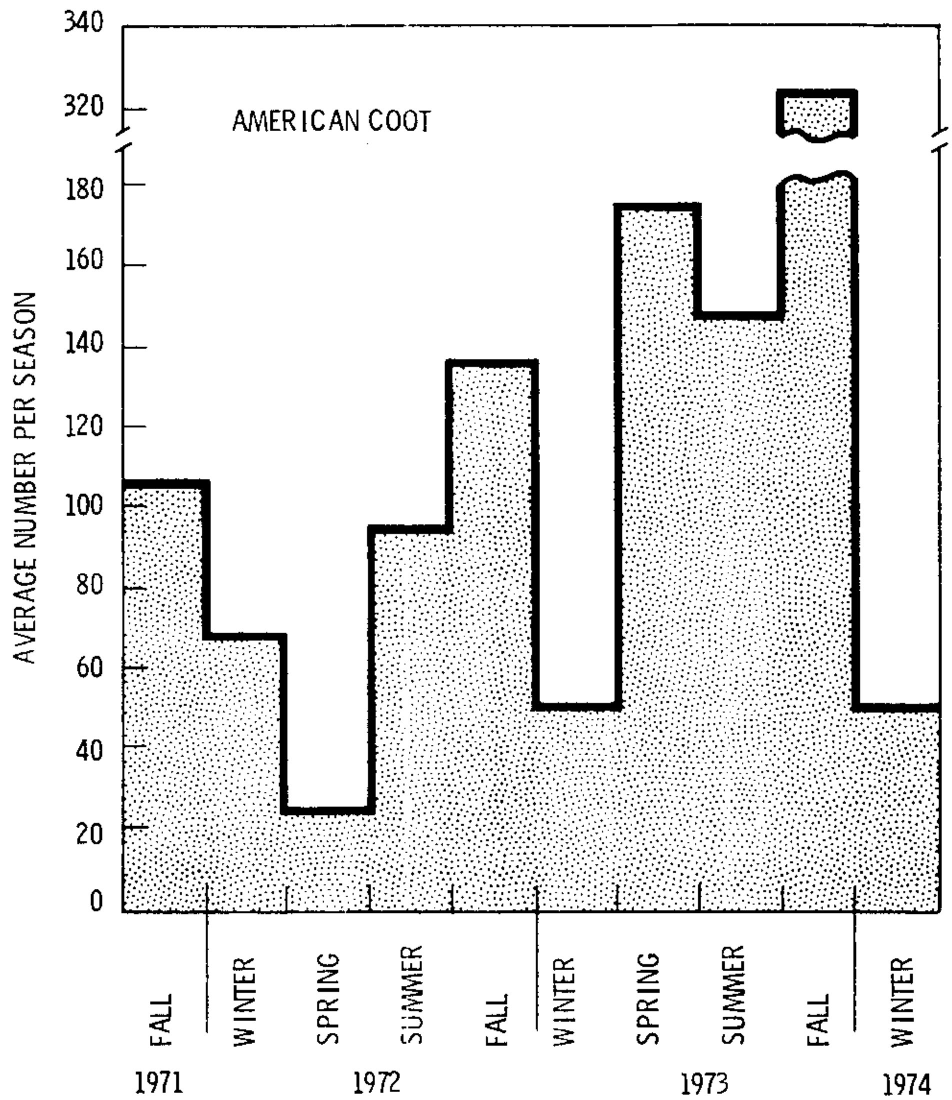

FIGURE III-5. Seasonal Distribution of the American Coot at Gable Mountain Pond

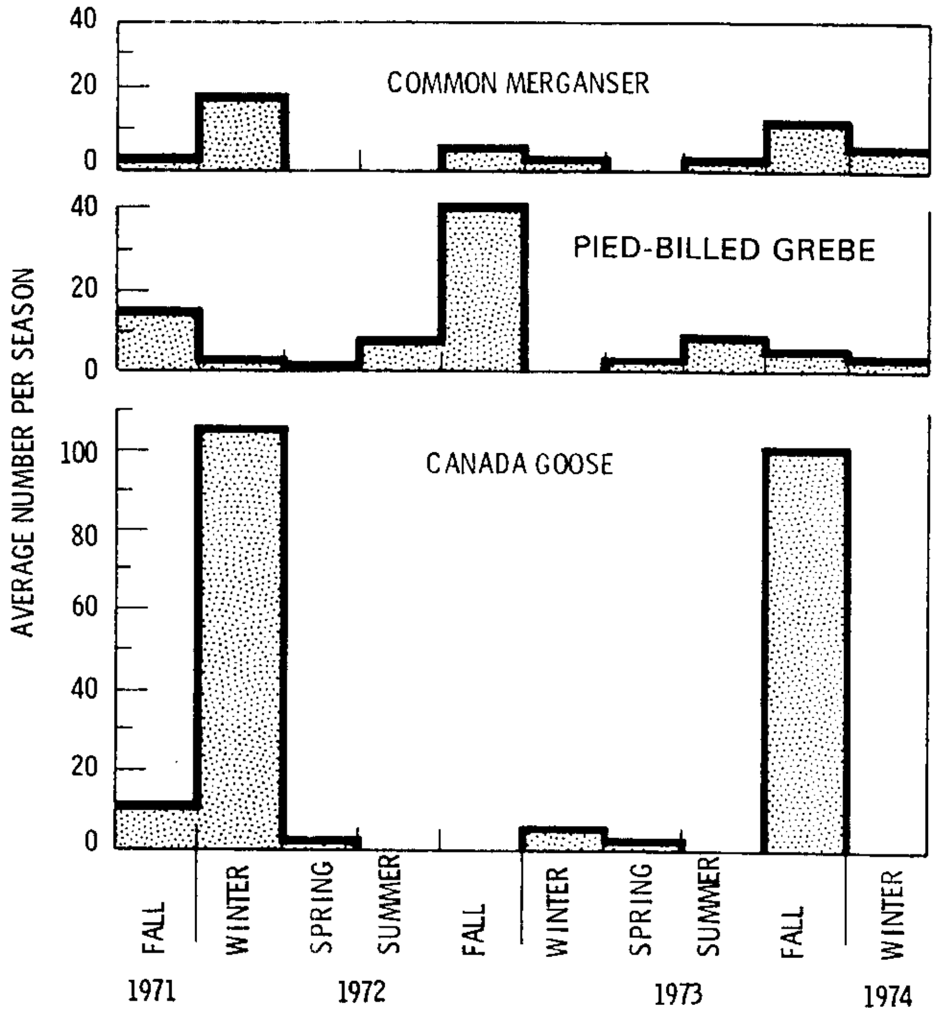

FIGURE III-6. Seasonal Distribution of the Canada Goose, Pied-billed Grebe and Common Merganser at Gable Mountain Pond

RAPTORS

Large birds of prey have historically received little attention on the Hanford Reservation, although their position as a top carnivore in the food chain suggest they may be a controlling factor in the variety of prey populations. The first documentation of the use of the Hanford Reservation was a census by Olendorff (1973).

Olendorff divided the Hanford Reservation (which includes the ALE Reserve) into 10 more or less homogeneous regions and intensively searched each one for raptor nests. His results are given in Figure III-7 and show quite clearly the patchiness of the distribution of these birds. Densities of large raptors ranged from 16.9 pairs/100 sq. km (Region V) to zero (Region III and X, X being poorly censused). Dividing the Reservation into high and low density areas (essentially north-south) yields an average high density of 10.9 pairs/100 sq. km and an average low of 0.3 pairs/100 sq. km. The overall density was estimated to be about 6.1 pairs/100 sq. km.

Interestingly, this overall density is precisely the same as Olendorff (1972) estimated for a shortgrass prairie in eastern Colorado, although distributional patterns there showed much less clumping. He attributes this difference to a similar variance in the dispersion of trees (i.e., nest sites) in each area, which in turn is largely due to differences in patterns of human settlement. The Colorado study site was more or less uniformly occupied and farmed in the early 1900's, while most people in the Hanford basin settled along the Columbia River (Region V, Figure III-3). Since naturally-occurring trees are generally rare in arid regions, human activity (i.e., planting shade trees, windbreaks, and orchards) can have a major effect on raptor abundance.

Assuming that biomass partitioning in the raptor communities of Eastern Washington is similar to that in Eastern Colorado, and that 16 pairs/100 sq. m is a reasonable estimate of their densities in both areas, data provided by Olendorff (1972) show that the standing crop biomass of raptors, including both adults and young fledglings, is only about 100-150 g/km^2, or 1.0-1.5 g/ha. This is considerably less than that observed for passerines (30-110 g/ha). Likewise, converting pairs/100 sq. km to individuals/km^2 shows raptors to be far outnumbered (0.12 birds/km^2 *vs.* about 200 birds/km^2).

These biomass differences (average weight per individual and grams per hectare) imply that the passerines are more likely to exert a significant impact on their prey population than raptors on theirs. Although it may be easily demonstrated that large predators require absolutely more food per unit time than do smaller ones, it takes more grams of prey to support a gram of small bird than it does to support a gram of large bird. Confirmation of impact, however, requires considerably more information on prey population dynamics and availability, especially for insects, than is now available. Consideration must also be given to the weight distributions of potential prey populations, since they are quite obviously different for raptors and passerines. For that matter, the dietary habits of many birds, including raptors, are also poorly known.

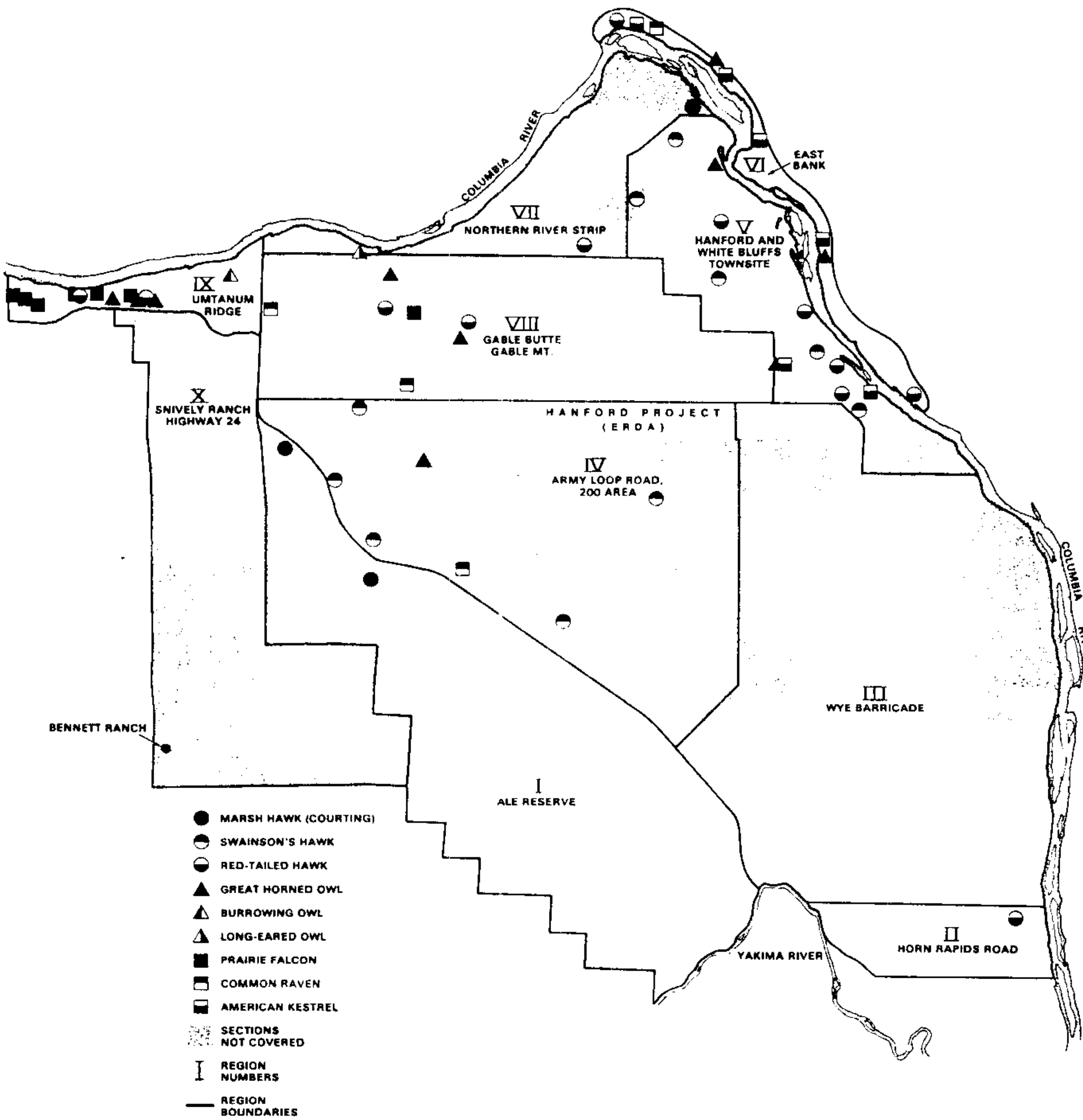

FIGURE III-7. Map of the USDOE Hanford Reservation Showing the Location of Nesting Raptorial Birds Observed During February-May 1973. Modified from Olendorff (1973).

THE PLANT COMMUNITY AS BIRD HABITAT

The relationship between the physical structure and appearance of the vegetation and the organization of avian communities has received a great deal of attention in the ecological literature. The correlation between bird species diversity and foliage height diversity or other similar measures of habitat complexity has been demonstrated both within (MacArthur and MacArthur, 1961; MacArthur, 1964; Karr, 1968; Orians, 1969) and between (Cody, 1970; Karr and Roth, 1970; Wilson, 1974) a wide variety of vegetative types.

On the ALE Reserve, Rotenberry (1975) noted that two bird/structure relationships were clearcut. Horned lark densities were strongly inversely correlated with sagebrush coverage; sage sparrows, appropriately enough, had a high positive correlation. Responses to increasingly or decreasingly favorable conditions appeared to differ in the two species. As sage cover increased, sage sparrows increased their density by decreasing the size of their territories (1.8 to 1.0 ha) while increasing the number of territories per plot (4.7 to 6.2). Horned lark territory sizes remained about the same as sage cover increased (2.0 to 2.1 ha), but there were simply fewer of them (3.4 to 0.3 per 9 ha plot). These changes are not statistically significant. Meadowlark densities were uncorrelated with brush cover. Unexpectedly, horned lark numbers were uncorrelated with the coverage of bare ground.

One method of examining the habitat specificity (or generality) of each species is to compare its diversity and evenness over all study plots. This measure equates with the niche breadth of a species. For all three of the main species present on these plots, this measure is quite high: horned larks, 0.91; sage sparrow, 0.97; meadowlarks, 0.96 (maximum value of 1.00). This suggests that these species are all rather general in their selection of habitats in the shrub-steppe (at least in reference to the eight study plots on ALE), and subsequently, have rather broad niches.

All of the foregoing analyses suggest one thing. Unlike many bird communities in other vegetational types, associations of birds within the shrub-steppe are not finely tuned to the structure of the plant community, an important point in planning for revegetation strategy for wildlife purposes.

INSECTS

Insects are an important, though largely little understood, component within semi-arid ecosystems. Intensive studies have been conducted within sagebrush/bunchgrass and cheatgrass communities on the ALE Reserve. Results from these studies probably have little application to the 200 Area plateau since the community structure is very dissimilar. Insect studies near waste management facilities have concentrated on major groups, i.e., beetles and grasshoppers. Characterization studies of shrub-inhabiting insects were initiated but await final processing.

Darkling beetles are a dominant part of the insect community in most semi-arid regions of the West. The seasonal distribution of common darkling beetles of the Hanford Reservation is shown in Table III-9. Most occur throughout the year as long as favorable weather conditions permit. Others, such as Philolithus densicollis, are restricted to a few months' activity period in the fall before their numbers are decimated by winter weather. A comparison of beetle abundance on the 200 Area plateau is shown in Table III-10. Dramatic changes in beetle abundance commonly occur within different communities and in different years. It is not surprising, therefore, to capture 318 Conisattus nelsoni from the control area in 1974 and only 2 specimens in 1975.

Grasshoppers are also conspicuous components of the 200 Area plateau ecosystem. Since they are predominantly herbivores and known for occasional population outbreaks, their presence in large numbers can exert a significant impact on energy flow and nutrient cycling patterns. A study of grasshopper populations inhabiting the B-C Cribs and REDOX Pond sites of the 200 Area plateau was conducted during 1974 and 1975. A total of 14 grasshopper species was collected from the B-C Cribs area and REDOX Pond area (Table III-11). Population density was low during spring months, increased in late May and reached a peak of 4 grasshoppers/m^2 in early July. Particulars concerning individual species are included in the overall analysis provided by Sheldon and Rogers (1976) for 200 Area plateau grasshopper populations.

TABLE III-9. Seasonal Distribution of Darkling Beetles

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Anemia californicus (ANCA)					X	X		X	X			
Blapstinus sp. (BLSP)			X			X	X	X				
Coniontis setosa (COSE)			X						X	X		
Conisattus nelsoni (CONE)					X		X	X		X		
Eleodes granulata (ELGR)			X		X		X		X	X		
Eleodes humeralis (ELHU)						X	X	X		X		
Eleodes nigrina (ELNI)			X			X	X			X		
Eleodes novoverrucula (ELNO)				X	X	X	X	X		X		
Eleodes obscura (ELOB)					X	X		X				
Eusattus muricatus (EUMU)				X	X		X			X		
Oxygonodera hispidula (OXHI)			X				X	X	X	X		
Philolithus densicollis (PHDE)									X	X		
Stenomorpha puncticollis (STPU)									X	X		

TABLE III-10. A Comparison of Beetle Abundance on the 200 Area Plateau with a Control Area on the ALE Reserve

Species[1]	REDOX Pond Area	B-C Cribs Area	Control Area
		1974	
ANCA	1	2	7
CONE	29	0	318
COSE	3	0	1
ELHI	20	16	48
ELHU	1	1	5
ELNI	0	0	15
ELNO	1	0	2
ELOB	3	1	0
EUMU	8	89	0
PHDE	4	70	9
Total	70	179	405
		1975	
ANCA	0	0	1
CONE	1	2	2
COSE	5	0	1
ELHI	3	7	9
ELHU	0	1	0
ELNI	0	0	1
ELNO	0	0	0
ELOB	0	0	0
EUMU	19	4	1
PHDE	11	3	8
Total	39	17	23

[1]Species names are given in Table III-9. The abbreviation consists of the first two letters of both genus and species names (i.e., ANCA = Anemia californicus).

TABLE III-11. Grasshopper Species Inhabiting the 200 Area Plateau

Ageneotettix deorum
Amphitornus coloradus
Apote notabilis
Arphia pseudonietana
Aulocara elliotti
Conozoa wallula
Hesperotettix viridis
Melanoplus cinereus
Melanoplus sanguinipes
Melanoplus yarrowii
Oedaleonotus enigma
Paropomala pallida
Steiroxys sp.
Trimerotropis bilobata
Trimerotropis caeruleipennis
Trimerotropis pallidipennis
Xanthippus lateritus

RARE, THREATENED, AND ENDANGERED SPECIES

Three endangered or threatened species of vascular plants are known to occur on the Reservation: Balsamorhiza rosea, Erigeron piperianus, and Eriogonum thymoides. All occur on the ALE Reserve rather than where waste management activities are conducted or planned. Allium robinsonii may occur in the gravel bars along the Columbia River, and is noted as a threatened species.

Reptiles and amphibians on the Reservation are restricted to a few wide-ranging species, none of which can be classified as endangered, although the desert night snake is seldom seen at Hanford.

Mammals on the Reservation are not endangered at the species level, although their presence on the Reservation may be in very small numbers. Mink and bobcat are examples of low-density species.

Birds are a different matter. The Hanford Reservation provides a refugium for several rare, threatened, or indeterminate species. The Prairie falcon (Falco mexicanus) nests in several regions on the Reservation, with the number of nesting pairs probably about 6. This species is listed as a threatened species in the United States Department of the Interior Red Book.

The American peregrine falcon (Falco peregrinatus anatum) apparently does not nest on the Reservation but in the neighboring regions, perhaps in small numbers. Species lacking specific data to attest to their status but considered to be possibly in danger (i.e., indeterminate) include: 1) the Ferruginous rough-leg hawk (Buteo regalis); 2) the American osprey (Pandion haliaetus carolinensis), only visitors; 3) the Western burrowing owl (Speotyto cunicularia hypugaea); and 4) the long-billed curlew (Numenius americanus). The last two nest on the Reservation in significant numbers, particularly around the 200 Areas.

Species Accounts

1) Long-billed curlews (Numenius americanus) nest in cheatgrass fields. This species is abundant around the 200 Area but its nesting density is highest around the 300 Area. The bird is a migrant to Washington and arrives in Richland around March 18. It nests and raises young in the cheatgrass fields and sagebrush areas, and then leaves the Reservation to migrate southward in late June. During the March through June period, these birds are sensitive to human disturbance and will abandon their nest if disrupted. Care should be taken to keep personnel (vehicles and pedal traffic) out of nesting areas at all times.

   The long-billed curlew is a bird of "undetermined" status and should, therefore, be afforded all possible protection.

2) The burrowing owl has been observed nesting on and adjacent to the 200 East and West areas. This bird nests in burrows dug into the ground by other animal species (badgers and coyotes).

3) At least 6 pair of Swainson's hawks (Buteo swainsoni) nest around the 200 Areas. These birds arrive on the Hanford Reservation by April 20 and stay until September. During this period, they lay eggs, raise young, and forage for food throughout the 200 Area environs. Radio-telemetry studies conducted in 1976 revealed that the 200 Areas were used for hunting by these birds. Noises and traffic (foot travel and automobile) may be disruptive to the birds, but these factors can be controlled so that the impact will be negligible to the nesting Swainson's hawk. All hawks, owls, and eagles are protected by Federal law and many are listed as rare, threatened, or endangered by state and Federal governments. The Swainson's hawk is not considered as rare or endangered by the Federal government, but surveys conducted in Washington indicate that the Hanford Reservation is one of the most important nesting habitats in the state.

COLD-BLOODED VERTEBRATES

The Hanford Reservation supports a variety of cold-blooded vertebrate species. Reptiles (snakes and lizards) are most abundant since they are physiologically adapted to a hot-arid environment while amphibians require moisture in order to survive. Amphibians also require standing water (ponds, streams, etc.) in order to reproduce. Reptiles lay eggs which are encased in a hard shell making them resistant to dessication - amphibians have no egg shell and must lay their eggs in a liquid environment in order to keep them moist.

Table III-12 lists the reptiles and amphibians which occur on the Hanford Reservation. All of these species could also occur on 200 Area plateau. To date, however, we have only observed one of the amphibians species listed, the Great Basin Spadefoot Toad, and have observed all of the reptiles listed.

Trapping studies using drift fences and pit traps were begun in a sagebrush/cheatgrass community near the B-C Cribs Area in April of 1976. Three other study areas were also established in a sagebrush/cheatgrass community on the ALE Reserve and in sagebrush-bitterbrush/cheatgrass and bitterbrush/cheatgrass communities near the Washington Public Power Supply Systems Nuclear Powerplant construction sites.

The only snake species captured in the sagebrush/cheatgrass ALE and B-C Crib plots were the Green Racer and Gopher Snake. Both species occurred in approximately the same numbers. A striped whip snake was also observed near the B-C Crib area during a June visit. This species is semi-arboreal residing in sagebrush canopies which may explain the lack of captures in any of the ground drift fence traps. Desert night snakes occur primarily in rocky areas, particularly near Gable Butte. Two specimens were captured near the 200 W badge house in 1973. Rattlesnakes are not abundant around the B-C Crib area or in similar habitats. This species also tends to be associated more with rocky areas.

Lizards are perhaps the most important group of cold-blooded vertebrates of the 200 Area plateau. Three species are common to the area. These are the sagebrush lizard, pigmy short-horned lizard and side-blotched lizard. The sagebrush and short-horned lizards are mainly restricted to sandy areas while the side-blotched lizard seems to occur in virtually every habitat present. The pit trap studies at the B-C Crib and ALE Site provide data on populations. Figure III-8 shows a graphic representation of population levels, hatching dates, and dates of hibernation for the side-blotched and sagebrush lizard (note: the sagebrush lizard was restricted solely to the sandy area, i.e. the Bitterbrush Plot). The leveling off period noted for the B-C Crib and Manipulation Plots represents the maximum number of adults captured on each plot. The plots were 20 x 20 m (400 sq. m) providing a rough

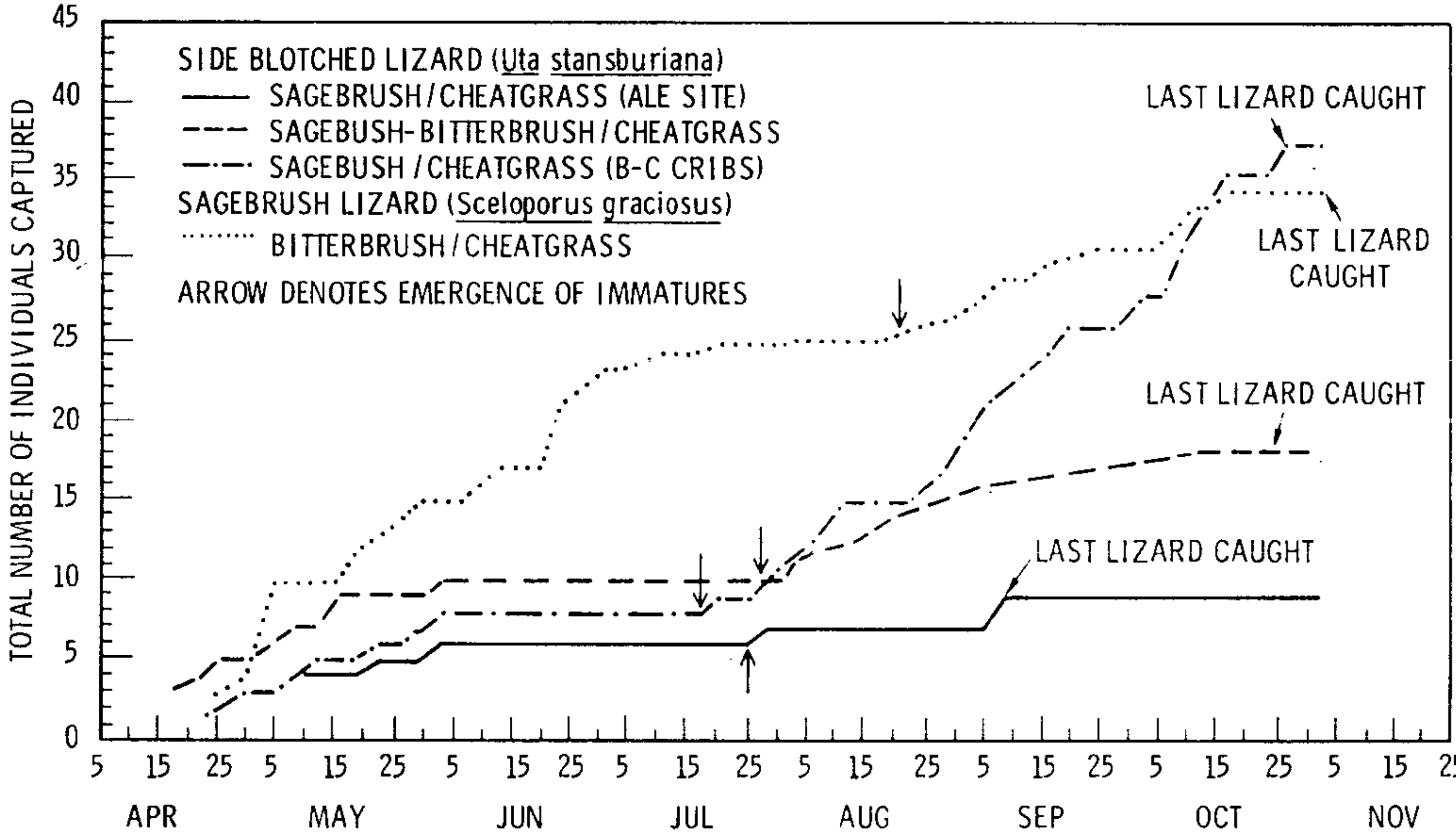

FIGURE III-8. Seasonal Variations in Lizard Populations

TABLE III-12. Amphibian and Reptile Species Observed on the Hanford Reservation.

Common Name	Scientific Name	Occurrence
Amphibians		
Great Basin Spadefoot	Scaphiopus intermontanus	U
Western Toad	Bufo boreas	U
Pacific Treefrog	Hyla regilla	
Reptiles		
Sagebrush Lizard	Sceloporus graciosus	U
Side-blotched Lizard	Uta stansburiana	C
Pigmy Short-horned Lizard	Phrynosoma douglassi	U
Striped Whipsnake	Masticophis taeniatus	O
Western Yellow-bellied Racer	Coluber constrictor	C
Gopher Snake	Pituophis melanoleucus	C
Desert Night Snake	Hypsiglena torguata	R
Northern Pacific Rattlesnake	Crotalus viridus	C
Reptiles and Amphibians which may occur on the Hanford Reservation but sightings have not yet occurred		
Long-toed Salamander	Ambystoma macrodactylum	
Tiger Salamander	Ambystoma tigrinum	
Woodhouse's Toad	Bufo woodhousei	
Leopard Frog	Rana pipiens	
Bullfrog	Rana catesbeiana	
Painted Turtle	Chrysemys picta	
Western Fence Lizard	Sceloporus occidentalis	
Western Skink	Eumesces skiltonianus	
Common Garter Snake	Thamnophis sirtalis	
Western Terrestrial Garter Snake	Thamnophis elegans	

[1] U = Uncommon, C = Common, R = Rare.

estimate of 15 lizards per hectare in the B-C Crib area and 25 per hectare on the Manipulation Plot. The average weight of approximately 3.5 g per individual provides an estimate of between 52.5 and 87.5 g of lizard biomass per hectare. In Utah, researchers have found springtime biomass levels of 108 to 285 g per hectare.

No amphibians were collected during these trapping efforts. The only amphibians which commonly occur on the 200 Area plateau are mainly associated with waste ponds. Here one can find tadpoles and adults of the Pacific tree frog, Western toad and Great Basin spadefoot toad.

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CHAPTER IV. ENERGY FLOW AND MINERAL CYCLING MECHANISMS

L. E. Rogers

Analysis of energy flow patterns and mineral cycling mechanisms provides a first step in identifying major transport pathways away from waste management areas. A preliminary food web pattern is described using results from ongoing and completed food habit studies. Biota possessing the greatest potential for introducing radionuclides into food chains leading to man include deer, rabbits, hares, waterfowl, honeybees and upland game birds and are discussed separately.

One of the long-term objectives of the 200 Area plateau ecological studies is to evaluate the potential for biota to introduce radioactive waste materials into food chains. The transport route could possibly lead to man, be transported away from waste management areas or off the Hanford Reservation. Meeting these objectives presupposes a thorough understanding of ecosystem structural characteristics and mechanisms governing energy flow and element cycling.

ENERGY FLOW

Assessment of energy flow patterns documents how the chemical energy fixed by green plants during photosynthesis is utilized. This is of interest here in that it identifies major transfer pathways within the 200 Area plateau ecosystem (Figure IV-1). It is never possible to examine all ecosystem segments in detail--it is too complex. An estimate of energy flow patterns provides the necessary information to logically decide which components must be examined in detail. For example, if energy flow pattern analysis shows the Russian thistle → grasshopper → horned lark food chain to be a major transfer pathway, then detailed studies concerning radionuclide uptake and transport would be justified. Energy flow and mineral cycling are basic ecosystem parameters that are also valuable in evaluating ecosystem quality.

FOOD HABIT STUDIES

Analysis of energy flow and mineral cycling patterns requires detailed knowledge concerning the food habits of particular consumers. Much of this information has already been gathered for Hanford Reservation consumers either as part of the biotic transport program or under separate DOE funding:

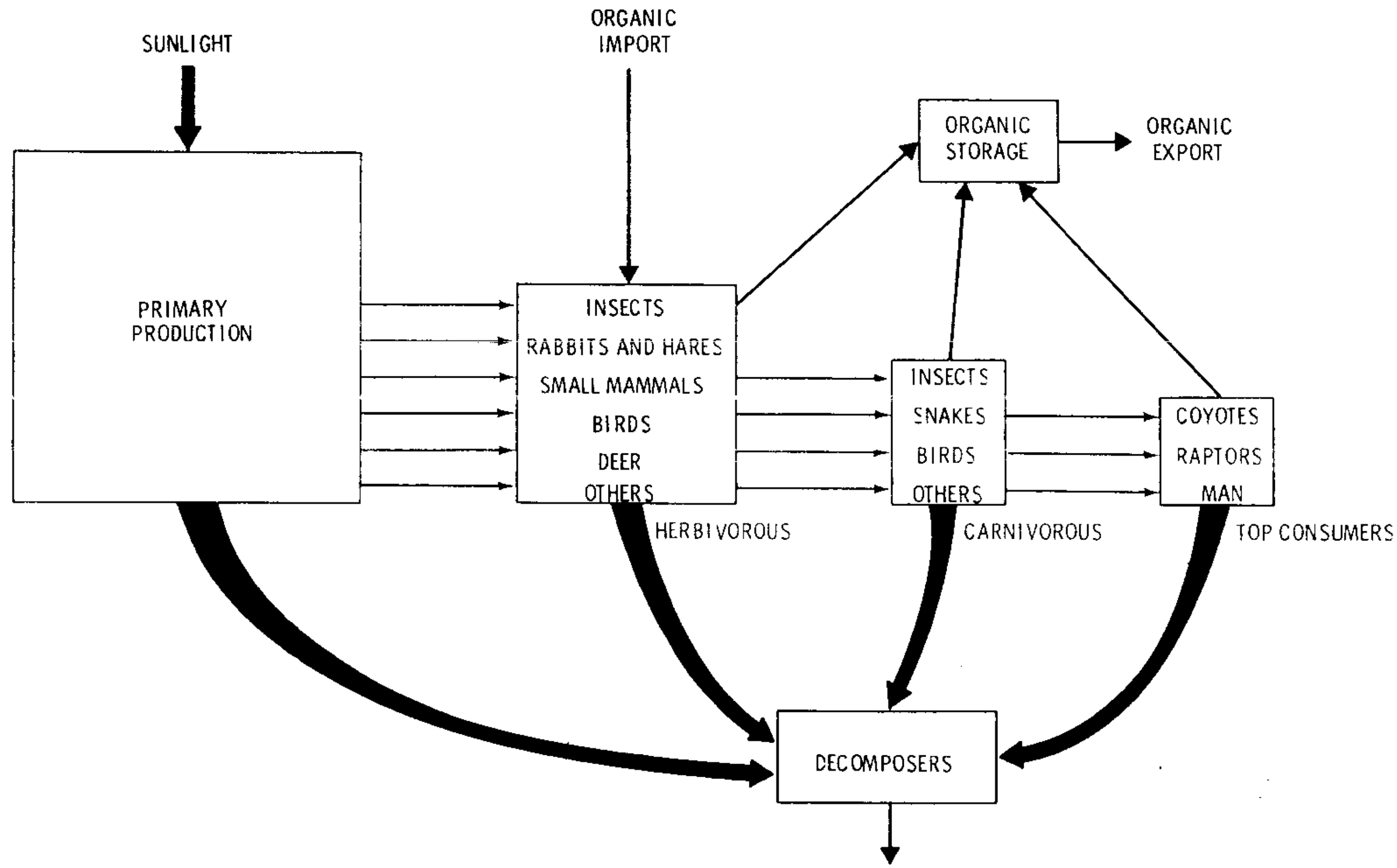

FIGURE IV-1. Ecosystem Energy Flow Pattern

• Diets of Black-tailed Hares Inhabiting the 200 Area Plateau	Uresk et al., 1975
• Diets of Deer Mice, Pocket Mice, and Townsend Ground Squirrels of the ALE Reserve	Johnson, 1975
• Diets of Grasshoppers Inhabiting the 200 Area Plateau	Sheldon and Rogers, 1976
• Diets of Darkling Beetles Inhabiting the Hanford Reservation (includes 200 Area)	Rogers et al., In press
• Diets of Coyotes Inhabiting the Hanford Reservation	Stoel, 1976
• Diets of Deer Inhabiting 200 Area Plateau (Near Ponds and B-C Cribs)	Uresk, In process
• Diets of Cattle on Sagebrush/Bunchgrass Pastures, ALE Reserve	Uresk and Rickard, 1976
• Diets of Townsends Ground Squirrel on the ALE Reserve	Rogers and Uresk, In preparation
• Diets of Migratory Grasshopper in a Cheatgrass Community (ALE Reserve)	Rogers and Uresk, 1974
• Food and Foraging Behavior of Deer Mice and Pocket Mice on the ALE Reserve	Kritzman, 1970

Dietary analysis of grasshoppers inhabiting the 200 Area plateau showed that 7 of the 28 species of vascular plants recorded from the area were major components in grasshopper diets. These include needle-and-thread grass (*Stipa comata*), turpentine cymopterus (*Cymopterus terebinthinus*), Carey's balsamroot (*Balsamorhiza careyana*), western tansymustard (*Descurainia pinnata*), Jim Hill mustard (*Sisymbrium altissimum*), big sagebrush (*Artemisia tridentata*), and green rabbitbrush (*Chrysothamnus viscidiflorus*). The plant most heavily utilized was big sagebrush, followed by turpentine cymopterus, green rabbitbrush, and Carey's balsamroot. Other species were less frequently eaten. Several plants were present in the diet at a much higher frequency than they occurred in the environment, indicating that they were preferred food items. These included turpentine cymopterus, Carey's balsamroot, Jim Hill mustard, and green rabbitbrush. Some plants were apparently avoided by the grasshoppers since they were encountered at a much lower diet frequency (or were not eaten at all) than one would expect based on their natural abundance. Included in this group of plants were cheatgrass (*Bromus tectorum*) slender fescue (Festuca octoflora), Sandberg's bluegrass (Poa sandbergii), western tansymustard (Descurainia pinnata), matted cryptantha (Cryptantha circumscissa), winged cryptantha (Cryptantha pterocarya), and microsteris (Microsteris gracilis).

Similarly, a fecal pellet analysis showed that back-tailed hares (jackrabbits) were selective in plants chosen as food (Uresk et al., 1975). The most abundant herbaceous plant, cheatgrass, was not found in the pellets. Sagebrush and bitterbrush, woody plants, were not an important part of their diet. Forbs, rabbitbrush, and certain grass species were preferred foods. The percent relative frequency of plant fragments contained in jackrabbit fecal pellets is shown in Table IV-1.

Analysis of the dietary relationships within a community of birds can provide information on a varity of ecological processes. The number, size, and types of prey items taken may offer some insight into the niche breadths and competitive relationships among the species involved. Insofar as food may at times be a limiting resource, it might be expected that food supply plays a role in determining the structure of the community it supports. Since energy fluxes and nutrient cycles are probably the two most important elements of ecosystem processes, it is necessary to know trophic relationships and the nature of energy and nutrient transfers between trophic levels to understand fully these processes.

Results from studies on the ALE Reserve (Rotenberry, in press) show the high degree of insectivory exhibited by birds in the spring samples (April and May), including even the sage sparrow, possessor of a deep conical bill presumably adapt for the efficient handling of seeds. Seasonal trends in the insect proportion of horned lark and sage sparrow diets seemed consistent: about 75% in early spring, increasing to nearly 100% later on and dropping off to 10% or less in the winter. On a percent dry weight basis insects contribute even more, always being in excess of 80%. In the winter samples of horned larks (October 1973, November 1972), insects made up 27-45% of the diet by weight. The most common insect prey were beetles, particularly weevils (Curculionidae) and beetle larvae (mostly Tenebrionidae). Although ants, grasshoppers, small hemipterans, Lepidopteran larvae, and spiders were consistently found in spring samples, they generally contributed less than 10% to either total biomass or total items consumed.

Grass seeds and forb seeds were important items only in winter samples of horned larks, not unexpected since insects generally are scarce at that time of year. Horned larks seem to switch from grass seeds in October to forb seeds in November. This, perhaps, reflects the fact that the majority of grasses on the ALE shrub-steppe are cold season species whose seeds germinate in the fall and, hence, become unavailable to birds later in the winter. Most of the forbs, especially those of the tumbleweeds (Salsola kali) which form the greater proportion of the forb seed diet of birds, do not germinate until early spring. The lack of available food in the November samples suggests that it may be a limiting resource.

TABLE IV-1. Plant Fragment Relative Frequency (%) Contained in Jackrabbit Fecal Pellets (Uresk et al., 1975)

Plant Taxa	B-C Cribs %	Wye-Barricade %	Average %
Grasses			
Stipa comata	14	13	13
Poa sandbergii	<1	8	4
Total	14	21	17
Forbs			
Achillea millifolium	27	22	25
Cymopterus terebinthinus	16	18	17
Aster sp.	14	17	15
Sisymbrium altissimum	13	7	10
Cryptantha circumscissa	4	2	3
Psoralea lanceolata	<1	4	2
Balsamorhiza careyana	-	<1	<1
Cryptantha pterocarya	-	<1	<1
Draba verna	<1	-	<1
Total	74	70	72
Shrubs			
Artemisia tridentata	4	-	2
Chrysothamnus nauseosus	5	9	7
Total	9	9	9
Unknowns	<1	<1	<1

FOOD WEB DEVELOPMENT

Consumers inhabiting the 200 Area plateau are exposed to a wide variety of food sources. Through a process of food selection, some sources are heavily utilized while others are not. This is true for both herbivores (plant eaters) and carnivores (meat eaters). The development of these feeding preferences results in formation of food chains originating from some plant species and leading through higher order consumers, terminating with the top consumers. The interaction of food chains results in a complex food web depicting predator and prey.

Concern for the well-being of both human and animal populations requires detailed knowledge concerning the environmental availability of hazardous materials, such as radioactive wastes and how these materials might be distributed through food webs associated with the 200 Area plateau.

A preliminary food web, based on cheatgrass, showing the expected flow of material through consumer populations inhabiting the 200 Area plateau is shown in Figure IV-2. Similar food webs could be constructed for other important producer species.

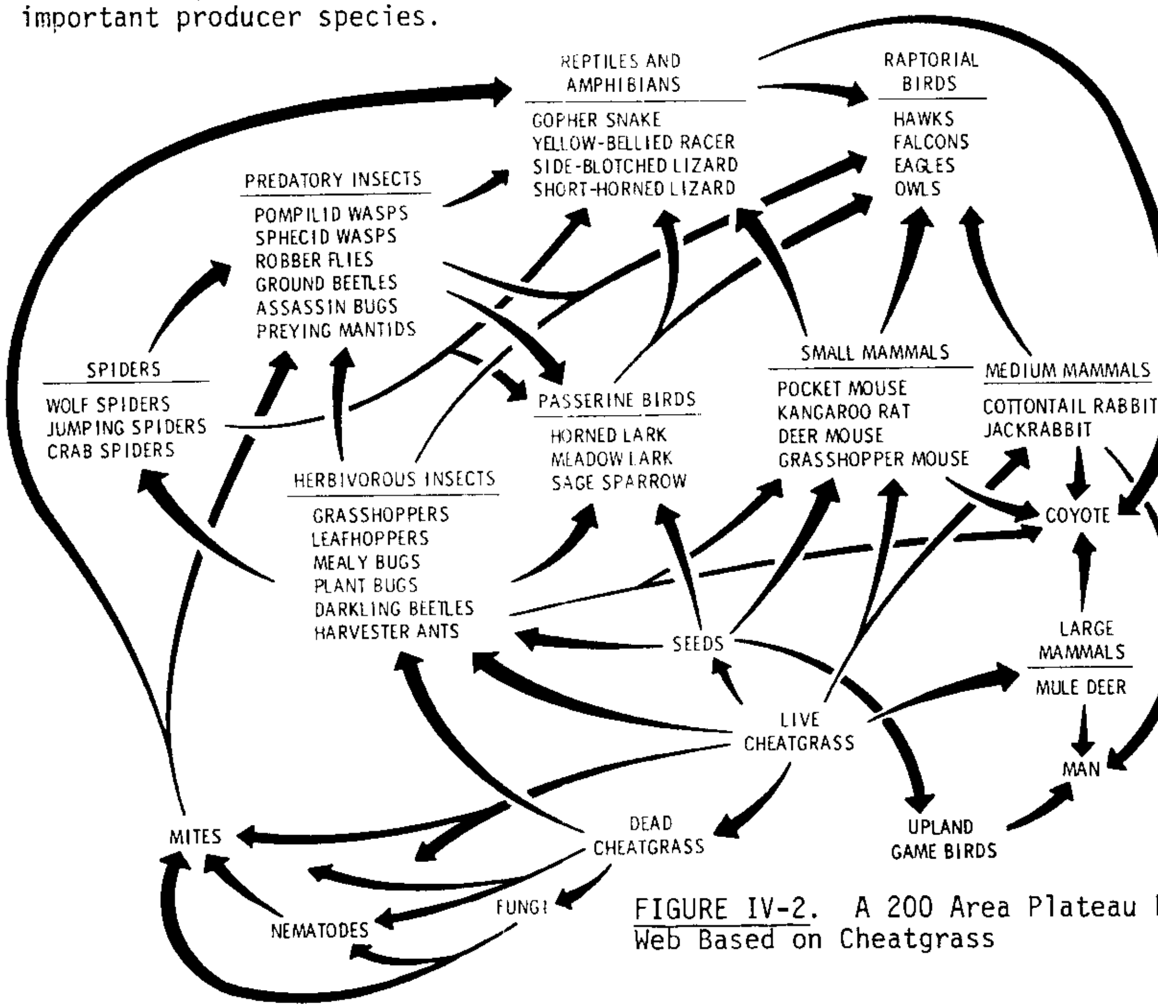

FIGURE IV-2. A 200 Area Plateau Food Web Based on Cheatgrass

Important primary consumers include birds, insects, and medium- and large-sized mammals, in addition to the small mammals present. The small mammals which function as primary consumers include the deer mouse, pocket mouse, and ground squirrel. The grasshopper mouse is primarily carnivorous, feeding on insects and other small animals and is, therefore, a secondary consumer. All small mammals are preyed on by higher-level consumers, such as raptorial birds, snakes, and coyotes. These larger consumers are, for the most part, more mobile than the smaller mammals. Coyotes are known to range over territories exceeding 130 km^2. The Swainson's hawk is known to migrate as far away as Argentina. These top-level consumers provide a pathway for transport of material great distances from the biotic community under study on the 200 Area plateau.

Detailed knowledge concerning transfer rates of material through these pathways must await completion of current and planned studies concerning uptake, assimilation, and transfer of materials between ecosystem components. Integration of these studies will permit construction of an ecosystem model to predict ecosystem behavior in response to perturbations associated with waste management operations.

FOOD CHAINS TO MAN

A major impetus for understanding food chain transfer patterns within the 200 Area plateau ecosystem involves the potential for transfer of radionuclides along these pathways. Such transfers would result in creating body burdens of radioactive substances for the native biota involved in such transfers, which ultimately could lead to man. Several factors severely minimize the potential risk of such inadvertent transfers:

1) The aridity of the region naturally results in a low biological productivity. As a result, there are relatively few native organisms normally consumed by mankind.

2) Irrigated crop lands and domestic livestock are absent from waste management environs--a major pathway to man.

3) The substantial protected areas surrounding the waste management facilities serve to minimize the possibility for transport of hazardous materials off the Hanford Reservation.

4) Native organisms known to possibly represent a pathway to man are routinely sampled for radionuclide analyses as part of the radiological monitoring program.

Recognizing the potential for food chain transfers of waste radionuclides to man to be minimal does not, however, remove the necessity of documenting ecological transfers within the 200 Area ecosystem. The public and scientific communities will probably continue to demand that any statements concerning hazards to man from Hanford waste management operations be based on as detailed and scientifically acceptable basis as existing state-of-the-art permits.

Biota possessing the greatest potential for introducing radionuclides from the 200 Area waste management areas into food chains leading to man include:

- mule deer
- cottontail rabbits
- hares (jackrabbits)
- waterfowl
- honeybees (honey)
- upland game birds

Mule deer have been observed foraging near B-C Cribs and Redox waste management areas and along the edge of waste ponds. They presumably use the ponds both as watering and foraging sources and, therefore, have the opportunity to accumulate waste radionuclides in their flesh. They have been documented as moving off the Hanford Reservation where they may be killed and eaten by hunters (Hedlund, 1975).

Black-tailed hares have been implicated as a dispersal agent for radionuclides away from a burial site on the 200 Area plateau (O'Farrell et al., 1975). The maximum dispersal appeared to be 1.6 km as evidenced by fecal pellet distribution, but, of course, no one knows how far the hares may have traveled or the risk they represented in terms of total body burden. Black-tailed hares are occasionally consumed by man but are not a dietary staple, further minimizing any risk. Cottontails represent a similar pathway although they are more frequently consumed than Black-tailed hares. Black-tailed hares are generally taken for sport while cottontails are taken for food.

Waterfowl will represent a major pathway to man as long as contaminated ponds and ditches remain part of the waste management system. Some consume microscopic organisms while others take larger organisms, such as goldfish. In addition, certain individuals may be residents while others may remain on a pond only a few days, feeding and resting; still others may rest without feeding and continue along migratory routes without ingesting contaminated materials. This lack of uniformity in nature makes the ecological monitoring process a risk. Most organisms may be "clean" while a few may build up substantial body burdens of waste radioactive materials.

Honeybees have been known to forage as far as 5 miles although 2 miles is generally recognized as the practical limit to foraging distance. These estimates, however, were made in areas with abundant nectar reserves. No one knows how far honeybees may fly to reach a source of nectar or water in this arid environment. Honeybees do forage around the waste ponds and probably use them as a water source and providing they nest within the confines of the Hanford Reservation pose little threat to the public.

Upland game birds are not abundant on the 200 Area plateau. Pheasants, chuckar and quail are probably the only ones present, although Hungarian partridge occur on the nearby ALE Reserve.

The aridity of the region has resulted in development of a relatively simple ecosystem--simple as compared to other systems (tropical forest etc.) but it is still extremely complex. Radiation monitoring techniques will probably need to be continuously updated as new pathways are discovered and a clearer understanding of ecosystem functioning unfolds.

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CHAPTER V. RADIONUCLIDE TRANSPORT

D. A. Cataldo, D. Paine, C. E. Cushing,
R. M. Emery and B. E. Vaughan

The availability of radionuclides to biota is discussed especially with reference to specific elements in local soils. Two annual plant species have received concentrated study. These are cheatgrass and tumbleweed—both important inhabitants of waste burial sites. Little is known concerning the radionuclide dynamics of perennial grasses, forbs or shrub species. The potential for radionuclide transport by jackrabbits, waterfowl, small mammals and biota inhabiting pond systems is discussed. Concentration ratios are tabulated.

An ecosystems approach to waste management problems at Hanford has provided a basis for understanding the overall environmental impact associated with the long-term operation of a nuclear facility. The history of "radionuclide movement" dates back to the early 1940's. Initially, emphasis was placed on containment of wastes generated as a result of the processing of nuclear material, with the major consideration being to reduce the potential hazard of these materials to nuclear workers and the general population. With the advent of atmospheric nuclear weapons testing, interests were shifted to the fate and effects of fallout. It is this latter work which set the stage for current, broadly based ecological studies which were initiated in the 1960's and greatly expanded in the present decade. Current studies are concerned with site specific problems relating to waste management. In the area of radionuclide availability and transport, soil-plant studies have concentrated on the behavior of specific elements in local soil types and their uptake by two annual plant species indigenous to the Hanford Reservation, namely tumbleweed and cheatgrass. The literature on environmental behavior of radioactive contaminants has been critically reviewed recently (Vaughan et al., 1976), especially with regard to elements considered important in connection with fuel reprocessing, particle size, and chemical form.

MINERAL UPTAKE AND CYCLING

The need to understand the cycling of materials within an ecosystem has been given special emphasis in recent years. Effluent substances, such as heavy metals or radioisotope pollutants, can accumulate or become concentrated in the environment and pose health hazards. Additionally, their availability to biota apparently vary considerably from a regional standpoint. Cycling of man-made and natural elements in terrestrial, freshwater and marine environments inherently involves modeling concepts based on mechanistic processes. Complete studies of elemental cycling frequently attempt to quantify transfer of elements among all ecosystem compartments, however comprehensive studies of this nature are rare. Therefore, the literature primarily encompasses elemental concentration comparisons within ecosystem compartments.

Therefore, it seems reasonable to assume that important considerations in mineral uptake and cycling should focus on verification of techniques, documentation of data with statistically determined confidence intervals, interpretation of results and synthesis leading to comprehensive predictable cycling models. Distribution and fate or behavior of radionuclides and heavy metals have been the most extensively studied aspects of mineral cycling within the Hanford ecology programs.

In order to develop waste management models for transport of radioactive materials, it is important to identify those parameters within a particular ecosystem which are the driving variables in uptake and mineral cycling. The basic transport pathways essential to most food chain transfer evaluations concern the plant-soil relationships. For this discussion of the relative importance of understanding mineral uptake and cycling as related to waste management, examples will be limited to the soil-forage-livestock-man food chain cycle.

Cline and Rickard, 1973, explored two factors which could be limiting to vegetation growth, namely, soil moisture and assimilated nitrogen. Soil water, herbage assimilated nitrogen, and herbage biomass were measured in the field and used to estimate the effectiveness of nitrogen fertilization to increase cheatgrass community yields. They estimated fertilizer requirements needed to increase herbage production in relationship to available soil moisture. When herbage nitrogen was added in the range of 0.5 to 0.7% at the end of the spring growing season, nitrogen rather than soil water appears to limit herbage production. Year-to-year variation at the highest altitude investigated was less pronounced than that at the two lower elevations and was thought to be attributed to a more stable soil moisture supply.

Another example of a mineral cycling study employed controlled climate chambers and a non-stressed soil moisture regime to determine influence of soil excavated from beneath and between halophytes upon the growth of cheatgrass (Rickard, et al., 1973). Differential accumulation of mineral nutrients beneath and between halophytes is well documented. This type of information is extremely useful in the spatial heterogenity which exists for radionuclides in waste management areas. A considerable portion of the total variability observed under field conditions can be explained if differential accumulation is occurring for the radionuclide of concern.

Mineral composition of three perennial grasses in a shrub-steppe community in south-central Washington was investigated by Uresk and Cline (1976). The purpose of their study was to determine if perturbations due to cattle grazing would change the mineral composition of important forage plants. Cusicks bluegrass, Thurber needlegrass, and bluebunch wheatgrass tissues, live and standing dead, were chemically analyzed in pastures with and without a history of cattle grazing. Two years of spring grazing by cattle did not affect the mineral composition of these grasses. Live herbage was generally richer in minerals than standing dead herbage, but ash content of standing dead tissues was always higher.

These results can be extrapolated to radioisotope considerations. Obviously, isotopes of metabolic utility would be expected to be more persistent and, thus, of more concern during the growing season and less important upon senescence. However, more structurally important radionuclides would continue to be of concern from a vegetative standpoint even after senescence had occurred. This type of information can be extremely important where vegetational controls are employed for waste management areas.

A more involved mineral cycling study considered mineral relations and livestock forage (Uresk and Rickard, 1976). This study provided quantitative information concerning nutrition, diets, consumption rates, and selectivity of forage plants and cattle production which is essential for long-term management of arid and semi-arid rangeland resources so that plant growth, vigor, and reproduction by the most palatable and productive plants can be maintained or improved. In addition, the study provided valuable modeling information on basic ecological parameters needed in transport evaluation and resulting dose-commitments to man. A similarly designed study investigated the radioiodine transport through the soil-forage-livestock food chain. Results of this study are still pending radiochemical analysis. This does, however, point to how basic mineral cycling phenomena can be utilized to explore specific radionuclide pathways.

RADIONUCLIDE TRANSPORT BY PLANTS

The potential for transfer of radionuclides from soils to plants is mediated by both abiotic and biotic factors. Abiotic parameters which influence plant uptake include physiochemical characteristics of soils (pH, cation exchange capacity, mineralogy, organic matter content, and concentration of stable analogs) and the presence of complexing agents resulting from waste processing. In addition, environmental conditions such as temperature and precipitation not only affect soil processes but have a direct effect on the growth and, therefore, the nutrient demand of plants. Biotic factors which have an ultimate effect on ion transfer include soil microbial transformations, especially in the case of relatively insoluble elements, and metabolic aspects of the plant uptake process and the relationship of mineral demand to root and shoot growth which has a subsequent effect on plant uptake.

Studies over the past 5 years have been concerned with developing an understanding of the potential for transfer of nuclear wastes from ground disposal sites to aboveground plant parts. These studies employed local soils and two plant species--cheatgrass and tumbleweed. They have provided information as to the relative bioavailability of fission products (Sr, Cs and Tc) and transuranics (Pu, Am, Np, and Cm) for a narrow range of soil types and plant species.

Transuranic Elements

Transuranic elements present a special problem in waste management due to their potential health hazard at low concentrations and relatively long half-lives. Although transuranics are not routinely stored in open ditches and ponds, they can present a problem when accidently released to the environment. Price (1972) investigated the relative availability of ^{239}Pu, ^{237}Np, ^{241}Am and ^{244}Cm. Acidic nitrate solutions were amended to a Burbank loamy sand, common to the 200 Areas, using a layering technique and concentration ratios (CR) determined for cheatgrass and tumbleweed after 2 months of growth. CR values obtained are reported in Table V-1 (column A). The relative order of uptake by both tumbleweed and cheatgrass was $^{237}Np > ^{244}Cm > ^{241}Am > ^{239}Pu$. Total accumulation by tumbleweed was 2.1, 0.047, 0.032 and 0.00093% for ^{237}Np, ^{244}Cm, ^{241}Am and ^{239}Pu, respectively. Cheatgrass was slightly less efficient in uptake of these radionuclides with 0.012, 0.0057, 0.0072 and 0.00019% of the supplied ^{237}Np, ^{244}Cm, ^{241}Am and ^{239}Pu, respectively, being accumulated.

The processing of nuclear materials and resultant separation procedures generate varying quantities of organic wastes which are potentially present in radioactive wastes. Price (1973) investigated the effect of various organic acids on the availability of transuranics for uptake by tumbleweed and cheatgrass (Table V-1, columns B-E). Concentration factors for plant shoot uptake of transuranics added to soil in combination with the organic acids are compared with uptake from nitrate forms. Plant uptake of the transuranics added to the soil with organic acids was in the same order as uptake from nitrate, i.e., Np > Cm $\sim$ Am > Pu. Differences in uptake between the species used as

TABLE V-1. Concentration Ratios[(a)] for Tumbleweed and Cheatgrass Shoot Uptake. Transuranics were added to soil in dilute nitric acid or in the presence of the organic acids inidicated.

	A	B	C	D	E
	Nitrate[(b)]	Acetate[(c)]	Glycolate[(c)]	Oxalate[(c)]	Citrate[(c)]
Tumbleweed					
^{237}Np	11 E-02 ± 2[(d)]	24 E-02 ± 5	23 E-02 ± 7	28 E-02 ± 5	28 E-02 ± 2
^{239}Pu	46 E-06 ± 7	48 E-06 ± 4	254 E-06 ± 60	273 E-02 ± 50	310 E-06 ± 8
^{241}Am	14 E-04 ± 2	17 E-04 ± 3	21 E-04 ± 4	15 E-04 ± 3	15 E-04 ± 2
^{244}Cm	22 E-04 ± 3	12 E-04 ± 1	42 E-04 ± 1	42 E-04 ± 7	14 E-04 ± 2
Cheatgrass					
^{237}Np	12 E-03 ± 1	15 E-03 ± 3	13 E-03 ± 2	7 E-03 ± 1	11 E-03 ± 2
^{239}Pu	17 E-06 ± 2	14 E-06 ± 3	43 E-06 ± 4	53 E-06 ± 5	51 E-06 ± 2
^{241}Am	60 E-05 ± 10	23 E-05 ± 2	8 E-05 ± 1	6 E-05 ± 1	10 E-05 ± 2
^{244}Cm	48 E-05 ± 5	33 E-05 ± 3	19 E-05 ± 2	8 E-05 ± 1	16 E-05 ± 1

(a) Concentration ratio = $\frac{\text{pCi/g plant}}{\text{pCi/g soil}}$

(b) Results reported in BNWL-1688
(c) Results reported in BNWL-1755
(d) 11 E-02 ± equals 11×10^{-2} (S.E. mean)

test plants frequently amounted to more than 10-fold. When added to soil in the presence of organic acids, plant uptake of Np and Pu was generally increased compared to uptake from nitrate forms. Americium and Cm uptake, however, was decreased. It is unclear whether soil, plant mechanisms, or actinide chemistry itself plays a critical role in the availability pattern, since pH of the soils after addition of the stock solution ranged from 6.5 to 9.1.

Studies on the effect of chemical form were extended to include the effect of EDTA and DTPA (Price, 1974) on transuranic uptake by tumbleweed and cheatgrass. EDTA increased Pu percent uptake compared to uptake from dilute nitrate solutions in both tumbleweed and cheatgrass, while Am and Cm uptake was only slightly affected by EDTA in either plant species, whereas, Np uptake was reduced in tumbleweed but remained constant in cheatgrass. The influence of DTPA on plant uptake was dramatic. Plutonium percent uptake was increased by more than 800-fold relative to the nitrate form. Americium and Cm uptake was increased by about 100-fold. Neptunium uptake again was reduced relative to nitrate in tumbleweed but less than with EDTA and slightly reduced relative to the nitrate in cheatgrass. The concentration factors for the Pu-DTPA treatments are 0.143 for tumbleweed and 0.031 for cheatgrass, using only the concentration in the contaminated soil layer. DTPA treatment results in a change in the order of plant uptake from Am $\simeq$ Cm $>$ Pu $>$ Np. Neptunium chelation with EDTA or DTPA is known to require a reduction in oxidation number, however the variation in the behavior of the two plant species would indicate some other controlling mechanisms.

In addition to the effect of chemical form on the uptake of transuranics by plants from soils, several preliminary studies were undertaken to elucidate the behavior of transuranics within plant structures (Price, 1974). These included: 1) the distribution of Pu, Np, Am and Cm between roots and shoots; 2) the influence of waste burial depth on plant uptake and redistribution within the soil; and 3) the relationship between plant age and uptake of transuranic elements from soil.

From these studies it is apparent that the chemical form of waste radionuclides stored in the environment can influence their behavior in soil-plant systems. Complexing or chelating agents present in environmental waste storage sites can be expected to enhance plant uptake of actinides. Moreover, transuranium elements appear to be unevenly distributed within the plant body in space or time, and downward translocation in root systems favored over upward movement.

Fission Products

The fate and biological transport of long-lived fission products, namely Cs and Sr, have received much attention. From a waste management standpoint they represent a major concern with respect to long-term storage and their availability for uptake by deep-rooted plants growing over waste burial sites. In addition, studies have been initiated on ^{99}Tc, a long-lived, high yield fission product, which has been shown to pose special waste management problems due to its high plant availability and low retention in soil.

The large data base for both Cs and Sr, has led to an in-depth understanding (rarely attained for non-nutrient elements) of the soil, plant and environmental factors which influence their transport in the ecosystem. However, little information is available on the effect of soil concentrations of Cs and Sr on plant uptake, especially at background concentrations. Routson (1975) studied the uptake of Cs and Sr at soil concentrations ranging from 4.5×10^{-4} to 1.6 and 6.5×10^{-6} to 1.2 µg/g soil, respectively. CR values were determined for tumbleweed at 4,8 and 12 weeks (Table V-2). For a given plant age, CR values are constant and independent of the soil concentration of Sr and Cs over more than five and three orders of magnitude, respectively. CR values for Sr were 10.1, 9.6 and 19 for 4, 8 and 12 week old plants, respectively; while those for Cs were 0.025, 0.033 and 0.053, respectively. This would suggest that the CR values obtained for a given age of plant can be extended to even lower soil concentration. Although Cr values for Cs and Sr are constant over a broad range of concentration, this will not be the case for the actinides since soil solution does not contain any significant concentration of potential analog elements for the actinides.

TABLE V-2. Plant Uptake of Sr and Cs by Tumbleweed as a Function of the Soil Concentration

Sr Soil Concentration --------µg/g-------	CR[a] 4 Weeks	CR[a] 8 Weeks	CR[a] 12 Weeks
6.5×10^{-6}	12.3 ± 0.35[b]	11.0 ± 1.8	20 ± 5.1
1.2×10^{-4}	10.0 ± 1.2	9.0 ± 1.2	19 ± 4.5
0.012	10.8 ± 0.88	10.0 ± 2.1	17 ± 1.7
1.2	10.1 ± 0.61	8.7 ± 2.0	19 ± 2.4
Average	10.8 ± 0.83	9.6 ± 0.36	19 ± 1.5
Equivalent Cs-137 Soil Concentration --------µg/g-------			
4.5×10^{-4}	0.022 ± 0.003	0.031 ± 0.008	0.051[c]
0.016	0.026 ± 0.002	0.031 ± 0.008	0.061 ± 0.008
0.16	0.025 ± 0.002	0.032 ± 0.005	0.054 ± 0.003
1.6	0.026 ± 0.002	0.039 ± 0.008	0.047 ± 0.014
Average	0.025 ± 0.002	0.033 ± 0.007	0.053 ± 0.008

(a) CR = µg/g in the shoot divided by µg/g in the soil.
(b) ± standard deviation
(c) Based on 1 value due to breakage in the experiment.
(d) Wilcoxon's Sign Rank Test shows these sets to increase significantly with age.

The change in CR values for Sr and Cs with harvest time indicates an influence of plant age on accumulation processes in tumbleweed. Analysis of shoot dry wt gain, shoot content and shoot concentrations of radiocesium and strontium for the three sampling periods shows an interesting trend. Shoot dry weight gain increases sharply between 4 and 8 weeks with a reduction in growth rate between 8 and 12 weeks. During this same period (4-12 weeks), shoot content of both radiocesium and strontium is increasing linearly. It is this imbalance in ratios of Cs and Sr uptake and shoot dry matter production which result in the observed changes in CR values with plant age.

Recent studies of Wildung et al. (1974a) indicated that technetium supplied as pertechnetate was efficiently accumulated by plants, with CR values as high as 1000 being reported. This, coupled with low soil retention rates for pertechnetate (Wildung et al., 1974b), prompted studies on uptake of $^{99}TcO_4^-$ by typical plant species using representative soils from the Hanford Reservation (Routson and Cataldo, 1977).

Table V-3 gives the shoot concentration of ^{99}Tc and concentration ratios calculated for tumbleweed grown on five Hanford soils for 1, 2, and 3 months. The order of uptake based upon percent uptake from soils was Lickskillet < Burbank < Rupert $\leq$ Warden < Ritzville and ranged from 23-82% at the 3 months' harvest time. A large portion of the total uptake occurred in the 1st ($\sim$ 75%) and 2nd ($\sim$ 95%) months. Tumbleweed shoot concentration for these soils ranged from 0.065-0.33 ng/g and generally decreased from 1 month to the two 3 three month harvest times. This concentration decrease with increasing growth time is the reverse of that found for Sr and Cs (Routson, 1975). In the case of Sr and Cs, the percentage of uptake from the soil is small and the pool of these elements (or analogs) in the soil remains constant, never limiting uptake. In the case of Tc, uptake from the soil is large, reducing the soil pool which limits subsequent plant uptake.

TABLE V-3. Plant Uptake of ^{99}Tc by Tumbleweed Shoots from Five Hanford Soils Traced by 2.2 x 10^{-4} μCi/g of ^{95m}Tc/gm Soil at 1, 2, and 3 Months' Harvest Times

Soil	Uptake in Shoots, Month			Shoot Concentration, Month			Concentration Ratio[a], Month		
	One	Two	Three	One	Two	Three	One	Two	Three
	%			ng/g					
Rupert	32	48	45	0.33 ± 0.02[b]	0.22 ± 0.01	0.10 ± 0.001	357	342	315
Burbank	23	28	34	0.29 ± 0.01	0.19 ± 0.008	0.16 ± 0.005	225	232	213
Ritzville	73	81	82	0.22 ± 0.01	0.093 ± 0.005	0.078 ± 0.004	314	368	390
Warden	29	44	46	0.17 ± 0.01	0.11 ± 0.004	0.10 ± 0.004	183	155	169
Lickskillet	18	23	23	0.13 ± 0.01	0.087 ± 0.004	0.065 ± 0.003	127	99	76

(a) CR = ng/g in the shoot divided by ng/g in the soil.

(b) ± Standard deviation.

CR values for tumbleweed, grown on Hanford soils, range from 76-390. Except for the Lickskillet soil, the CR values for all soils at the three harvest times are reasonably constant. This suggests that the reduction in plant Tc concentration observed during the latter 2 months resulted from a marked reduction of soil Tc following the rapid uptake of Tc during the 1st month. The lower CR values found with the Lickskillet soil during the latter 2 months may have resulted from a change in Tc form and may be related to relatively high organic matter content of Lickskillet compared to the other soils studied. In fact, Wildung et al. (1974b) demonstrated that pertechnetate sorption by soils, representing a broad range in properties, was a function of soil organic matter content and pH. Reduction of Tc to the IV valence state and precipitation as TcO_2 or TcS_2 by organic matter or microbial processes is one possible mechanism which may explain the reduced availability of Tc in both the Lickskillet and other high organic matter soils. Other factors which could affect the availability of Tc include complexation and assimilation into microbial tissues. These factors would also be expected to have the greatest effect in high organic matter soils.

Table V-4 gives the plant uptake of ^{99}Tc by cheatgrass at 1, 2, and 3 months' harvest times. The relative soil order of Tc uptake based upon percent uptake by soils was Burbank < Lickskillet < Rupert < Warden < Ritzville and ranged from 10-60% at the 3 months' harvest time. Cheatgrass shoot concentration ranged from 0.045-0.37 ng/g. The decrease in shoot concentration seen with tumbleweed was not as consistent in cheatgrass. There is a decrease in shoot concentration, with time, for plants grown on Ritzville, Warden and Lickskillet, while Burbank and Rupert exhibit some variation in this trend. Although the CR values are ultimately constant with time of harvest for all soils except Lickskillet, there is some variability in the data which results from the variability in shoot concentration.

TABLE V-4. Plant Uptake of ^{99}Tc by Cheatgrass Shoots from Five Hanford Project Soils Traced by 2.2×10^{-4} μCi ^{95m}Tc/gm Soil at 1, 2, and 3 Months' Harvest Times

Soil	Uptake in Shoots, Month: One	Two	Three	Shoot Concentration, Month: One	Two	Three	Concentration Ratio[a], Month: One	Two	Three
	%	%	%	ng/g	ng/g	ng/g			
Rupert	19	26	28	0.32 ± 0.009[b]	0.36 ± 0.03	0.29 ± 0.02	357	421	357
Burbank	6	8	10	0.12 ± 0.01	0.11 ± 0.003	0.11 ± 0.006	112	104	112
Ritzville	76	77	69	0.17 ± 0.008	0.15 ± 0.03	0.055 ± 0.008	190	192	158
Warden	16	36	37	0.22 ± 0.02	0.14 ± 0.02	0.091 ± 0.01	220	180	130
Lickskillet	18	24	21	0.10 ± 0.004	0.10 ± 0.004	0.047 ± 0.007	103	114	54

(a) CR = ng/g in the shoot divided by ng/g in the soil

(b) ± standard deviation

Although there are no literature values available for uptake of Tc by tumbleweed and cheatgrass, data is available for several agricultural plants including soybeans, corn, radishes, oats, barley, and wheat. CR values for the above plants and a variety of soils range from 30-1,200; this is in general agreement with the values found in the present study.

LIMITATIONS TO THE CONCEPT OF CONCENTRATION RATIO (CR)

While of utility in modeling, the concept of a plant/soil CR is not without its drawbacks. It may even be inapplicable for certain radioelements like ^{99}Tc. The drawbacks result in an unreasonably wide range over which plant/soil CR's are reported to vary for a given radioelement. One major drawback arises because of failure to distinguish between operational definitions referable to a particular set of circumstances, and, definitions referable to particular plant/soil physiological processes. Other drawbacks arise because we are only beginning to understand many of the biological processes in soil systems. Some of the underlying soil chemical processes have been discussed above and in several reviews (Keeney and Wildung, 1976;) (Vaughan et al., 1975; Price, 1973; Francis, 1973). Plant and microbial processes are less well understood; e.g., foliar uptake and transport were not accurately measured in many past studies, as discussed earlier; energetic mechanisms within the plant, may lead to facilitated transport (Vaughan et al., 1975).

One field demonstration shows quantitatively the importance of the foliar pathway relative to the soil-to-root pathway (Romney et al, 1973). In this study the radioelements were probably wind-resuspended from contaminated soil; forage plants were new-grown in the soil with and without plastic enclosures. By comparison, it was determined that 87% of the ^{90}Sr, 81% of the ^{137}Cs, and 73% of the ^{144}Ce in the plant came from aerial exposure. ^{90}Sr taken up by the protected plants was about 1/8th that measurable in the unprotected plants, which clearly shows that the dominant pathway was through leaf interception. Unfortunately in these, and most earlier field studies, the aerosol distribution above the site where green plants had been sampled was not characterized, and the existence of a foliar contamination route had evidently not been anticipated.

It should be clear from discussions here and above that any particular value of plant/soil CR represents an operational definition, in which a number of processes become confounded with the simple process of solubility in soil solution, from the soil particle. This fact is manifested by a wide range of CR values, to be found in the literature, for any given radioisotope. Particular caution should be exercised in applying a set of plant/soil CR's derived from one set of exposure circumstances, e.g., old contaminated soil, to a new set of circumstances, e.g., contaminated soil including recent airborne sources (Vaughan et al., 1976). In fact, any time that a measured plant/ soil CR value, for a particular species and soil type, exceeds by 10-fold that of a laboratory determination validated on the same soil/plant system, the possibilities must be carefully considered of airborne contamination, ligand formation, or other unusual conditions.

Transport Models for Plant-Soil System

Current studies are concerned with developing a predictive capability to permit evaluation of the transport behavior of a given radionuclide based on soil properties. Investigations were undertaken using five Hanford area soils (Ritzville, Lickskillet, Burbank, Warden and Rupert), amended with ^{134}Cs and ^{85}Sr, and planted wth tumbleweed and cheatgrass. CR values obtained from plants grown on these five soils are shown in Table V-5. CR values for cheatgrass ranged from 0.0154 to 0.0641 and 3.54 to 12.3 for ^{134}Cs and ^{85}Sr. Data obtained for tumbleweed exhibited similar ranges with CR values for ^{134}Cs and ^{85}Sr ranging from 0.0078 to 0.0662 and 4.44 to 16.0, respectively. CR values obtained for these plants are being compared with physical and chemical properties of the individual soils. These include organic matter content, particle size distribution, mineralogical properties and pH. In addition, nonradioactive elemental analysis of chemical analogs (Rb, K, Ba, Mg, Cs and Sr) is being performed on both plant tissues and soils, along with extractable (soluble) radioactive and nonradioactive Cs and Sr in the five soils. Extractants currently employed include 0.2M ammonium oxalate, 0.01M $CaCl_2$ 1M ammonium acetate, and H_2O. These various parameters for each soil are being tabulated and statistical correlations performed to determine those soil factors which influence the bioavailability of Sr and Cs.

TABLE V-5. Plant Uptake Data for ^{85}Sr and ^{134}Cs Amended to Five Hanford Area Soils[a]

	Cheatgrass		Tumbleweed	
	^{134}Cs	^{85}Sr	^{134}Cs	^{85}Sr
	CR[a,b]			
Lickskillet	0.015 ± 0.002[c]	3.5 ± 0.2[c]	0.0078 ± 0.0033[c]	4.4 ± 0.6[c]
Ritzville	0.031 ± 0.004	7.4 ± 0.4	0.066 ± 0.021[b]	6.1 ± 0.2[c]
Warden	0.018 ± 0.002	5.8 ± 0.5	0.027 ± 0.007	10 ± 0.2[b]
Burbank	0.059 ± 0.004	12 ± 0.2	0.024 ± 0.003	8.7 ± 0.4
Rupert	0.064 ± 0.002	12 ± 0.6	0.014 ± 0.001	16 ± 0.3

(a) Soil amendment levels were 3.11 to 6.30 nCi/gm and 0.165 to 4.03 nCi/gm for ^{134}Cs and ^{85}Sr, respectively.
(b) Concentration ratio = nCi/gm dry wt shoot/ nCi/gm dry wt soil.
(c) Each value represents $\bar{x} \pm$ SD for 4 replicate samples, except as noted in brackets ( ).

RADIONUCLIDE TRANSPORT BY ANIMALS

Jackrabbits

The only documented dispersal of radioactive materials away from a 200 Area plateau burial site occurred as a result of jackrabbits dispersing radioactive wastes in their fecal pellets (O'Farrell et al., 1973). Native burrowing animals burrowed into one of the backfilled trenches exposing the contaminated salt cake. Native wildlife were probably attracted to the area since salt licks are rare. The burrow was sealed with asphalt in 1964, but an unknown quantity of radioactivity had been dispersed. Radioactively contaminated feces and urine were distributed in all directions from the cribs, but the area to the south and southwest was more densely and uniformly contaminated. Most droppings with count rates above 20,000 cpm were found within 400 meters of the crib, but some with counts in excess of 100,000 cpm occurred up to 1.6 km from the cribs. The pellets appeared to be distributed into the prevailing wind directions and contrary to immediate contours. The only correlation seemed to be with increased vegetation density to the south and southwest, vegetation that is prime jackrabbit habitat.

Waterfowl

Coots and waterfowl utilizing waste ponds were analyzed for radioactivity (Hanson and Browning, 1959). They found total beta activity to average 0.6 microcuries in muscle (mostly ^{137}Cs) and 1.7 microcuries in bone (mostly ^{90}Sr).

Two ducks collected from a reactor effluent ditch during routine environmental monitoring operations were found to have radionuclide concentrations measuring .003 and .110 microcuries/g in the respective ducks (Wilson and Essig, 1970). These examples clearly show the potential for radionuclide transport by waterfowl populations.

A current study has shown that the coot probably possesses the greatest potential for radionuclide transport by waterfowl. They inhabit all waste ponds and because their dietary habits have the highest body burdens of any waterfowl species on the Hanford Reservation. The concentration of ^{137}Cs in the coots' breast muscle averaged over 2 years was 722 pCi/g dry weight. A similar study conducted at DOE's Savannah River Reservation showed that coots obtained increasing amounts of ^{137}Cs over time (Brisbin et al., 1973). Coots newly arrived on Parr Pond, a cooling water reservoir, averaged 4-8 pCi/g live weight (whole body count). This increased to 15-20 pCi/g at departure. They concluded that migratory birds could remove up to 3.75×10^{-5} of curies of radiocesium per year and redistribute along migratory pathways.

The ^{90}Sr content of bird bones was studied in relationship to Hanford Operations (Silker, 1958). These results are shown below and suggest a relationship between ^{90}Sr content and feeding habits. Shorebirds probe the wet mud and shallow waters around waste ponds. Puddle ducks feed on aquatic plants, insects and snails. The fish eating birds are highly mobile--probably feeding at many locations both on and off the Reservation.

Small Mammals

Small mammals such as mice serve as a food base for a variety of higher order consumers but little is known concerning the accumulation of radionuclides in their bodies. A current study analyzed small mammal tissue samples for ^{239}Pu, ^{238}Pu and ^{241}Am. Results showed the highest level detected to be 2.04 pCi/g dry of ^{239}Pu in a hide sample (Gano, personal communications). These animals resided near a waste pond.

RADIONUCLIDE TRANSPORT IN POND SYSTEMS

The distribution of transuranic elements in freshwater waste ponds were studied by Emery and Klopfer (1976). The major sink for plutonium and americium was in the sediments.

Organic floc was also a major concentrator. Aside from the seston and floc, no other ecological components of the pond appeared to have concentrations significantly greater than those of the sediment. Dragonfly larvae, watercress, and snails showed concentrations which approximated those of the sediments. Nearly all other food web components had levels of plutonium and americium lower than those of the sediments. Thus, plutonium and americium seem to be relatively immobile in the aquatic ecosystem. Concentration ratios for the pond's ecological components are shown in Table V-6.

TABLE V-6. Concentration Ratios for Waste Pond Ecological Components (Emery and Klopfer, 1976)

	^{238}Pu	$^{239,240}Pu$	^{241}Am
Sediments[a]	1×0^4	2×10^4	7×10^3
Water	1	1	1
Seston[b]	2×10^5	2×10^5	3×10^5
Floc[b]	4×10^4	4×10^4	1×10^4
Algae (filamentous)[c]	2×10^3	2×10^3	1×10^3
Algae (nonfilamentous)[c]	7×10^3	8×10^3	9×10^3
Macrophytes (submergent)[c]	5×10^3	5×10^3	3×10^3
Macrophytes (emergent)[c]	5×10^2	6×10^2	2×10^3
Noninsect Arthropods[c]	4×10^2	6×10^2	4×10^2
Insect Larvae[c]	2×10^4	2×10^4	2×10^4
Insect Adults (aquatic)[c]	3×10^2	3×10^2	3×10^2
Snails[c]	3×10^4	3×10^4	4×10^4
Goldfish[c]	6×10^2	6×10^2	7×10^2
Ducks[c]	1×10^0	2×10^0	2×10^0
Adult Insect (emergent)[c]	3×10^2	3×10^2	8×10^1

[a] Dry weight to wet weight conversion factor is 0.38.
[b] Dry weight to wet weight conversion factor is 0.22.
[c] Dry weight to wet weight conversion factor for all biota is 0.26.

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CHAPTER VI. IMPACT OF RADIOACTIVE WASTE MANAGEMENT OPERATIONS

D. Paine, L. E. Rogers and D. W. Uresk

Impact assessment of radioactive waste management operations is considered separately for nonradiological impact on biota, impact on ecosystem structure and function and radiological impact on biota. Localized effects related to facility construction and maintenance activities probably occur but the large expanse of relatively undisturbed surrounding landscape minimizes any overall effects.

The impact on existing biota inhabiting the 200 Area plateau could occur through several routes: 1) road construction and maintenance; 2) building construction; 3) release of toxic chemicals; 4) release of radioactive materials; 5) construction of waste control sites; 6) application of herbicides or pesticides; 7) man-originated fires; 8) vehicular traffic--noise, dust, etc., or 9) introduction of riparian areas (ponds and ditches) to a semi-arid environment. All except number 4 pertain to nonradiological impact on biota.

NONRADIOLOGICAL IMPACT ON BIOTA

An assessment of nonradiological impact on 200 Area plateau biota presupposes knowledge concerning the status of biotic components prior to establishment of waste management operations on the 200 Area plateau, but little information exists concerning the ecological condition of this area prior to the establishment of Hanford.

Originally, the 200 Area plateau was probably comprised of a sagebrush/bluegrass community. Introduction of cattle and sheep undoubtedly tended to break up surface soils accelerating wind erosion processes. The practice of using much of the Hanford area for winter holding areas for sheep with subsequent movement to nearby mountain pastures during spring and summer months may have influenced the environmental status of the area.

The disturbance of the soil also permitted the ready introduction of cheatgrass during the latter part of the 19th century. The plant community is now comprised of a combination of native and introduced species. Much of the 570 square mile Hanford Reservation has never been committed to Hanford operations. This provides a comparison between areas within the confines of the 200 Area plateau used for waste management operation with nearby areas relatively undisturbed since establishment of the Hanford Reservation.

Nonradiological Impact On Vegetation

The 200 Area sites were originally farmland and undisturbed pristine plant communities. During the time of farming much of the native vegetation was eliminated. The influence of livestock grazing upon the vegetation of the 200 Area plateau is mostly conjecture (Daubenmire, 1970). A commonly held belief is that perennial bunchgrasses were once common on the plateau but overgrazing diminished these grasses. It seems probable that bunchgrasses did not occupy this area in significant amounts due to the low amount of precipitation. Cline et al., 1975 revealed that perennial grasses are only a minor constituent of the vegetation after 30 years of protection from grazing. In areas of high precipitation bunchgrasses are common.

The major impact on the vegetation within waste management areas is associated with construction activities; e.g. roads, and disposal sites. This is a permanent loss to the existing flora and fauna but represents such a small part of the total land area that overall effects are minimal. Some revegetation practices have been conducted on the disturbed waste management areas, but with limited success. Natural succession has provided for most of the vegetation currently in place on disposal areas.

A description of the biological environment of disposal sites is being conducted to provide a basis for determining the effects of any action on the biological system. Measurements (frequency of occurrence) were collected in a near pristine sagebrush/sandberg bluegrass-cheatgrass community which is probably representative of the area prior to construction activities. Frequency of occurrence is a measure of the chance of finding a species with one throw of a quadrat (metal frame plot) in a given area. Thus, if a species has a frequency of 10%, then it should occur once in every 10 quadrats examined. Average frequency of occurrence values were calculated from data collected by Cline et al., 1975 on the 200 Area plateau from the pristine sagebrush/sandberg bluegrass-cheatgrass community (Table VI-1). The bitterbrush community on the 200 Area plateau has been described by Uresk et al., 1975. In addition, frequency of occurrence values were averaged over eleven disposal sites in the 200 Areas (Uresk, in preparation). These data were subjected to a Chi square analysis to determine the relationship of plants and sites.

The values presented in Table VI-1 (PI) are probability values expressing the chance (%) that an impact will occur. For biological impacts a value of 80% or above indicates that an impact either positive (+) or negative (-) has occurred.

Positive impacts are identified where plants have increased in frequency of occurrence on the disturbed areas as compared to more pristine study areas. A negative response is defined as a decrease in frequency of occurrence.

Six plants occupying the disturbed sites showed statistically significant increases. These included:

TABLE VI-1. Biologial Impacts on the Vegetation in the 200 Area Waste Burial Sites when Compared to a Pristine Sagebrush/Sandberg-cheatgrass Community

Scientific Name	Frequency of Occurrence (%) C[a]	I[b]	PI (%)[c]	Response of Impact (+-)	SI (%)[d]
GRASSES					
Bromus tectorum	94.5	91.0	66	-	98
Festuca octoflora	66.5	5.6	100	-	16
Poa sandbergii	12.2	4.7	94	-	56
Stipa comata	5.2	0.0	98	-	0
Poa canbyi	0.6	0.0	56	-	0
Agropyron dasytachyum	2.5	0.0	78	-	0
Sitanion hystrix	0.1	0.0	24	-	0
Oryzopsis hymenoides	0.0	2.5	89	+	0
FORBS					
Descurainia pinnata	66.7	20.5	99	-	47
Cryptantha circumscissa	52.7	6.0	100	-	20
Brodiaea douglasii	0.8	0.0	62	-	0
Eriogonum sp.	1.5	0.7	41	-	64
Comandra sp.	0.3	0.0	42	-	0
Oenothera pallida	0.7	1.1	24	+	78
Balsamorhiza careyana	0.4	0.0	47	-	0
Phacelia linearis	3.3	0.0	93	-	0
Amsinckia sp.	0.5	0.1	39	-	33
Aster sp.	6.6	0.0	99	-	0
Erodium cicutarium	1.4	0.0	76	-	0
Microsteris gracilis	33.4	0.0	99	-	0
Cryptantha pterocarya	11.9	0.6	99	-	10
Salsola kali	6.3	62.6	99	+	18
Cymopterus terebenthinus	3.6	0.0	94	-	0
Sisymbrium altissimum	11.5	6.0	83	-	69
Aster canescens	0.4	2.6	80	+	27
Calochortus macrocarpus	0.5	0.0	52	-	0
Astragalus sp.	1.5	0.0	78	-	0
Lupinus sp.	1.1	0.0	24	-	0
Lactuca serriola	0.0	1.9	83	+	0
Holosteum umbellatum	0.0	1.2	73	+	0
Ambrosia acanthicarpa	0.0	4.9	97	+	0
Draba verna	0.0	0.4	47	+	0
Epilobium sp.	0.3	0.3	0	0	100
SHRUBS AND HALF-SHRUBS					
Phlox longifolia	2.1	0.0	85	-	0
Chrysothamnus nauseosus	0.0	4.5	97	+	0
Artemisia tridentata	24.7	0.0	99	-	0

(a) C = content; average frequency values for pristine sagebrush/sandberg-cheatgrass communities (Cline et al., 1975; Uresk et al., 1975).
(b) I = Impacted area; average frequency values for 11 burial sites in 200 West and 200 East Areas (Uresk, 1977, in preparation).
(c) PI = Probability values that differences occur. Biological impact occurs with values 80% and above.
(d) Similarity index calculated by Kulcyznskis formula (Oosting, 1956). This represents the percentage of the plant species shown by the two sites that was identical.

	Common Name	Scientific Name
GRASSES	Indian Ricegrass	*Oryzopsis hymenoides*
FORBS	Russian Thistle	*Salsola kali*
	Aster	*Aster canescens*
	Prickly Lettuce	*Lactuca serriola*
	Bursage	*Ambrosia acanthicarpa*
SHRUBS	Grey Rabbitbrush	*Chrysothamnus nauseosus*

Present conditions favor these plants on the disturbed sites. The forbs and the shrub are considered to be deep-rooted plants. Indian ricegrass is a semi-deep rooted plant and is generally associated with disturbed lands.

Thirteen plant species showed a statistically significant negative biological response to waste burial practices and seventeen did not show any biological response, below the 80% limit. Thick-spiked wheatgrass (*Agropyron dasytachyum*) was not found to have a statistically significant negative response but its absence from waste management areas may have biological significance.

Similarity indices were determined for each of the plants represented in the 200 Areas. This index shows the percent of a plant species shared by the pristine and disturbed areas. The average similarity index shared by the two sites was 18%. This indicates that the disturbed sites are different from the more pristine plant communities.

The creation of ponds and ditches on the 200 Area plateau permits develment of plant species unique to wet-land areas. Common species include bulrush, cattail, nettles, canary grass, and cottonwood trees. A more complete listing of species common to ditchbanks, ponds and moist areas is included in Appendix A.

Nonradiological Impact On Invertebrates

Any major impact on invertebrates would be associated with large scale habitat removal. As an example, the occurrence of fire on the 200 Area plateau removes all sagebrush and bunchgrasses. Bunchgrasses would recover during the following season but sagebrush would require several years before becoming reestablished. Invertebrates associated with these microhabitats would be affected accordingly. The most important microhabitat for invertebrates on the nearby ALE Reserve was bunchgrass (Rogers, In Preparation):

Microhabitat	% of Total Invertebrate Density
Big Sagebrush	1%
Bunchgrass	97%
Bare Areas	1%
Flying Insects (not associated with a microhabitat)	<1%

Since bunchgrass is the dominant plant taxa on the ALE Reserve, it is not surprising that it is the microhabitat accounting for the largest percentage of sampled invertebrates; however, the situation on the 200 Area plateau is different. Few bunchgrasses occur there--most of the area is divided into big sagebrush, bare, and cheatgrass microhabitats. Density samples have not been taken for these microhabitats so that quantitative data concerning potential impacts are not available. Most aboveground invertebrates are probably associated with the shrubs or the scattered forbs.

Not all habitat modifications necessarily result in a reduction of invertebrate biota. A count of harvester ant colonies inhabiting 300 Area burial sites showed burial grounds to be attractive to colony establishment (Rogers, unpublished data):

Burial Ground	Treatment (Inside Exclosure)	Control (Nearby Area)
	(No. Colonies/ha)	
WYE	96	24
300-North	32	14
300-6 & 7	55	2
300-West	0	0
200-4	12	9
Total	195	49

Disposal sites may be equally attractive to other ant species, but densities have not been estimated. Ants, in general, are attracted to disturbed areas--possibly due to the ease of colony establishment.

The small land areas set aside for physical facilities, burial grounds, or inadvertently modified in some manner are probably not extensive enough to cause serious perturbations of insect populations--but data are lacking.

Insecticide usage is restricted to areas immediately around buildings and would not be expected to harm field populations.

Nonradiological Impact On Reptiles And Amphibians

Any serious impact on this group would probably be directly associated with construction activities. Soil movement during seasons when these animals are inactive would probably result in the death of all individuals within the affected areas. Since such areas represent a small portion of the total area, impact would probably be minimal. Detailed data concerning 200 Area plateau reptile and amphibian populations have not been gathered.

Nonradiological Impact On Birds

There are relatively few bird species common to the 200 Area ecosystem. The construction of waste ponds has permitted establishment of riparian vegetation around the pond edges which serves as an attraction to small perching birds. A comparison of species numbers is shown below for riparian and sagebrush habitats:

Habitat Type	Number of Species
--------Riparian Habitat[1]-------	
B-Pond vicinity	18
U-Pond vicinity	55
Gable-Pond vicinity	23
West Lake vicinity	9
REDOX Pond vicinity	24
------Shrub-Steppe Habitat[2]-----	
ALE Reserve 1	3
ALE Reserve 2	3
ALE Reserve 3	3
ALE Reserve 4	1
ALE Reserve 5	3
ALE Reserve 6	2
ALE Reserve 7	2
ALE Reserve 8	3

[1]From Fitzner and Rickard, 1975
[2]From Rotenberry, 1975

The comparison between riparian and shrub-steppe habitats is biased by differences in sampling times and methods, but indicates the substantial change that creation of riparian habitats can have in an arid area. In addition, 40 species of waterfowl have been documented as using the pond waters for feeding, nesting, or resting stations.

Removal of large stands of sagebrush would adversely affect the sage sparrow population but would have little effect on the other common species--meadowlarks and horned larks. Conversely, shrub removal would improve the habitat for nesting curlews. These birds are involved in nesting activities during the period March through June in open grassland areas.

Magpies are scavengers common to the 200 Area plateau. The vehicular traffic and associated road-kills of animal life has undoubtedly resulted in maintenance of higher populations than occurred prior to settlement. Raptors (hawks and owls) have also benefited from modifications to the Hanford environment. Construction of power lines and tree growth around ponds, ditches, and former farm sites has increased the availability of suitable nest location and perching stations.

Nonradiological Impact On Mammals And Wildlife

In general, the small mammal populations inhabiting the 200 Area plateau are similar in composition and abundance as nearby areas on the ALE Reserve. Construction of burial grounds probably results in only temporary disruptions of local populations. A comparison of small mammal population on the WYE burial ground with a nearby control showed similarity in abundance and taxonomic composition (Gano, In Preparation):

Species	Treatment (Inside Exclosure)	Control (Nearby Area)
Deer Mice	3	0
Pocket Mice	47	43
Harvest Mice	2	0
Townsend Ground Squirrel	2	2

Information is currently lacking concerning the abundance of medium-and large-sized animals on the 200 Area plateau as compared to other parts of the Hanford Reservation. Deer are known to forage in areas around waste ponds as evidenced by their tracks and fecal droppings, but little is known concerning seasonal use patterns or abundance. A current study designed to ascertain abundance of medium- and large-size mammals (jackrabbits, coyotes, deer) on the Hanford Reservation is in place (Uresk et al., In Preparation).

Preliminary density data are shown below:

Species	No/Sq. Mi.
Jackrabbit	9
Mule Deer	2
Coyote	<1
Porcupine	<1
Badger	<1
Cottontail Rabbit	<1

This study is part of the Terrestrial Ecology program and is not focused on the 200 Area plateau, although some sample stations are located there. A preliminary observation emerging from these studies, however, has implications for the 200 Area ecosystem studies. Jackrabbits were noted as being concentrated near the B-C Cribs burial site during fall sample periods. Very little quantitative information is available concerning jackrabbit abundance, movement patterns, or habitat preferences. Since they are all highly mobile it is doubtful that the small reduction in habitat availability due to construction and burial activities has adversely affected their respective populations. The presence of vehicular traffic does result in some wildlife mortality--especially for jackrabbits and deer--but this is probably more than offset by the lack of pressure from hunting and human intrusions.

IMPACT ON ECOSYSTEM STRUCTURE AND FUNCTION

The major factors for altering the structure and function of grassland ecosystem in the semi-arid regions of the western United States are: 1) fire, 2) habitat removal due to construction activities, 3) soil plowing--either associated with agricultural practices or soil tilling as a by-product of other activities, and 4) large herbivore (cattle, deer) grazing.

Fire is the most dramatic factor and possesses the greatest potential for altering the 200 Area plateau ecosystem. Wildfires are a natural phenomenon and have altered vast areas of the Great Basin in the past, although they have been largely contained since settlement. Both natural and man-induced fires have regularly occurred on the Hanford Reservation. In July 1960, a lightning-induced wildfire burned over 17,000 acres of habitat similar to that of the 200 Area plateau. Despite the role played by fire during the evolution of grassland ecosystems, little is known concerning their effects. The most apparent effect concerns structure alteration. All shrubs are generally burned to ground level. Rabbitbrush has the capability of sprouting from its roots and can recover in a year or two; but the dominant shrub, sagebrush, is usually eliminated. Other effects include the elimination of stored organic matter and nutrients (litter), soil destabilization, alteration of microclimates, impact on some animal populations, and initiation of vegetative secondary succession. In general, small mammals are little affected since they are burrowers and can escape any direct effects (Hedlund, et al., 1976). Burning resulted in increasing the vegetative and reproductive vigor of bluebunch wheatgrass after a wildfire on the ALE Reserve, but decreased these characteristics for Cusick bluegrass and Thurbers needlegrass (Uresk et al., 1976). Burning of annual grasses, however, has adversely affected seed production at Hanford:

Taxa	Unburned Area	Burned Area
	-Average Number of Seedlings-	
Cheatgrass	8	<1
Forbs	7	<1

Wildfire can have a detrimental effect on aboveground invertebrate populations immediately after a burn, but the recovery is rapid. Soil-dwelling nematode populations appear to be unaffected by fire (Smolik and Rogers, 1976).

Although it is apparent that wildfire can affect some ecological parameters, its overall role as an ecosystem factor is poorly understood. This makes an assessment concerning the implications of fire on the 200 Area plateau difficult for the present. The construction of paved roads and railroad beds also serves to alter community structures; however, the total amount of land area removed is small (<1%) so that these activities are not regarded here as being a serious effect.

There are no agricultural activities (livestock grazing, plowing) currently in place on the 200 Area plateau. Construction of burial grounds and refilling creates a situation similar to the effects created by plowing. Existing plant communitites are removed and structural characteristics of the soil modified; but these burial grounds are surrounded by large expanses of relatively undisturbed landscape so that any overall effect would be minimal.

RADIOLOGICAL IMPACT ON BIOTA

In general, radioecological studies have dealt primarily with distribution and fate of radionuclides within an ecosystem or some smaller unit of an ecosystem. Although the literature is replete with information concerning the biological effects of radionuclides at an organism level, few investigations address effect problems at the community or population level. Rarely, if ever, have investigations been designed to adequately encompass complexity involved in assessing that amount of total variability observed for a particular biological effect which may be attributed to radiological damage.

The most obvious possible radiation effect is mortality and the most subtle probably is genetic aberrations. Others often considered include mean standing crop, mean litter crop, mean biomass (arthropods, small mammals), reproductive activity, sex ratio, juvenile/adult ratio, home range, skeletal sarcomas, lung tumors, general radiological pathology, as well as, community physiognomy, community composition, species diversity, and productivity. Consequently, it appears that the three main aspects of an effects study to be considered are: 1) method of study, 2) effects observed and/or anticipated, and 3) resulting impact not exclusive of recovery phenomena.

The Hanford Waste Management Sites represent some of the best available study areas in the United States to evaluate environmental impact of waste management operations. Their diversified nature, both from a radiological and an ecological standpoint, makes them suitable for a variety of effects studies.

Cline, Selders, and Rediske (1955) investigated chronic effects of reactor effluent water on cereal plants in 1954. Irrigation of crops with 100% effluent reduced the harvested weight of grain (Table VI-2). However, no increase in mutation frequency over time was observed.

TABLE VI-2. Summary of Results from Effluent-Watered Plots

Factor Tested	Control		100 Per Cent Reactor Effluent	
	Plot I	Plot II	Plot V	Plot VI
Harvest Weight of Vegetation (g)	1538	1830	1466	1061
Harvest Weight of Grain (g)	1447	1530	1115	1073
Activity Densities of Vegetation (μc/g)	1.5×10^{-5}	2.0×10^{-5}	1.8×10^{-5}	3.1×10^{-5}
Activity Densities of Grain (μc/g)	2.5×10^{-5}	1.5×10^{-5}	3.0×10^{-5}	3.1×10^{-5}
Total Seed Nitrogen (mg N/g)	20	19	24	22
Activity Densities of Soil (μc/g)	2.6×10^{-5}	2.7×10^{-5}	1.8×10^{-5}	2.7×10^{-5}
Germination (Per Cent Viable)	100	100	100	99

O'Farrell et al., (1973) showed effects of radiation on free ranging pocket mice, Perognathus parvus, during breeding season. Captive and free-ranging pocket mice were exposed to ionizing radiation during the breeding season, April-June, in 1971. The values for the median lethal dose (LD_{50}) at 30 days plus or minus the standard deviation were 880 ± 14 rads and 780 ± 27 rads, respectively, and the slopes of the survivorship curves were significantly different. These differences suggested that there was a synergism between radiation-induced and environmental sources of mortality, since the field data were corrected for natural mortality (5%) in the controls.

Current studies are mainly directed toward implantation and recovery of dosimeters (TLD) in small mammals occupying waste management areas such as U-Pond and "WYE" Burial Ground. In addition, dosimeters have been placed in soil along trapping transects (Table VI-3). Population densities appear stable within exposure areas when compared to controls, but these results are tenative.

TABLE VI-3. Meadow Transect Exposure (roentgens/year)

Soil Depth	Location #1	#2	#3	#4	#5	$\bar{X}$ ± S.E.
0 dm	40.31	52.22	64.24	206.52	10.54	74.76 ± 34.12
1 dm	36.73	80.12	51.94	199.13	7.80	75.15 ± 33.13
2 dm	9.36	22.74	14.25	46.34	2.13	18.97 ± 7.62
3 dm	3.66	9.09	4.06	14.47	0.58	6.37 ± 2.44
4 dm	1.11	3.26	1.51	4.43	0.24	2.11 ± 0.761
5 dm	1.42	1.54	1.06	3.37	0.23	1.53 ± 0.52

A study was conducted during May and June 1976 to assess the impact of a radioactive pond on the reproductive performance of coots (Fulica americana). Gable Mountain Pond was selected for study. It is a 28 ha impoundment, which was formed in 1957 to receive condenser coolant water from a chemical processing facility. Along with the coolant water, the pond has received low levels of radionuclides. The control ponds selected are known as Morgan Lake and Royal Slough. They are larger than Gable Mountain Pond and occur on the Columbia National Wildlife Refuge near Othello, Washington. All of the ponds support similar vegetation. The number of nests found, clutch sizes, and hatching success of coot eggs found at the three ponds are shown in Table VI-4 (Fitzner, Personal Communication). There were no statistical differences in clutch size or hatching success between ponds, indicating that the low-level contamination present in Gable Mountain Pond does not have an appreciable effect on species productivity.

TABLE VI-4. Number of Observed Nests, Clutch Sizes, and Hatching Success of Coots of a Radioactive Waste Pond and 2 Control Ponds in Southeastern Washington

Location	Number of Nests Found	Average Clutch Size	Nest Hatching 100%	Nest with 1-3 Infertile Eggs
Gable Mountain Pond (waste Pond)	12	6.00 ± 0.42	12	0
Royal Slough (control)	18	6.53 ± 0.98	16	2
Morgan Lake (control)	12	6.16 ± 1.02	11	1

Other studies include non-radiological effects such as chemical toxicity. Wildung, et al. (1976) have shown that long-lived radionuclides such as ^{99}Tc, although of little radiological concern can be extremely toxic chemically at very low concentrations. This represents a classic example why a multidisciplinarian approach to hazards from waste management operations is essential.

The present quantitative data base concerning environmental effects of waste management operations is insufficient to conclude that no significant impact will eventually occur. However, logic dictates that effects will be subtle, probably not harmful, temporarily and spatially distinct, and overall of little consequence. A naive approach such as "too complex to evaluate, therefore assume no anticipated impact" will not suffice if the credibility of the nuclear industry is to be maintained. Predictable cause-effect relationships need be developed to place waste management problems in proper perspective. Well designed, comprehensive investigations addressing known effects at the organism, community, and population level would result in a factual "no impact" concept instead of an uncertainity based on educated suppositions.

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CHAPTER VII. MANAGEMENT MODELS

R. Sauer, R. G. Schreckhise and D. W. Uresk

Management models are used here as a vehicle to organize the ecological research tasks required for the biotic transport program. Three kinds of models are described: 1) ecosystem level simulation models; 2) radionuclide transport models and 3) optimization models. The ecosystem simulation model is included here as a coupling agent between climatic variables and waste management practices with the transport and optimization models. Certainly the **potential** for radionuclide transport depends to a large degree upon the density, type and vigor of plant species inhabiting burial sites. These parameters, in turn, are related to past management practices, precipitation patterns, and successional stages—all predictable using current techniques.

Ecologically prudent management of radioactive waste storage areas requires simultaneous consideration of many variables. The interactions between waste materials, soils and biota are extremely complex and when the effects of climatic driving variables are included, a staggering array of probabilistic situations are created. The development of models often permits organization of these kinds of data with condensed output, permitting a clearer and more ready understanding both as to how a natural system operates and the consequences of man-induced perturbations to the environment.

It must be clearly stated here that ecosystem level modeling attempts do not represent a panacea. A few years ago such models were viewed as an ultimate management tool providing environmental managers with all the answers concerning the possible consequences of their actions or natural environmental occurrences. While this remains a worthwhile goal the state of the art has not progressed to the point where this is possible. Certainly within the foreseeable future (5-10 years) results of ecosystem modeling attempts will have to be interpreted by an ecologically knowledgeable management-analysis team.

It is assumed that over and above the first objective of understanding how radioactive waste materials might be transported through biotic components there is a second and even more desirable goal of coupling this knowledge with an understanding of ecosystem functioning. This approach will permit the management of nuclear wastes to proceed on a proactive basis rather than responding to situations after an event has occurred.

An important point is that it is not necessary or even desirable to wait until all the data gathering efforts are complete before beginning the task of model construction. Model building and data gathering efforts should proceed simultaneously.

One major benefit of ecosystem modeling is that it serves to integrate individual study programs. Past experience has shown that model construction frequently results in exposure of data base "holes" for essential parameters. Model construction, therefore, is an iterative process frequently generating more questions than answers during the earlier task stages.

The modeling effort is being approached on several levels including: 1) ecosystem level simulation models, 2) radionuclide transport models, and 3) optimization models. Figure VII-1 shows the envisioned relationships between these modeling tasks. Word modeling often serves as an organizational point for setting down what is known about system operation. In this case the system has been fairly well described as a result of past research at Hanford and the word modeling is probably not required. This approach permits consideration of the influence of normal climatic variation on transport processes within waste management areas.

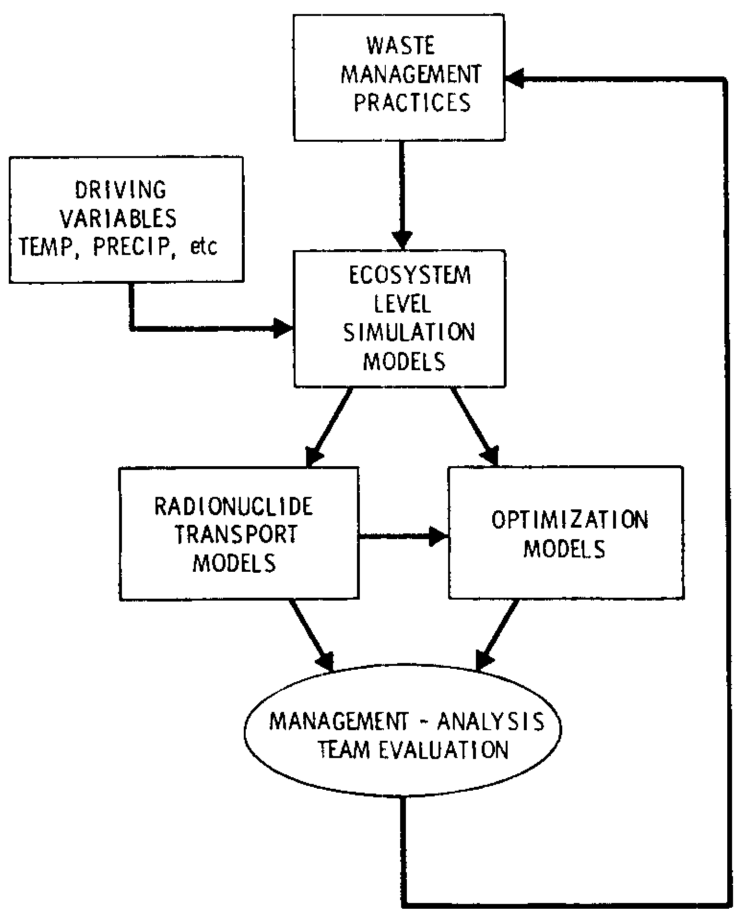


FIGURE VII-1. Interrelationships Between Modeling Subtasks, Driving Variables and Waste Management Models

ECOSYSTEM LEVEL SIMULATION MODELS

Simulation model construction can be essentially divided into five steps: 1) goals, 2) questions, 3) structure, 4) sensitivity analysis, and 5) validation. Any modeling effort must have goals to guide the work and prevent the model building process from becoming mixed with unrelated efforts. The questions serve as more specific expressions of goals and provide a focal point for model and data collection efforts. The structure of the model is derived from the goals and questions. Once an operational version of the model becomes available, a sensitivity analysis can be performed to determine which variables are the most sensitive in terms of predictive powers. In other words, the sensitivity analysis identifies which variable(s) must be backed-up with the best data.

At any point in the sequence, goals → questions → structure → sensitive analysis, frequent return to the "goals" step is necessary to assure that the project continues on course. The value in few questions and goals is now clear; too many aims and goals will dilute resources. It is better to have a good model that doesn't answer all questions, than no model that was planned to answer all the questions.

The first step after model construction is validation, which demonstrates the accuracy and reliability of the model output. Model outputs are compared to data not used to develop the model.

Goals

The goals of this simulation model project are the guidelines for the project. Subjects not included in the goals should be excluded so that time and resources are not used on low priority projects. The goals are:

- To simulate annual and seasonal biotic biomass dynamics of the 200 Area ecosystem under normal and abnormal climatic conditions. Simulations to be within 2 standard errors of the mean, for 80% of available data.

- Identify weaknesses in data base and concepts and thereby direct research to fill these needs.

The second goal will automatically result from the first goal as model development progresses. It is written here to explicitly show a value of the modeling process.

Questions

The questions are intended to be focal points for individual efforts in the modeling process. All questions must relate directly to the goals. It is most important not to dilute effort and resources on too many questions. The key issues must be identified and presented as questions. Hence, the questions and goals must receive careful thought as they guide the modeling effort. The questions are:

- What effects do perturbations in temperature (air, soil, water) precipitation, and contaminant concentration in substrates and foods have on contaminant movement by major biotic components?

- What effects do perturbations in temperatures (air, soil), precipitation, soil nutrient level, and contaminant concentration have on containment concentrations in primary producers?

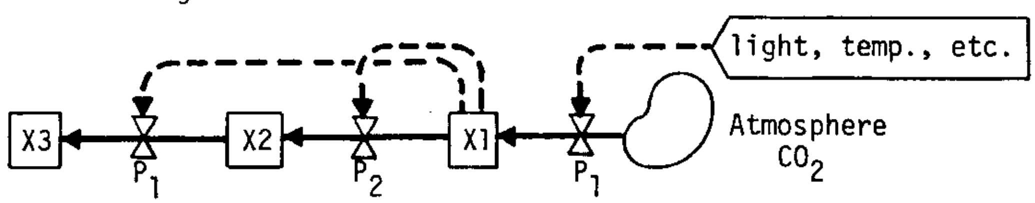
- What is effect of rooting depth and contaminant concentrations on contaminant concentration of primary producers?

- What are the major transport vectors away from radiation waste control areas?

Structure

The structure of the model is the content, level of detail, and mode of mathematical representation. The content and level of detail or resolution are determined in part by the goals and questions. The choice of the mathematical representation is based on what models are already available and the modelers' preference.

The structure of this model should be determined first by developing a box and arrow diagram:



where the boxes are state variables or physical entities and the arrows are processes moving material between the state variables. Boxes, X1, X2, and X3 could represent leaves, stems, or roots, and P's are the processes (i.e. P_1 is photosynthesis). The dashed lines going to the values on the arrows represent controls on the processes. For example, the control on the process of translocation of carbon from the leaf to the stem might be the amount of carbon available in the leaf.

The box and arrow diagram for the 200 Area plateau model should include separate state variables and processes for each species identified to date as a major vector of contaminant movement. The remaining species not involved in contaminant movement can be combined into a single group. The box and arrow diagram should also include submodels for plants, animals, weather, soils, minerals, including radionuclides and hydrology. To decrease the expense, available models could be used wherever available.

From a well thought-out box and arrow diagram, the coding of the submodels and subsequent linking of sub-models can proceed to result in an operational simulation model. At this point, it is important to emphasize that the development of the model is a continuous process of iteration from goals to questions to structure back to goals, etc. This iteration insures that no unnecessary effort is spent on topics outside the purpose of the modeling task.

Sensitivity Analysis

A sensitivity analysis is an evaluation of an operational simulation model to identify the most critical model parameters. The critical parameter is one that causes a large change in model output with a small change in parameter value. Such a parameter thus must be known with more precision than a parameter that can be varied 200% with little change in model output.

Validation

Validation is a test of the reliability of the model. Models cannot be shown to be valid, but only invalid for a given set of conditions. Validation requires that the model output or simulation be compared to data not used to develop the model. While this requires more data, it is the only way to check the model. Checking the model with data already in the model provides only a weak test of reliability.

The ecosystem simulation model would provide predictive output required by both radionulide transport and optimization modeling subtasks. Figure VII-2 shows interactions between simulation and radionuclide transport models. The boxes represent concentrations of radioactive waste materials in soil, plant, animal, and litter components. The arrows with solid lines show the flow of these materials between components. The valve (⧖) shown attached to the solid lines represents control points regulating the flow of materials between components. The dotted lines show the processes regulating the valves. All of the processes regulating the valves would be generated by the simulation model and ultimately control transport of waste nuclides from the soil to the plant, animal and litter components. This illustrates the necessity for approaching waste management from an ecosystem viewpoint.

Figure VII-3 shows an existing simulation model developed for a cheatgrass community. Little additional work would be required to parameterize this model for the 200 Area ecosystem.

RADIONUCLIDE TRANSPORT MODELS

Transport models are essential when attempting to predict movement of waste radionuclides between ecological components. An underlying premise for model development is that ecological compartments are physically linked by interchanges of water, minerals and energy. The concepts of compartmental model development have been described in detail by Shipley and Clark (1972) and Sheppard (1962). The processes (absorption, adsorption, ingestion, inhalation, etc.) and environmental behavior involved in radionuclide transfer are discussed by Schultz and Whicker (1974), Garner (1972) and Eisenbud (1973) and will not be repeated here. The development of mathematical relationships pertaining to compartmental transfers are included in Appendix B documenting the current state-of-the-art and providing ready reference for future modeling efforts.

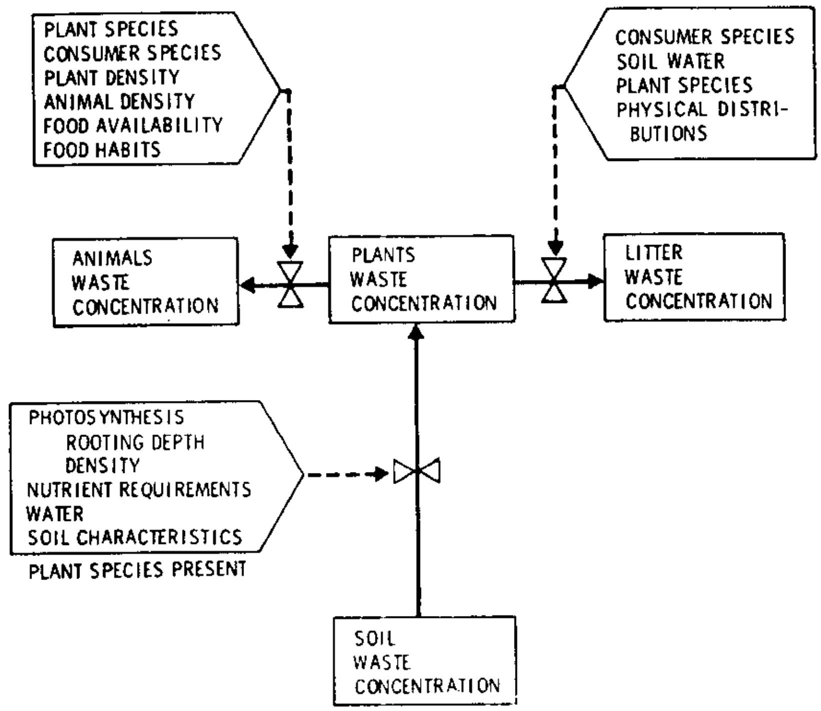


FIGURE VII-2. Showing the Relationship Between Simulation Model Predictions (⬠) and Radionuclide Transport Model (▭)

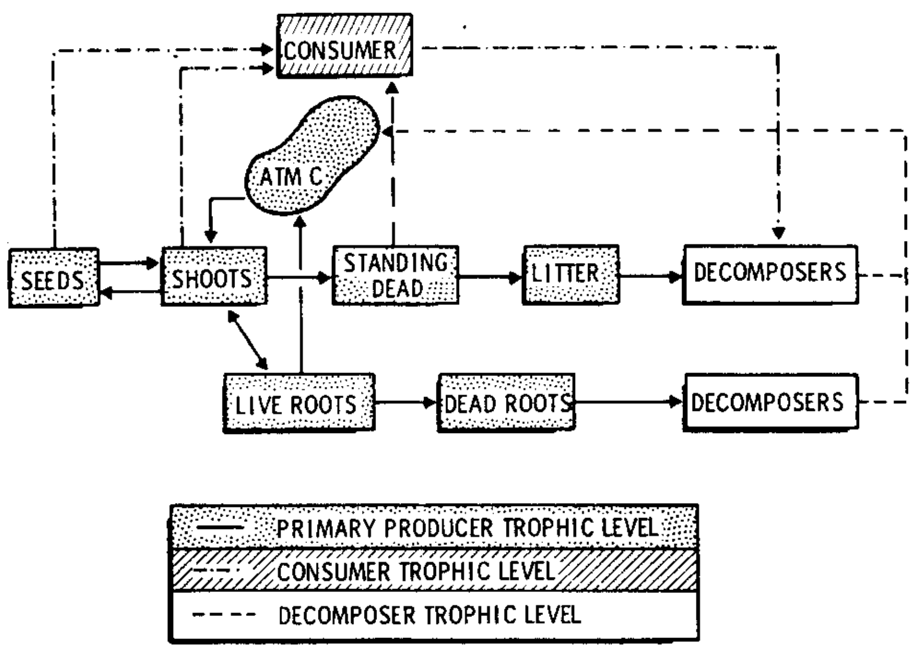


FIGURE VII-3. Simulation Model of Cheatgrass Community

Modeling Radionuclide Transport

Modeling can provide tools to help evaluate risks to man and other biota from rad-waste storage facilities. Of primary interest is the application of compartmental modeling to predict the movement of radionuclides through biotic pathways leading to man and the associated radiation doses to him and other components of the food chains.

Several approaches can be taken to develop deterministic expressions to predict movement through food chains. One approach is to evaluate the transfer between each trophic level individually. Transfer of rad-waste to the soil, water or directly to plants would probably best be described by probablistic expressions for accident occurances or as functions of leaching and sedimentation rates for continual releases to the environment. The simplest way to quantify the transfer from soil, sediment or water to plants is with the concentration ratio:

$$CR = \frac{\text{[unit activity]/[dry weight plant]}}{\text{[unit activity]/[dry weight soil or volume water]}} \qquad \text{(EQ. 1)}$$

$$\left(\text{i.e., } CR = \frac{\text{pCi/g dry plant}}{\text{pCi/g dry soil}}\right.$$

If the concentration of a particular radionuclide in a specific soil is known then the concentration in certain plants growing on the contaminated soils or sediments can be estimated. CR values for certain plants, soils and radionuclides are given in Chapter V (Radionuclide Transport) of this report. Other sources of CR values are summarized by Yook et al. (1968), Reichle et al. (1970) and Garner (1972).

The transfer from water or plants to animals and from animals to man may be approximated using Equations 12 or 22 (Appendix B). To do this, parameters such as consumption rates, radionuclide concentrations of the food stuffs, assimilation factors and acute retention functions for the particular radioisotope would have to be known in order to develop species specific deterministic expressions. As pointed out in Chapter IV, animals expected to have the greatest potential for introducing radiocontaminants into food chains leading to man include mule deer, cottontail rabbits, hares, waterfowl, honey bees, and upland game birds. Some of the parameters that are known or can be approximated for selected nuclides for these animals are summarized in Table VII-1. Information is lacking for many required parameters making it very difficult to construct the models. Man is the only organism for which almost all required parameters are known.

Another approach to modeling the rad-waste to man pathways would be to set up an ecosystems compartmental model as presented in Figure VII-4. The system can be evaluated using the Euler technique (Scarborough 1965) and resulting doses to each biotic component can be estimated if the transfer coefficients are known or can be approximated.

TABLE VII-1. Known Parameters Which Can be Used for Species Specific Models--for Particular Radionuclides in Selected Animals

Species	Parameters**	General	Nuclide* Sr	Tc	I	Cs	Pu	Am
Deer	R	✓						
	F_t		✓		✓	✓		
Cottontails	R							
	F_t	+						
Hares	R	+						
	F_t							
Waterfowl	R	+						
	F_t	+						
Honeybees	R							
	F_t							
Upland Game Birds	R F_t							
Man	R	✓						
	F_t	✓						

*✓ = Enough information is available to develop a deterministic model.
+ = Some information is available, but not enough to adequately produce a model.
**R = Consumption rate along with dietary preferences of the organism.
F_t = Acute retention functions, or effective half time and assimulation factor.

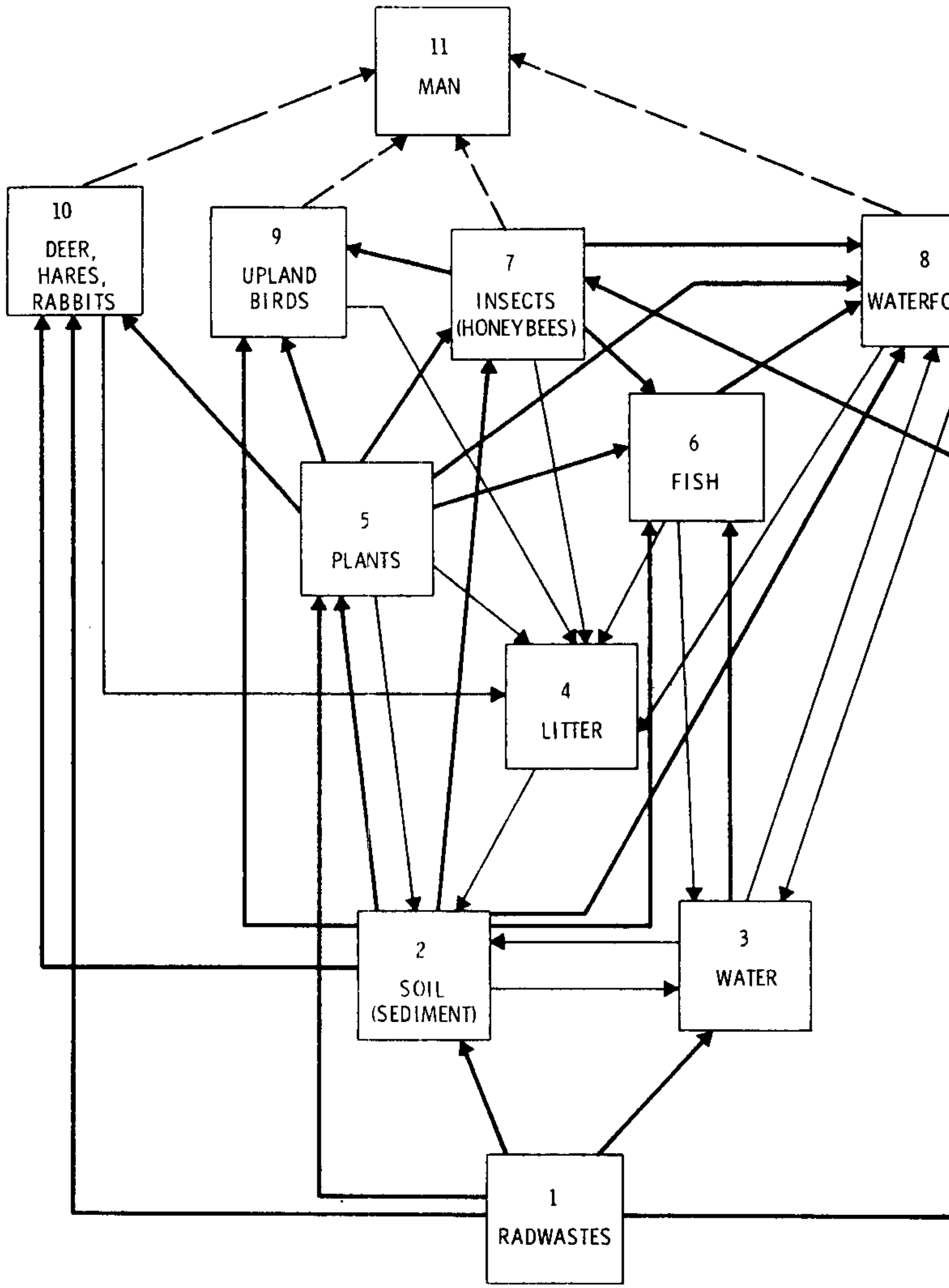


FIGURE VII-4. Compartmental Model Illustrating the Potential Biotic Pathways for Rad-Waste Materials to Reach Man

OPTIMIZATION MODELS

The radionuclide transport and ecosystem level simulation models provide predictive estimates based on current community parameters. Estimates of total Russian thistle production and radionuclide uptake as a function of climatic variables provide an example. The optimization model functions in a slightly different manner. These models use actual or simulated biotic community data to provide management alternatives for optimizing conditions at specific burial sites. As an example, vegetative cover (%) might be identified as a controlling agent in minimizing Russian thistle production. Those factors contributing to vegetative cover could then be managed for maximum benefit.

Linear programming techniques have been applied to similar problems in agricultural and natural resources and its application is becoming more frequent (Woodworth, 1973; D'Aquiano, 1974; Bartlett et al., 1974; Bottoms, 1974; and Connelly, 1974). There are three well-defined characteristics which are essential for resource management.

- Identification of management goals with environmental constraints.
- Explicit analysis of relationships between ecosystem components and alternatives for management goals.
- Guides to the evaluation of management alternatives.

The final evaluation of a decision should be measured on the degree to which the objectives of a system are achieved.

Two types of programming would be involved in resource management of waste burial sites. The first is linear programming and has three basic characteristics (Bottoms, 1974).

- The decision variables constituting a diverse environment are homogeneous and linear.
- Constraints on limited resources or requirements are linear. The objective function is homogeneous, linear, and usually involves either maximization or minimization of an ecological system.

The solution of a linear program provides a guide to the optimization of the single objective.

The second programming type is referred to as goal programming. Goal programming can provide a simultaneous solution to a system of conflicting multiple objectives (Bottoms, 1974). This technique is capable of handling decision problems that deal with a single goal with multiple subgoals. The basic assumption of goal programming is whether goals are attainable or not, an objective may be stated in which optimization gives a result which comes as close as possible to the indicated goals (Lee, 1972).

The basic concepts of goal programming are as follows (Bartlett, 1974):

- Goal programming is an extension of the conventional linear programming model in which the optimum attainment of goals is achieved with a given decision environment. This environment is defined by the decision variables, constraints, objective functions, priority factors, deviational variables and weights.

- Decision variables are the real variables in the model. These values are arbitrarily assigned and change in the search for the optimum set of values. The decision variables are related among themselves and to other variables by values which are specified by the environment. In the above models, the decision variables constitute a vector for all management (production) and product (user) alternatives.

- Constraints represent a set of linear relationships among resources and regulate the values of decision variables.

- An objective function is a mathematical expression involving some variables in the model. The values are computed when the coefficients of all other variables are determined. The values in the objective function of goal programming will differ from those used in linear programming. Instead of maximizing or minimizing a system, we minimize the deviations between the desired goal levels and the actual level attained within the established constraint system.

Each of the low-level radioactive waste burial sites may be optimized for maximum cheatgrass cover, while minimizing the growth of undesirable plants. For example, parameters were measured on several burial grounds (Table VII-2). These may be minimized, maximized, or optimized.

Linear programming techniques permit minimizing the undesirable aspects, such as the elimination of tumbleweed and optimizing or maximizing for cheatgrass. Analytical results will provide information concerning goal attainment. For example, the amount of cover to be provided by cheatgrass may require that additional nitrogen and phosphorus be added to the soil. The requirements will be given with alternatives to achieve the goal of adequate cheatgrass cover.

The optimization modeling task would interact closely with both transport and simulation models. The simulation model could predict probable system response to various man-induced or natural perturbation scenarios. These predictions would then provide input to the optimization model to provide possible management alternatives to foreseeable events. As an example, the management-analysis team might want to consider the possible impact on waste management operations from several drought years coupled with above average temperatures and using current waste burial practices. The simulation model would predict biotic responses (e.g. possibly less cheatgrass cover and more Russian thistle cover on burial grounds). An evaluation could then be made of the ecosystem response in terms of its impact on waste management operations.

If the response was judged undesirable, the optimization model could be employed to provide management alternatives (e.g. maximize cheatgrass and minimize Russian thistle by soil amendments, etc.). The same technique would apply equally well to consumer populations (jackrabbits, grasshoppers, coyotes) inhabiting burial sites.

TABLE VII-2. Management of Burial Ground Environmental Parameters

Measured Parameters	Minimize	Optimize	Maximize
Plants			
Cheatgrass cover		x	x
Tumbleweed cover	x		
Mustard cover	x		
Shrub	x		
Cheatgrass frequency of occurrence		x	x
Tumbleweed frequency of occurrence	x		
Mustard frequency of occurrence	x		
Shrub frequency of occurrence	x		
Soil Properties			
% Sand		x	
% Clay		x	x
% Silt		x	x
pH		x	
OM		x	x
P		x	
K		x	x
Ca			
Mg		x	
Total bases		x	
No_3		x	x
NH_4		x	x
Soluble salts		x	
S		x	
B		x	
Zn		x	
Mn		x	
Ca		x	
Water holding capacity		x	x

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CHAPTER VIII. APPLICATIONS TO WASTE MANAGEMENT OPERATIONS

D. Paine, V. Uresk, and R. G. Schreckhise

Ecological studies of the 200 Area plateau waste management environs have provided preliminary answers to questions concerning the environmental health of associated biota, potential for radionuclide transport through the biotic system and risk to man. More importantly creation of this ecological data base provides visible evidence of environmental expertise so essential for maintenance of continued public confidence in waste mangement operations.

ABIOTIC AND BIOTIC CHARACTERIZATION

Characterization studies as employed here represent initial investigative efforts for ecological studies. They often establish ecological baselines for later impact assessments associated with construction and operation activities. Characterization studies are usually very broad including fractions of most abiotic and biotic components. As a result little depth is usually attempted. Results are primarily expressed in terms of relative abundance, frequency of occurrence, and percentage composition.

The advantage in this approach is that important system components are identified early in the program. Detailed studies can then be designed emphasizing these major ecological components; minor segments can be grouped or ignored. This approach provides a rational basis for establishing research priorities and essentially represents the major contribution of the RHO-sponsored ecological research program to date.

Observations from the 200 Area characterization studies have proved valuable. Deer were found to utilize waste pond environs and bitterbrush communities more heavily than would have been expected from observations on the nearby ALE Reserve. As a result, dietary studies have been implemented to ascertain food plant preferences. This will show if deer are actually foraging on the emergent waste pond vegetation and in what proportions. Similarly the American coot was found to be an important component of waterfowl populations inhabiting waste ponds. They are known to be bottom feeders and local waste ponds contain detectable amounts of waste radionuclides. A study was initiated to identify their food habits, body burdens, and potential for waste nuclide transport away from management areas.

Jackrabbits appear to concentrate near the B-C Cribs vicinity (Uresk, In preparation). This suggests the need for detailed study concerning their movement patterns since they have been previously implicated as biotic vectors of waste nuclides (O'Farrell et al., 1973). Additional information arising from the characterization studies concerns the absence of ground squirrels from the 200 Area study areas. They do inhabit the 200 Area plateau but much more sparsely than anticipated from previous studies on the ALE Reserve.

Finally, the soil characterization studies conducted to date provide insight as to the kinds of plants capable of inhabiting the area and basic data permitting preliminary evaluations of interactions between waste nuclides, soils, and biotic uptake.

Complete characterization studies have also provided data suggesting alternative waste burial techniques. Conventional burial techniques have primarily consisted of placing wastes in a trench and covering with a soil overburden. This technique provides adequate protection against possible ionizing radiation resuspension by wind or leaching to groundwater but does not always prevent uptake by deep-rooted plants or exposure through animal burrowing. A modified burial technique under investigation (Cline et al., 1976) employs a stratified cobble/topsoil arrangement with shallow-rooted annual plants comprising the surface vegetation. This technique is designed to provide a self-sustaining biotic community with the shallow-rooted plants utilizing the annual precipitation to prevent water penetration into stored waste. The cobble layer is designed to discourage animal penetration. This design is currently being tested as part of a separate research program.

RADIONUCLIDE TRANSPORT AND BIOTIC RESERVOIRS

The potential for radionuclide transport along biotic routes has been recognized and under study nearly as long as Hanford's existence. Some of the major studies, in terms of application to waste management operations, are included here. Others are listed in Appendix C, but are not discussed in detail.

Studies actually conducted on biotic transport mechanisms have dealt with major potential vectors such as deer, waterfowl, fish, crops and tumbleweeds. Studies beginning about 1950 considerably expanded available knowledge concerning the ability of biota to function as radionuclide reservoirs and transport vectors.

Selders (1950) investigated the uptake and translocation of fission products by Russian thistle. This was one of the earlier studies concerned with the concepts of transport and biotic reservoir phenomena. Results indicated substantial uptake through roots and translocation of Strontium-yittrium to other plant parts. A follow-up study in 1951 showed the effectiveness of utilizing biotic components in identifying waste contamination problems. New contaminated Russian thistle plants were found in another location revealing a new break in the waste line. These observations prompted several studies over the next few years concerning plant-soil relationships involved in the radionuclide transport route (Rediske and Selders, 1953; Rediske et al., 1954; Cline, 1955; Rediske et al., 1955).

Vegetation analysis for gamma emitting nuclides was initiated in 1957. This was the first routine reporting of individual isotopes instead of the previous reporting of radioiodine and non-volatile beta's. Vegetative samples were collected from separate areas, Hanford project, Wahluke Slopes, residential areas, Eastern Washington, South Central Washington and Northern Oregon. This involved comparisons of gross techniques to gamma analysis techniques, reproducibility of compositing, and ^{131}I wet chemistry techniques comparison to gamma analysis. This opened a broad range of new environmental investigation concerning uptake and transport of radionuclides.

The primary emphasis of these early investigations was directed toward aquatic environments. Krumholz and Foster (1957) generalized on available data for the Columbia River and White Oak Lake bed. They recognized the existence of species variability, speculated on spatial variability and recognized three modes of uptake; 1) surface adsorption, 2) absorption from surrounding medium and 3) food chain transfer.

Pendleton (1957) instigated an early classic manipulative study in a concrete pond to determine bioaccumulation factors through an aquatic food chain. Higher CFs were noted in higher trophic level organisms due to a presumed increased efficiency of retention. This resulted in a continued interest in the indicator organism concept through 1959.

Concentrations of radioisotopes in the tissues of jack rabbits and shiners, as indicator organisms, and in ducks, whitefish and deer, the important game species, collected from the Hanford Reservation were investigated in 1959. Values were generally lower than those observed earlier. Factors considered responsible for this decrease were decrease in emitted curies of ^{131}I to the atmosphere from separations facilities and seasonal variations.

Thyroid glands of mule deer, Odocoileus hemionus hemionus obtained during the fall months contained lower concentrations of radioiodine than those of jackrabbits collected about the same time.

Comparison of Average I^{131} Concentrations in Thyroids of Jackrabbits and Mule Deer

	Average I^{131} Concentrations in Thyroid in Units of $\mu c/g$ Wet Weight x 10^{-4}		
	Oct. 26	Nov. 10	Nov. 18
Jack Rabbit	14	16	18
Mule Deer	2.5	15	9

The seasonal pattern of average concentrations of total beta emitters in river ducks was established during 1956 and 1957. Phosphorus-32 was the predominant radioelement contained in flesh of waterfowl utilizing the Columbia River, and accounted for at least 95 percent of the total beta radioactivity, although measurable amounts of Na^{24}, Zn^{65} and Sr^{90} were also found.

Relative concentrations of total beta emitters in different species of aquatic birds during the waterfowl hunting season are shown below.

Relative Concentrations of Beta Emitters in Six Major Groups of Birds Utilizing the Columbia River During the Waterfowl Hunting Season

Avian Type	Relative Concentration of Total Beta Emitters
Shorebirds	45
Diving ducks	30
Grebes	20
Gulls	7
Mergansers	6
River ducks	1

An aerial census of waterfowl utilizing the Columbia River within the Hanford Reservation during 1958 showed a summer resident population of approximately 200 river ducks; by November the population had increased to 150,000 which would produce a dilution factor of 750. Similar populations were present in 1959.

Interest in dietary analysis for transport modeling purposes resulted in the sampling of food items in stomachs of 522 wildfowl collected along the Columbia River and at waste ponds on the Hanford project. These were identified to correlate tissue concentrations of radioisotopes with wildfowl food habits.

Birds which consumed significant amounts of insects consistently contained greater P^{32} concentrations than those whose diet was primarily fish. Swallows which fed upon adult insects exclusively contained lesser concentrations than shorebirds, whose diet included insect larvae. Birds which fed upon small fish generally contained greater P^{32} concentrations than those which preyed upon large fish.

Research emphasis in the early 1960's shifted from studies specific to the Hanford Reservation to fallout studies emphasizing Alaskan food chains. Some interest concerning transport mechanisms did remain during this period. Cline (1969) studied the effects of substrate parameters on the uptake of cesium-137 by plants. Soil moisture proved to be an important parameter for radiocesium uptake. In addition, depth of contamination proved to be extremely important when considering various rooting habitats of important natural vegetation and important crop species.

Increased interest in transport mechanisms occurred in the early 1970's when buried waste nuclides were transported by <u>Lepus californicus</u>, the common jackrabbit. This event also emphasized the importance of understanding transport phenomena and identifying biotic reservoirs and indicator species to ensure a quality waste management program. Fecal pellets and coyote scats were surveyed for radionuclide content within and adjacent to the B-C crib area. Surveys indicated that most of the transport and dispersion was contained within the 2.4 Km area of the cribs. However, little correlation with field parameters inhibited a statistical evaluation of the overall contamination effect. This study pointed to the need for extensive and scientifically sound reservation specific data to permit sound waste management decisions concerning transport mechanisms.

The biotic transport research strategy has evolved from a basic, somewhat esoteric approach to a more applied nature considered to be more applicable for waste management needs. These studies have included effects of soil affixants on seed germination, seed emergence and plant growth in an attempt to reduce soil-plant transport of radionuclides from disposal sites without reducing vegetative cover important in reducing resuspension and controlling erosion conditions. Diet studies of important biotic species considered potential radionuclide reservoirs have increased considerably. Vegetation, long recognized as an important biotic reservoir for potential transport of radionuclides from waste management areas and subsequent incorporation and transfer through a variety of food chain pathways has recently received additional study. Root distribution profiles have been documented concomittant with soil affixant studies in order to evaluate transport mechanisms and control the dispersion of radionuclides at the source. Vaughan, et al. (1976) have summarized the need for further examination of transport in relation to the relative importance of environmental pathways.

Risk to Man

One of the concerns prompting evaluation of the risk to man from stored rad-waste materials is the potential for radionuclide transport through food chains to man. As noted previously, the organisms having the greatest potential of acting as radionuclide vectors are mule deer, cottontail rabbits, hares, waterfowl, honeybees, and upland game birds. Various approaches can be taken to make estimates on the types, quantities, and resulting radiation doses of rad-waste materials reaching man. One method would be to construct a compartmental ecosystem model, develop the transfer coefficients for each pathway, and then mathematically or numerically evaluate it to obtain estimates on doses to man and the various components within each trophic level (see Chapter VII).

Another approach is to look at each pathway leading to man individually. Data are available on the radionuclide content for the biota which are eaten by man. The waterfowl pathway, provides an example. Coots, represent a "worst possible case" for consuming contaminated wildlife since they inhabit all waste ponds. They have been collected from Gable Mountain Pond for two years from 1974 through 1976 and analyzed for radionuclide content as part of a waterfowl food chain study. The average concentration of ^{137}Cs in the coots' breast muscle averaged 722 pCi/g dry (approximately 180 pCi/g wet). Assuming a person consumed the muscle from one coot a day ($\sim$100 g/day), using values recommended by the International Commission on Radiological Protection (ICRP, 1959) for effective half-time for ^{137}Cs in muscle (138 days) and fraction from GI tract to muscle (0.4), the muscle burden Q_m in the person at equilibrium would be:

$$Q_m(eq) = \frac{(722\ \text{pCi/g dry})(0.25\ \text{dry/wet})(100\ \text{g wet/day})(0.4)}{0.693/138\ \text{day}}\ (1-e^{-\infty}$$

$$Q_m(eq) = 1.44\ \mu\text{Ci}.$$

Since 79% of ^{137}Cs in the body is in the muscle (ICRP, 1959), the total body burden (Q_{TB}) would be:

$$Q_{TB}(eq) = \frac{1.44\ \mu Ci\ muscle}{0.79\ muscle/TB}\ 1.82\ \mu Ci\ TB.$$

This would be 61% of the maximum ^{137}Cs body burden for non-radiation workers (3 μCi TB) and 1.8 times greater than that for the general public (1 μCi) as recommended by ICRP.

Another approach is to look at the total dose to the entire local population of people. There are approximately 300 coots using the Hanford ponds yearly. There are about 150,000 coots in Washington, and approximately 8,000 are shot yearly by hunters. The number of Hanford coots that might be taken annually would be:

$$\frac{300}{150{,}000}\ (8{,}000) = 16\ \text{birds/year.}$$

Then the total amount of ^{137}Cs introduced to food chains of Washingtonians would be:

$$16\ \text{birds/year}\ (722\ \text{pCi/g dry})(0.25\ \text{dry/wet})(100\ \text{g/bird}) =$$

$$0.3\ \mu\text{Ci/year.}$$

Assuming the 0.3 μCi would be distributed evenly to the people in the general area, the total dose commitment (D) from the Hanford coot population each year would be:

$$D = \frac{\left(51\ \frac{rem\cdot dis\cdot g}{mev\cdot day\cdot \mu Ci}\right)\left(0.59\ mev/dis\right)}{(7 \times 10^4\ gTB)(0.79\ muscle/TB)} \int_0^{\infty} \left[0.3\ \mu Ci\ (0.4) e^{-\frac{0.693}{138d} t}\right] dt$$

$D = 1.28 \times 10^{-2}$ man·rem/year

The dose commitment for each coot would be:

$$\frac{1.28 \times 10^{-2}\ \text{man·rem/year}}{16\ \text{coots/year}} = 8.02 \times 10^{-4}\ \text{man·rem/coot.}$$

Data on transuranics in waterfowl are limited. The average concentration of transuranics in coots from U-Pond was:

Sample Type	pCi/g dry ^{238}Pu	$^{239,240}Pu$	^{241}Am
Coots, muscle only	0.021	0.019	0.0081

Taking the same approach as with ^{137}Cs and using ICRP parameters, the dose commitments to the general population would be:

	man·rem/year
^{238}Pu:	3.33×10^{-7}
^{239}Pu:	8.15×10^{-7}
^{241}Am:	3.50×10^{-7}

The same method can be used as data becomes available to estimate the radiation doses to the general population of people living near the Hanford Project.

ECOLOGICAL SURVEILLANCE

Ecological surveillance techniques are generally employed to provide long-term documentation concerning the health of the environment. It is important to note that ecological surveillance programs are inherently different from environmental monitoring programs. Environmental monitoring functions to identify the existence of hazardous radioactive elements in the environment and the risk to biota, especially man. Ecological surveillance identifies deteriorating environmental conditions that could, over a period of time, risk exposure of waste materials to biota. An example might be the gradual degradation of biotic communities inhabiting waste burial sites with resultant increased risks associated with wind erosion and deep water penetration due to absence of cover and elimination of transpiring plants.

Ecological surveillance also serves to identify changes in the taxonomic composition of management areas. The recent re-establishment of elk on the ALE Reserve provides an example. These animals do not now range into waste management areas but they come close. Elk control measures (i.e. fences, browse elimination, etc.) may be required should they extend their range into these areas, especially waste ponds.

Changes in transport pathways should also be assessed as part of any ecological surveillance program. This is an important area of integration between ecological surveillance and environmental monitoring. Environmental monitoring emphasis should always focus on major transport pathways, (i.e. waterfowl), but these can change. The overall research program should identify major pathways and the ecological surveillance program should periodically verify that major changes have not occurred. Should changes occur, the radiation monitoring program should be amended.

Sampling programs associated with ecological surveillance require careful consideration. They are by definition long-term continuing programs. Data gathering methodology must be simple and analytical requirements inexpensive. A rigorous, expensive program may provide a lot of information over a short time period but support on a continuing basis would most assuredly falter.

The best approach is to establish reference environments in both control (undisturbed) and waste management areas. This is necessary since most natural communities change in abundance and composition both seasonally and on a year-to-year basis. Establishing baseline control and waste management study areas will permit population comparisons as a ratio of change in the respective areas. The appropriate test for environmental change is then a comparison of baseline ratios to sample period ratios. (Eberhardt and Thomas, 1974).

ENVIRONMENTAL MONITORING

A continuous monitoring program should be an integrated part of a waste management operation. Pre-operational baseline surveillance information is essential if a monitoring program is to provide reliable measurements of radioactive materials both released at the source and concentrated in the environment. The primary objective should be protection of the environment and more importantly protection of man. A comprehensive and sensitive surveillance of abiotic and biotic components indigenous to waste management areas will result in decreased potential hazards. A well-designed and implemented program should be supplemented by sound ecological principals formulated through site specific research efforts.

Prior to startup of the plutonium production reactors in 1945, scientists at the Hanford site recognized the potential for the radioactivity to be released to the biosphere as the result of plant operations to enter the food chain to man. They recognized the necessity of setting limits on the amounts of radioactive materials released so that inadvertant breathing or ingestion of hazardous amounts would be prevented. They were also concerned with restricting the external radiation dosages to both Hanford workers and the local population to minimize health hazards.

An environmental surveillance program consisting of measurements of radioactivity levels in Columbia River water, fish, and in the air near the reactors and fuel separation facilities was begun in 1945 shortly after startup of the reactors. Biological monitoring was included in this comprehensive site survey. Columbia River water used for once through cooling of the reactors contained radioactive materials when discharged back to the river. The major concern of the early biological monitoring programs was centered on determining the biological fate of this radioactivity released to the river via the reactor cooling water.

The determination of maximum activity densities (i.e. µCi/gm (tissue)) detected in tissues of Hanford Works fauna was initiated in 1947. Fish and waterfowl were regarded as critical biological exposure pathways to man and numerous studies of radionuclide concentrations in their tissues were conducted during the several years following startup of the reactors. The early emphasis was on detecting maximum activity densities in the tissues. The radioanalytical techniques were primitive by today's standards, lacking the sensitivity to measure several isotopes at environmental levels. Several years of data indicated that ingestion of fish containing ^{32}P was probably the critical exposure pathway for dose to man. Ingestion of waterfowl containing ^{32}P was regarded as a secondary exposure pathway.

Early biology research studies conducted on the reservation supported on-going environmental monitoring efforts to ascertain which biota were useful as trend indicators of radioactive contamination and which radionuclides were biologically important. Working independently of the environmental surveillance group biologists studied interactions of biota with radioactive materials to discover whether any unanticipated hazardous situations might exist. The biologists transmitted their findings to the surveillance personnel when potentially hazardous conditions were discovered. For example, researchers found that certain plant species were able to rapidly concentrate fission products from their soil substrate and were thus valuable as indicator organisms.

The environmental monitoring effort expanded to include extensive biological sampling of upland game birds, deer, rabbits, muskrat, mice, coyotes, grasses, aquatic vegetation and even marine shellfish from the Pacific coast. Biology research studies on the dynamics and toxic effects of various radionuclides in living systems grew into numerous sophisticated programs.

Routine monitoring reports detailing radiation levels detected in river water, drinking water, fish, waterfowl, rain, vegetation and air near the stacks of reactors and fuel separation plants have been issued begginning in 1945. The early biological sampling plan was concerned primarily with measuring ^{32}P in tissues of fish and waterfowl from the river and separation plant cooling water ponds and ^{131}I in thyroids of local livestock and jackrabbits. By 1948 numerous instances of contaminated plants had been noted, leading to increased surveillance of vegetation to detect both externally deposited and internally concentrated radionuclides. Extensive sampling of upland game birds in the environs of hanford showed that ^{131}I constituted the most significant potential dosage to man from this source.

Beginning in 1951 a "Biological Monitoring" section was included in the Biology Research Annual Reports. Included in these early reports were attempts to devise ratios between measured radioactivity in wildlife tissues and the emission rates of the detected radionuclides. More applicable methods of specimen collection for upland wildlife and waterfowl and analysis of data were also instituted during 1951. This involved relating tissue activity densities or concentrations to discharge at the source of radioactive wastes from project operations.

Collection of jackrabbits in the vicinity of separation areas during 1951 examined the complexity of deriving a ratio expressed as:

$$\frac{\text{Tissue activity density } (\mu\text{Ci/gm})}{\mu\text{Ci emitted/day}}$$

Variability with the measurement of the ratio resulted in order-of-magnitude differences over a three-month period. Meterological conditions were suspected and investigated further. However, other data derived from the revised collection system proved accurate when applied to other range animals of the Hanford Works. The observed thyroid activity of a feral goat inhabiting the project for eight years was within 10 percent of the predicted value. Significant contamination of waterfowl utilizing a waste-water pond in one of the Separations Areas was also investigated. A maximum total beta activity density of 42,000 d/m/g was noted in muscle and liver. Fission product contamination was noted in feces, kidney and lung samples of all upland game species. This represented fall-out of air-borne particles from Nevada and Enewetak nuclear tests. Maximum total beta activity density observed in the above sample was 120 d/m/g.

Experiments to determine the concentration ratios in ducks were also begun. Ducks were maintained at a disposal ditch containing fission products and on the Columbia River downstream from the pile effluent release points on the reactors. Biological half times of the isotopes in the waterfowl were also calculated, leading to the judgment that ^{32}P and the rare earths were the principal isotopes concentrated in the tissues with Zn and Co representing minor activity.

Extensive ecological and radiological characterization of Columbia River biota was undertaken in 1952. Activity density measurements of fauna within the reservation were expanded by sampling mice thyroids, insects and vegetation near the fuel separation stacks for ^{131}I. Fission products were measured in the muscle, organs and feces of upland game birds. Studies on the radionuclide content in crops irrigated with reactor pile effluent were continued. In addition aquatic food chain studies of radionuclide transfer rates from algae to fish were initiated. Studies continued also on plant uptake of fission products. Metabolic studies on plutonium and tritium in rats were begun. Studies on developing a concentration ratio to relate ^{131}I thyroid activity densities to discharge rate were expanded to include the relationship between activity in vegetation at several sites near separation plant stacks.

During 1953, the Hanford reservation biological monitoring program was concerned with the determination of amounts of radioisotopes assimilated by reptiles, birds, and mammals. Of particular interest were those species which were termed game animals, as many were migratory in habit and may have represented a potential health hazard to consumers. Three principal phases of the problem were under investigation: (a) ^{131}I concentrations and concentrations of mixed fission products in upland wildlife, (b) ^{32}P concentrations in tissues of waterfowl utilizing the Columbia River, and (c) concentrations of fission products in tissues of waterfowl inhabiting waste ponds containing trace amounts of fission products. Plant uptake studies measured the accumulation of ^{144}Ce. The accumulation of ^{106}Ru in waterfowl muscle was also studied.

Comparison of thyroid activity densities with vegetation activity densities at collection sites suggested stability of this ratio as the distance from the radioiodine source increased. Evaluation of the possible influence of inert iodine on this stability, begun in September of 1952, showed no significant difference between the various collection sites in ^{129}I content of thyroid glands.

Hanson and Browning, 1953, investigated the relationship of the ratio (thyroid activity density/^{131}I emission rate) in rabbits on the Hanford project from a temporal and meteorological sense. The general conclusions were that the observed variability was a response to wind dilution, rainfall, temperature and fallout of airborne particulates of offsite origin.

Tissue samples of immature ducks maintained at a disposal ditch containing fission products exhibited an activity density in cranium exceeding that of the water by a factor of 1.5×10^5 following 45 days exposure to the effluent mixture. All tissues then exhibited a steady decline at a half-time rate of 32 to 35 days over a four-month period. Preliminary decay curve and radiochemical analyses indicated ^{32}P and rare earths to be the principal isotopes in most tissues, with the copper-arsenic and zinc-cobalt groups representing approximately eight percent of total activity present.

New studies in 1954 included studying tritium absorption by aquatic organisms. Studies began on ^{131}I toxicology in sheep. Researchers discovered that cliff swallows with access to radioactive mud from the river shore and near the cooling water ponds had accumulated detectable levels of radioactivity in their bones.

Following the 1954 year of observation, the number of rabbit sampling sites utilized for monitoring purposes was increased from five to seventeen to relate tissue concentrations of radioactive substances to the discharge of airborne radioactive wastes from the Hanford reservation. Typical seasonal variation was again noted. Comparison of the relation of ^{131}I concentrations in thyroid glands to that on vegetation at three selected sites (Table VIII-I) showed a decrease in concentration with increased distance from ^{131}I emission points.

TABLE VIII-1. Relation of I^{131} Concentrations in Thyroid Glands to that on Vegetation

Distance from I^{131} Emission Point (Miles)	I^{131} Concentration in thyroid/ I^{131} Concentration on Vegetation	
	Average	Range
1.5	4000	1000 - 10,000
6	1300	200 - 3,500
13	1100	200 - 2,500

Studies on activity levels in fauna were expanded to include reptiles in 1956. Radioanalytical techniques had progressed to the point where detection of ^{137}Cs and ^{90}Sr in pond and river waterfowl tissues with the activity in their food items was completed. Radioecological characterization of the Columbia River was still of primary concern, and studies on the effects of reactor effluents on crops and fish continued. Plant uptake studies on ^{90}Sr were expanded in 1957. Attempts began to devise a ratio between Sr and Ca uptake in plants. A simulated cooling water pond spiked with ^{137}Cs was constructed for studying the transfer of Cs through aquatic food chains.

Simulated cooling water pond studies were continued in 1958. Feeding studies with trout assessed toxic effects of ^{32}P. Sheep and swine fed with ^{131}I spiked food were studied to assess biological effects. Shells and yolks of Canada goose eggs were analyzed for ^{32}P content. Feeding studies on trout to determine toxic effects of ^{90}Sr and ^{90}Y were initiated in 1959. Studies continued to assess plant uptake of ^{90}Sr and ^{131}I. Attempts to correlate Cs uptake with K uptake by plants were begun. Mapping of plant communities on the reservation began and a series of plots were established for assessing long-term plant succession.

New studies in 1960 included feeding ^{90}Sr to swine to determine the metabolism and assess any toxic effects. Expanded efforts in estimating dosages to the local population led to a cooperative wildlife study during the local hunting season in the Hanford vicinity. Approximately 601 waterfowl heads were submitted for ^{32}P and ^{65}Zn analysis. After about 1961 the focus of biological field studies other than those associated with the Columbia River was shifted to Alaska. Studies of ^{90}Sr and ^{137}Cs in the lichen-caribou-Eskimo food chain resulting from the atmospheric testing of nuclear devices were receiving world-wide attention at the time. Hanford biologists involved in conducting field studies were reassigned to study food chain transfers of Sr and Cs in Alaska.

Biological monitoring programs continued as part of the site-wide environmental surveillance effort. The river water and organisms downstream from the reactors were routinely sampled for ^{32}P and ^{65}Zn content. Native grasses, local hay and produce from a large area surrounding Hanford including locations in Oregon and Idaho were analyzed routinely for ^{131}I, ^{106}Ru and ^{144}Ce.

Ingestion of fish from the Columbia River was still regarded as the critical exposure pathway to man in 1966. Surveillance personnel at that time undertook the task of whole body counting representatives of the local population, especially fisherman, to determine their body burdens resulting from ingestion of contaminated fish.

A new facet of biological sampling in 1968 involved inclusion of game bird samples collected from a large area of land northeast of the reactor areas recently opened for hunting.

Beginning in 1970 offsite and onsite surveillance results were reported annually by Battelle-northwest in two separate documents entitled "Environmental Status of the Hanford Reservation" and "Environmental Surveillance at Hanford". In addition, the master sampling schedule for the upcoming year was published in advance of the new sampling year.

The "Environmental Status" series of documents reports and evaluates surveillance results obtained from sampling within the plant boundaries. Radiation levels in wildlife, vegetation, air, drinking water and sediments are reported and interpreted in terms of radiation dosage and potential hazard to man. Tables VIII-2 through VIII-7 show results of biological sampling from onsite locations for 1970-1975.

Table VIII-2 shows the average radionuclide concentrations in muscle of waterfowl collected within the site. This shows that since 1970 ^{137}Cs has been the radionuclide found in greatest quantities in waterfowl, with birds collected from Gable Pond and U-Pond containing the highest concentrations. Table VIII-3 shows that ^{32}P and ^{65}Zn levels were elevated in upland game birds collected from the river area until the last reactor shut down in 1971. Levels of ^{137}Cs, ^{90}Sr, and ^{60}Co have remained low in recent years.

Jackrabbits have been used as indicators of environmental radiation since 1948 and are still serving that purpose today. Table VIII-4 shows that bone ^{90}Sr levels are elevated in rabbits collected near the B-C Cribs in the 200 East area. This area was the site of extensive surface contamination with ^{137}Cs and ^{90}Sr when Jackrabbits gained access to buried radioactive salts, subsequently depositing contaminated fecal pellets and urine spots over a wide area. The jackrabbit data are sparse and inconsistent since variations in sample number and radionuclide analysis have occurred.

Mice have also been used as indicators of environmental contamination for over 20 years. The highest concentrations in mice tissues have usually occurred in the 100 areas where mice are able to drink water from open reactor waste water trenches. (Table VIII-5)

Limited numbers of deer have been sampled from within the Hanford environs to provide information on radionuclide content in the tissues of big game animals. (Table VIII-6) Examination of the limited data available reveal no significant concentrations of radionuclides in Hanford deer.

The series of monitoring reports, "Environmental Surveillance at Hanford" presents and evaluates data from the offsite surveillance program. The documents report on radiation levels in the Hanford environs and evaluates their source, whether from natural causes, fallout or Hanford operations. Environmental data on nonradioactive pollutants in the air of the Hanford vicinity and on the chemical and biological quality of the Columbia River are also included. The radioactive and nonradioactive pollutants are compared with standards set by DOE, Washington State and the EPA to determine whether compliance has been achieved.

Routine onsite surveillance for the chemical processing areas has been conducted since 1967. The purpose of the monitoring program is to evaluate the effectiveness of waste management procedures and to demonstrate compliance for effluent releases as established in DOE Manual chapters 0524 and 0510. In 1975 the first of a new series of annual reports describing and evaluating the results of this onsite program were issued. Included in this program is biological monitoring of aquatic vegetation in the cooling water pond and ditches, vegetation from the areas where unplanned releases have occurred (B-C Cribs Controlled Areas), jackrabbits, mice and waterfowl. This onsite program is being continually upgraded and an expanded biological monitoring program with adequate sampling of control areas is planned.

In addition the last of the once through cooling water reactors was shut down in early 1971 leading to a reduction in biological studies on the Columbia River. Since the early 1970's numerous research studies have been conducted in the 200 Areas. These include studies on the dynamics of radionuclide cycling in the aquatic ecosystem of the cooling water ponds and characterization studies of vegetation, mammals, reptiles, insects and birds. These studies take the total ecosystem approach and are geared toward understanding and quantifying the cycling of radioactive materials through all of the ecosystem compartments existing in the vicinity of the chemical separation and waste management areas. Increased understanding and awareness of the ecological processes existing in these areas is leading to development and implementation of environmentally sound land and wildlife management technology.

A chronological listing of important references pertaing to the biological research program is included in Appendix C. Appendix D contains a partial listing of references for the biological monitoring portion of the environmental surveillance program at Hanford. These references served as the data source for much of this discussion concerning past environmental monitoring activities. Appendix E details the surveillance effort as it exists today.

TABLE VIII-2. Average Radionuclide Concentrations in Muscle of Waterfowl 1970 - 1975

Units of 10^{-6} μCi/gm wet weight

	^{137}Cs		^{90}Sr		^{60}Co		^{65}Zn	
Gable Pond								
1970	133	(5)	0.97	(5)	0.8	(3)	0.48	(5)
1971	34	(4)	0.005	(4)	<0.15	(4)	0.34	(4)
1972	26	(4)	0.003	(4)	<0.15	(4)	<0.20	(4)
1973	31	(6)	0.036	(6)	0.25	(6)	<0.20	(6)
1974	66	(5)	0.06	(5)	0.08	(5)	<0.20	(5)
1975	72	(4)	0.03	(4)	<0.2	(4)	<0.3	(4)
B-Pond								
1970	12.3	(28)	9.1	(27)	0.75	(5)	0.96	(26)
1971	2.2	(4)	0.04	(4)	<0.15	(4)	0.03	(4)
1972	3.3	(4)	0.003	(4)	<0.15	(4)	0.11	(4)
1973	6.7	(4)	0.008	(4)	<0.15	(4)	<0.20	(4)
1974	4.6	(3)	<0.005	(3)	<0.11	(3)	<0.3	(3)
1975	9.7	(4)	<0.03	(4)	<0.2	(4)	<0.3	(4)
U-Pond								
1970	32.6	(14)	0.33	(14)	1.0	(5)	1.83	(14)
1971	78	(4)	0.001	(4)	<0.15	(4)	<0.2	(4)
1972	27	(2)	0.006	(2)	<0.15	(2)	<0.2	(2)
1973	22	(1)	0.020	(1)	<0.15	(1)	<0.2	(1)
1974	29	(3)	0.007	(3)	<0.2	(3)	<0.3	(3)
1975	25	(3)	<0.02	(3)	<0.2	(3)	<0.3	(3)
Redox (S-16)								
1970	8.5	(3)	0.09	(3)	0.51	(1)	1.11	(3)
1971	51	(4)	0.005	(4)	<0.15	(4)	<0.2	(4)
1972	3.1	(2)	0.054	(2)	<0.15	(2)	<0.2	(2)
1973	3.8	(3)	0.10	(3)	<0.15	(3)	<0.2	(3)
1974	120	(1)	0.007	(1)	<0.2	(1)	<0.2	(1)
1975	Deactivated							
T-Pond								
1970	26	(1)	<0.42	(1)	1.0	(1)	2.7	(1)
1971	---		---		---		---	
1972	70	(1)	0.003	(1)	0.20	(1)	0.4	(1)
1973	---		---		---		---	
1974	---		---		---		---	
1975	47	(1)	0.01	(1)	1.8	(1)	13	(1)

Table VIII-2 (continued)

	^{137}Cs		^{90}Sr		^{60}Co		^{65}Zn	
100-F Trench								
1970	0.11	(1)	8.3	(5)	---		0.4	(1)
1971	0.17	(2)	0.11	(2)	<0.15	(2)	0.36	(2)
1972	0.14	(3)	0.11	(3)	<0.15	(3)	0.14	(3)
1973	<0.1	(3)	0.008	(3)	6.3	(3)	<0.20	(3)
1974	<0.1	(2)	0.05	(2)	<0.17	(2)	<0.3	(2)
1975	0.06	(2)	0.02	(2)	<0.2	(2)	<0.3	(2)
300 Area Pond								
1970	<0.1	(3)	<1.6	(2)	0.34	(3)	2.38	(4)
1971	0.06	(2)	0.001	(2)	<0.15	(2)	0.04	(2)
1972	<0.11	(5)	<0.002	(5)	<0.15	(5)	<0.20	(5)
1973	0.23	(3)	0.017	(3)	<0.15	(3)	<0.20	(3)
1974	<0.1	(2)	<0.005	(2)	<0.2	(2)	<0.3	(2)
1975	0.05	(2)	<0.005	(2)	<0.2	(2)	<0.3	(2)

Data taken from series "Environmental Surveillance at Hanford for CY-19xx" for years 1970-1975.
Number in parentheses indicates sample size.

TABLE VIII-3. Maximum Radionuclide Concentrations in Muscle of Upland Game Bird 1968 - 1975
P Ci/g Wet Weight

	^{137}Cs	^{90}Sr	^{65}Zn	^{60}Co	^{32}P
1968	<0.61		12.0		490
1969	0.28		11.0	<0.15	340
1970	2.4		8.4	0.41	26
1971	0.13	0.013	0.35	0.14	
1972	0.24	0.008	0.56	<0.15	
1973	0.02	0.019	0.07	0.03	
1974	<0.11	<0.004	<0.20	<0.10	
1975	0.10	0.08	<0.26	<0.14	

Blank spaces indicate no analysis was done.
Data for 1968-1969 taken from series "Evaluation of Radiological Conditions in the Vicinity of Hanford"
Data for 1970-1975 taken from series "Environmental Surveillance at Hanford for CY-19xx"

TABLE VIII-4. Average Radionuclide Concentrations in Muscle of Jackrabbits 1970 - 1975
pCi/gm Wet Weight (muscle)

	^{137}Cs	^{90}Sr	^{60}Co	^{65}Zn	U	Pu
200 West						
1970	0.53 (1)[1]	0.021 (1)	-	0.72 (1)	-	-
1971	-	0.007 (1)	-	-	-	0.004 (1)*
1972	9.8 (1)	0.066 (1)	-	-	-	0.004 (1)*
1973	-	-	-	-	-	
1974	-	-	-	-	-	-
1975	3.05 (1)	1.98 (2)**	0.4 (1)	-	-	0.0005 (2)
200 East						
1970	2.3 (1)	0.22 (1)	-	0.68 (1)	-	-
1971	0.64 (2)	0.011 (2)	-	0.02 (2)	-	0.0002 (1)*
1972	1.3 (1)	0.020 (1)	-	-	-	0.0003 (1)*
1973	3.0 (1)	0.089 (1)	-	-	-	0.003 (1)*
1974	2.47 (4)	103.7 (5)**	0.09 (1)	-	-	-
1975	1.1 (2)	184.0 (3)**	3.0 (2)	-	-	0.0013 (3)
100-N						
1970	-	-	-	-	-	-
1971	-	-	-	-	-	-
1972	0.13 (1)	0.004 (1)	-	-	-	-
1973	-	-	-	-	-	-
1974	-	-	-	-	-	-
1975	-	-	-	-	-	-

*Liver
**Bone
1 Number in parenthese indicates sample size.
Data taken from series "Environmental Status of the Hanford Reservation for CY-19XX" for years 1970-1975.

TABLE VIII-5. Average Radionuclide Concentrations in Muscle of Mice 1970 - 1975 pCi/gm Wet Weight (muscle)

	^{137}Cs	^{90}Sr	^{60}Co	^{65}Zn	U	Pu
200 West						
1970	-	-	-	-	-	-
1971	26.0 (4)[1]	7.0 (3)	0.2 (2)	0.7 (2)	0.2 (1)	<0.02 (2)
1972	-	5.0(2)	-	-	0.34 (1)	0.02 (2)
1973	1.03 (6)	0.31 (6)	0.7 (4)	0.92 (2)	0.36 (4)	0.006 (2)
1974	59.0 (3)	4.4 (3)	0.4 (1)	1.1 (1)	0.4 (2)	0.20 (2)
1975	-	-	-	-	-	-
200 East						
1970	-	-	-	-	-	-
1971	1.8 (4)	5.8 (5)	-	1.52 (3)	0.27 (1)	<0.02 (2)
1972	3.4 (1)	0.92 (1)	-	-	-	0.006 (1)
1973	-	-	-	-	-	-
1974	-	0.91 (1)	-	-	-	-
1975	5.0 (3)	1.38 (6)	-	-	-	-
100-N						
1970	2.7 (4)	1.3 (4)	0.67 (4)	5.9 (4)	-	-
1971	190.0 (1)	3900.0 (2)	240.0 (1)	-	0.52 (1)	<0.02 (1)
1972	102.0 (4)	21.0 (4)	3220.0 (4)	172.0 (3)	-	<0.10 (2)
1973	57.0 (5)	46.0 (6)	19,520 (5)	337.0 (3)	-	0.43 (2)
1974	1200.0(2)	54.0 (2)	11,000 (3)	68.0 (1)	-	-
1975	500.0 (3)	57.0 (3)	2347.0 (3)	-	-	-

* Liver
1 Number in parentheses indicates sample size
Data taken from series "Environmental Status of the Hanford Reservation for CY-19XX" for years 1970-1975

TABLE VIII-6. Maximum Concentration of Radionuclides in Deer 1970 - 1975
(pci/g Wet Weight)

Year	Tissue	^{137}Cs	^{90}Sr	^{65}Zn	^{60}Co	^{40}K	^{239}Pu
1970	Muscle	1.5	0.15	9.6	1.0		
	Liver						
1971	Muscle	0.06		0.11			
	Liver	0.07[2]	0.02[1]				0.01
1972	Muscle	0.24	0.48[3]	0.081			0.009[3]
	Liver						0.00008
1973	Muscle	0.51	*	0.097			
	Liver						0.0002
1974	Muscle	1.8	*	*		2.3	
	Liver						0.0004
1975	Muscle	*	0.022[3]		0.05	2.8	
	Liver	*					0.0004

[1] Lung

[2] Heart

[3] Bone

*Less than analytical limit: Blank indicates no analysis was done
Data taken from series "Environmental Status of the Hanford Reservation" for CY1970-1975

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CHAPTER IX. FUTURE RESEARCH NEEDS

L. E. Rogers and D. A. Cataldo

The future research needs of the biotic transport program are identified in terms of six research categories. Each category is identified with a starting date, period of emphasis and completion date. Research tasks are identified for each category and scheduled in a milestone chart. Task interrelationships are identified in a flow diagram to facilitate program management.

RESEARCH STRATEGY

Consideration of long-term funding pattern requirements must be based on a carefully considered research program. Intermediate goals must be established so that research results become available as particular program categories progress. The biotic transport studies appear to fall into six general categories as outlined below:

- characterization
- biotic production
- transfer processes
- radionuclide transport
- environmental assessment
- management modeling

This section provides a research outline for the creation of a substantial data base for the 200 Area waste management system. This structure will provide adequate environmental characterization, permit prediction of radionuclide movement within the environment, and provide ecological surveillance techniques to assure preservation of environmental quality. It is essential that waste management techniques remain in close association with the evolution of ecological theory. Only in this way will waste operations demonstrate current ecological state-of-the-art capabilities and maintain the support of both scientific and public communities.

The pattern of past and future research emphasis is shown in Figure IX-1. This figure was constructed by placing past studies into the proposed research structure. It shows that characterization studies were emphasized for about

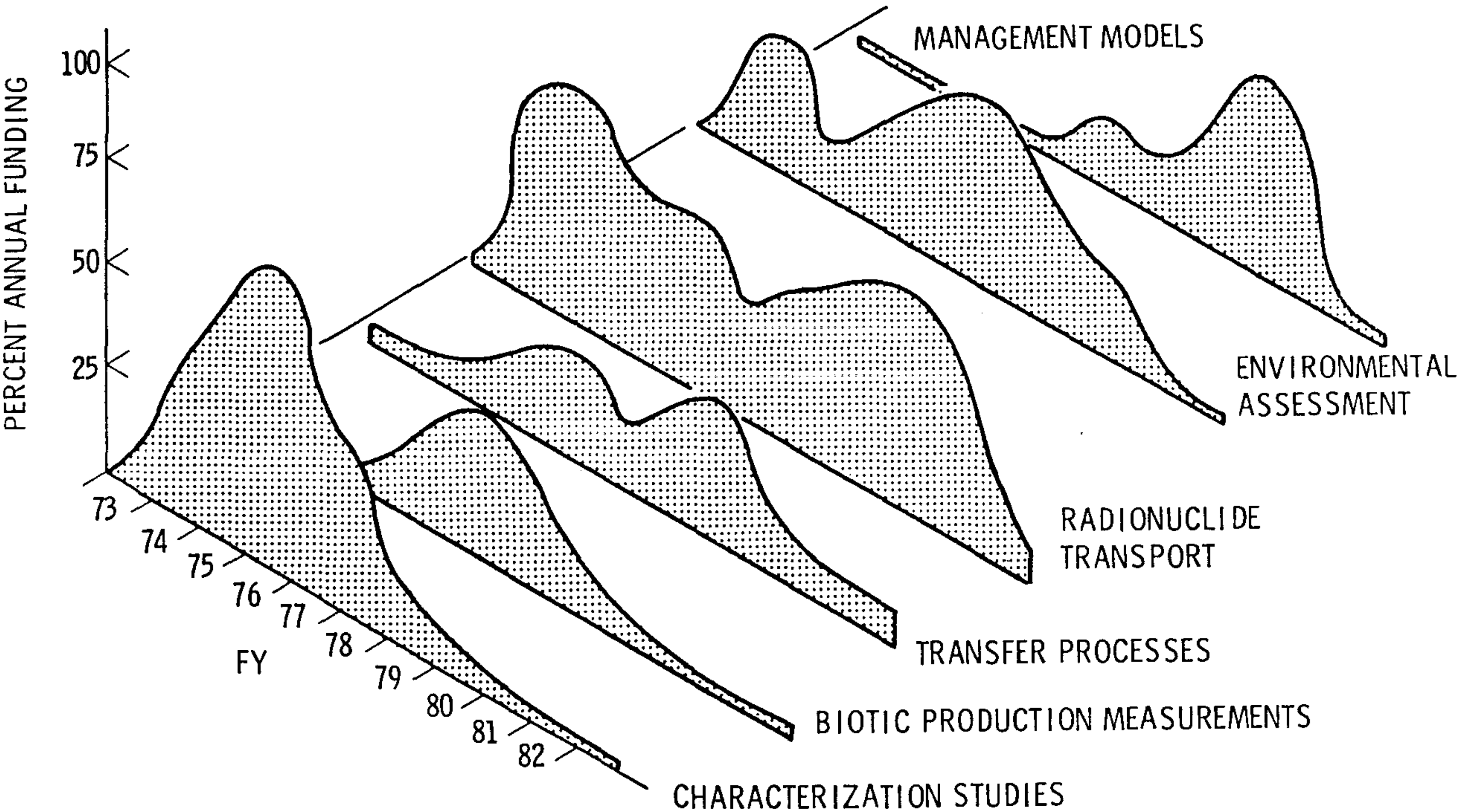


FIGURE IX-1. Past and Projected Biotic Transport Funding Patterns

3 study years. Studies concerning biotic production estimates and transfer pathways should receive greater support as characterization studies decline in emphasis. Radionuclide transport studies were heavily supported during early study years when little was known about biotic uptake of even very common plants (i.e., Russian thistle). Greater emphasis will again be required as biotic production, environmental assessment, and transfer process studies identify important producer and consumer components. Environmental assessment studies need to be maintained at a fairly high level to permit special studies of potential problem areas concerning interaction of biota with waste storage systems (i.e., burrowing animals, jackrabbits, herons, etc.). Finally, modeling efforts will provide the methodology integrating a vast and complex array of ecological data into an understandable ecological management program. It is important to recognize that a continual flow of research results will be available throughout the program duration. These research results will continue to be documented in some mutually agreeable format.

CHARACTERIZATION STUDIES

These studies represent initial efforts in ecological assessment of 200 Area plateau waste management areas. This phase is essentially complete. A great deal is now known concerning the kinds of biota occupying the general area, their relative abundance and habits. This work has resulted in the issuance of several research documents with several more planned for release this year.

The only studies remaining for characterization include: 1) soils, and 2) dose distribution evaluation. Soils work is necessary to verify some of the old area soil maps and to provide a characterization of soil types according to texture, carbon content, and exchange capacity. An evaluation of dose distribution is needed to document the dose associated with above and below ground biotic components of waste burial sites. Analysis of characterization results will assist in the design of quantitative studies to assess potential transfer rates for radioactive materials.

BIOTIC PRODUCTION ESTIMATES

Estimates of biotic production in terms of density and biomass are needed as basic data for input to other study segments. When coupled with body burden data derived from the environmental assessment phase, an evaluation of the role biota play as reservoirs of radionuclide material will be obtained. Integrating production estimates with studies planned for the transfer pathway and radionuclide movement phases will provide an estimate of the rate of radionuclide uptake and potential for transport away from management areas. Quantitative estimates are needed for most biotic components (i.e., plants, mammals, insects, birds). Additional data are needed pertaining to the impact of seasonal climatic variations on annual biotic production values. Although biotic production studies have been emphasized at Hanford for the past several years, each year essentially represents one data point--making extrapolation difficult for possible future climatic events. A combination of manipulative experimental and field data gathering studies should be conducted to further document system dynamics.

The status of producer studies is shown in Figure IX-2. Assessment of plant frequency and cover is reasonably complete for all taxa. Density estimates are not required for grasses and forbs and are judged to be about 60% complete for shrubs. Biomass estimates (g/m^2) are nearly adequate for the live (green) component but little is known about the dead, crown or root components. The dead category refers to both standing dead and litter. Data pertaining to this category have been gathered during related studies but may not directly apply to waste management sites. Accurate biomass estimates are needed as a basis for radionuclide transfer predictions. The status of secondary producer (consumer) studies is shown in Figure IX-3.

TRANSFER MECHANISMS

This research category would support those studies designed to evaluate mechanisms whereby radionuclides could be transported via both abiotic and biotic system components. The abiotic studies should involve an experimental assessment of the relationship between vegetative cover, soil erosion, and radionuclide movement. Biotic studies would identify mechanisms whereby radionuclides might be introduced into food chains and the potential for transport through resulting food webs to higher order consumers or to points away from management areas. Energy flow studies would document how material flows through the system, i.e., through many small channels or a few major channels. This sort of information has important management implications. Food chain knowledge is developed by an understanding of interactions between consumers and their food base. The food habits of some consumer groups are well established for 200 Area populations. Little work remains to be done on raptors but much less is known about some of the other groups--shorebirds, large mammals, etc. Consumption rate data is fairly well documented in the scientific literature for most groups and probably need not be repeated here.

RADIONUCLIDE UPTAKE AND TRANSPORT

Studies concerned with radionuclide uptake by plants inhabiting waste burial sites represent some of the first ecological studies funded. These studies are continuing for major plant species occupying burial sites. Data concerning radionuclide uptake and transfer rates needs to be gathered for consumers as well as producers since a greater potential exists for transfer of radionuclides away from management areas by animals (i.e., jackrabbits).

Results of radionuclide movement studies will be integrated with results from production and transfer categories to permit construction of management models predicting radionuclide transfer patterns and ecological response to environmental perturbations.

The radionuclide dynamics of annual grasses (cheatgrass) is well known. Less is known about forbs and shrubs. A dearth of information presently exists for perennial grasses of the 200 Area ecosystem. A similar situation exists for consumer groups. A substantial literature exists concerning radionuclide dynamics of small mammals and to a lesser extent large mammals, (deer, cattle, etc.). Less is known about the insect and bird species.

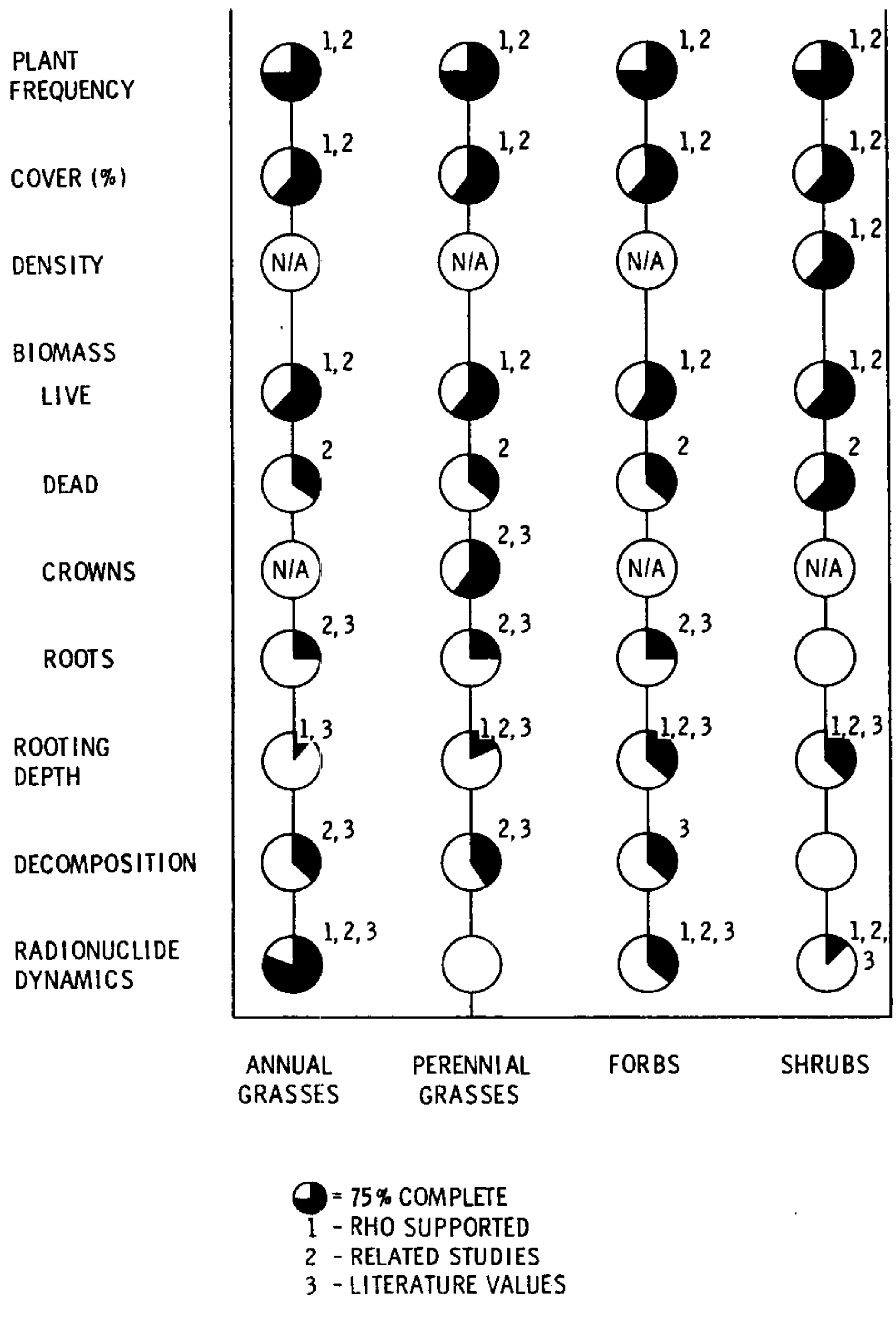


FIGURE IX-2. Status of Producer Studies on the 200 Area Plateau

These studies should receive greater emphasis during the next 5 year period. The present status of the data base for radionuclide dynamics is shown in Figures IX-2 and IX-3.

Future efforts in the area of soil-plant relations should be addressed not only to specific waste management problems but encompass a broad scope to understand transport problems of the ecosystem as a whole. Several study areas are proposed. These relate to both short-term waste management problems, development of a basic understanding of the mechanisms involved and factors controlling the availability of radionuclides for plant uptake, and the potential for transfer of radionuclides, contained in plant tissues, along the food web.

The availability of radionuclides for transfer from soils to plants is the result of a complex set of conditions, both biotic and abiotic. Since soils indigenous to the 200 Area plateau are physically very similar, it becomes difficult to develop predictive criteria in evaluating short or long-term potential with respect to plant availability of radionuclides and subsequent transport in the environment. In this type of situation, the major factors affecting radionuclide uptake by plants may, in fact, be changes in soil characteristics as a result of waste management practices. Factors known to affect plant uptake of elements, and which would be operational in waste management areas include pH, salinity, organics and presence of competitive analogs. Studies designed to evaluate the effects of these parameters would provide a basis for understanding mediating influences and be useful in specifying remedial practices for waste management.

The extensive use of herbicides to control deep-rooted annuals and perennials around waste storage areas and the presence of large quantities of organic complexing agents in wastes presents a special problem. Organic compounds can complex otherwise insoluble elements making them more available for bioaccumulation. The problem becomes even more complex when one considers the effect of these added organic substrates on soil microbial populations and their subsequent modification of noncomplexing organics to forms which do possess the potential for complexing radionuclides, and their metabolic potential for producing metal binding ligands. This aspect of waste management has received little attention in the past and must be considered with respect to long-term containment problems.

Although the soil-plant transfer rate is employed to predict the flow of radionuclides in the environment, many assumptions are employed to evaluate transfers from one trophic level to another. Two areas requiring study include the fate and availability of radionuclides contained in litter-fall and the availability of radionuclides contained in plant tissues upon ingestion by foliar feeding animals (insects and vertebrates). Nutritional studies have shown that required inorganic nutrient elements derived from plant tissues are more available on ingestion than ingestion of inorganic forms. These studies have shown many plant-derived elements to be present as organic complexes which increase their rate of gut transfer. Although a similar situation may exist with respect to radionuclides, predictive models seldom account for

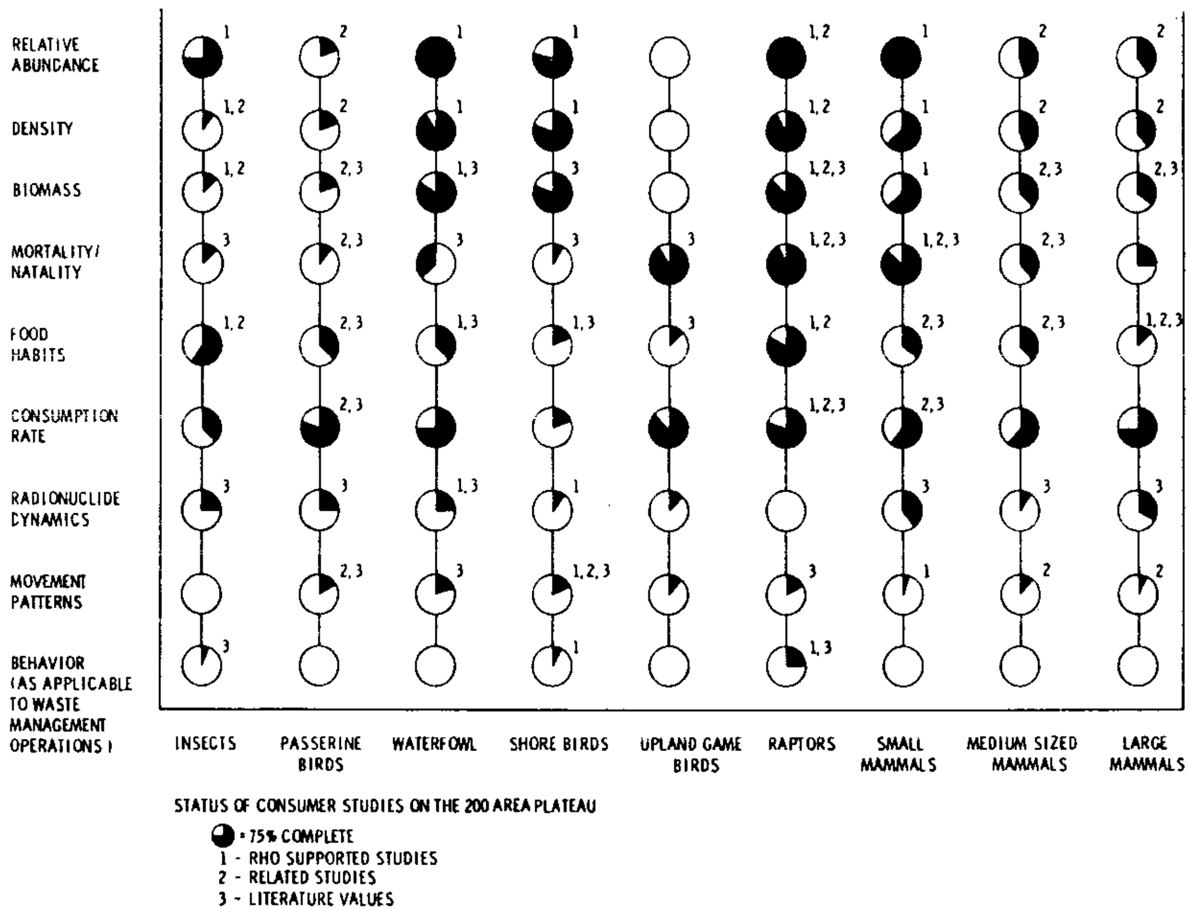


FIGURE IX-3. Status of Consumer Studies on the 200 Area Plateau such behavior. This problem of biomodification also relates to the fate of radionuclides in litter-fall. Radionuclides present in litter may be more available than inorganic forms on ingestion by ground-dwelling invertebrates, or on decomposition of the litter by microbial action may be more mobile in the soil profile and more available for subsequent plant uptake.

Although these various problems are complex and interrelated, an understanding of these complex interactions are essential to a long-term commitment to safe and effective waste management practices. Future studies will also need to be broadened in scope to include many other fission products, and actinides and investigations performed under closely-controlled conditions, especially with respect to chemistry.

ENVIRONMENTAL ASSESSMENT

This category represents, in many ways, those special studies needed to answer particular questions or solve particular ecological problems related to waste management operations. Examples include: 1) burrowing animal studies--designed to ascertain their role in exposing radioactive wastes; 2) Great blue heron pond usage--to document the importance of this pathway as a dispersal route via goldfish and other biota from waste ponds; 3) jackrabbit population studies--they are periodically abundant around the B-C Cribs area and need close surveillance since they have been implicated in waste dispersal; 4) honeybees--a direct link to man and they frequently occur near ponds at Hanford; and 5) waterfowl studies--another link to man; possibly needs population turnover or population management study orientation.

Surface water is also of concern as a source for biotic transport as long as ponds and ditches remain part of the waste management environment. Some data now exist for the ditches and ponds, mostly collected under ERDA-funded projects. While these data are available, the studies are mostly designed to understand basic system interactions and may not fully meet RHO needs as management tools. We suggest close interaction with these studies and RHO funding of appropriate study segments to clarify the interaction between aquatic and terrestrial systems and to document potential transport away from aquatic areas.

In addition, future land use scenarios would be considered here as well as assessment of biota as radionuclide reservoirs. No attempt has been made to document the total amount of radioactive waste residing in the biotic component. This should receive intensive study during the period FY 78-79. Radiological surveillance reports provide some insight as to body burdens for some biotic segments but does not permit ecological inferences to be drawn for all components. Knowledge concerning amounts of radioactive materials residing in particular biotic components will be used to direct radionuclide uptake and transfer study efforts.

MANAGEMENT MODELING

Construction of management models should be the final goal of the biotic transport program. One major benefit of ecosystem modeling is that it serves to integrate individual study programs. Past experience has shown that model construction frequently results in exposure of data base "holes" for essential parameters. For this reason, an initial, low-level modeling effort should be initiated in FY 78. This would identify model parameters, data base sources, and assure successful model completion once an adequate data base has been established. Flow sheets describing the requirements for model construction, percent of the data base currently available and data source within the proposed research structure are shown in Figures IX-4 to IX-9. As an example, the producer submodel requires data concerning plant species present (Figure IX-5). This need is met in the characterization category where we have 100% of the needed information available. This type of approach clearly shows where the responsibility rests for providing needed information and identifies requirements that must be met when establishing plans for particular research categories.

RELATED STUDIES

There are currently several other ecological studies being conducted at Hanford that relate in some manner to RHO's role in managing radioactive waste burial sites. These include:

- ALE Animal Ecology Studies
- ALE Plant Ecology Studies
- Transuranic Weathering in Vegetation
- Transuranic Complexation, Soil, Plant
- Radioecology of Uranium
- Radioecology of I-129 and Tc-99
- Ecological Distribution of Radionuclides in U-Pond
- Radioecology of Waste Management Areas

The ALE studies were most beneficial during the initial phase of the 200 Area studies. General characterization techniques and methodologies developed under these programs have been applied to the RHO-supported work. Long-term studies concerning plant uptake of transuranic elements will provide information valuable to RHO although these studies are not designed for the specific conditions existing at the 200 Area burial site. The program most compatible with RHO needs concerns the radioecology of waste management areas (ROWMA). The objectives of the ROWMA programs are oriented more toward understanding mechanisms associated with the interaction of biotic and abiotic components with radioactive wastes. There are, however, ample opportunities to integrate ROWMA and RHO-supported studies for the benefit of both.

INTENSIVE STUDY AREAS

Ecological research of any large area usually requires establishment of smaller representative study sites. This permits a focusing of effort on specific locations rather than diluting the effort over a broad landscape. Past characterization studies utilized study sites near the B-C Cribs, REDOX Pond, several pond areas, burial grounds, and some scattered sites associated with raptor studies.

The research emphasis is now shifting from characterizing the environment to understanding the mechanisms of radionuclide transport. This will require establishing research sites in some new areas to expand the present data base. Study areas presently under consideration as representative of the 200 Area waste management operations include:

- undisturbed (control) area
- liquid subsurface disposal site
- solid disposal site
- shallow dispoal site
- aquatic/riparian site

This list represents the general kinds of sites presently considered. The criteria for site selection is an important consideration and needs to be established after careful consideration of both short- and long-term, planned studies. Characterization studies were usually located along side rather than within control boundaries obviating the need for expensive monitoring procedures and increasing program cost effectiveness. It is now necessary to establish study areas within control boundaries, particularly in areas with above background radiation levels if possible, to begin analyzing transport mechanisms.

The major consideration for selection of study sites must rest on the applicability for specific sites to RHO-sponsored research program. However, a major intent of the future research program is to closely integrate RHO-sponsored ecological research with other related studies. The site selection process will include input from the principal investigators of related studies. Hopefully, selected sites will be compatible to both RHO and other DOE funded studies--expanding thr ecological data base for all in the most cost effective manner.

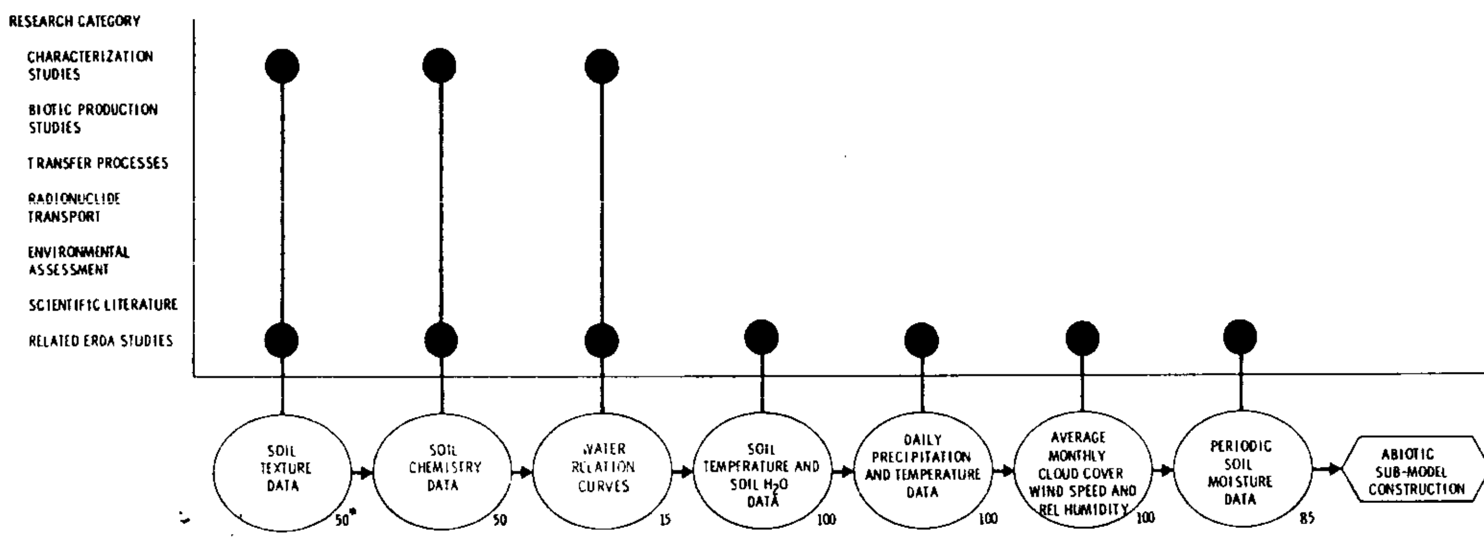


FIGURE IX-4. Data Sources for Construction of Abiotic Simulation Model. (* = % data requirement currently available)

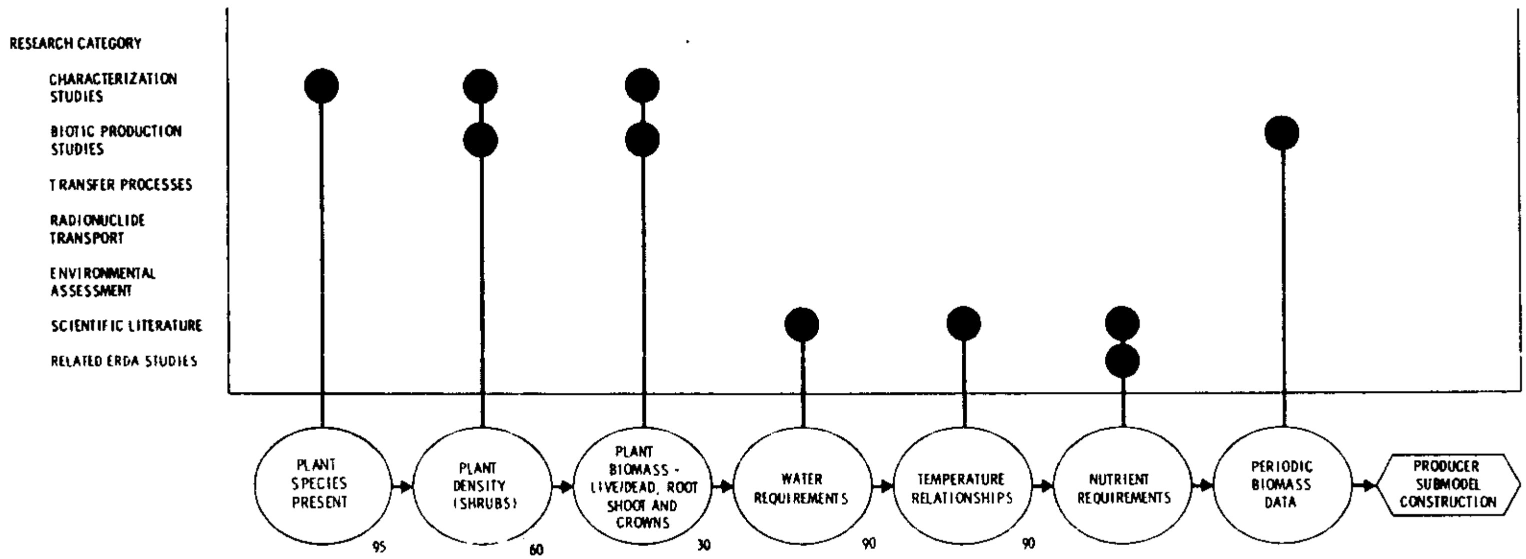


FIGURE IX-5. Data Sources for Construction of Producer Simulation Model (* = % data requirement currently available)

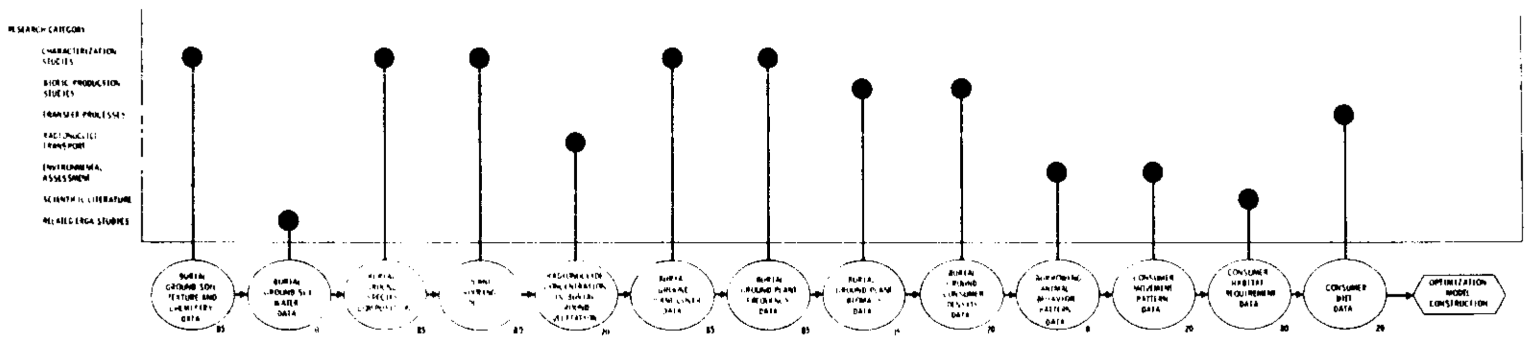


FIGURE IX-6. Data Sources for Construction of Optimization Model
(* = % data requirement currently available)

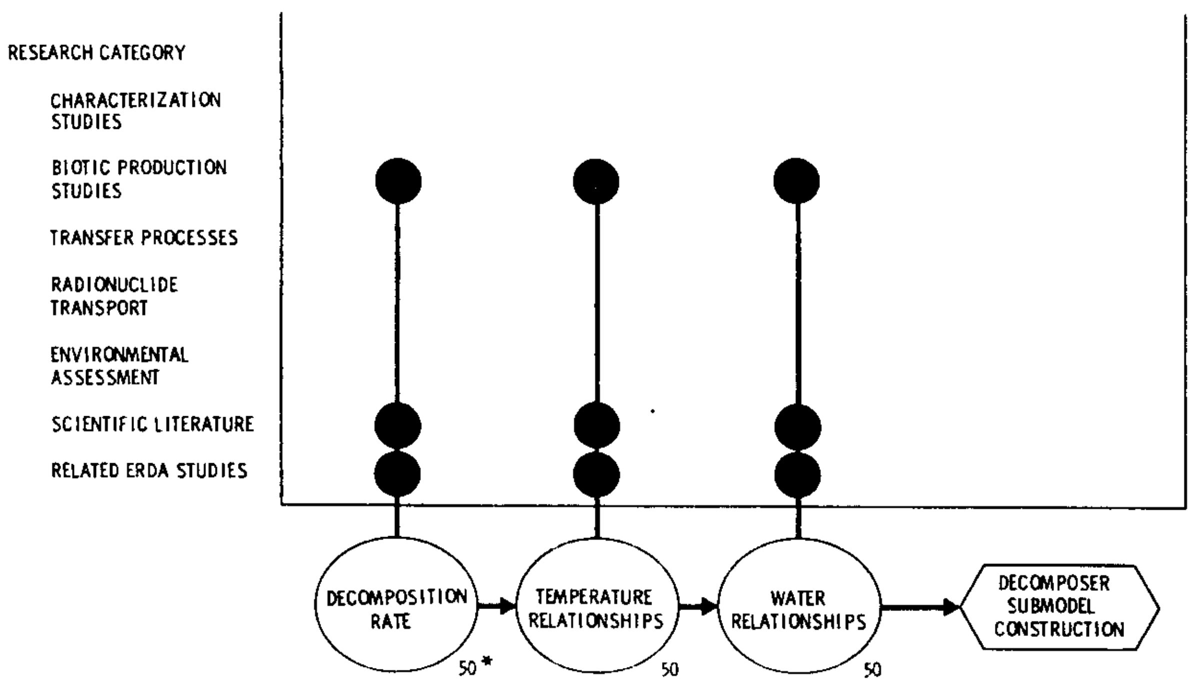


FIGURE IX-7. Data Sources for Construction of Decomposer Model (* = % data requirements currently available)

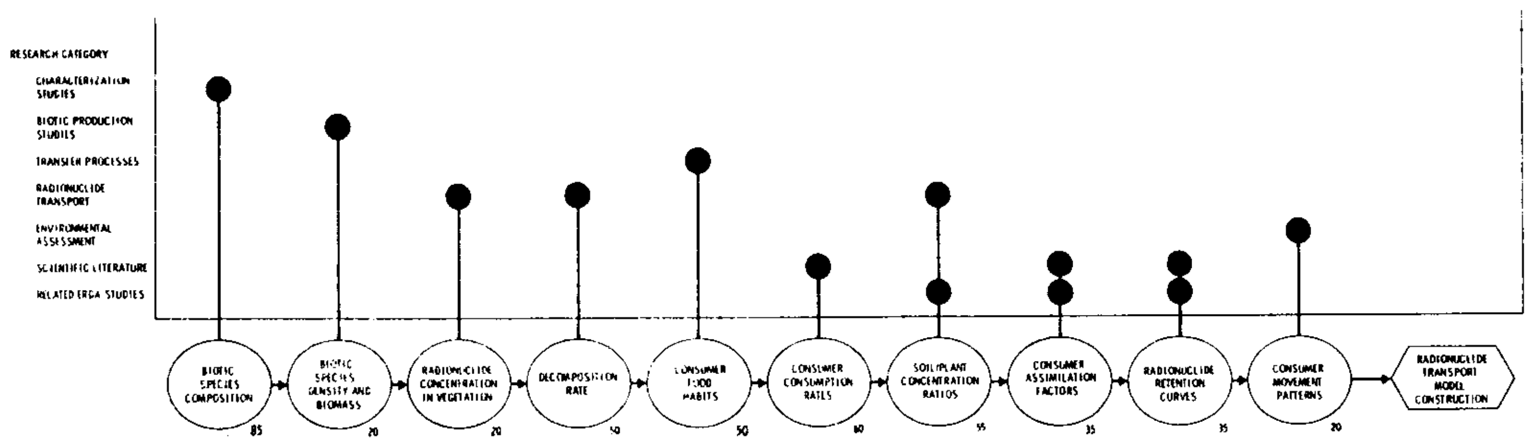


FIGURE IX-8. Data Sources for Construction of Radionuclide Transport Model (* = % data requirement currently available)

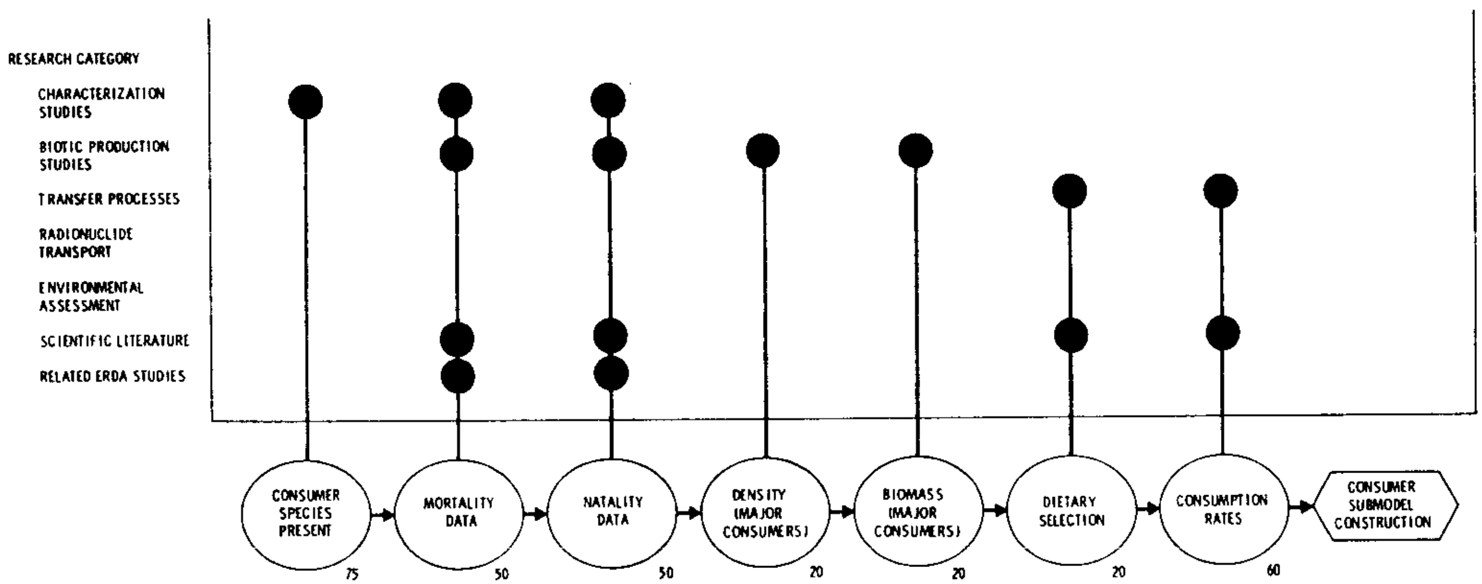


FIGURE IX-9. Data Sources for Construction of Consumer Simulation Model
(* = % data requirements currently available)

TASK SCHEDULING

The planned research events associated with the 200 Area ecology studies are shown in Figure IX-10. This milestone chart serves as an overall program summary identifying planned research categories, research tasks, schedule of events and task duration. Each task is required for an overall understanding of 200 Area ecosystem operation. Specific ground rules pertaining to data acceptability and reliability needs to be established. This can best be accomplished on a task by task basis, since the level of required precision and reliability may vary. Task interrelationships are illustrated in Figure IX-11. These interrelationships must be considered when planning year-by-year project funding. Failure to complete a seemingly minor task early in the program may later jeopardize final analysis or model construction.

We recognize that the research program outlined here probably exceeds the available level of RHO support. Much of the ecological data base now available was acquired through separate DOE funding, either as part of project ALE or radioecology studies. The overall research outline presented here presupposed such continued support. RHO support should focus on those tasks specific to 200 Area waste management needs and not of general application to environmental problems associated with the nuclear fuels cycles which are probably more applicable to DBER funding goals.

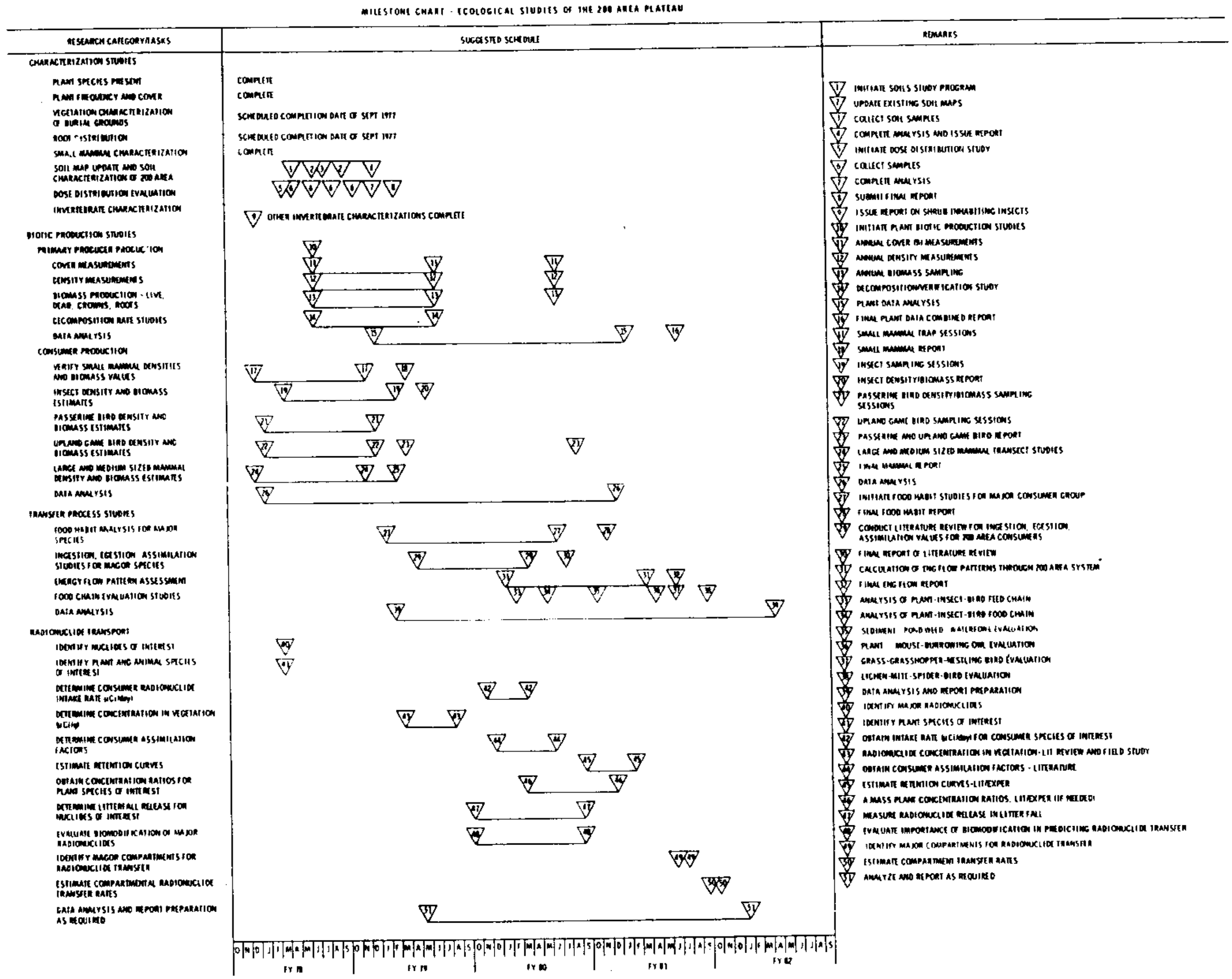
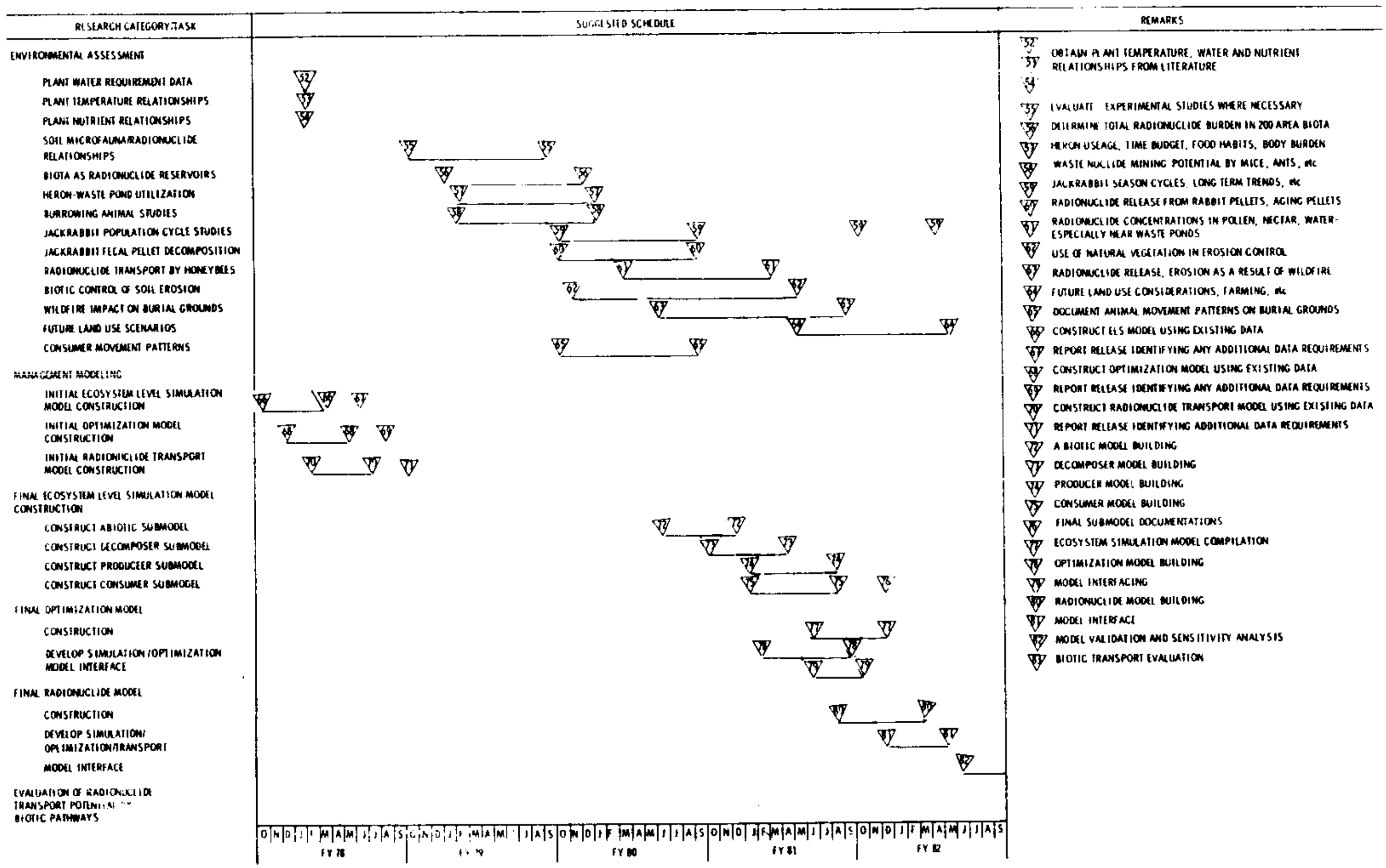


FIGURE IX-10. Planned Research Milestone Chart



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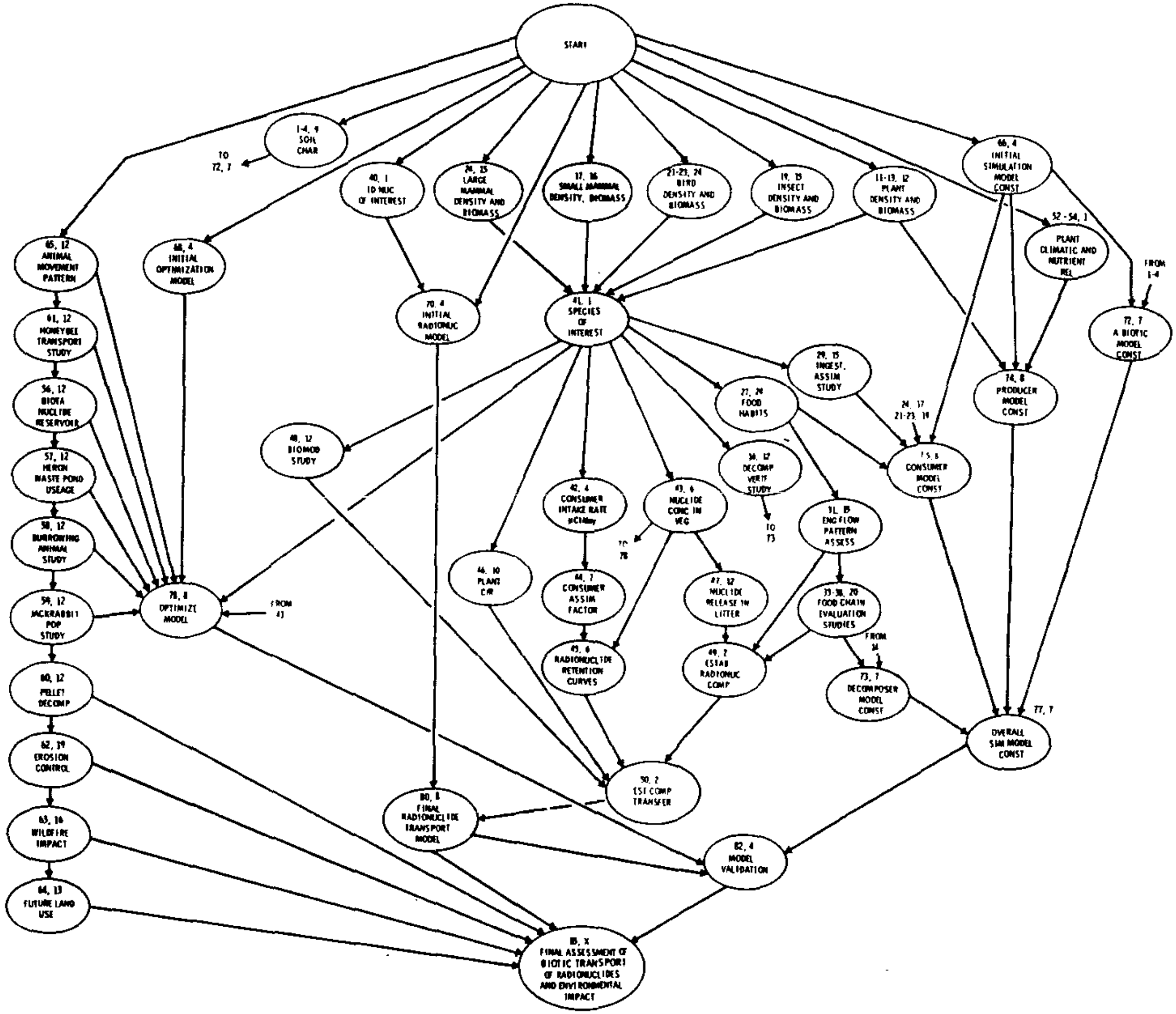

FIGURE IX-11. Interrelationships of Research Tasks

APPENDICIES

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APPENDIX A

Vascular Plants of Waste
Management Sites in the
200 Areas of the Hanford
Reservation (Price and
Rickard 1973).

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VASCULAR PLANTS OF WASTE STORAGE SITES IN THE 200 AREAS OF THE HANFORD RESERVATION

Common Name	Scientific Name	General Occurrence
Annual fescue	*Festuca pacifica*	Dry areas
Asparagus	*Asparagus officinalis*	Ditch banks and moist areas
Aster	*Aster canescens*	Disturbed dry areas
Barnyard grass	*Echinochloa crusgallii*	Ditch banks and moist areas
Bassia	*Bassia hyssopifolia*	Disturbed dry areas
Bastard toad-flax	*Comandra pallida*	Dry areas
Beggar-tick	*Bidens faronosa*	Ditch banks and moist areas
Big bluegrass	*Poa ampla*	Dry areas
Big sagebrush	*Artemisia tridentata*	Undisturbed dry areas
Blazing Star	*Mentzelia albicaulis*	Dry areas
Bluegrass	*Poa canbyi*	Dry areas
Bracken fern	*Pteriduim aquilinum*	Ditch banks and moist areas
Bristlegrass	*Setaria viridis*	Ditch banks and moist areas
Brodiaea	*Brodiaea douglasii*	Dry areas
Brodiaea	*Brodiaea howellii*	Dry areas
Bulrush	*Scirpus maritimus*	Ditches and ponds aquatic emergent
Bulrush	*Scirpus validus*	Ditches and ponds aquatic emergent
Cattail	*Typha latifolia*	Ditches and ponds aquatic emergent
Chaenactis	*Chaenactis douglasii*	Dry areas

Common Name	Scientific Name	General Occurrence
Cheatgrass	Bromus tectorum	Solid waste burial grounds Disturbed dry areas
Common mullen	Verbascum thapsus	Ditch banks and moist areas
Cottonwood	Populus deltoides	Ditch banks and moist areas around pond
Cryptantha	Cryptantha circumscissa	Dry areas
Cryptantha	Cryptantha pterocarya	Dry areas
Cudweed	Gnaphalium chilensis	Disturbed moist areas
Daisy	Townsendia florifer	Dry areas
Dandelion	Taraxacum officinale	Ditch banks and moist areas
Desert mallow	Sphaeralcea munroana	Dry areas
Desert parsley	Lomatium grayi	Dry areas
Desert parsley	Lomatium spp.	Dry areas
Dock	Rumex spp.	Old pond bottom, disturbed moist areas
Dogbane	Apocynum sibiricum	Ditch banks and moist areas
Dogbane	Apocynum androsoemifolium	Old pond bottom, moist areas
Draba	Draba verna	Dry areas
Evening primrose	Oenothera andina	Dry areas
Evening primrose	Oenothera pallida	Dry areas
Fiddleneck	Amsinckia tesselata	Disturbed dry areas
Fleabane	Erigeron filifolius	Dry areas
Fleabane	Erigeron pumilus	Dry areas
Gilia	Gilia leptomeria	Dry areas

Common Name	Scientific Name	General Occurrence
Goldenrod	Salidago spp.	Old pond bottom and moist areas
Green rabbitbrush	Chrysothammus nauseosus	Solid waste burial grounds, disturbed dry areas
Grey rabbitbrush	Chrysothammus viscidiflorus	Solid waste burial grounds, disturbed dry areas
Hardstem bulrush	Scirpus acutus	Ditches and ponds, aquatic emergent
Hawksbeard	Crepis atrabarba	Dry areas
Horsetail	Equisetum laevigatum	Shoreline, wet areas
Horsetail	Equisetum hyemale	Ditch banks and moist areas
Horseweed	Conyza canadensis	Disturbed dry areas
Indian ricegrass	Oryzopsis hymenoides	Dry, sandy areas
Jimhill mustard	Sisymbrium altissimum	Solid waste burial grounds, disturbed dry areas
Larkspur	Delphinium nelsonii	Dry areas
Layia	Layia glandulosa	Dry areas
Locoweed	Astragalus purshii	Dry areas
Locoweed	Astragulus spp.	Dry areas
Microsteris	Microsteris gracillis	Dry areas
Muhlenbergia	Muhlenbergia asperifolia	Ditch banks and moist areas
Mustard	Thelypodium laciniatum	Dry areas
Needle and thread	Stipa comata	Sandy, dry areas
Nettle	Urtica dioica	Disturbed moist areas
Panic grass	Panicum capillare	Ditch banks

Common Name	Scientific Name	General Occurrence
Peachleaf willow	*Salix amygdaloides*	Ditch banks, pond shoreline
Penstemon	*Penstemon accuminatus*	Dry areas
Phacelia	*Phacelia linearis*	Solid waste burial grounds, dry areas
Phlox	*Phlox longifolia*	Dry areas
Pigweed	*Chenopodium leptophyllum*	Dry areas
Plantain	*Plantago patagonica*	Moist areas
Plectritis	*Plectritis macrocera*	Moist areas
Canary grass	*Phalaris arundinacea*	Moist areas
Russian Napweed	*Centaurea repens*	Disturbed moist areas
Russian thistle	*Salsola kali*	Solid waste burial grounds, tank farms, dry areas
Sand dropseed	*Sporoblus cryptandrus*	Ditch banks, disturbed areas
Sandbar willow	*Salix exiqua*	Ditch banks, pond shoreline
Sandbur	*Franseria acanthicarpa*	Solid waste burial grounds, disturbed dry areas
Sandberg bluegrass	*Poa sandbergii*	Undisturbed dry areas
Sand verbena	*Abronia mellifera*	Dry areas
Smartweed	*Polygonum persicaria*	Ditch banks and pond shoreline
Speedwell	*Veronica anagallis-aquatica*	Ditch banks, pond shoreline, moist areas
Spiny hopsage	*Grayia spinosa*	Solid waste burial sites, dry areas
Squirrel tail	*Sitanion hystrix*	Dry areas
Stickseed	*Lappula redowskii*	Disturbed dry areas

Common Name	Scientific Name	General Occurrence
Sunflower	*Balsamorhiza careyana*	Dry areas
Swainsona	*Swainsona salsula*	Ditch banks, moist areas
Sweet bullclover	*Melilotus alba*	Ditch banks, disturbed moist areas
Tansy mustard	*Descurainea pinnata*	Solid waste burial grounds, disturbed dry areas
Thistle	*Cirsium brevifolium*	Moist areas
Three-square bulrush	*Scipus americanus*	Ditches and ponds, aquatic emergent
Tumbleweed	(see Russian thistle)	
Wallflower	*Erysimum asperum*	Dry areas
Watercress	*Rorippa nasturtium-aquaticum*	Ditches, running water
Willow herb	*Epilobium suffruticosum*	Disturbed dry areas
Wild lettuce	*Lactuca serriola*	Ditch bank, disturbed moist areas
Yarrow	*Achillaea millifolium*	Disturbed dry areas

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APPENDIX B

Radionuclide Modeling - Development of Mathematical Relationships

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RADIONUCLIDE MODELING - DEVELOPMENT OF MATHEMATICAL RELATIONSHIPS

Concepts used in multicompartmental models can be described by starting with a one compartment system as illustrated in Figure B-1. At time equal to zero, the quantity in the compartment with mass S is Q_o and the change in amount of Q per unit time can be described by the differential equation:

$$\frac{dQ}{dt} = -kQ \qquad \text{(EQUATION 1)}$$

The loss rate is proportional to the amount in the compartment at any times t. Integrating equation 1 between limits t=Q ($Q=Q_o$) to t=t (Q=Qt),

$$\int_{Q_t}^{Q_o} \frac{dQ}{Q} = \int_{t}^{o} -\,kdt$$

$$\Big[\ln Q\Big]_{Qt}^{Q_o} = \Big[-\,kt\Big]_{t}^{o}$$

$$\ln Q_o - \ln Q_t = -k0 - (-kt)$$

$$\ln \frac{Q_o}{Qt} = kt$$

$$\left(\frac{Q_o}{Qt}\right) = e^{kt}$$

rearranging terms and solving for Qt gives,

$$Q_t = Q_o e^{-kt} \qquad \text{(EQUATION 2)}$$

Where, Q_t = amount of tracer in the compartment at any t, and

k = transfer coefficient, or fractional loss rate, of tracer Q from the compartment per unit time.

If K was equal to 0.02/day, then 2% of the tracer in the compartment would be removed each day. If there was 200 units of tracer in the compartment on day one, then 4 units would be removed the first day, leaving 196, 3.9 removed the second leaving 192.1, 3.8 the third leaving 188.3 unit and so on.

To show the relationship between transfer coefficients and half-time, set Q_t equal to 1/2 of Q_o and solve for $t = T_{1/2}$:

$$Q_{T_{1/2}} = \frac{Q_o}{2} = Q_o e^{-kT_{1/2}}$$

$$\frac{2Q_o}{Q_o} = e^{kT_{1/2}}$$

$$kn2 = kT_{1/2}$$

$$k = \frac{\ln 2}{T_{1/2}} = \frac{0.693}{T_{1/2}} \qquad \text{(EQUATION 3)}$$

$$T_{1/2} = \frac{\ln 2}{k} = \frac{0.693}{k} \qquad \text{(EQUATION 4)}$$

If the compartment is a living system, $T_{1/2}$ is normally called the biological half-time (T_B). If the tracer was a short-lived radionuclide with a physical half-time T_P ($\lambda_P = \ln 2/T_P$). Then the total fractional loss rate (effective transfer coefficient, λ_E) would be equal to the sum of the loss due to physical decay and biological removal from the compartment ($\lambda_E = \lambda_P + \lambda_B$). The relationship associating effective, physical, and biological half-time is:

$$\lambda_E = \lambda_P + \lambda_B \qquad \text{(EQUATION 5)}$$

$$\frac{\ln 2}{T_E} = \frac{\ln 2}{T_P} + \frac{\ln 2}{T_B}$$

$$T_E = \frac{T_P \quad T_B}{T_P + T_B} \qquad \text{(EQUATION 6)}$$

If the input into the compartment was constant, or chronic, as shown in Figure B-2, then the differential equation would take the form:

$$\frac{dQ}{dt} = I - kQ \qquad \text{(EQUATION 7)}$$

Where I is the intake rate and kQ is the loss rate. This can be integrated as was done previously with equation 1, or it can be evaluated using the convolution integral concept as described by Shipley and Clark (1972). The concept used in the convolution integral is best understood if one thinks of a dose of tracer as a collection of small bits which each has separate times of transit through a compartment. This technique is used in systems in which a continuous response curve is generated by combining an acute impulse response expression with a chronic input or signal function.

The basic formula is:

$$Q_t = \int_0^t \left[I_{(t-\tau)} \right] \left[F_\tau \right] d\tau \qquad \text{(EQUATION 8)}$$

$$Q_t = \int_0^t \left[I_\tau \right] \left[F_{(t-\tau)} \right] d\tau$$

Where, $I_{(t-\tau)}$ = input function, or instantaneous intake rate into a compartment where τ is the time of sojourn for any bit of tracer taken in by the compartment. For this example, $I_{(t-\tau)} = I$, since the intake is constant, and F_τ = equation that describes the response of the compartment to an acute impulse of tracer. In this case F_τ is derived from Equation 2, $F_\tau = e^{-k\tau}$. Evaluating the convolution integral:

$$Q_t = \int_0^t \left[I \right] \left[e^{-k\tau} \right] d\tau \qquad \text{(EQUATION 9)}$$

$$Q_t = I \int_0^t e^{-k\tau} d\tau = I \left[\frac{e^{-k\tau}}{-k} \right]_0^t$$

$$Q_t = I \left[\frac{e^{-kt}}{-k} - \frac{e^{-o}}{-k} \right]$$

$$Q_t = I \left[\frac{1}{k} - \frac{e^{-kt}}{k} \right]$$

rearranging terms,

$$Q_t = \frac{I}{k} \left(1 - e^{-kt} \right) \qquad \text{(EQUATION 10)}$$

The intake rate is often expressed as:

$$I = RCa \qquad \text{(EQUATION 11)}$$

Where, R = consumption rate (i.e., g/day),
C = concentration of tracer in the foodstuff (i.e., p Ci/g), and
a = assimilation factor, or faction of ingested material that is taken up by the compartment or organism.

Then equation 9 can be written as,

$$Q_t = \frac{RCa}{k} \left(1 - e^{-kt} \right) \qquad \text{(EQUATION 12)}$$

For situations in which there is a quantity of the tracer in the compartment at time t = 0, equation 11 is expressed as,

$$Q_t = \frac{RCa}{k}\left(1 - e^{-kt}\right) + Q_o e^{-kt} \quad \text{(EQUATION 13)}$$

Where, Q_o = amount of tracer in compartment at time t = 0. Solving equation 13 for time t equal to infinity gives,

$$Q_\infty = \frac{RCa}{k}\left(1 - e^{-k\infty}\right) + Q_o e^{-k\infty} = \frac{RCa}{k}$$

$$kQ_\infty = RCa$$

The level of tracer in the compartment remains constant because the loss rate (kQ_∞) equals intake (RCa) (from Equation 7: $\frac{dQ}{dt} = 0$) and the system is said to be at dynamic equilibrium.

The convolution integral is very useful for evaluating systems in which the input is not constant. If the input into a single compartment changed according to the equation: $I_t = I_o e^{-ft}$, as illustrated in Figure B-3, the resulting response expression could be derived by integrating:

$$Q_t = \int_0^t \left[I_o e^{-f(t-\tau)}\right]\left[e^{-k\tau}\right] d\tau$$

$$Q_t = \frac{I_o}{k - f}\left[e^{-ft} - e^{-kt}\right] \quad \text{(EQUATION 14)}$$

Where, I_o = intake rate at time t = 0. Substituting for I according to equation 11,

$$Q_t = \frac{RC_o a}{k - f}\left[e^{-ft} - e^{-kt}\right] \quad \text{(EQUATION 15)}$$

Where, C_o = concentration of tracer in the foodstuff at time t = 0. Again, if there was a quantity of tracer (Q_o) in the compartment at time t = 0, expressed as,

$$Q_t = \frac{RC_o a}{k - f}\left[e^{-ft} - e^{-kt}\right] + Q_o e^{-kt} \quad \text{(EQUATION 16)}$$

An example of the use of equation 16 would be to mathematically describe the body burden of an organism introduced into a contaminated environment at time t = 0. The value of k would be equal to the effective loss rate (transfer coefficient) of the tracer from the organism ($k_E = \ln 2/T_E$). The loss rate of tracer (i.e. radioactive fallout material) from the vegetation, described by f, would be due to removal by biological and physical processes (i.e., wind and rain) along with the physical decay of the radionuclide.

Compartmental modeling can be extended to include 2, 3 or more compartments as illustrated in Figures B-4 and B-5. However, solution for these models are rather complicated and are beyond the scope of the subjects presented here. The retention function of the 2 compartmental model presented in Figure B-4 following an acute input (Q_o) into the first compartment takes the general form:

$$Q_1(t) = Q_o \left[C_1 e^{-\lambda_1 t} + C_2 e^{-\lambda_2 t}\right] \quad \text{(EQUATION 17)}$$

Where, Q_1 = total amount of tracer on compartment 1,
C_1 = fractional intercept for the first component,
λ_1 = slope associated with first component,
C_2 = fractional intercept for the second component, and
λ_2 = slope associated with second component.

For compartment number 2:

$$Q_2(t) = Q_o \left[D_1 e^{-\lambda_1 t} + D_2 e^{-\lambda_2 t}\right] \quad \text{(EQUATION 18)}$$

Where, D_1 and D_2 are the fractional intercepts. The values of the slopes (λ's) and fractional intercepts (C's and D's) are functions of the transfer coefficients (k's) and compartmental sizes. An example of this model would be the removal of a compound from the gastrointestinal tract of an organism by the blood stream and elimination of endogenous excretion only with no interchanges between other compartments. The retention of the compound in the total body can be expressed as,

$$Q_t = Q_1(t) + Q_2(t)$$

or,

$$Q_t = Q_o \quad A_1 e^{-\lambda_1 t} + A_2 e^{-\lambda_2 t} \quad \text{(EQUATION 19)}$$

Where, $A_1 = C_1 + D_1$,
$A_2 = C_2 + D_2$,

Then,

$$A_1 + A_2 = 1.0$$

The general retention function describing the total amount of tracer in the 3 compartments in Figure B-5 is a three component exponential expression:

$$Q_t = Q_1(t) + Q_2(t) + Q_3(t)$$

$$Q_t = Q_o \left[A_1 e^{-\lambda_1 t} + A_2 e^{-\lambda_2 t} + A_3 e^{-\lambda_3 t}\right] \quad \text{(EQUATION 20)}$$

An example of this model would be the uptake of a tracer by the blood stream from the gastrointestinal tract which interchange with the muscle and elimination via endogenous and renal excretion.

Equations 19 and 20 both take the general form:

$$Q_t = Q_\circ \sum_{i=1}^{N} A_i e^{-\lambda_i t} \qquad \text{(EQUATION 21)}$$

Where, N = number of components in the retention function,
Q_t = total amount of tracer in all compartments as a function of time following the acute intake,
A_i = fractional intercept of component i, and
λ_i = slope of component i.

For most situations the 3 or even the 2 component expressions can be used to describe the retention of a radionuclide by an individual following an acute ingestion. If the transfer coefficients and compartment sizes are known, the retention functions can be derived, or if the retention function and compartment sizes are known, then the transfer coefficient can be calculated as detailed by Shipley and Clark (1972) and Sheppard (1962).

To apply equation 21 to situations in which the input is chronic, one can either mathematically derive the expressions or use the convolution integral (Equation 8) according to the expression:

$$Q_t = \int_0^t \left[I_{(t-\tau)} \right] \left[\sum_{i=1}^{N} A_i e^{-\lambda_i \tau} \right] d\tau$$

Where $I_{t-\tau}$ = constant intake rate (i.e., pCi/day).

Evaluating the integral gives the general form:

$$Q_t = I \sum_{i=1}^{N} \frac{Ai}{\lambda i} \left(1 - e^{-\lambda_i t} \right) \qquad \text{(EQUATION 22)}$$

An example of the use of this expression is to describe the total body burden of ^{137}Cs an animal, for which the 3 component acute retention function is known, consuming contaminated vegetation at a constant rate. The resulting expression would approximate the levels of ^{137}Cs in the organism as a function of time following introduction into the contaminated environment. At time equal to infinity Equation 22 takes the form:

$$Q_\infty = I \sum_{i=1}^{N} \frac{Ai}{\lambda i} \qquad \text{(EQUATION 23)}$$

The convolution integral can also be applied to situations in which the input function can not easily be expressed mathematically. In this case the response curve is approximated numerically by application of the trapezoid rule (Shipley and Clark, 1972) using a computer program. This technique is very useful for instances in which the intake rate of a tracer changes as is often the case for animals under realistic situations. Often times their consumption rates or foodstuff concentrations vary due to differences in food sources, movement patterns or dietary habits. An example is presented in Figure B-6 in which Hanson (1973) projected estimates of the body burden of ^{90}Sr in Alaskan Natives. The input function was generated by combining data on ^{90}Sr levels in caribou muscle with estimates on consumption rates of meat by adults. The impulse function was a 3 component retention curve which described the retention of Sr by adults following an acute oral ingestion. Values from the resulting response curve corresponded closely with observed data on ^{90}Sr levels in rib samples from Alaskan Natives.

The rates of buildup or loss of a tracer in individual organisms can usually be described by use of one or more of the preceeding equations. Of course, certain parameters must be known such as transfer coefficients, initial compartmental concentrations, consumption rates, acute retention function expressions, etc. As illustrated in Equations 19 and 20, the complexities of the mathematical derivation increases very fast as the number of compartments increase. Analysis of a multi-compartmental system can be facilitated by using numerical approximation techniques to evaluate the integrals of differential equation which describe the instantaneous rate of change in the amount of tracer in each compartment. A good example of using this approach to modeling was presented by Olson (1965). In this study, the movement of Cs in a forest environment was simulated following application of ^{137}Cs to the trunks of trees. The differential equations describing the instantaneous rate of change for each of the seven compartments as presented in Figure B-7 were:

$$\frac{dQ_1}{dt} = k_{13}Q_3 - k_{21}Q_1 - k_3Q_1$$

$$\frac{dQ_2}{dt} = k_{21}Q_1 + k_{23}Q_3 - k_{32}Q_2 - k_{52}Q_2 - k_{62}Q_2$$

$$\frac{dQ_3}{dt} = k_{31}Q_1 + k_{32}Q_2 + k_{34}Q_4 - k_{13}Q_3 - k_{23}Q_3 - k_{43}Q_3$$

$$\frac{dQ_4}{dt} = k_{43}Q_3 + k_{47}Q_7 - k_{34}Q_4 - k_{74}Q_4$$

$$\frac{dQ_5}{dt} = k_{52}Q_2 - k_{65}Q_5 - k_{75}Q_5$$

$$\frac{dQ_6}{dt} = k_{62}Q_2 + k_{65}Q_5 - k_{76}Q_6$$

$$\frac{dQ_7}{dt} = k_{74}Q_4 + k_{75}Q_5 + k_{76}Q_6 - k_{47}Q_7$$

The general form of these equations is:

$$\frac{dQ_i}{dt} = \sum_{j=1}^{N} \left[k_{ij}Q_j - k_{ji}Q_i \right] \qquad \text{(EQUATION 24)}$$

Where, Q_i = amount in compartment i,
N = number of compartments, and
k_{ij} = transfer coefficient describing the fractional rate of transfer to compartment i from j. For non-existing pathway (i.e., k_{35}) the values are set equal to zero.

Set k_{jj} equal to the negative sum of all existing transfer coefficients leading into compartment i as,

$$k_{jj} = - \sum_{\substack{i=1 \\ i \neq j}}^{N} k_{ij}$$

then equation 24 can be written as,

$$\frac{dQ_i}{dt} = \sum_{j=1}^{N} k_{ij}Q_j \qquad \text{(EQUATION 25)}$$

The general expression used to numerically evaluate differential equations using the Euler technique (Scarborough, 1965) is:

$$Q_{(t + \Delta t)} = Q_{(t)} + \Delta t \left[\frac{dQ}{dt} \right] \qquad \text{(EQUATION 26)}$$

The value of Q at time $t + \Delta t$ is approximated by adding the product of Δt times the instantaneous rate of change to the amount that was present at time t. Of course this is only true as Δt approaches zero. Combining equations 25 and 26 gives the general form:

$$Q_i\ (t + \Delta t) = Q_i\ (t) + \Delta t \left[\sum_{j=1}^{N} k_{ij}Q_j \right] \qquad \text{(EQUATION 27)}$$

Equation 27 is usually evaluated using a computer program. At each time interval, all $Q_i(t + \Delta t)$ values are evaluated, and another set of values for $t + 2\Delta t$ are generated using the new values for Q_i, and so on. As noted previously, this only holds true as Δt approaches zero. In actuality, the "smallness" of Δt is limited by the computing costs associated with making the time interval smaller and smaller. Another benefit of using this technique is that the values of the transfer coefficients can be changed. This is very useful when simulating natural systems where the transfer rates vary due to changes in climatic conditions, food preference, age, etc.

(1) References noted in Appendix B are included with Chapter 7.

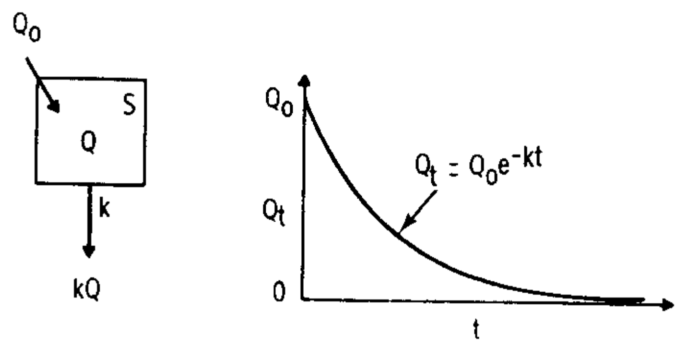

FIGURE B-1. One Compartment Model with an Acute Input, $Q_\circ$, into the Compartment Which has Mass, S, and a Transfer Coefficient or Fractional Loss Rate, k.

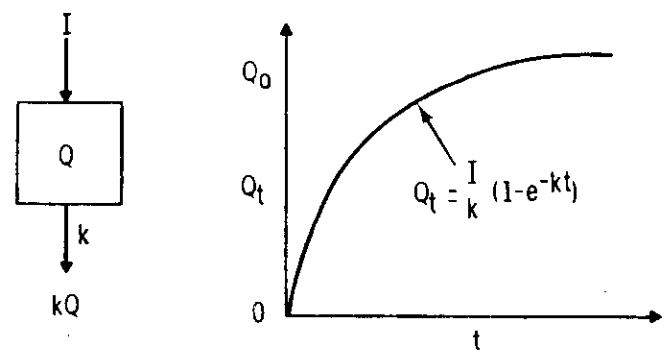

FIGURE B-2. One Compartment Model with a Constant Input, I.

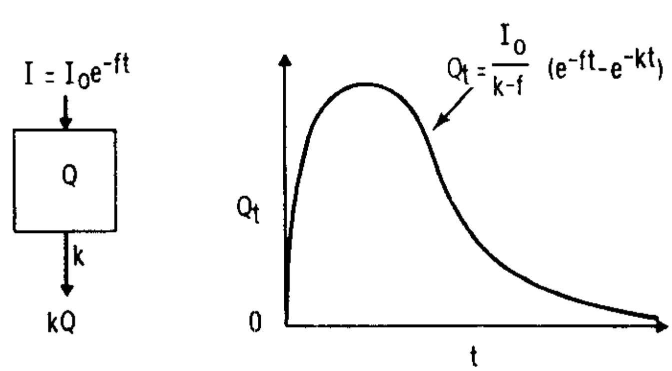

FIGURE B-3. One Compartment Model with an Input Changing According to $I_t = I_\circ e^{-ft}$.

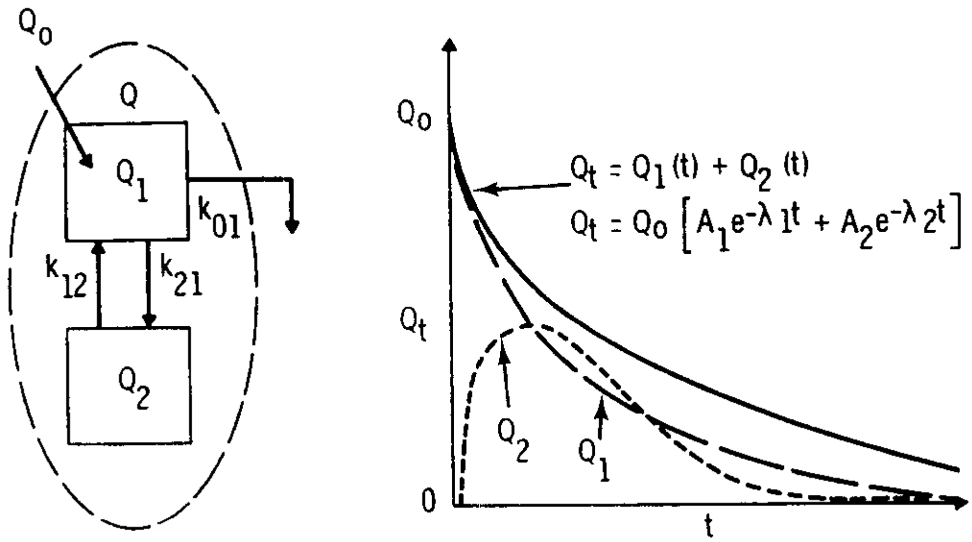

FIGURE B-4. Two Compartment Model With an Acute Input Into Compartment 1.

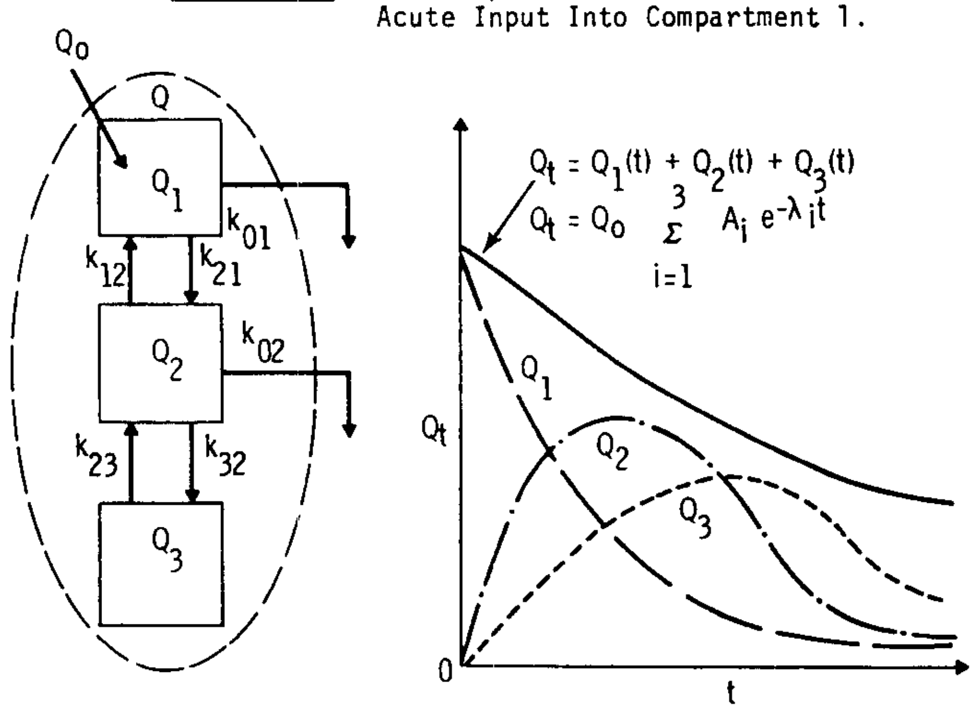

FIGURE B-5. Three Compartment Model With an Acute Input into Compartment 1 and Losses from Compartments 1 and 2.

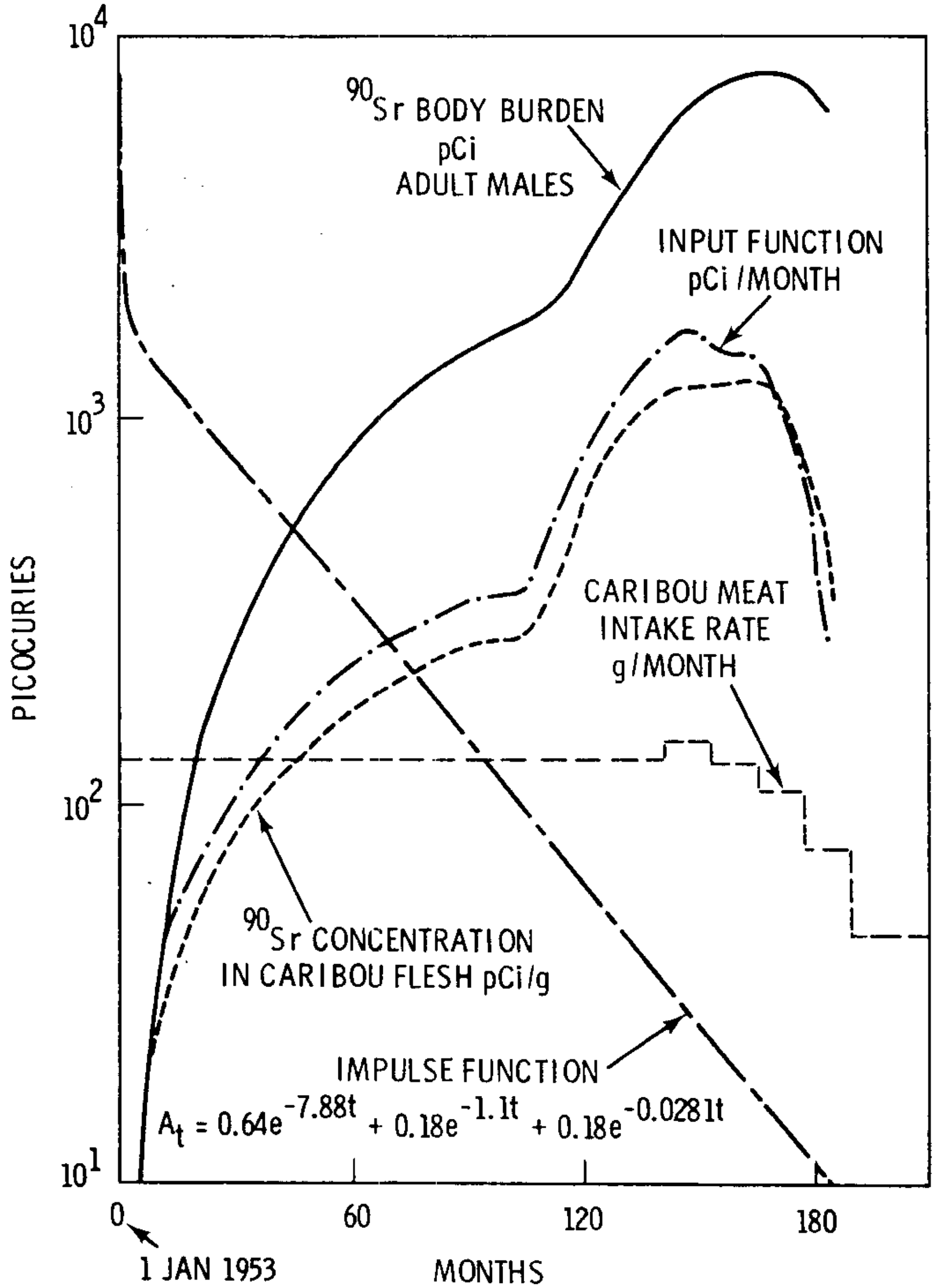

FIGURE B-6. Calculated Levels of ^{90}Sr Body Burdens in Adult Alaskan Natives from 1953 Through 1969 (from Hanson, 1973).

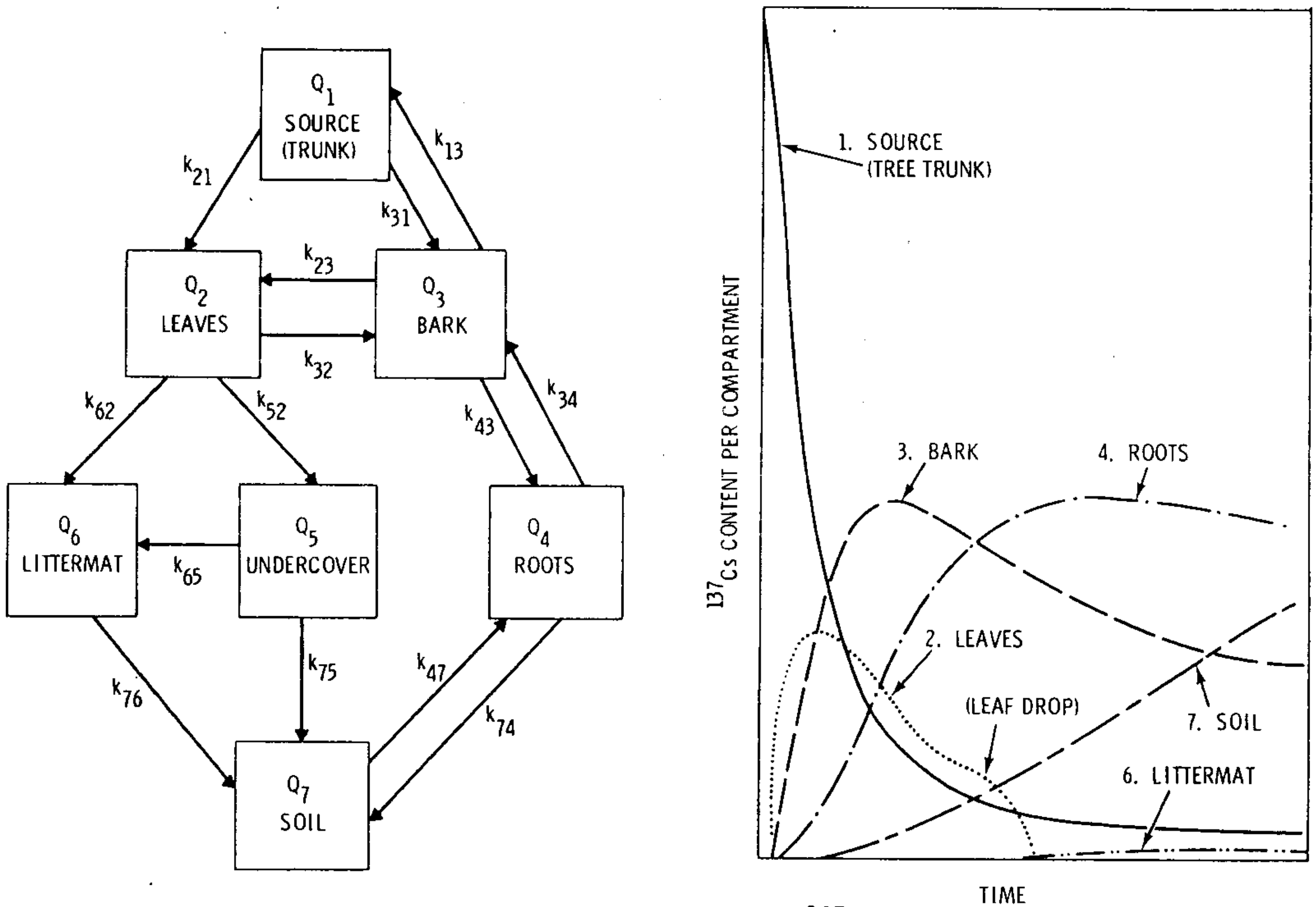

FIGURE B-7. Model for Simulating the Movement of ^{137}Cs in a Forest Environment Following the Introduction into Tree Trunks (from Olson, 1965).

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APPENDIX C

Bibliography of Biological Research Studies Pertinent to the 200 Area Plateau

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APPENDIX D

A Partial Listing of Biological Monitoring References for the Environmental Surveillance Program

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A PARTIAL LISTING OF BIOLOGICAL MONITORING REFERENCES FOR THE ENVIRONMENTAL SURVEILLANCE PROGRAM

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Biology Research Annual Report HW-28636

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1963

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1964

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1971

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APPENDIX E

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APPENDIX E

Present Environmental Surveillance Program (taken from the master schedule for CY 1975, Hanford Environmental Surveillance Routine Program, BNWL-B-455).

Waste Disposal Sites: Active, inactive, and retired waste disposal sites require periodic monitoring to assure appropriate maintenance. The following sites require surveillance:

Description	Frequency[1]
100-N Crib	SA
100-N Trench	A
100-N Burning Ground	SA
100-K Trench	SA
100-K Solid Waste B.G.	Q
100-K Burning Pit	SA
100-BC SE B.G. (105-C Solid Waste)	SA
100-BC SW B.G. (105-B Solid Waste, N. Solid Waste)	Q
100-BC Construction B.G.	SA
100-BC B.G. East of 108-B	SA
100-BC Irradiated Metal Storage Basin Waste	SA
108-B Ball 3x Burial Ground	SA
108-B Crib	SA
105-C Trench	SA
105-B Trench	SA
107 Basin Sludge Burial	SA
105-C Metal Examiniation Waste Tank	SA
100-BC Overflow Pluto Crib	SA
107-C Retention Basin	SA
107-B Retention Basin	SA
100-BC Effluent Diversion Box	SA
100-BC Minor B.G.'s East of 105-B	SA
100-BC Outfall Structures	SA
100-DR Outfall Structures	SA
100-DDR Trench	SA
107-D Retention Basin	SA
107-DR Retention Basin	SA
100-DDR Effluent Lines	SA
100-D Dummy Decontamination Waste	SA
100-DDR Solid Waste B.G. (VSR Thimbles)	SA
100-DDR Construction B.G.	SA
100-DDR #3 B.G. NE of DR	SA
100-DDR Pluto Crib	SA
100-DDR 105 Basin Sludge B.G.	SA
100-DDR #1 B.G.	SA
100-DDR #2 B.G.	SA
100-H Trench	SA
107-H Basin	SA
100-H Effluent Lines (Junction Boxes)	SA
100-H Liquid Waste Burial	SA
100-H #1 B.G.	SA

Description	Frequency[1]
100-H #2 B.G.	SA
100-F Lewis Canal	SA
100-F Swampy Area	SA
107-F Trench	SA
100-F Retention Basin	SA
100-F Trench Drain and Adjacent Wood Covered Pit	SA
100-F Ball Washer Crib	SA
100-F #3 B.G.	SA
100-F #2 B.G.	SA
100-F #1 B.G.	Q
100-F Sawdust Burial	Q
100-F Leaching Trench	Q
100-F 60" Overground Pipe	SA
100-F Happy Valley Farm Plots	SA
200-W Redox Labs Pond (216-S-19)	Q
200-W New Redox Pond (216-S-16)	Q
200-W Old Redox Pond (216-S-17)	SA
200-W Part of Perimeter of U Pond (216-U-10)	Q
200-W U Pond Overflow (216-U-11)	SA
200-E Gable Mountain Ponds (216-A-25)	Q
200-E West Lake	SA
200-E B Pond (216-B-3)	Q
200-E B Pond Ditch #1	SA
200-E B Pond Ditch #2	Q
200-E B Pond Ditch #3	Q
200-E Snow's Canyon; Purex Chemical Sewer (216-A-29)	Q
200-E Purex crib #1 (216-A-6)	SA
200-E Purex Crib #2 (216-A-30-1)	Q
200-E North of Purex Crib #3 (216-A-37-1)	SA
200-E NE Perimeter Fence	SA
200-E 216-BC Crib Area	SA
200-E California Nuclear B.G. Perimeter	Q
200-E - 200-W Transfer Lines	SA
300 Area 300 N B.G.	SA
300 Area 300 Wye B.G.	SA
300 Area #1 B.G.	SA
300 Area #2 B.G.	SA
300 Area #3 B.G.	SA
300 Area #4 B.G.	SA
300 Area #5 B.G.	Q
300 Area #7 B.G.	SA
300 Area #8 B.G.	SA
300 West B.G.	SA
300 Area Equipment Storage	SA
300 Area N. Process Pond at Perimeter Fence	Q
300 Area S. Process Pond at Perimeter Fence	Q
200-N, P, and R Areas	SA

Soil and Vegetation

Location	Soil	Vegetation	Frequency	Analyses
Waluke #2 Air Sampling Station	6007	6053	A	Gamma Scan, ^{90}Sr, U, P.
Berg Ranch Air Sampling Station	6008	6054	A	Gamma Scan, ^{90}Sr, U, P.
NE Corner of 100-N Area	6275	6290	A	Gamma Scan, ^{90}Sr, U, P.
100-F (control Plot 58)	6018	6064	A	Gamma Scan, ^{90}Sr, U, P.
Yakima Barricade	6004	6050	A	Gamma Scan, ^{90}Sr, U, P.
Intersection Rts, 4 and 11 A (CP #59)	6019	6065	A	Gamma Scan, ^{90}Sr, U, P.
Hanford townsite (CP #57)	6017	6063	A	Gamma Scan, ^{90}Sr, U, P.
SW of 200-W Area (CP #60)	6020	6066	A	Gamma Scan, ^{90}Sr, U, P.
E of 200-W Area (CP #60)	6276	6283	A	Gamma Scan, ^{90}Sr, U, P.
200-E Hill (CP #61)	6022	6068	A	Gamma Scan, ^{90}Sr, U, P.
E of Nuclear Eng. Burial Grounds	6281	6284	A	Gamma Scan, ^{90}Sr, U, P.
Inter. of Rt. 4 and Army Loop Rd.	6223	6232	A	Gamma Scan, ^{90}Sr, U, P.
Ringold	6009	6055	A	Gamma Scan, ^{90}Sr, U, P.
0.5 mile NE of FFTF	6282	6285	A	Gamma Scan, ^{90}Sr, U, P.
SW of FFFF	6277	6286	A	Gamma Scan, ^{90}Sr, U, P.
E of ALE Field Laboratory	6278	6287	A	Gamma Scan ^{90}Sr, U, P.

Soil and Vegetation (continued)

Location	Soil	Vegetation	Fequency	Analyses
Prosser Barricade	6225	6227	A	Gamma Scan ^{90}Sr, U, P.
N of 300 Area Perimeter	6279	6288	A	Gamma Scan, ^{90}Sr, U, P.
SE of 300 Area Perimeter (CP #50)	6014	6060	A	Gamma Scan, ^{90}Sr, U, P.
NE Corner of Exxon Site	6280	6289	A	Gamma Scan, ^{90}Sr, U, P.
100-N Springs vegetation		6271	M	Gamma Scan, ^{131}I

Wildlife

Location	EMA Number	Frequency	Analyses
FISH			
Columbia River	According to species	M	Gamma scan, ^{90}Sr
DUCKS			
100-K to Richland	Depends on species and location	20/Oct-Dec	Gamma scan; ^{90}Sr
U Pond	According to species	Q (4/year)	Gamma scan, ^{90}Sr ^{239}Pu (Liver)
Gable Pond	According to species	Q (4/year)	Gamma scan, ^{90}Sr
B Pond	According to species	Q (4/year)	Gamma scan, ^{90}Sr
T Pond	According to species	Q (4/year)	Gamma scan, ^{90}Sr
West Lake	According to species	Q (4/year)	Gamma scan, ^{90}Sr U (Liver)

Wildlife (Continued)

Location	EMA Number	Frequency	Analyses
300 Area Pond	According to species	Q (4/year)	Gamma scan, ^{90}Sr ^{239}Pu (Liver), U (Liver)
100-F Trench	According to species	Q (4/year)	Gamma scan, ^{90}Sr
GEESE			
100-K to Hanford	According to species	10/Oct-Dec	Gamma scan
PHEASANTS			
100-K to 100-D and 300 Area Vicinity	According to species	10/Oct-Dec	Gamma scan ^{90}Sr
DEER			
Varies	According to location	3/Hunting Season	^{90}Sr (Femur) Gamma scan, ^{90}Sr (Muscle) ^{239}Pu (Liver)
RABBITS			
BC Crib Area	6084	2 in May 2 in Nov	Gamma scan (Muscle) ^{90}Sr (Bone) ^{239}Pu (Liver)
MICE[2]			
100-N Trench	1775	BM (Mar.-Sept.)	Gamma scan, ^{90}Sr
Surface Ponds	According to species and location	BM (Mar.-Sept.)	Gamma scan (Muscle) ^{90}Sr (Bone) ^{239}Pu (Liver)[3] U (Liver)[3]
SMALL MAMMALS			
Selected Waste disposal sites	According to species and location	As requested	Gamma scan (Muscle) ^{90}Sr (Bone) ^{239}Pu (Liver)[3] U (Liver)[3]

[1] SA = Semiannual; Q = Quarterly; M = Monthly.

[2] Up to three mice may be composited in a sample and analyzed as a whole.

[3] ^{239}Pu for mammals from U Pond and BC Crib Area; U for mammals from U Pond, West Lake, and 300 Area Pond.

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