Hanford National Environmental Research Park (NERP)

A Descriptive Summary of the Site and Site-Related Research Programs, 1952-1977

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HANFORD NATIONAL ENVIRONMENTAL RESEARCH PARK (NERP) A DESCRIPTIVE SUMMARY OF THE SITE AND SITE- RELATED RESEARCH PROGRAMS, 1952-1977

INTRODUCTION

The Hanford Site is especially suitable for environmental research because of its large size and its land-use history. Although the primary technological use of the Hanford Site for 30 yr has been plutonium production, most of the land surrounding the reactors and chemical processing buildings has remained devoid of any significant environmental impact from the nuclear technology. The land has benefited from protection from livestock grazing and agricultural uses that most likely would have been imposed upon the land in the absence of the nuclear technology.

The Hanford Site has many environmental attributes that make it a favorable site for the biological containment of nuclear energy by-products. The land is low in biological productivity and low in species diversity, with very few organisms that occur in the food chain to man. The low precipitational regime also means that radioactive materials fixed in the soil will not be moving downward as a result of precipitational leaching and into the underlying groundwater for possible movement beyond the Site boundaries.

The significance of natural landscapes as baseline examples (controls) is often overlooked by laboratory scientists who obtain experimental results in short time spans. However, dramatic changes in plant and animal populations on a landscape scale can occur over a 50-yr time span and will not be detected early because year-to-year changes are too slight to detect without careful field sampling programs. Also, the amount of time required to confirm results often discourages individual investigators. In this respect, field biological observations are like climatological data, in that a series of consecutive years are required before sufficient data are accumulated to provide enough material for synthesis and

analysis. Nevertheless, environmental assessments are needed over 50- to 100-year time spans to detect trends in environmental quality.

Recently, major portions of the Hanford Site were dedicated as a National Environmental Research Park. The National Environmental Research Park concept seeks to provide landscapes representing different biological environments to assess the impact of technology upon environmental quality (Figure 1).

Hanford is uniquely suited for NERP purposes because the area presently meets EPA's stringent air and water quality standards, and because over 25 yr of long-term ecological monitoring has shown no significant environmental impact from the quarter-century operation of its nuclear facilities.

Historically, steppe lands with high agricultural potential have been difficult to preserve with their native complements of plants and animals intact because of need to provide food for an ever-increasing human population. As a result, there is essentially no acreage representative of tall grass prairie communities in existence today, although these communities once occupied millions of acres in the middle parts of the United States. Less than 20 acres of native Palouse Prairie now exist in eastern Washington. The demise of the Palouse Prairie is clearly related to its agricultural potential as the world's most productive wheat raising region.

Steppe lands in eastern Washington that are not suitable for crops because of shallow soil or steep topography usually have been intensively grazed by domestic livestock, resulting in dramatic changes in plant species composition. The nonforested (steppe) region

FIGURE 1. Location of the Four U.S. DOE National Environmental Research Parks (NERP)

of Washington has been exploited with little thought of preserving land for ecological study. Forested lands have fared somewhat better than steppe lands in this respect, because substantial acreages have been designated and are protected as national parks or wilderness areas. Today, the only sizeable acreage of Washington steppe land in nearly pristine condition exists on the Hanford Site.

THE NATIONAL ENVIRONMENTAL RESEARCH PARK (NERP) IN RELATION TO OTHER FEDERAL RESEARCH AND NATURAL AREAS

The designation of the Hanford Site as a National Environmental Research Park insures the preservation of study areas over periods of time sufficiently long to: 1) obtain useful results, 2) encourage its use by scientists located throughout the United States, and

3) provide a base site from which to integrate Pacific Northwest steppe research into ecosystem research done at other sites in other ecosystems, e.g., forest and deserts.

The Hanford NERP is coterminous with DOE's Hanford Site. It is about 570 square miles in extent. Within this area lies the ALE Reserve, a smaller area of 120 square miles, and certain smaller areas withdrawn from the NERP for construction and operation of energy-related facilities. Although Hanford's NERP was dedicated in March 1977, major elements of the NERP program have been in place for over a decade, and the program has antecedents dating to 1952 and earlier (Foster, 1952). The Hanford Site represents a major ecosystem in the northwestern United States.

The Hanford NERP provides areas where supporting data may be obtained in order to

validate the nature and extent of environmental impact caused by the installation and operation of energy facilities. In contrast to the ALE Reserve, the larger Hanford Site includes areas where there exist new facilities for commercial nuclear electric power generation, the Federal nuclear production and reprocessing plants, and other high technology developments. Huge stretches of the 570-square-mile NERP Site also remain comparatively undisturbed. To date, possible radiological emissions from the nuclear facilities have been very tightly controlled so that measurable environmental impact of radiation has neither been expected or has ever been detected. Also, operation of these facilities has been remarkably free from other adverse ecological impact on this region; e.g., thermal effluent discharges from the nuclear reactors. This is validated by a variety of long-term ecological monitoring studies that have continued over 10- and 25-yr intervals (e.g., Becker, 1973b; Becker et al., 1971; Becker and Fujihara, 1978; Foster, 1972; Foster et al., 1972; Gilbert et al., 1971; Harrison and Eberhardt, 1971; Vaughan, 1977; Watson, 1970; Watson, 1973).

The ALE Reserve is a segregated portion of the Hanford NERP. Special policies for land use apply within its boundaries, chief of which are: 1) the dedication to long-term preservation of pristine vegetational locations and 2) the restriction to "modulation" experiments of those other locations where landscape perturbation is allowed. Modulation experiments are defined as procedures which do not irreversibly alter the landscape; e.g., controlled grazing, modification of the precipitation regime by controlled overhead sprinkling, etc. Other types of intervention procedures that permanently alter the landscape will be carried out on locations in the Hanford NERP outside of the ALE Reserve. With the exception of the Columbia River shoreline communities, all major landscape types within the Hanford NERP are represented both inside and outside the ALE Reserve.

In 1971, the Arid lands Ecology Reserve also became the Rattlesnake Hills Research Natural Area as part of a five-agency federal

cooperative agreement. A key element in that designation was the idea of preserving undisturbed sites and the gene pools represented by all types of organisms found naturally at those sites, especially rare and endangered or threatened types (Anon, 1972). These goals were consistent with the prior intent in establishing large segments of the ALE Reserve. In 1977, Dr. Jerry Franklin of the U.S. Department of Agriculture examined suitable sites over the whole of the U.S. for the Biosphere Reserve Program (Franklin, 1977). He stated that. . ."It was seldom possible to identify a single area that satisfied all criteria—a large, strictly preserved tract for conservation of a full array of organisms with a substantial history of research and monitoring and potential for major experimental treatments. (The only area that is clearly of this type is the Arid Lands Ecology Reserve at Hanford, Washington. . .)" One should note that policies for the ALE Reserve are more restrictive than those for other parts of the Hanford NERP.

The following are recommendations concerning the role of natural areas as prepared by the committee on ecological research for the Council on Environmental Quality and the Federal Council for Science and Technology (CEQ, 1974). They describe the role of baseline studies and the role of manipulative studies in research on a landscape scale:

- Complete the existing National System of Natural Areas, with full representation of major ecosystems, to provide sites for studies of naturally functioning systems that can serve as ecological reference points for baseline monitoring, and as controls for experimental research. Utilize existing Federal lands to the maximum extent possible. Classify the natural areas into a useful system.
- Complete the National System of Ecological Research Areas to provide sites for manipulative experiments, management, testing, and observations of the results of human impact. Utilize existing Federal lands to the maximum extent.

The concept of a National Environmental Research Park for ecological studies is ideally suited for the Hanford Site for several reasons: 1) the large resource of DOE-supported personnel, facilities, and available land, 2) the ongoing research studies which are supportive to broad ecological research goals, and 3) the proximity of nuclear facilities. Studies may be broadened to include nuclear and non-nuclear pollutants as regards the mechanisms of distribution and factors influencing their transfer in aquatic and terrestrial ecosystems. Specific transfer routes can be investigated which may be important pathways from aquatic and terrestrial systems to man. The Hanford Site offers an unusual opportunity for conducting such research because of isolation, exclusion, physical security, availability of radiation monitoring and research personnel and the existence of radioactively-tagged environments. Another useful result will be information for establishing policy on release of land for public use after nuclear energy technology use has been terminated.

GENERAL DESCRIPTION OF THE HANFORD SITE

The Hanford Site is located in south-central Washington in Benton and Franklin Counties (Figure 1). It occupies mostly undeveloped steppe land. The major geographic features are the Columbia River, the Rattlesnake Hills, Saddle Mountains, Gable Butte, Gable Mountain, and interconnecting plains (Figure 2). The lowest elevation (350 ft) occurs at the point where the Columbia River leaves the Site. The highest elevation occurs along the crest of the Rattlesnake Hills, 3600 ft above mean sea level. Other topographic features are "sand dunes," an extensive zone of advancing dunes; "White Bluffs," a series of vertical cliffs located on the east bank of the Columbia; and, a few hundred acres of "kame and kettle topography" (formerly termed "knob and kettle").

The climate of the Site is known from a 30-yr record collected at the Hanford Meteorological Station located at an elevation of 700 ft above mean sea level and centrally located in

respect to the Site boundaries. The average annual precipitation amounts to slightly less than 7 in. with most falling in autumn and winter months. Winter minimal temperatures can exceed -20°F. Summer maximal temperatures often exceed 100°F.

Although some of the land that comprises the Hanford Site has been developed, including the construction of railroads, highways, and transmission lines, much of the acreage has not been developed at all.

Since its incorporation into the Hanford Site in 1943, the land has been protected from livestock grazing, agricultural encroachment, off-road recreational vehicular traffic, and other stresses customarily imposed upon steppe lands by people. At the present time, the Hanford Site represents the only sizeable tract of steppe land that is not stressed by livestock grazing use and has not been subjected to such use for 30 yr. Formerly productive fields abandoned 30 yr ago now provide a basis for assessing the biological recovery of abandoned fields following plowing, a severe environmental stress for native plants and associated animals.

Surface waters, other than the Columbia River, are scarce on the Site. West Lake is a natural pond located northwest of Gable Mountain. Gable Mountain Pond, a waste water holding pond, is near the 200 Areas at the foot of Gable Mountain. Several large lakes have also been recently formed on the Franklin County side of the Columbia River by waste water releases from U.S. Bureau of Reclamation projects located on the south-facing slopes of the Saddle Mountains.

At this writing, the only section of the Columbia River in the United States above Bonneville Dam that is not impeded by artificial dams crosses the Hanford Site. This makes this part of the river especially important as a spawning area for anadromous fishes: salmon and steelhead trout. This river section also has many archeological study sites related to human occupation of the Columbia River Valley before the advent of European man.

FIGURE2. The Hanford Site

Other archeological study sites are located on Gable Mountain and at Rattlesnake Springs (Rice, 1968).

The geology of the Site has been studied over the years mostly in regard to Pleistocene and Holocene sediments as related to placement of radioactive waste material in the central portion of the Site. However, all of the late Miocene and Holocene (recent) geological formations known in the Pasco Basin occur at or near the surface at Rattlesnake Springs (Brown, 1970). These springs are approximately 700 ft above mean sea level. The level of periodic and ephemeral Lake Lewis at the latter part of the Pleistocene epoch is represented at Rattlesnake Springs. It is also the level of deposits laid down during the glacial Lake Missoula floods. Sodium rich sediments in the vicinity of Rattlesnake Springs presently support salt tolerant plants (i.e., greasewood). Sodium sediments deposited on the flood plain during altithermal times 8 to 10,000 yr ago probably represent saline floodplain or near-playa evaporite. Many large mammals occupied the Pasco Basin at the same time, then became extinct.

Early man coexisted with these mammals. Rattlesnake Springs itself is probably a recent feature of the environment and is therefore not an ancient camp site.

Data concerning the stratigraphy of the basalt layers beneath the Site are available from the Rattlesnake number 1 well. The well shows the basalt to be at least 10,000 ft deep (Raymond and Tillson, 1968). The oldest strata are probably eocene in age and long periods of time elapsed between basalt flows which number near 100. Anticlinal uplift in the Pasco Basin began in earliest Pliocene time accompanied by Cascade volcanism and uplift. Basing and anticlinal uplift evidently continues in the Pasco Basin but at a much slower rate than the 1 ft per 1000 yr indicated for the Cascade Range.

The groundwater regime beneath the Site consists of an unconfined aquifer of approximately 400 square miles ranging up to 300 ft thick (Figure 3). The unconfined aquifer

FIGURE 3 Hanford Site Water Table Map, April 1973

system is bounded on the west and south by high ridges and on the north and east by the Columbia River. Several confined aquifers lie deep beneath the Ringold clays and upper basalt flows.

The unconfined aquifer has been artificially changed by ground disposal of process waste water. These waste disposal practices have deposited radioactive material on the sediment layers above the unconfined aquifer. Groundwater management techniques [groundwater analysis and aquifer models are used to avoid release of environmentally significant quantities of contaminants to the groundwater system (Cearlock, 1972; Cearlock et al., 1974)].

An extensive research program has been underway for over 30 yr dealing with many aspects of the ecology and radioecology of the Hanford Site. This program will be reviewed in the subsequent sections of this report.

Other studies performed on the Hanford Site include archaeological investigations of historic and prehistoric habitation (Rice, 1968; 1969). Village sites of the historic Wanapum Indians are well preserved. Artifacts dating from 6000 BC were found during archaeological surveys conducted by Washington State University and the University of Idaho. Several sites of particular importance are being considered for nomination for inclusion on the National Register of Historic Places, established under the Historic Preservation Act of 1966. Some excavation of pit house sites has been performed by archaeologists from the Mid-Columbia Archaeological Society under the supervision of the University of Idaho.

PLANT COMMUNITIES AND SPECIAL BIOLOGICAL HABITATS

One of the most useful indicators of biological potential of land is the mosaic of natural plant communities that occur with changes in elevation, topography, and soil substrates. The most important plant communities on the Hanford Site are the following:

Sagebrush-Bluebunch Wheatgrass Community

These communities once occurred over thousands of acres in eastern Washington (Daubenmire, 1970). Today the number of acres is small because the soil and climate are favorable for the growth of wheat. When soils are too steep or too stony to plow, they are used for livestock grazing. The only sizeable acreage of ungrazed sagebrush-bluebunch wheatgrass communities in Washington are located on the Arid lands Ecology Reserve. These communities, on agricultural quality soil, are exceedingly scarce and would be lost to science if not purposefully preserved from agricultural encroachment (Figure 4).

Thyme Buckwheat Community

These communities are confined to the very stony soils and ridge crests at high elevations (Figure 5). They are floristically characterized by plant species not found elsewhere. For the most part, these communities are located on the Arid lands Ecology Reserve where they occupy about 100 acres. These communities are easily disrupted by vehicular

FIGURE 4 Sagebrush-Bluebunch Wheatgrass Community on the Arid lands Ecology Reserve

FIGURE 5. Thyme Buckwheat Community at the Crest of the Rattlesnake Hills on the Arid Lands Ecology Reserve

traffic, especially when the ground is wet after winter snowmelt. In the flowering season, these communities rate high in aesthetic appeal because of the display of flowers and unusual low-growth life forms. Because the plants occupy the highest ground, they are presently vulnerable to destruction by placement of communication towers and the roads needed to service the towers. Although thyme buckwheat communities occur on basaltic heights elsewhere in the steppe region, the ALE Reserve is the only site that offers protection against sheep and cattle grazing and off-road recreational vehicular traffic, and other kinds of man-induced disturbance.

Sage-Sandberg Bluegrass Community

These communities occur on the low elevation land on the Hanford Site and are the most extensive in terms of acres occupied

(Figure 6) (Cline et al., 1977). The climate is generally too dry for dryland wheat, but with irrigation it has great agricultural potential. The waste management areas of the Hanford Site are located in this community type. The type is also well represented on the low elevations of the Arid land Ecology Reserve. The type has low livestock grazing potential and is easily invaded by alien weeds when the soil is disturbed. Only a few acres of this type persist without visible invasion of alien weeds. livestock grazing prior to the establishment of the Hanford Site is thought to be the agent primarily responsible for the successful mass invasion of alien plants. Although the invasion of alien weeds into western steppe regions is widely recognized in the ecological literature as occurring within the past 100 yr or so, the botanical composition of native communities has not been well documented. The impact of weed invasion upon native animal populations is even less known than for native plants.

FIGURE 6. Sagebrush-Sandberg Bluegrass Community on the Arid Lands Ecology Reserve

Sagebrush-Bitterbrush Community

This community type is extensive in the southeastern quarter of the Hanford Site. In appearance it is much like the sagebrush-sandberg bluegrass community, but it supports bitterbrush, and the soils tend to be more sandy and more susceptible to wind erosion (Figure 7). This community type is represented by only a few acres on the ALE Reserve. ERDA's Fast Flux Test Facility and WPPSS nuclear power stations 1, 2 and 4 are located in this community type.

Salt Desert Shrub Communities

Greasewood communities are represented on the Hanford Site. The best developed and largest stand occupies about 100 acres near Rattlesnake Springs on the ALE Reserve. This community is of special interest because of the unusual ability of greasewood plants to concentrate mineral salts in their leaves, especially sodium, and because of the ability

to obtain water from a deep water table (Harr and Price, 1972).

Spiny hopsage communities are scattered over ALE Reserve and elsewhere on the Hanford Site, but at lower elevations. Hopsage is of ecological interest because of its ability to absorb large quantities of a potassium from the soil (Rickard, 1965a).

Winterfat communities occupy several thousand acres on the low slopes of the Rattlesnake Hills and also in the Saddle Mountains (Figure 8). These native plants are of ecological interest because of a relatively high protein content and high palatability as livestock forage.

Special Habitats

The banks of the Columbia are characteristically devoid of trees (Figure 9). However, gravel bars inundated by water during periods of spring runoff support herbaceous plants

FIGURE 7. Sagebrush-Bitterbrush Community on the Hanford Site

FIGURE 8 Winterfat Plant Community on the Arid lands Ecology Reserve

not found elsewhere. With the construction of hydroelectric dams and greatly fluctuating water levels, these gravel bar communities have receded. These communities are expected to disappear entirely if another dam is built on the Columbia because gravel bars exist only in conjunction with freeflowing streams.

The cliff faces of the White Bluffs provide nest sites for swarms of swallows that feed upon flying aquatic insects emerging from the Columbia River.

River islands provide the isolation needed by nesting Canada goose populations. Should these islands be inundated by a reservoir, the nesting goose population would probably disappear.

A large acreage of dune sand is present in the Hanford Site. The acreage is unsuitable for conventional land use purposes, but does

support a few species of plants that can maintain populations in concert with shifting sands and low nutrient content soil.

Kame and kettle topography of glacio-fluvial origin occurs near the 100-N Reactor site (Figure 10). This topography is unusual and provides landscape diversity to an otherwise drab surrounding landscape. The kames also provide slopes that create microclimatic contrasts that dramatically change plant species composition and productivity with slope angle and exposure (Rickard, 1975).

The streamside plant communities along the Columbia River shoreline are essential for the continued existence of the mule deer herd on the Hanford Site by providing fawning habitat, cover, and forage (Hedlund, 1975). Stream-side communities also occur at Rattlesnake Springs (Figure 11).

IMPORTANT BIRD, MAMMAL, AND FISH POPULATIONS OF THE HANFORD SITE

Mammals

1. Mule Deer: A resident population of about 200 animals, 30 to 50 fawns, are tagged and released each year to determine longevity and dispersal patterns (Figure 12).
2. Coyote, Bobcat, Badger: Resident populations of undetermined size.
3. Black-Tailed Hare: Resident populations of variable density are localized in extent. Hares are a major food source for large mammalian predators and the golden eagle.
4. Small Mammals: A large population of pocket mice with smaller populations of deer mice, ground squirrels, sagebrush voles, and grasshopper mice.
5. Furbearers: Raccoon, muskrat, beaver, mink, skunk.

FIGURE 9. Columbia River Shoreline

FIGURE 10. Kame and Kettle Topography on the Hanford Site

FIGURE 11. Streamside Trees at Rattlesnake Springs on the Arid lands Ecology Reserve

FIGURE 12. Mule Deer Fawn with Ear Tag

Birds

1. **Raptors:** Nesting populations of Swainson's hawk, red-tailed hawk, marsh hawk, great-horned owl, prairie falcon, kestrel, burrowing owl, and golden eagle.
2. **Hérons:** A nesting colony of approximately 40 pairs of great blue herons and several pairs of black-crowned night herons (Figure 13).
3. **Gulls:** Mixed nesting colonies of ring-billed and California gulls on Columbia River islands amounting to several thousand breeding pairs.
4. **Gallinaceous Birds:** Chukar partridges, scattered coveys of California quail, ring-necked pheasants, and a few sage grouse in the Rattlesnake Hills.
5. **Waterfowl:** Nesting populations of the Canada goose on Columbia River islands—about 140 nesting pairs in 1974. American coots and grebes nest in 200-Area ponds.

FIGURE 13. Great Blue Heron Nesting on the Hanford Site

6. Other Birds: Large populations of bank and cliff swallows nest on the White Bluffs; horned larks, meadowlarks, and sage sparrows are the important steppe birds. Other nesting birds that are abundant are the black-billed magpie, mourning dove, loggerhead shrike, and long-billed curlew.

Fish

Chinook salmon, steelhead trout, small-mouth bass, squawfish, Rocky Mountain whitefish, sturgeon, carp, chiselmouth, sculpin. Aerial counts of salmon redds on the Columbia River have been regularly censused for 25 yr.

ECOLOGICAL STUDY AREAS OF THE HANFORD SITE

Study Areas

1. ALE Reserve • Headquarters: Control plots, experimental cattle grazing, mammal and bird population studies, lysimeter studies of transuranic uptake by plants from soil, invertebrate population studies, soil and decomposer organism studies, microclimate and micrometeorology, fire as an environmental stress.
2. ALE Reserve • Snively Area: Abandoned agricultural fields, primary and secondary productivity studies, insects and small mammal populations, soil and decomposer studies, mineral uptake, secondary plant succession, bird census of streamside communities.
3. ALE Reserve • Natural Areas: These areas are preserved for nondestructive sampling and observations only.
4. ALE Reserve • Rattlesnake Springs: Freshwater ecology studies, saline-sodic soils and halophyte ecology, sprinkler irrigation trails and herbicide applications, darkling beetle population studies.

5. Ponds and Ditches near 200 Areas: lake and pond radioecology, transuranics, strontium and cesium, cobalt, isotopes in water, sediments, phyto- and zooplankton, algae, fish, waterfowl, and mammals.

Cribs near 200 Areas: Terrestrial ecology of waste burial practices, revegetation of disturbed soil, dispersal of radionuclides via food habits of insects and jackrabbits, small mammals, root distribution of native plants, soil-plant uptake studies, food-chain dynamics.

6. Kame and Kettle Topography: Plant communities, small mammal populations.
7. Columbia River and Shoreline: Anadromous and resident fish populations, plant siting, water intake structures, thermal and chemical effluent outfalls, mule deer tagging studies, Canada goose nesting studies, heron and gull colonies, swallows.
8. Sand Dunes: Plant communities, small mammals, birds.

The NERP at Hanford includes all lands except the operating areas of the plant, the reactor areas, the 200 Areas, the 300 Area, those lands utilized by private firms, and other lands to be designated from time to time. The Wahluke Slope will be included with the approval of Washington State Department of Game and the U.S. Fish and Wildlife Service, who manage it for DOE. lands occupied by dismantled facilities may be included in the NERP.

Figure 14 locates the ecological study areas of the Hanford Site.

TERRESTRIAL ECOLOGICAL RESEARCH

Basic research concerning the biological environment on the Hanford Site is conducted for DOE by Battelle, Pacific Northwest Laboratory (PNL). Arid land research has been mostly confined to the Arid Lands Ecology Reserve,

FIGURE 14. Ecological Study Areas of the Hanford Site

a 110 square mile tract of relatively undisturbed steppe vegetation (Figure 15). The research includes a network of climatological stations to measure temperature and precipitation variations associated with the elevational and topographic changes from the basal plain to the crests of the Rattlesnake Hills (Figure 16). These data have then related to the more sophisticated climatological and meteorological data collected at the Hanford Meteorological Station located between the 200-E and 200-W Areas (Figure 17) (Hinds and Rickard, 1968; Rotenberry et al., 1975; Thorp and Hinds, 1977). Insolation and soil thermal budgets also have been studied on contrasting slope exposures (Hinds, 1975).

Botanical specimens have been collected and preserved on herbarium sheets deposited at the Marion Ownbey Herbarium at Washington State University, Pullman, Washington (Anon, 1972; O'Farrell, 1972). Mammals and birds of the Hanford Site are well known from

a taxonomic point of view (Fitzner, 1975; Fitzner and Fitzner, 1973; Fitzner and Rickard, 1975; Hanson, 1958, 1963; Hanson and Browning, 1959; Hedlund, 1975; Johnson, 1975; Olendorff, 1973; Olendorff and Stoddart, 1974; O'Farrell et al., 1974; O'Farrell and Hedlund, 1972; Rickard, 1960, 1964a, 1964b; Rickard et al., 1977).

Several insects and other invertebrates have been studied as to food habits, energetics, and emergence (Hinds and Rickard, 1973; Lavigne and Rogers, 1974; Rickard, 1967, 1970a, 1970b, 1971; Rickard and Haverfield, 1965; Rogers, 1974; Rogers and Uresk, 1974; Sheldon and Rogers, 1977; Rogers et al., 1972, 1977). Reference specimens are on hand for taxonomic verification. Of particular interest is the multi-factor analysis of temperature, moisture and other variables affecting emergence at earlier instars of the darkling beetle (Hinds and Rickard, 1973).

FIGURE 15. Arid Lands Ecology Reserve

FIGURE 16. Five-Year Averages of October to May Precipitation as a Function of Elevation in the Rattlesnake Hills on the ALE Reserve

Ecosystems level data have now been established for energy and carbon balances during differential exposure of plants (Hinds, 1975; Rickard et al, 1971), for soil erodibility and secondary succession following brushfire (Hinds and Sauer, 1975), and for response of perennial grass communities to controlled grazing stress (Rickard et al, 1975). The inter-relationships between plants and soils have also been investigated as regards mutual adaptation and modification of mineral and water resources (Harr and Price, 1972; Rickard, 1964c, 1965a, 1965b; Rickard and Cline, 1965).

Soil microbial activity has been determined under the natural variation of its prime factors—temperature and moisture (Wildung et al., 1975a). Mineral weathering, wind erosion and the chemical Characterization of Hanford soils also have been under active study for several years now (Hajek and Wildung, 1969; Hsieh and Wildung, 1969; Keeney and Wildung 1977; Routson et al, 1972, 1975;

FIGURE 17. Summary of Precipitation for 1974 on the ALE Reserve

Wildung et al., 1965, 1969, 1971b). The physicochemical properties of particulates suspended in the Columbia River have been established as have seasonal changes in river particle distribution (Wildung et al., 1971a, 1975b). In other soil studies degradative pathways of plant lignins have been investigated as a possible source of soil humic colloids (Wildung et al., 1970).

The following projects are currently in progress:

- Fate of Heavy Metals in Soils and Plants
- Terrestrial Ecology
- Animal Ecology
- Comprehensive Study Grassland Biome
- Ecological Micrometeorology and Climatology
- Characterization of Arid Land Soils

Current research in plant ecology is centered around the productivity of native steppe communities and their responses to universal stresses such as soil drought, temperature extremes, and wildfire. Imposed stresses and manipulations have included cattle grazing, plowing, fertilizer applications to soils (Figure 18), and the uptake of radio-nuclides from different soils by different species of plants (Figure 19). Current animal ecology studies include the dietary habits of herbivorous animals such as cattle, small mammals, blacktailed hares and insects, as well as insectivorous and seed-eating horned larks and meadowlarks. Estimation of the abundance of small mammals has been made in all major community types over the Site using live trap, mark and recapture techniques. Currently, insect populations have been characterized by pitfall trap and sweepnet sampling. Studies are in progress to define energy flow and mineral transfers in steppe ecosystems and the mathematical modeling of ecosystem process. One location has been studied as a comprehensive study site for the International Biological Program's Grassland Biome, and summarization of this effort is in progress.

FIGURE 18. Helicopter Applying Fertilizer to a Sagebrush Community in a Controlled Experiment on the Hanford Site

Modeling efforts are presently well underway arising out of basic ecology programs supported by both the DOE and the National Science Foundation (Grasslands Biome). Based on these programs, participation of modelers from both University and Federal laboratories has been part of the organizing program. The ELM model of the Grasslands Biome, among others, is operational at PNL (Anway et al., 1972; Sauer, 1976), and opportunities exist to use the PNL data base. Excellent onsite computer capability is available with interties to other computer installations.

Synthesis is underway for a several-volume description of primary production under the stress of controlled grazing, carried out earlier under the NSF/IBP Grasslands Biome Program.

FIGURE 19. lysimeter Experiment on the Arid Lands Ecology Reserve

AQUATIC ECOLOGICAL RESEARCH

Research on aquatic ecosystems includes the characterization of the freshwater spring brook at Rattlesnake Springs, quantitative estimates of primary productivity in this system (Figure 20), and certain studies on the Columbia River (Cushing et al., 1975; Gilbert et al., 1971; Watson, 1970, 1973; Wolf and Olson, 1974; Wolf et al., 1971, 1975).

The Columbia River has been investigated over a long period of years, both as to radioecology of the nuclear reactor operations and as to its general ecological impacts. Radioecology will be described at a later point. Ecological studies include the upstream and downstream movements of anadromous fishes

as either immatures or adults, and the dietary habits of juvenile downstream migrants (Becker, 1970a, 1970b, 1973b, 1973c). Salmon redds have been counted for 25 yr in the Hanford reach of the Columbia River, its last **free-flowing stretch. No adverse effect on salmon spawning was detected during the years of the nuclear development (Watson, 1970).**

Current laboratory studies have investigated the response and survival of Columbia River fish and other species to imposed stresses such as thermal shock and the stresses imposed by chemical additives (Becker, 1973d; Becker and Thatcher, 1973; Becker et al., 1971, 1975, 1977; Coutant, 1972a, 1972b; Olson and Foster, 1952; Schneider and Templeton, 1973; Schneider et al., 1975; Thatcher et al., 1975). Gas bubble disease has also been investigated and river areas of supersaturation have been mapped (Fickeisen et al., 1975; Fickeisen and Schneider, 1975).

Modeling of the thermal plumes from reactor outfalls has been done in relation to potential impact on fisheries mortality (Jaske and Synoground, 1970; Jaske et al., 1969; Templeton and Coutant, 1971). Beyond 400 m, approximately, mixed temperatures of the outfall plumes were far lower than accepted lethal temperatures for migrant fish (Jaske et al., 1970). Studies of swimming performance in juvenile chinook, 50-60 mm, show ability to withstand velocity gradients of less than 12 fps (Nakatani, 1963, 1964).

Bacterial pathogens of local fish and shellfish have been under study for several decades, as have various protozoan and other parasites (Becker, 1976, 1977). In a monographic study, the synecological relationships of disease caused by the widespread *Columaris* bacterium have now been delineated (Becker and Fujihara, 1977). Several decades of research at Hanford have gone into this difficult problem, and it is now clear that a second fish vector is responsible for the wide spread of the disease in the Columbia River. The bibliography should be consulted for related and earlier work on fishery pathogens (Vaughan and Helbling, 1976).

FIGURE 20. Measuring Stream Flow at Rattlesnake Springs on the Arid Lands Ecology Reserve

The following research projects are currently in place:

- effects of water quality on fish behavior,
- combined effects of heat and environmental factors on fish,
- fish diseases,
- biogeochemical cycling.

The data developed in these projects are necessary to the understanding of processes inherent to conducting applied research associated with nuclear and nonnuclear energy facilities.

Benthic organisms have received attention principally on ongoing studies for the Washington Public Power Supply System. They are an important food base for the fish populations. Because bottom sediments are major repositories of mineral nutrients and pollutants, the physical-chemical processes associated with the water-sediment interfaces are currently also under investigation. Recent issues of the Annual Report in the

Ecological Sciences, or, the *Bibliography of Environmental Research*, should be consulted for the reporting status of these projects (Vaughan, 1977; Vaughan and Helbling, 1976).

RADIOECOLOGICAL RESEARCH

The study of environmental pathways and food chain relationships has been greatly facilitated by radioactive tracers. Such work has been underway at Hanford for over 30 yr. Since the early reports are too extensive to cite here, the *Bibliography of Environmental Research: Ecosystems Department* should be consulted for details (Vaughan and Helbling, 1976). In some cases on the Hanford Site current radioactivity levels are only slightly above general background levels; nevertheless, sensitive detection techniques can be brought to bear for their measurement in environmental samples. Specific transfer routes are currently being investigated for several less well-understood radionuclides as a means of more accurately predicting their environmental

behavior over extremely long intervals of time; e.g., technetium, plutonium, americium, ¹²⁹I, etc. (Cataldo et al., 1976; Garland and Wildung, 1975; Robinson et al., 1975; Wildung and Garland, 1974; Wildung et al., 1977a, 1977b).

Soil-to-plant concentration ratios ("discrimination factors") have been a topic for study over many years. There is now an increasing realization that the values of this ratio represent an operational definition, at best. Values for any given radioelement may vary over several orders of magnitude depending on possibilities of foliar uptake, chelation, microbial ligand formation in the soil, soil type, plant type and other factors (Vaughan et al., 1976). Thus for actual technology sites it becomes necessary to investigate the CR for appropriate conditions if dose pathways are being considered (Price, 1973; Routson, 1975; Schreckhise and Whicker, 1975).

In several of the studies cited above, organic ligand forms have been identified and found to be quite diverse. Electrophoretic and thin-layer chromatographic isolations were used for the characterizations.

Also, renewed attention has been directed to the generally overlooked phenomenon of direct air to leaf, or foliar, uptake by green plants (Cataldo and Vaughan, 1977; Cataldo et al., 1975; Craig et al., 1975; Vaughan, 1975; Vaughan et al., 1976). At submicron particle sizes, the green leaf will provide a larger effective source of radionuclide to the plant than will a comparable area of soil.

Surface soil exchange soil migration and transport of radionuclides have been under active study for several years (Cearlock et al., 1970; Cline and Rickard, 1972, 1973; Routson and Wildung, 1969, 1970; Routson et al., 1975; Wildung et al., 1977c).

Biotic vectors for the dissemination of radioactivity have been examined in the nuclear fuel reprocessing and waste holding areas, particularly (Fitzner and Price, 1973; Hedlund and Rogers, 1976; O'Farrell et al., 1975; Sheldon and Rogers, 1977). Although the

radioactivity levels are low and not hazardous to people, this work is important in connection with plans for ultimately decontaminating and decommissioning ("D&D") former nuclear technology sites. Ecological aspects of both D&D and current operations have been reviewed comprehensively for the Hanford Site (Rickard and Klepper, 1976; Rogers and Rickard, 1977).

Dispersal has, in one case cited above, occurred by means of fecal pellets, urine and carcasses of the black-tailed hare, a common resident mammal of the shrub-steppe regions. Access to the wastes was probably made by a deep-burrowing animal such as the badger. Hares presumably licked exposed nitrate salts of strontium and cesium which were dispersed by fecal droppings. This dispersal pattern was unusual in that biota rather than physical environmental factors (wind or water) were the vectors. The resulting pattern has been mapped both by radiation sensors carried by helicopter and by a ground survey of line transects laid out in a radial pattern. These Occurrences are clearly associated with fecal deposits at various distances from the B-C Cribs. Since the original source has been sealed by a thick asphalt cover for over 10 yr, the surface contamination is presently associated with aged fecal pellets. Fresh pellets are probably radioactivity-free unless hares have been eating contaminated plant materials such as Russian thistle, a plant noted for its ability to send roots into burial sites and bring strontium to the surface in aboveground shoots (Berry, 1948; Selders, 1950).

In other cases involving the invertebrates, in particular, recent effort has been directed towards better validating food chains for organisms potentially able to act as vectors for radioactivity dissemination (Rogers and Uresk, 1974; Sheldon and Rogers, 1977; Uresk et al., 1975).

Several Hanford pond systems have also been investigated with respect to both radioecological considerations and potential vector dissemination of the radioactivity they contain (Cushing and Watson, 1975; Emery and Garland, 1974; Emery et al., 1974). Each

of these systems supports a well-developed aquatic ecosystem of considerable diversity. Goldfish have lived apparently in normal conditions over numerous generations even in the presence of transuranic elements released at an earlier time.

Work in progress currently includes the following projects:

- suspended particle interaction and uptake in terrestrial plants;
- transuranic complexation in soil and uptake by plants;
- quantitative aspects of plutonium field studies;
- ecological distribution and fate of plutonium and americium in a processing waste pond on the Hanford Site;
- use of analog elements to predict the equilibrium and behavior of transuranic elements in the environment;
- weathering and aging of transuranics;
- radioecology of waste management areas (ROWMA);
- radioecology of ^{129}I and ^{99}Tc ;
- influence of soils and aquatic sediments on the chemical behavior, transport, and bio-availability of pollutants.

Three efforts not described earlier include the 1) statistical approach to inventorying environmentally dispersed pollutants (Romney et al, 1976; Gilbert et al, 1976; Essington et al, 1976); 2) the botanical and seeding approaches developed for minimizing the further dissemination of low levels of buried radioactivity, to be described below; and 3) other studies dealing with long-term, possibly progressive, changes in the biological availability of deposited radioelements. Increased biological availability with time can be anticipated as a function of variable climatic conditions and secondary processes dependent on climatic factors. The aim of this work is to quantitatively establish the range over which such variables might alter biological uptake. Current issues of the Annual Report should be consulted for status of this work (Vaughan, 1977).

Demonstration sites in the vicinity of nuclear operations are needed to promote public awareness. Approaches require more complete knowledge of the infrastructure of individual sites on the Hanford Site. These questions require also that deliberate manipulation be carried out to determine quality and range of response of the natural system. Some of the techniques for measuring changes in environmental quality have been developed in basic ecology programs; others are under development. The data will be used primarily to plan "strategies" for managing disturbed sites. Such strategies must be adequate for maintaining radioactive materials in place for decades-long intervals, consistent with public safety and beneficial use.

One such demonstration project involves the layering of native silt-loam soil above a thick layer of coarse gravels and cobbles. At present, wastes are covered by backfilling trenches with a mixture of earth materials which were removed from trenches, and no attempt is made to layer during backfilling. Rock and gravel layering might well serve as a deterrent to burrowing animals. The layering is expected to discourage plant roots from growing into buried wastes and confine the percolation of soil water to the silt-loam soil layer. Cheatgrass is a good ground cover because it is an annual and is not so deeply rooted as to be likely to exploit the buried wastes. It effectively prevents wind erosion from the soil surface. Abandoned agricultural fields in the 100-F Area and elsewhere on the Hanford Site have maintained more or less even swards of cheatgrass without management of any kind for 30 yr (Cline and Rickard, 1973). Other arrangements of layers, other depths, and other cover crops may be tried as well.

For the approaches suggested above to be feasible, better quantitative data are needed. In the present environment there are at least three abiotic factors that cause rearrangement of surface radioactivity or other chemical burden; these are wind, precipitation and associated runoff, and wildfire.

Wind is an important and persistent force in the movement of surface soil. Although sagebrush and associated grasses and forbs reduce wind speeds near the soil surface, the plant cover in the B-C Cribs area historically has not been dense enough to completely restrict surface soil movement. As black-tailed hare fecal pellets disintegrate due to decomposition and weathering, wind will tend to resuspend and redistribute them over the landscape. For the most part, this redistribution is expected to result in a dilution rather than a concentrating process. However, the dilution factors should be determined quantitatively. Precipitation tends to leach most pollutants deeper into the soil profile. Annual precipitation averages less than 7 in. and, consequently, soil moisture penetration is shallow. However, as pollutants are leached into the upper few decimeters of soil, they may become more available for uptake by plant roots and may then enter a number of food chains. The uptake of radionuclides by plants from soils depends upon numerous factors requiring improved quantitation in order to be able to predict more accurately contaminant levels over future time. Finally, wildfire can cause a rapid dispersal either from the ash of burned pellets, or years later, from burned plant material contaminated by plant root uptake

from soils. Wind may rearrange ashes; and in the absence of a protective vegetation cover, materials may be broadly disseminated. Experiments planned will determine how much activity can be dispersed in a number of ecologically distinctive locations.

There are several ongoing aquatic ecology studies investigating the ecological distribution and fate of radionuclides in process-waste ponds (Figure 21). Attention is directed specifically toward transuranic elements (plutonium and americium). Ecological transfer and specific sites of concentration of transuranics are of primary concern, and particular emphasis is being placed on transfer routes from the pond and the possible pathways to man. Since plutonium-contaminated freshwater systems are scarce, the uniqueness of this research opportunity is obvious. It is noteworthy that a complete aquatic ecosystem has colonized the several ponds with no evident abnormalities.

The data which may be developed are generally applicable in determining principles of pollution ecology; e.g., how ecological systems are stressed by pollutants, or what the ecological consequences may be of such stress.

FIGURE 21. Walkway System Installed on U Pond for Sampling

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