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INTERIM RECLAMATION REPORT BASALT WASTE ISOLATION PROJECT NEAR SURFACE TEST FACILITY 1990

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SUMMARY

In 1968, a program was started to assess the feasibility of storing Hanford Site defense waste in deep caverns constructed in basalt. This program was expanded in 1976 to include investigations of the Hanford Site as a potential location for a mined commercial nuclear waste repository. When the initial basalt storage program began, a Near Surface Test Facility (NSTF) was conceived for the initial testing program. In 1978, construction began on the NSTF. Three tunnels were excavated into Gable Mountain by drilling and blasting. The tunnels consisted of three 180-m-long entrance tunnels connected at their ends by a 105-m-long test room. Excavated materials were used to build a bench on which operations and maintenance facilities were constructed. On December 22, 1987, the signing of the Nuclear Waste Policy Amendments Act suspended all research at the NSTF and began the process of site closure.

This report describes the development of the reclamation project for the NSTF, its implementation, and preliminary estimates of its success. The goal of the reclamation project is to return disturbed sites as nearly as practicable to their original conditions using native species.

Constraints on the reclamation program include climatic factors, soil characteristics, competition from native and non-native species, and seed germination and growth characteristics of the desired species. In arid areas such as the Hanford Site, moisture availability and interspecific competition from alien annuals are the key constraints to reclamation. Annual precipitation may be expected to range between 12.5 and 20 cm, although nearly 20% of the years between 1912 and 1987 experienced less than 12.5 cm. The year may be subdivided into three phases, based on temperature and precipitation features important to plant growth: a dry, hot season from July through October; a relatively wetter cool season between November and February; and a dry, warm season from March to June. On average, some 52% of annual precipitation falls from November through February.

Gable Mountain is dominated by two plant communities: a big sagebrush(*Artemisia tridentata*) - Sandberg's bluegrass (*Poa sandbergii*) community and a stiff sagebrush (*Artemisia rigida*)-Sandberg's bluegrass community. The former community occurs in areas with relatively deep soils. Stiff sage is confined to very shallow soils over basalt outcrops. Native grasses all germinate during the early fall period after the first significant rains, a period when soil temperatures remain high, but occasional freezing air temperatures may be expected. All are cool-season species that perform most of their growth and nutrient storage during the November-to-March period. Cheatgrass can be expected to invade reclamation sites at some point. Establishment of native grasses early in the successional cycle before that invasion is essential to their continued presence.

Disassembly of the site installations began on March 15, 1988, and the site was returned to original contours by December 12, 1988. Disassembly consisted of emptying buildings of their contents and trucking both buildings and contents offsite, removing fences, breaking up paved parking lots and roads, closing and capping ventilation holes, removing and salvaging equipment, removing power lines and poles back to the main power lines at the NSTF boundary, pumping and removing septic tanks and lines, and removing all buried utilities back to the NSTF boundary. The bench material was used to backfill the NSTF tunnels. A concrete curtain wall was cast in place at each tunnel portal, and the associated box cuts were returned to original profile using bench material. Bench material was also trucked to the nearby gravel borrow pit to return that area to original contours. Artificial basalt outcrops were constructed on the box cuts, emergency generator area, and ventilation fan area using rocks salvaged from the bench.

Two separate revegetation methods were employed at the NSTF to meet differing site constraints. The strategy employed on Gable Mountain areas included seeding native grasses and forbs important to Native Peoples by means of broadcasting and establishing the less robust shrub species by planting tubeling stock. Revegetation on Gable Mountain consisted of five steps: seedbed establishment using composted municipal sludge, seedbed preparation, broadcast seeding of grasses and forbs, mulching the seedbed with hydromulch, and planting shrubs using tubelings. Areas other than on Gable Mountain were revegetated using an alternative method that relies heavily on irrigation to support germination and growth of shrubs introduced from seed. Shrub seeds were introduced by broadcasting, followed by drilling of grass seeds. Irrigation by sprinklers was conducted during the spring growth phase to supplement rainfall during that period. Revegetation of the non-

Gable Mountain areas also consisted of five activities: cultivation and site stabilization, seedbed preparation using composted municipal sludge, broadcast seeding of shrubs and drill seeding of grasses, mulching with straw, and irrigation.

Vegetative cover and density in the revegetation plots were assessed in April 1989 and again in June 1989 and 1990. Bluegrass grew on all revegetated sites except the sand pit, trenches, and borrow pit. Estimates of bluegrass cover in the remaining revegetated sites were approximately one fourth that found in the surrounding habitats. Bluebunch wheatgrass produced an estimated cover in excess of that found in the neighboring control sites. Bottlebrush squirreltail also established well in all areas except the explosives magazine. No shrubs were identified in any samples on areas where only shrub seed was used. Planted shrubs fared exceptionally poorly on the non-native soils. Currently, there are virtually no shrubs surviving on the box cuts, ventilation fan area, generator pad area, or the borrow pit. Species of concern to Native Peoples, such as buckwheat, parsley, and balsamroot, were found on the sites where seeds were broadcast, except on the pit run material. The sand pit was devoid of vegetation.

It is extremely unlikely that the sand pit, borrow pit, box cuts, generator pad area, or ventilation fan area will reach the reclamation objectives set for these areas within the next 50 years without further intervention. These areas currently support few living plants. Vegetation on revegetated native soils appears to be growing as expected. Vegetation growth on the main waterline is well below the objective. To date, no shrubs have grown on the area, growth of native grasses is well below the objective, and much of the area has been covered with the pit run material, which may not support adequate growth. Without further treatments, the areas without the pit run material will likely revert to a nearly pure cheatgrass condition.

ACKNOWLEDGMENTS

The reclamation program for the Basalt Waste Isolation Project involved the cooperative efforts of the U.S. Department of Energy (DOE), Westinghouse Hanford Company, Morrison-Knudsen, Morrison Mechanical, the Pacific Northwest Laboratory (PNL), and other contractors and individuals. Those persons at PNL involved with this task include Tom Page, Carol Schuler, Bob Newell, Jim States, and Ray Bienert. Regina Lundgren provided thorough editorial assistance.

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1.0 INTRODUCTION

The restoration of areas disturbed by activities conducted under the auspices of the Basalt Waste Isolation Project (BWIP) has been undertaken by the U.S. Department of Energy (DOE). The objective of this restoration is to return disturbed areas to their original condition as nearly as practicable using only native species. The BWIP reclamation program comprises three separate projects: borehole reclamation, Near Surface Test Facility (NSTF) reclamation, and Exploratory Shaft Facility reclamation. This report describes the development of the reclamation program for the NSTF, its implementation, and preliminary estimates of its success.

1.1 BWIP HISTORY

In 1968, a program was started to assess the feasibility of storing Hanford Site defense waste in deep caverns constructed in basalt (Deju 1978). In 1976, the National Waste Terminal Storage Program, initiated by the DOE, expanded the studies of basalt to investigate the potential for a national commercial nuclear waste repository at Hanford. Eight other locations in a variety of host media (i.e., type of rocks) were also defined as possible commercial waste disposal locations by the initial studies (Babad 1985).

On January 7, 1983, President Reagan signed into law the Nuclear Waste Policy Act of 1982 (Public Law 97-425), which mandates the development of repositories in deep geologic formations as the primary disposal strategy for high-level commercial wastes (Babad 1985).

The Nuclear Waste Policy Act of 1982 required DOE to develop specific guidelines for establishing a repository site. In December 1984, the DOE published final guidelines for narrowing the nine sites under investigation by DOE to five. The five sites nominated were Richton Dome, Mississippi; Yucca Mountain, Nevada; Deaf Smith County, Texas; Davis Canyon, Utah; and the Reference Repository Location on the Hanford Site in Washington State (Babad 1985). The Reference Repository Location was selected in 1981 after extensive geotechnical studies. This location is a 4660-ha area within the Hanford Site that met all of the initial DOE guidelines for safety which were required before site characterization.

Geologic and hydrologic field data were needed to determine if the Reference Repository Location on the Hanford Site could become one of the three candidate sites recommended to the President for final approval. An extensive site characterization program was begun as the BWIP to determine the feasibility of using the basalts beneath the Hanford Site for the repository. Site research focused primarily on determining the direction and travel times of ground-water movement, the uniformity of basalt layers, and tectonic stability.

When the initial basalt storage program began in the late 1960s, a Near Surface Test Facility was conceived for the initial testing program because the deep basalts were not readily accessible. Similarities existed between the basalt flow where the NSTF was to be located and the deep subterranean basalt flows under consideration for the repository. In 1978, a year after DOE established the BWIP at Hanford, construction began on the NSTF. Three tunnels were excavated into Gable Mountain by drilling and blasting. The tunnels consisted of three 180-m-long entrance tunnels connected at their ends by a 105-m-long test room.

Two phases of experiments (demonstrations) were conducted in the NSTF. Phase 1, which used electric heaters to simulate the heat of fuel elements encased in nuclear waste canisters, provided both basic engineering data on the thermal and mechanical response of basalt to heating and a demonstration of the maximum allowable thermal input per canister. The heaters were activated in July 1980. Phase 2, which was not initiated, involved storing nuclear waste material in a geometry similar to that proposed for a full-scale repository to demonstrate the safe, temporary storage and handling of nuclear waste material in an underground basalt environment.

On December 22, 1987, President Reagan signed into law the Nuclear Waste Policy Amendments Act of 1987 that provided, among other things, that DOE must proceed with the suspension of all site characterization activities (other than reclamation activities) at all candidate sites except the Yucca Mountain site within 90 days of the date of enactment of the Act. Consequently, all site characterization for BWIP ceased, and Yucca Mountain was established as the official site for the repository.

No specific standards and criteria were identified in the Nuclear Waste Policy Amendments Act governing reclamation at the Hanford Site; therefore, other guidelines and commitments were applied. The Nuclear Waste Policy Act requires DOE to reclaim sites disturbed during civilian radioactive waste management activities. In Section 7.6 of the Mission Plan for the Civilian Radioactive Waste Management Program (DOE 1985), the guidelines for decommissioning sites found unsuitable for repository development are presented. In general, the Mission Plan states that a site shall be returned as nearly as practicable to its original condition, which is the objective of the BWIP reclamation program. Although the Hanford Site was not determined to be unsuitable for licensing, for purposes of decommissioning, the provisions spelled out in the DOE Mission Plan were applied to the NSTF.

1.2 SITE HISTORY

The areas outside of the industrial zones on the Hanford Site constitute the only extensive areas of ungrazed shrub-steppe habitat in Washington. As a consequence, the Hanford Site constitutes a preserve for a number of natural wildlife species whose populations are diminishing elsewhere in the Columbia Basin region of eastern Washington (Rickard and Poole 1989).

1.2.1 Pre-Nuclear History

Lewis and Clark, who traveled the Columbia and Snake rivers during their 1803-1806 exploration of the Louisiana Territory, were the first Euro-Americans in the region. Fur trappers soon followed, passing through on their way to more productive lands to the west. In the 1860s, merchants established stores, a freight depot, and the White Bluffs Ferry on the Hanford Reach of the Columbia River. Chinese miners began to work the gravel bars for gold. In the 1880s, cattle ranches and farms developed. In the early twentieth century, the small towns of Hanford, White Bluffs, and Ringold thrived. These towns were razed and the people relocated after the U.S. government acquired the land for nuclear materials production in the early 1940s (Cushing 1987).

1.2.2 Nuclear (Since 1943) History

The Hanford Site was chosen in 1943 as the location for the plutonium production facilities needed to produce an atomic bomb. Three reactors began producing plutonium in 1944-1945. Chemical separations facilities began operating in 1944, separating plutonium from the irradiated uranium fuel elements (Chatters 1989).

After World War II the reactors continued to produce plutonium. In August 1947, a major expansion was announced, including construction of six additional reactors.

In 1964, a reduction of nuclear arms production began. By 1972 all reactors were shut down except the N Reactor, and all of the separation plants were shut down except the Plutonium-Uranium Extraction Plant (Chatters 1989).

In the 1970s, the Washington Public Power Supply System, a not-for-profit joint operating agency of public utilities in the Pacific Northwest, began constructing three nuclear power reactors in the southeastern portion of the Hanford Site. Reactor WNP-2 has been generating electricity for commercial use since 1984. Reactors WNP-1 and WNP-4 have been mothballed (an extended construction delay) (Chatters 1989).

Today the Hanford Site is managed by the DOE. The Hanford mission includes conducting research, developing new technology, managing the disposal of radioactive wastes, and conducting environmental, health, monitoring, and safety studies. The only large-scale DOE reactor operating on the Hanford Site is the Fast Flux Test Facility located in the 400 Area. This sodium-cooled reactor began full-scale operations in April 1982 to test reactor fuels and materials (Chatters 1989).

Because public access to the Hanford Site has been restricted since the 1940s, it is the only expanse of nearly pristine shrub-steppe habitat in the state of Washington. Consequently, much of the Site is designated as wildlife refuges and ecological reserves.

1.3 SITE DESCRIPTION

The Hanford Site is located in southeastern Washington State, occupying an area of approximately 1450 km^2 (Figure 1.1). The Hanford Site lies within the Pasco Basin, the structural and topographic low of the Columbia Plateau. The terrain of the basin is relatively flat with subtle topographical features formed by large, glacially related floods that occurred in the Pasco Basin before 13,000 years ago. The semiarid land has a sparse covering of desert shrubs and

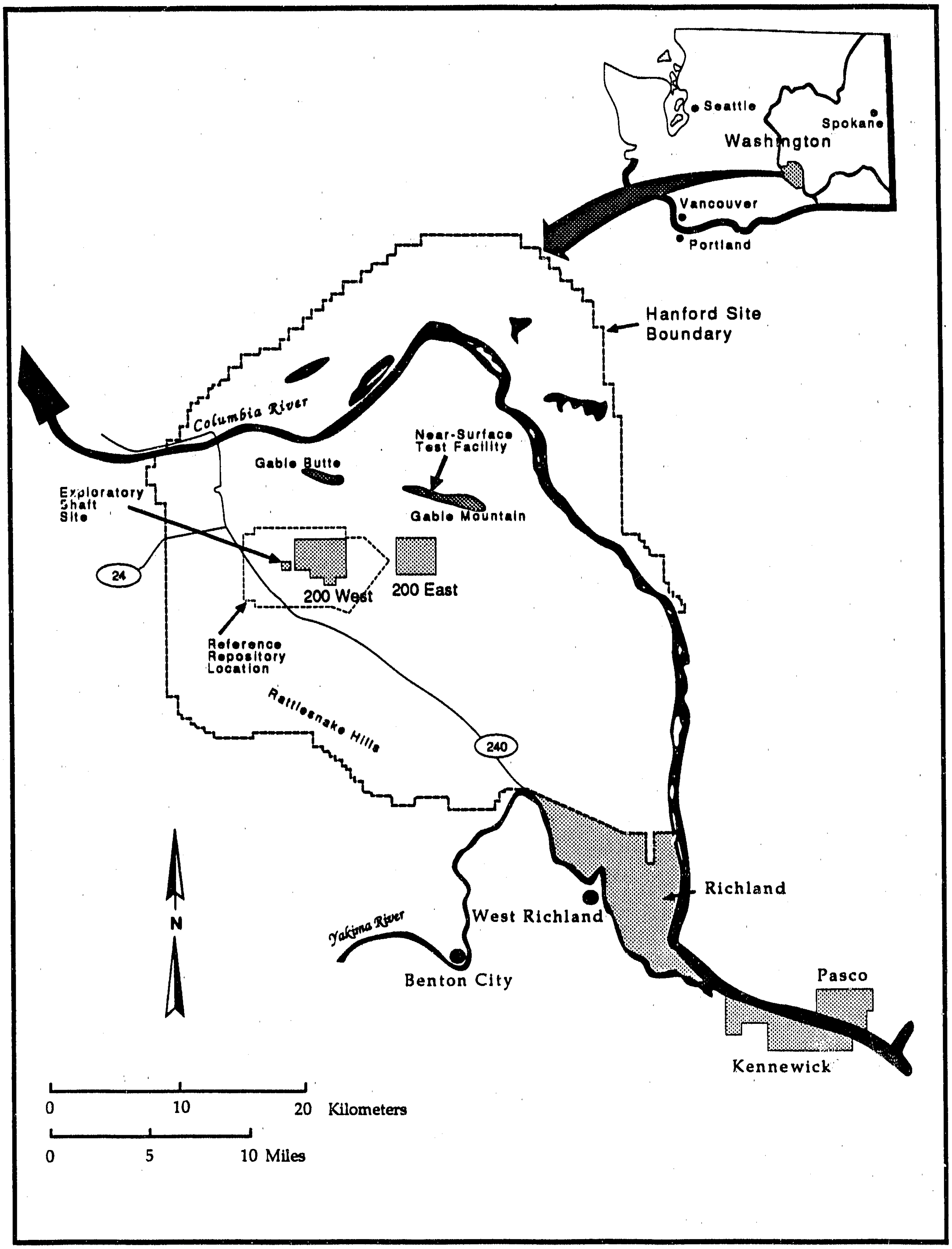

Figure 1.1. Location of the Reference Repository Location and the Hanford Site

drought-resistant grasses. The most broadly distributed vegetation type on the Site is the sagebrush/cheatgrass/bluegrass community.

Gable Mountain, the site for the NSTF, and Gable Butte are two prominent anticlinal ridges of basalt located near the center of the Hanford Site. Gable Mountain is 17.7 km long and 2.4 km wide, and has eastern and western summits approximately 4.8 km apart. The altitude of the eastern summit is approximately 324 m, and the altitude of the western summit is approximately 339 m.

2.0 RECLAMATION PROGRAM

The DOE determined on the basis of commitments made in several National Environmental Policy Act documents that sites disturbed by BWIP would be restored to conditions similar to natural plant communities adjacent to disturbed areas unless alternative land uses were to be implemented (DOE 1978, 1982, 1986). Primary goals were to establish self-sustaining vegetation and to produce cover conditions comparable to those existing before the disturbance. Restoration focused on re-establishment of native plant species and suppression of invading exotic species.

For the purpose of reclamation, natural vegetation is defined as the pre-existing vegetation of sites before BWIP disturbance and can generally be determined by the plant communities surrounding a disturbed site. Native vegetation is defined as plants endemic to southeastern Washington as opposed to exotic vegetation. Exotic or alien vegetation is defined as plants that are not native to southeastern Washington (i.e., have been imported in historical times from outside this region).

The DOE has determined in their reclamation plans that recovery of natural vegetation on disturbed sites and eventual restoration success will be evaluated for 1 year after completion of the reclamation activities, and a determination will be made relative to the need for additional work to meet the reclamation objective. Success will be determined by how well the planted stands resemble nearby undisturbed plant communities.

2.1 STATUS AT CLOSE OF SITE CHARACTERIZATION

The artificial features on the western end of Gable Mountain were a direct result of the construction and operation of the NSTF, with the exception of the microwave repeater station (Figure 2.1). Three tunnels were excavated by drill-and-blast underground mining methods. The surface expression of the underground test facility included three cement-faced tunnel portals and related box cuts, an emergency generator station, and a ventilation (exhaust) fan facility.

When the underground facility was excavated, broken rock removed from the tunnels was placed on the existing slope outside the tunnel portals or entrances to form a bench on which the operations and maintenance facilities were located. Additional gravel and fine crushed rock were imported to surface this bench. The volume of the bench was estimated to be approximately 92,500 m^3.

Several mobile office trailers and permanent structures were located on the tunnel bench. Permanent electrical power and water was run to these structures. Buried holding tanks disposed of sanitary waste.

The emergency generator station and the ventilation fan facility were located higher on the Gable Mountain slope above the tunnels. The emergency generator station consisted of two concrete block generator buildings and a series of six small-diameter boreholes used to run electric cables to the underground excavation. The ventilation fan facility was located further up the mountain slope and ventilated the underground area by means of eight 12 in.-dia. drill holes. These facilities were on concrete pads and surrounded by security fences.

During the construction of the NSTF, separate explosive and blasting cap magazines were set on the Gable Mountain slope. These magazines were removed before BWIP closeout, but the disturbed surface area and the access road were barren, compacted, and in need of revegetation.

Approximately 300 m east of the microwave repeater station along the crest of the mountain were five exploratory trenches totalling at least 160 m in length that pre-date the NSTF. These sites were included within the scope of BWIP reclamation, as were 6 small drill holes (CH-1 to -6) located approximately 60 m east of the ventilation fan facility.

Road access to the NSTF was provided via a two lane asphalt road from the intersection with Route 4 N up to the NSTF bench. A graveled spur road left the black top approximately 150 m east of the NSTF gates and provided access to the microwave repeater station on the crest of the hill.

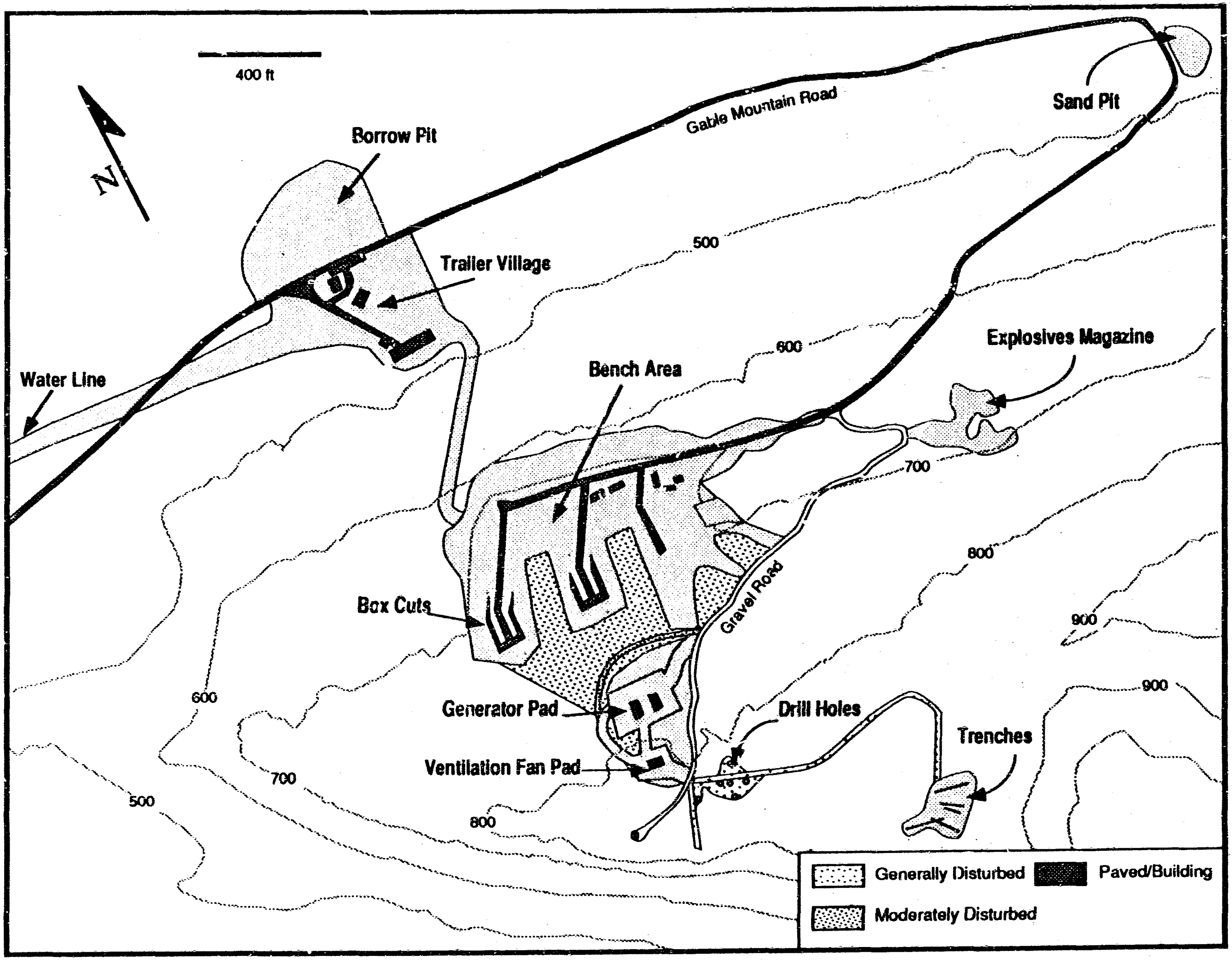

Figure 2.1. NSTF at Close of BWIP. Contours in ft.

A trailer village was constructed at the base of Gable Mountain on a flat, alluvial valley floor directly north of the test facility. The purpose of the trailer village was to provide office space for researchers and facility management personnel, and to support the public information visitor's center. The trailer village included permanent power, water, and a septic tank system. Asphalt-paved sidewalks, roadways, and parking areas were constructed. A gravel borrow pit across Gable Mountain Road from the trailer village supplied gravel for roadway construction.

Electric power was supplied to the NSTF by a 13.8-kV, 3-phase overhead power line that entered the area from the west. The line split near the trailer village with one branch going up the mountain slope. The line split again (above the bench area) with one branch going to the facilities on the tunnel bench and the other going to the emergency generator station. Near the emergency generator station, a trunk line split off to provide power to the microwave repeater station atop the mountain.

Originally, water service was provided to the NSTF by a 4-in. NIPAK line. This waterline was abandoned in place, and a new 10-in., ductile iron pipe waterline was installed along the same right-of-way in late 1987. The lines entered the area from the west, parallel to the overhead power line. Near the trailer village, the lines split, with one branch serving the trailer village and the other branch advancing up the slope of the mountain. On the slope, the new line was laid on the surface with fill material mounded over it. It entered the tunnel bench on the west side.

2.2 ENVIRONMENTAL CONSTRAINTS

A successful reclamation program must account for a number of environmental constraints and processes that impinge on a site. The primary process is that of plant succession, which involves five stages: seed migration, plant establishment, soil reaction, competition, and stabilization. Propagule migration can be enhanced by seeding or planting appropriate species; subsequent plant establishment may be influenced by manipulation of soil and microclimatic features of the site. Soil reaction follows, in which the biotic and abiotic characteristics of the soil are modified by growth and development of the resident plants. At some point, competition between plants will become important, changing the community structure on the site. Competition can be modified by manipulating species types, rates of interaction, and timing of interaction. Ultimately, succession is expected to produce a stable mix of species and edaphic characteristics.

Constraints that define the rates and endpoints of succession at any particular site include climatic factors, soil characteristics, competition from native and non-native species, and seed germination and growth characteristics of the desired species. In arid areas, moisture availability and interspecific competition from alien annuals are the key constraints to reclamation.

2.2.1 Climate

Air temperature, precipitation, and wind are key influences governing the distribution of plants on the Hanford Site. The following climatological summaries for the Hanford Site are based on data gathered from the Hanford Meteorological Station since 1953 and from the Hanford Townsite between 1912 and 1944.

High temperatures average in excess of 32°C during July and August, with a record high of 46°C in July of 1939 (Figure 2.2). Winter (November to February) minimum temperatures average between -7 and -1°C, with a record low of -33°C (in December 1919). Annual precipitation may be expected to range between 12.5 and 20 cm, though nearly 20% of the years between 1912 and 1987 experienced less than 12.5 cm.

The year may be subdivided into three phases based on temperature and precipitation features important to plant growth: A dry, hot season from July through October; a relatively wetter cool season between November and February; and a dry, warm season from March to June (Figure 2.3). On average, some 52% of annual precipitation falls from November through February. Monthly precipitation rates decline from the December high of 2.3 cm, but increase again from April to a secondary maximum in June of 1.3 cm. July is the driest month, with an average of only 0.4 cm of precipitation.

The November-through-February period is most important in terms of input to soil moisture. This 4-month period experiences an average of 8.5 cm of rainfall and a mean temperature of 1.4°C. At least some rain has occurred during this period every year since 1912. Thirty-three percent of all years since 1912 had between 7.5 and 9.5 cm of rainfall in these

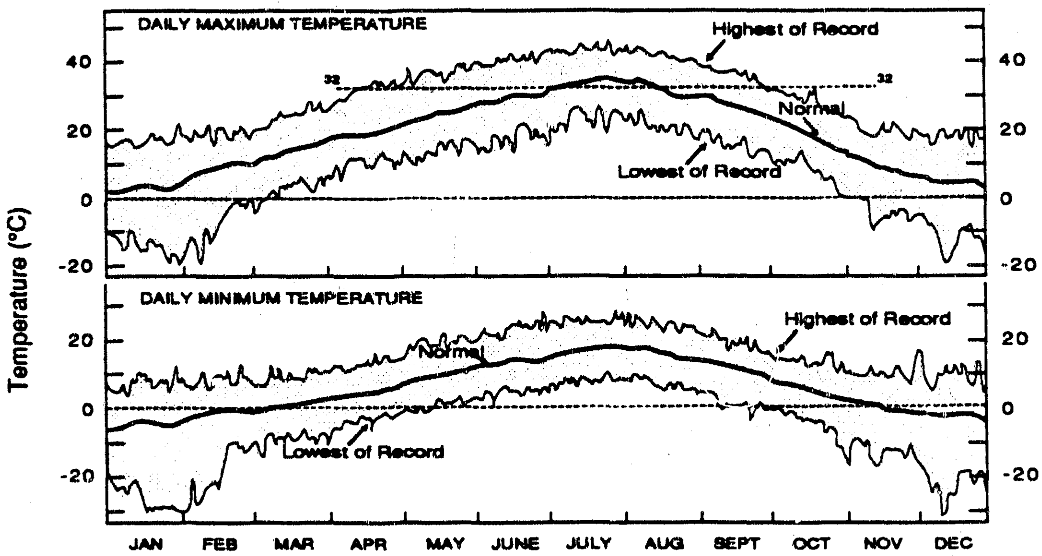

Figure 2.2. Normal and Extreme Daily Temperatures at Hanford (Stone et al. 1983)

months. Together with the low temperatures and high relative humidity (70 to 80%) during this period, evapotranspiration losses are minimal. Most of the precipitation remains in the topsoil, except when Chinook winds or warm rains occur after a period of subfreezing temperatures. In such cases, much of the precipitation and melting snow may run off.

The period from March to June represents a transition from the relatively wet, cool winter to the hot, very dry summer and early fall. Temperatures during this transition period average 14°C, and precipitation averages 4.5 cm (Figure 2.3). Precipitation ranges from a low of 0.62 cm to a maximum of 11.2 cm, with most of this occurring in the month of June. Thirty-four percent of years received between 1.1 and 4.2 cm.

The dry season occurs from July through October, a period especially stressful for plant survival. These months include the hottest and driest of the year; only rarely are winter and spring moisture accumulations sufficient to provide a carry-over of available soil moisture through this period (Hinds and Thorp 1972). Temperatures average 19.7°C, and rainfall averages

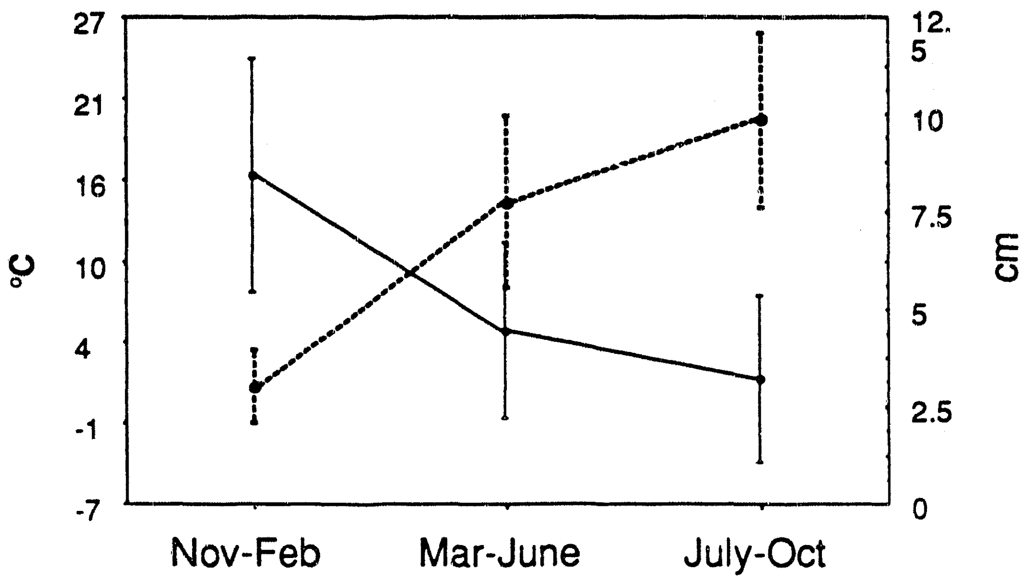

Figure 2.3. Average Temperature (broken line) and Precipitation (solid line) Profiles for Three Periods of the Year

3.2 cm (Figure 2.3). Precipitation during this period ranges from a low of 0.17 cm to a high of 12.2 cm. Most of this precipitation is episodic, falling during summer thunderstorms (Stone et al. 1983).

Precipitation over the Hanford Site generally increases with increasing elevation. Precipitation during the wet season is some 20% greater in and around the Rattlesnake Hills and Gable Mountain than in the surrounding lowlands and the 200 Area Plateau. Dry season precipitation also follows elevational changes (Thorp and Hinds 1977).

The key implication of these data for revegetation is that the NSTF and its associated facilities lie in an arid zone that experiences a net input to soil moisture between November and February and a severe moisture deficit from July to October. Summer storms occasionally drop large amounts of moisture, but these are very infrequent and cannot be relied on to sustain plant growth. Precipitation during any period is unreliable: droughts have occurred in 1 of 5 years. Temperatures during the winter months are usually not so low as to preclude some plant growth at that time: indeed most of the shrubs and grasses are physiologically very active during this period. However, arctic air masses occasionally push the temperatures down to -20°C or -30°C. At these temperatures, damage to unprotected growing plants may be severe.

The transition period between March and June may be of primary importance to plant establishment. Temperatures ameliorate greatly from the winter lows, and moisture inputs usually increase. However, 15% of years received less than 2.5 cm of precipitation during this period. Thus, providing adequate moisture to revegetated plants will be a critical to their success, at least during the first growth year. Options include irrigation, microtopographic modifications, and planting schemes that will enhance snow harvesting and modify the soil moisture profile.

Prevailing winds at the Hanford Meteorological Station, near the NSTF, are from the northwest in all months (Figure 2.4). Winds from the northwest quadrant occur most often during the winter (December through February) and summer (June through August). During the spring and fall, the frequency of southwesterly winds increases with a corresponding decrease in northwesterly flow.

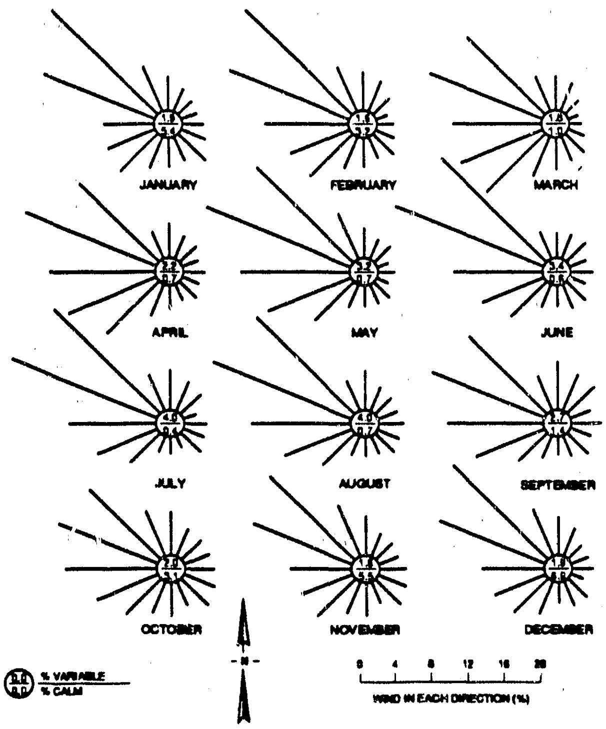

Figure 2.4. Monthly Wind Roses for the Hanford Meteorological Station Based on 50-ft Wind Data, 1955 - 1980

Monthly average wind speeds are lowest during the winter months, averaging 9 to 11 km/h, and highest during the summer, averaging 14 to 16 km/h. Wind speeds that are well above average are usually associated with southwesterly winds. In the summer, high-speed winds from the southwest are responsible for most of the dust storms experienced in the region.

High wind and the lack of precipitation combine to make wind erosion potential highest in the summer months. Winds at the NSTF during this period will generally be from the west to northwest. The types of soils at the NSTF (see next section) are very susceptible to wind erosion. Consequently, erosion control measures are necessary to prevent disruption of the soil-root contact for seeded plants and to avoid burying growing plants too deeply. Erosion control measures that could be employed at a site include using tacking agents, incorporating mulches such as straw into the soil, mechanically compacting the soil surface, and irrigating.

2.2.2 Soils

Soils are classified according to general type, such as the Ritzville or Warden series, and subdivided according to texture. Soil series are named for towns or other geographic features near the place where soils of that series were first described (Rasmussen 1971). Further characterization of soils reflects differences in vegetative history, soil depth, parent material, and nature of deposition.

Soils on Gable Mountain, where the NSTF is located, are classified as Kiona silt loam, consisting of medium-textured soils underlain by basalt. This soil varies in depth from a few centimeters to a meter or more in wind-deposition areas. Rock outcrops are common. Drainage is considered to be good, although water-holding capacity is low in stony areas (Rasmussen 1971). Other disturbances included in the NSTF reclamation project lie in Burbank loamy sand and Ephrata sandy loam. Both soils have very rapid water permeability and low water-holding capacity (Rasmussen 1971).

Generally, the boundaries of plant communities and soil types do not necessarily coincide (Daubenmire 1970). However, soil characteristics important to plants on the Hanford Site include waterholding capacity, depth, and parent material. Waterholding capacity is a function of texture and organic content: fine-textured soils, such as silt loams, have higher waterholding capacities than do sands (Bradshaw and Chadwick 1980). Thus the waterholding capacity of the deeper NSTF soils is expected to be fairly high. Silt loams are susceptible to erosion, and the high elevation of the site will increase the likelihood of wind erosion in disturbed areas. Furthermore, soils imported to the site for reclamation purposes require remedial treatments, such as fertilizers or organic amendments, to improve tilth and enhance mineral cycling.

2.2.3 Plant Communities

The Hanford Site lies within the shrub-steppe ecosystem, which is characterized by desert shrubs [e.g., sagebrush (*Artemisia* spp.), rabbitbrush (*Chrysothamnus* spp.), and bitterbrush (*Purshia tridentata*)] and bunchgrasses [e.g., bluegrasses (*Poa* spp.) and wheatgrasses (*Agropyron* spp.)] in roughly equal proportions, at least under pristine conditions (Daubenmire 1970).

Gable Mountain is dominated by two plant communities: a big sagebrush (*Artemisia tridentata*) - Sandberg's bluegrass (*Poa sandbergii*) community and a stiff sagebrush (*Artemisia rigida*)-Sandberg's bluegrass community. The former community occurs in areas with relatively deep soils. Stiff sage is confined to very shallow soils over basalt outcrops (Daubenmire 1970). Besides Sandberg's bluegrass, the principle native grasses in these communities include bottlebrush squirreltail (*Sitanion hystrix*), needle-and-thread grass (*Stipa comata*), and bluebunch wheatgrass (*Agropyron spicatum*). All are cool-season perennial species.

Native plants on Gable Mountain comprise mainly cool-season species (Rickard 1988). Vegetative growth occurs primarily during the late fall after the first rains and during spring before the extreme temperatures of summer (Rickard and Schuler 1988). The primary shrub species, big sagebrush, is capable of photosynthesis year-round, provided sufficient water is present in the soil, and air temperatures are between 10°C and 20°C (DePuit and Caldwell 1973). Usually, however, growth is greatest in the cool season. Flowering and seed set occurs in late November to early December. Germination of big sagebrush seeds occurs during the spring when continuous temperatures are above 5°C (Evans and Young 1986).

The most problematic shrub species as far as revegetation is concerned is spiny hopsage (*Atriplex spinosa*). Spiny hopsage drops its leaves at the onset of hot weather and remains dormant until late winter (Rickard and Schuler 1988). Its peak growth period is thus limited to the cool, moist conditions of spring. Spiny hopsage flowers in early spring and sets seed just before leaf-drop. Seed germination probably occurs after the first significant rains in the fall (Wood et al. 1976).

Germination of Sandberg's bluegrass seeds is inhibited until the first rains of October to November (Evans et al. 1977). Needle-and-thread grass seeds germinate in early winter (Rickard and Schuler 1988); bottlebrush squirreltail germinates in late fall and early winter. Seed germination may be inhibited by low soil moisture (Young and Evans 1977).

Alien annual species occur in the vicinity of the NSTF. Most are early successional species that rapidly colonize areas of soil disturbance. Such colonizers include prickly lettuce (*Lactuca serriola*), tumble mustard (*Sisymbrium altissimum*), Russian thistle (*Salsola kali*), and cheatgrass (*Bromus tectorum*). The most aggressive and ubiquitous of these is cheatgrass. Areas occupied by cheatgrass are resistant to invasion by native species (Rickard and Sauer 1982).

Cheatgrass is a Eurasian native that was introduced to the State in the 1890s (Mack 1988). Although the first plants to colonize an abandoned disrupted (e.g., plowed) area are usually Russian thistle and tumble mustard, these are completely eliminated in a few years by cheatgrass without appropriate management (Daubenmire 1970). In arid areas such as the Hanford Site, cheatgrass occurs in nearly pure stands on abandoned, disturbed ground. Old fields abandoned on the Site in the early 1940s continue to be dominated by cheatgrass, to the exclusion of native species (Rickard and Vaughan 1989). Other areas outside the Hanford Site have remained as nearly pure stands of cheatgrass despite the elimination of human-caused disturbances at least as far back as 1911 (Daubenmire 1970).

Three considerations for reclamation derived from the above discussion are significant for revegetating the NSTF with native vegetation. First, the native grasses all germinate during the early fall period after the first significant rains, a period when soil temperatures remain high, but occasional freezing air temperatures may be expected. Being cool-season species, these grasses perform most of their growth and nutrient storage during the November-to-March period (Chapin 1980). Grasses planted too close in time to ground freeze or in the spring may not have sufficient time to establish an adequate nutrient and moisture base to carry them successfully through summer dormancy. Irrigation may enhance the rate of survival should planting be performed late, but if dormancy is triggered by day length or temperature, such actions will be futile.

The second consideration for reclamation deals with competition from cheatgrass. As a component of nearly all communities on the Hanford Site, cheatgrass can be expected to invade the reclamation site at some point. Establishing native grasses early in the successional cycle before that invasion is essential to their continued presence at that site (Daubenmire 1970).

The third consideration relates to soil-plant relationships. The stiff sage-Sandberg's bluegrass community occurs only in very shallow soils, often less than 6 cm (Daubenmire 1970). Re-establishment of this community will have to overcome problems of water retention, planting difficulties (rough terrain, lack of tilling depth), and erosion.

2.3 DERIVATION OF RECOMMENDATIONS FOR RECLAMATION

A specific reclamation objective was formulated for the NSTF, its ancillary support facilities, and related sites. The considerations used in defining appropriate objectives included pertinent regulations; documented commitments made by the DOE; considerations for the interests of Native Americans as interpreted by the DOE; technical issues regarding the climate, soil, and plant communities of the Hanford Site; specific details of the nature of the disturbances at the various NSTF components; and information collected from onsite and elsewhere regarding revegetation practices in arid environments.

The NSTF and its related reclamation areas were visited by Pacific Northwest Laboratory (PNL) reclamation staff to determine the nature and extent of each disturbance, identify the type of habitat surrounding the disturbance, compare soil parameters in disturbed and undisturbed areas, and identify the primary deterrents of revegetation. Land disturbance at the NSTF covered a range of levels. The greatest disturbances were in the box cuts and the facility pads where original contours were destroyed and all native soils removed to bedrock (see Figure 2.1). Soils had also been removed from the borrow pit. The waterline right-of-way soil profile had been mixed and in some places inverted, exposing areas of little more than cobbles. The five geologic trenches had been excavated in very shallow, rocky soils. Even though the spoil piles remained alongside each trench, little soil was retained.

Rock removed from the NSTF tunnels had been piled beneath the box cuts atop exposed native rock and soils of mixed depths. The area called the sand pit had been excavated, leaving steep barren contours in nearly pure medium-grit sand. The trailer village area was partially paved with asphalt and had general surface disturbance in medium sand. The soils at the explosives magazine area also had been disturbed, with little disruption of the natural contour. Finally, an extensive area between the bench and the generator pad had been moderately disturbed as a consequence of sporadic vehicular travel and minor road construction.

The area around the CH drill holes had been similarly disturbed, but was recently self recolonized by stiff sagebrush.

Westinghouse Hanford Company and Morrison-Knudsen staff were consulted to identify the intended use of the site and any decommissioning constraints that might affect site reclamation. Several key constraints were identified during this review:

- The decommissioning plan called for filling the NSTF box cuts and the gravel borrow pit at the base of the facility to original grade using mined materials. Soils in the area were of insufficient depth to permit borrowing topsoil to cover these fills.
- Soils in the area were occasionally extremely shallow.
- Much of the NSTF reclamation site proper lay in a relatively steep zone subject to apparent sheet and rill erosion.
- The main east-west waterline right-of-way north and west of Gable Mountain was supporting the only dense stand of cheatgrass in the area.
- The entire area except for the gravel road to the microwave repeater station was to be returned as near as practicable to its original condition.

A decision framework was developed that identified the important considerations and provided resolution to those problems (see Figure 2.5).

2.4 ASSESSMENT METHODS AND MATERIALS

After the preliminary screening, the NSTF and associated reclamation areas were revisited to characterize the nearby undisturbed communities to determine appropriate seeding and planting mixes for each reclamation location. Literature pertinent to reclamation was surveyed, and interviews were conducted with individuals involved in land reclamation at the Hanford Site, eastern Washington, and arid lands in the western United States. This information was used to design revegetation specifications for the site.

Vegetative communities were analyzed on May 16 and 17, 1988, in relatively undisturbed areas representing the least-disturbed native community near each site. Two locations were sampled near the CH drill holes, eight around the NSTF proper, one at the explosives magazine area, one at the geologic trenches, two near the trailer village area, nine along the waterline right-of-way, and one at the sand pit (Figure 2.6).

Sampling locations consisted of 10-by-10-m plots located at least 10 m distant from the edge of the reclamation site. Plots were marked with wooden stakes bearing the site and location designations. Canopy cover of grasses and shrubs was measured along the side of the plot nearest the disturbed area. Plant cover was measured using the point-interception method (Goodall 1953) by means of an optical point bar. The bar consists of 10 ocular scopes with cross hairs. Species were recorded whenever they intersected the view beyond the cross hairs. Sampling using the optical point bar was repeated at 1-m intervals starting 1 m from one corner of the plot. Percentage cover for any species at any sampling location was therefore simply the sum of the point interceptions for that species at that location. Shrub density was determined by counting all shrubs, by species, within the plot.

The NSTF proper was surrounded by two communities: big sagebrush-Sandberg's bluegrass and stiff sagebrush-Sandberg's bluegrass communities. The trenches lie in a mixed zone of stiff sagebrush, big sagebrush, and Sandberg's bluegrass, whereas the CH drill holes lie in a stiff sagebrush-Sandberg's bluegrass community (Figure 2.6). The trailer village lies in a mixed big sagebrush/green rabbitbrush (*Chrysothamnus nauseosus*)-Sandberg's bluegrass community with a large Indian ricegrass (*Oryzopsis hymenoides*) component. The waterline right-of-way is bounded by two communities: a big sagebrush-Sandberg's bluegrass community and a big sagebrush-cheatgrass community. The borrow pit lies in the big sagebrush-Sandberg's bluegrass commmunity. Quantitative plant community data obtained from each of these areas are given in Table 2.1.

Soil samples were collected on April 15, 1988, to determine the physical and chemical characteristics of undisturbed soils near the borehole sites. Samples were taken at a 15-cm depth at four locations: near tunnels 1 and 2 (composite of two subsamples); between boxcuts (composite of two subsamples); near the water line right of way at Route 4N (composite of two subsamples); and at the trailer village (composite of three subsamples). Parameters analyzed were texture (% sand, silt, and clay), pH, phosphorus, potassium, total Kjeldahl nitrogen, organic carbon, and cation exchange capacity. Data are presented in Table 2.2.

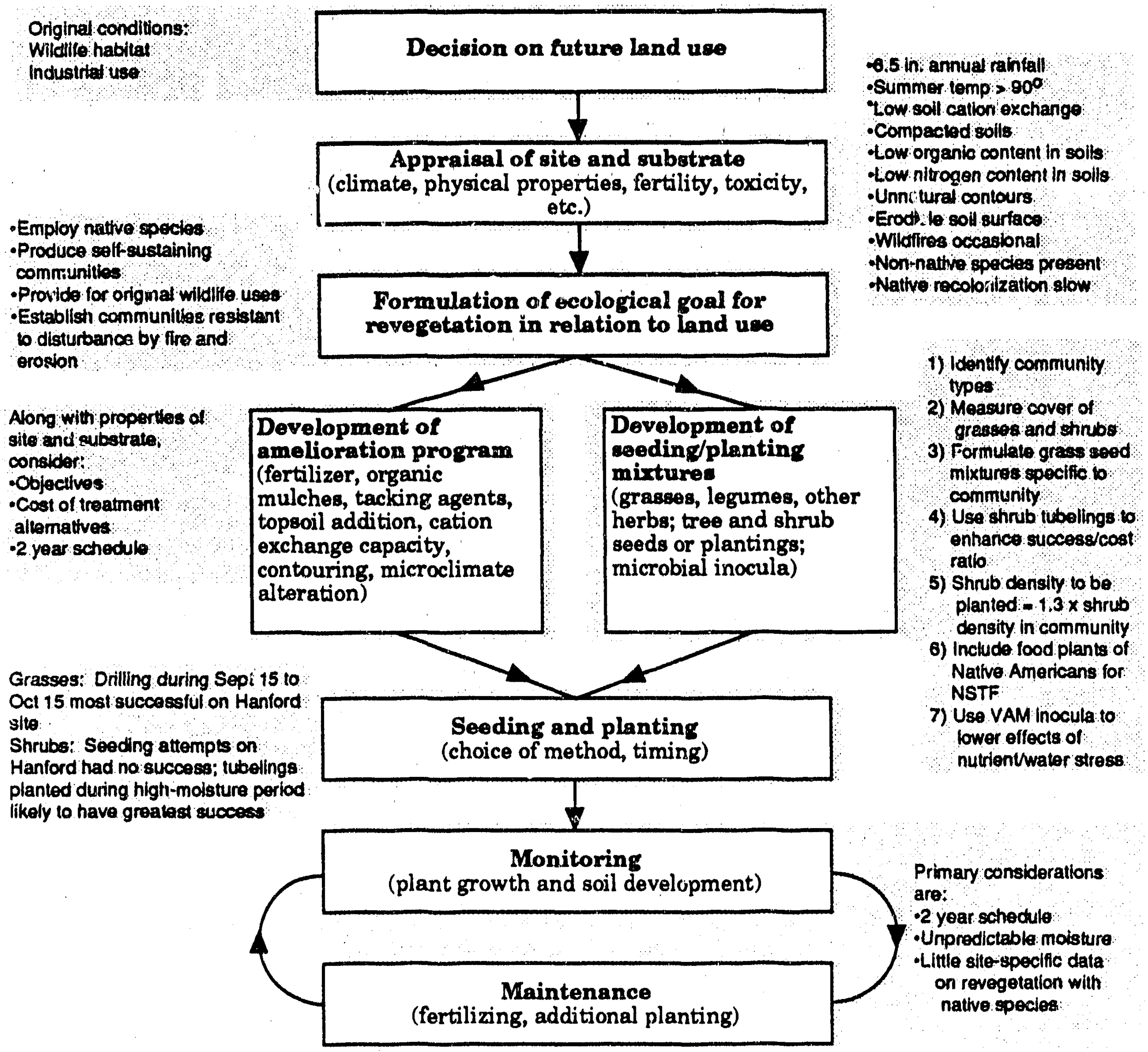

Figure 2.5. Framework for Reclamation Decisions at the NSTF

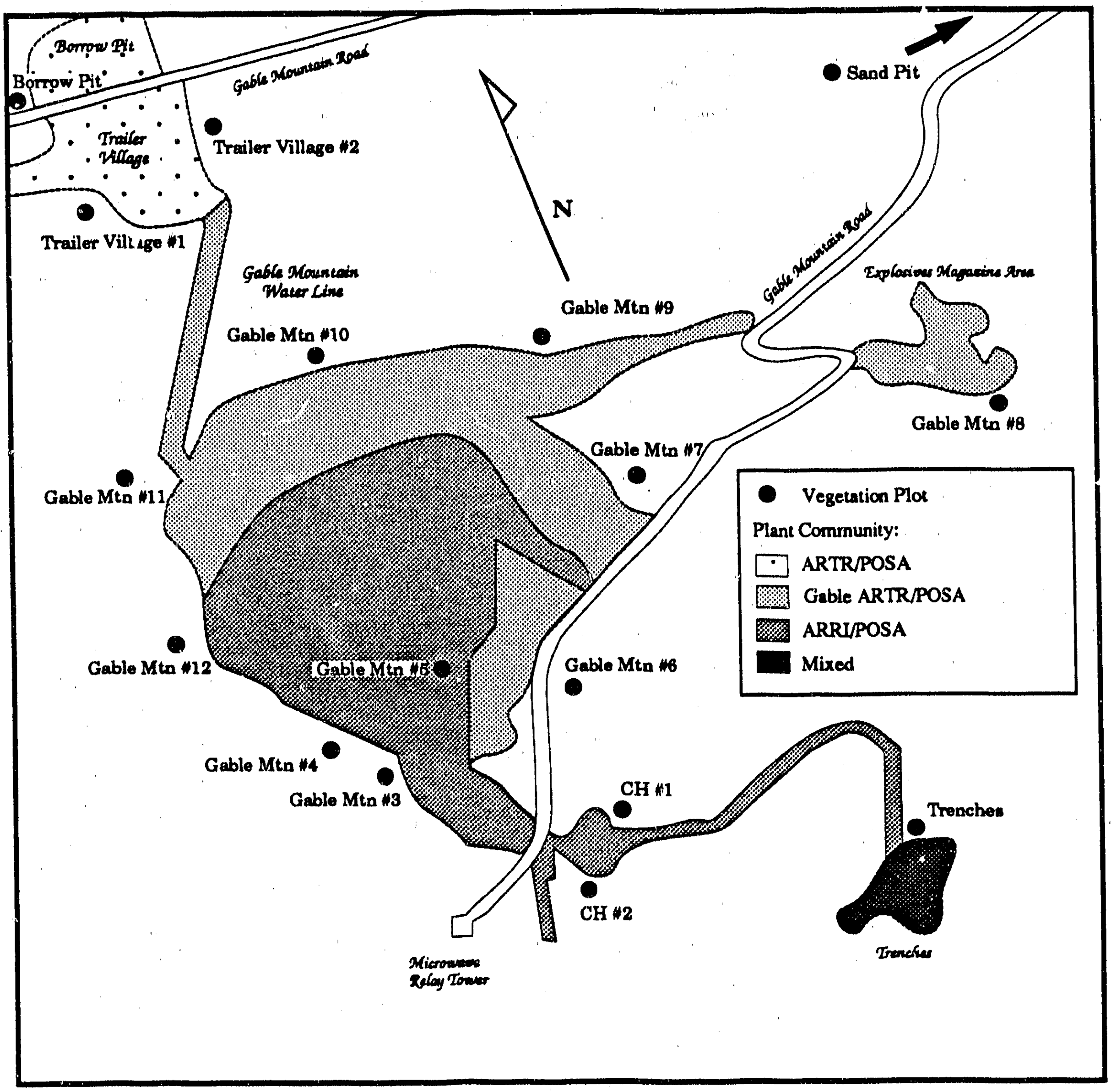

Figure 2.6. NSTF Plant Communities and Preliminary Vegetation Assessment Plots (ARTR/POSA: big sagebrush/Sandberg's bluegrass; Gable ARTR/POSA: Gable Mountain big sagebrush/Sandberg's bluegrass; ARRI/POSA: stiff sagebrush/Sandberg's bluegrass; Mixed: Gable Mountain big sagebrush/Sandberg's bluegrass and stiff sagebrush/Sandberg's bluegrass)

Table 2.1. Average Cover and/or Plant Density for Species in Undisturbed Habitats at the NSTF

Species	Percent Cover	Density./m^2
NSTF — big sagebrush-Sandberg's bluegrass		
Cheatgrass	21	N/A
Sandberg's bluegrass	30	N/A
Needle-and-thread grass	0.2	N/A
Bottlebrush squirreltail	1	N/A
Bluebunch wheatgrass	2.5	N/A
Big sagebrush	4	0.13
Green rabbitbrush	0.1	0.003
Stiff sagebrush	0	0.01
Grey rabbitbrush	0	0.001
Spiny hopsage	0	0.007
NSTF — stiff sagebrush-Sandberg's bluegrass		
Cheatgrass	6	N/A
Sandberg's bluegrass	34	N/A
Big sagebrush	0	0.015
Stiff sagebrush	9	0.62
CH drill holes		
Cheatgrass	10	N/A
Sandberg's bluegrass	19	N/A
Needle-and-thread grass	2	N/A
Bottlebrush squirreltail	1	N/A
Big sagebrush	10	0.39
Stiff sagebrush	6	0.49
Spiny hopsage	0	0.06
Trenches		
Cheatgrass	14	N/A
Sandberg's bluegrass	23	N/A
Bluebunch wheatgrass	1	N/A
Big sagebrush	20	0.33
Stiff sagebrush	0	0.04
Grey rabbitbrush	0	0.01
Trailer Village		
Cheatgrass	6	N/A
Sandberg's bluegrass	16	N/A
Indian ricegrass	4	N/A
Big sagebrush	2	0.70
Grey rabbitbrush	0	0.12
Green rabbitbrush	4	0.16
Waterline — big sagebrush-Sandberg's bluegrass		
Cheatgrass	10	N/A
Sandberg's bluegrass	27	N/A
Bottlebrush squirreltail	0.2	N/A
Big sagebrush	6	0.12
Green rabbitbrush	2.6	0.078
Grey rabbitbrush	0.2	0.044
Spiny hopsage	0	0.01
Waterline — big sagebrush-cheatgrass		
Cheatgrass	35	N/A
Sandberg's bluegrass	10	N/A
Bottlebrush squirreltail	0.2	N/A
Big sagebrush	12	0.11
Green rabbitbrush	0	0.01
Spiny hopsage	3.5	0.002

Table 2.2. Soil Parameters From Undisturbed Soils Surrounding the NSTF

Location	pH	P, ppm	K, ppm	% N	% Organic C	CEC[a]	% Sand)	% Silt	% Clay
Tunnels	8.0	11.7	257	0.02	0.41	8.0	51.4	43.5	5.1
Box cuts	8.2	4.6	277	0.02	0.16	9.0	28.0	69.5	2.5
Trailer village	7.9	10.4	429	0.02	0.25	5.3	86.0	11.0	3.0
Water line	7.6	13.3	363	0.03	0.28	4.3	82.3	15.3	2.4

[a]CEC = Cation Exchange Capacity

3.0 RECLAMATION METHODS

In formulating reclamation recommendations, our consideration were, in order of priority

- the objective stated in the reclamation plans: returning sites as near as practicable to their predisturbance condition
- the time frame available in which to accomplish that objective: 2 years
- the technical factors that would prevent obtaining that objective
- cost: how to approach the objective at a reasonable cost.

Technical constraints and considerations for the revegetation sites and the means selected to overcome or minimize each constraint are identified in Table 3.

3.1 DECONSTRUCTION PHASE

Disassembly of the site installations began on March 15, 1988, and was completed on June 10, 1988. Disassembly consisted of emptying buildings of their contents and trucking both buildings and contents offsite, removing fences, breaking up paved parking lots and roads, closing and capping ventilation holes, removing and salvaging equipment, removing power lines and poles back to the main power lines at the NSTF boundary, pumping and removing septic tanks and lines, and removing all buried utilities back to the NSTF boundaries.

The CH drill holes were cemented and capped. Before workover, this area was densely repopulated with stiff sage seedlings, Sandberg's bluegrass, and round-headed buckwheat (*Eriogonum sphaerocephalum*). Little disturbance of the naturally regenerating plant community resulted from this activity, so this area was exempted from further reclamation work.

Earthwork began in July 1988 and was completed by December 12, 1988. The bench material was used to backfill the NSTF tunnels. A concrete curtain wall was cast in place at each tunnel portal, and the box cuts were returned to original profile using bench material. Bench material was also trucked to the gravel borrow pit to return that area to its original contours. The remaining bench material was trucked to the Gable Mountain quarry. Fine cleaning of the bench area was done by hand, including removal of rocks and exposure of existing basalt outcrops. Revealed natural soils were disturbed as little as possible. Connector roads were ripped and blended with surrounding contours. The emergency generator area, ventilation fan area, and explosive magazine area were blended to match surrounding contours. Pit run material removed from borehole pads was salvaged by screening rocks larger than 3.8 cm and hauling the finer materials for placement on the recontoured box cuts, generator area, ventilation fan area, and gravel borrow pit. Artificial basalt outcrops were constructed on the box cuts, generator area, and ventilation fan area using rocks salvaged from the bench. These outcrops break up the artificial contour of these areas and provide valuable cover for wildlife, such as rock wrens (*Salpinctes obsoletus*) and Nuttall's cottontails (*Sylvilagus nutttallii).*

After completion of earthwork, an organic tacking agent (J-Tac) was sprayed on all areas except the trenches at a rate of 90 kg/ha to control soil erosion. A dyed wood fiber tracer was added at the rate of 112 kg/ha.

3.2 REVEGETATION PHASE

Numerous studies of succession in disturbed arid regions have shown that recovery after severe disturbance, such as topsoil removal or high-temperature wildfires, will be delayed by anywhere from 6 to 50 years or more, depending on the type and extent of the disturbance (e.g., Allen 1988). Often, especially in the presence of cheatgrass, the final community type may be much different than that present before the disturbance (Biondini et al. 1985). Intervention in the form of appropriate seedbed preparation and seeding or planting appropriate vegetation is the best way to increase the chances of redeveloping the original native community.

Table 3.1. Site-Specific Constraints and Considerations and Their Solutions to be Implemented in the NSTF Reclamation Project

Site Constraint	Site Solution
Sites occur in widely different vegetative conditions. Each site is unique in terms of surrounding vegetation.	Sites were grouped according to common habitat classification, and all sites within a given classification received the same revegetation treatment.
Constant soil moisture is critical to planting success.	Irrigation water was not available at the majority of sites; therefore, seeds were planted in the bottom of 7-cm furrows to maximize the time of seed contact with moisture.
Cheatgrass is a dominant element of the vegetation surrounding the site.	Where possible, sites were cleared after cheatgrass had set seed, and were seeded before growth of the next generation of cheatgrass. Otherwise, sites were allowed to lie fallow for 1 year, during which they were subjected to chemical herbicide treatment.
Previous attempts at establishing big sagebrush from seed elsewhere on the Hanford Site had met with little success.	Shrubs will be established from containerized (tubeling) stock. Shrubs will be grown at a commercial nursery from seed collected on the Hanford Site. Potting media will be inoculated with vesicular-arbuscular mycorrhizae to enhance resistance to drought and nutrient stress. Plants will be placed 3 cm below grade and in clumps of three to provide favorable microclimate. Plants will be watered at time of placement in ground.
Some sites will be cleared of top course materials several months before seeding.	Site surface will be held from wind erosion by applying an organic tacking agent.

Two separate revegetation methods were employed at the NSTF to meet differing site constraints. The strategy employed on reclamation areas that lie on Gable Mountain included seeding native grasses and three forbs important to Native Peoples [Carey's balsamroot (*Balsamorhiza careyana*), round-headed buckwheat, and large-flowered desert parsley (*Lomatium macrocarpum*)] by means of broadcasting, and establishing the less robust shrub species by planting tubeling stock. Revegetation on Gable Mountain consisted of 5 steps: seedbed establishment, seedbed preparation, broadcast seeding of grasses and forbs, mulching the seedbed with hydromulch, and planting shrubs using tubelings.

Sites other than on Gable Mountain were revegetated using an alternative method that relies heavily on irrigation to support germination and growth of shrubs introduced from seed. Shrub seeds were introduced by broadcasting, followed by drilling of grass seeds. Irrigation by sprinklers was conducted during the spring growth phase to supplement rainfall during that period. Revegetation of the non-Gable Mountain sites also consisted of 5 activities: cultivation and site stabilization, seedbed preparation, broadcast seeding of shrubs and drill seeding of grasses, mulching with straw, and irrigation.

Each reclamation subdivision is described in Table 3.2.

3.2.1 Revegetation of Gable Mountain Sites

Seedbed Establishment

This activity served two purposes: to create a suitable medium for supporting plant growth and eliminate cheatgrass that had established on the site. The order of activity was to harrow areas not requiring topsoil, tackify all disturbed areas, fallow with herbicide application, and disc in composted municipal sludge to all areas receiving topsoil.

Table 3.2. Approximate Area Revegetated at Each Subdivision of the NSTF

Location	Disturbed Area, ha	Description
Waterline	2.42	East waterline: east of Route 4N to Gable Mtn Access Rd.
	2.91	West waterline: west of Route 4N to N-S main waterline
Borrow Pit	1.94	North of trailer village across Gable Mtn Access Rd.
Trailer Village	3.52	Includes waterline from G. ·ie Mtn Access Rd to base of Gable Mountain
NSTF	11.29	Total NSTF
	(5.99)	Total Gable Mountain big sage/ bluegrass community planting
		0.69 ha at explosives magazine
		0.53 ha upper area (Figure 3.1)
		4.77 ha lower area (Figure 3.1)
	(5.18)	Total stiff sage/bluegrass community planting
	(0.12)	Total mixed community planting at trenches (Figure 3.1)

Scarification is recommended in shallowly compacted soils (e.g., Redente et al. 1984). A commercial organic tacking agent (J-Tac) was applied to the site at a rate of 90 kg/ha. Wood cellulose fiber was incorporated with the tacking agent as a tracer at the rate of 112 kg/ha. The area of the trenches was exempted from tacking because of its remoteness and small surface area. Harrowing and tacking were completed on December 12, 1988.

Fallowed areas were sprayed in May 1989 with a nonselective contact herbicide (glyphosate) to kill broad-leafed weeds and cheatgrass where such weeds had established on the seedbed.

Municipal sludge that had been composted for 1 year with wood fiber (GroCo™) was applied to the imported soils on the box cuts, ventilation fan pad area, generator pad area, explosives magazine area, and parts of the exposed soils under the former bench. Composed sludge was applied in August 1989 at the rate of 7% sludge on a weight basis. This material was incorporated into the surface using a disc harrow. The advantages of sludges in land reclamation have been reviewed by Brandt and Hendrickson (1990).

Seedbed Preparation

Seedbeds were prepared by texturing the soil using a spike tooth harrow to break up clods and provide a stable base for seeding. Following cultivation, all areas were compacted and pitted using a cultipacker to prevent of wind and water erosion (Toy and Shay 1987) and provide a stable base for drilling seeds to the appropriate depths (Haferkamp et al. 1987). Seedbed preparation began October 19, 1989.

Seeding

All portions of Gable Mountain requiring seeding were to be seeded with grass between September 15 and October 15, 1989. Work actually began October 26 and was completed on November 2. Seeding was done by broadcasting using hand-carried cyclone seeders. Broadcast seeding was chosen over drill seeding because the extremely shallow soils and the prevalence of natural and artificial rock outcrops precluded the use of a drill. Typically, broadcast seeds fare nearly as well as drilled seeds (but not as well as furrowed seeds) if 1) the seeding rate per acre is double that for drilling, and 2) the seeds are impressed or otherwise incorporated into the soil (Biondini et al. 1985; Haferkamp et al. 1987). Seeds were impressed into the Gable Mountain seedbed using a split-wheel packer.

Revegetation categories of disturbed sites on Gable Mountain were based on plant data obtained from neighboring undisturbed communities and from expected soil depths in the reclamation areas. These categories are shown in Figure 3.1. Table 3.3 lists the

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specific seeding mixes for each of the revegetated habitats on Gable Mountain. Rates are given in terms of pounds Pure Live Seed (PLS) per ha. The percentage PLS of a given batch of seed is the product of the percentage purity of the batch and the percentage germination of the batch divided by 100. Seeding mixtures were based on the assessment of native grasses and forbs present in the surrounding habitats (Table 2.1); rates were based on information provided in Wasser and Shoemaker (1982). The seed was mixed to the appropriate proportions before broadcasting.

Mulching

Mulches are commonly applied to soils to increase water retention and decrease susceptibility to erosion (e.g., Scholl and Pase 1984). Organic mulches have the added benefit of stimulating mycorrhizal growth (Whiford 1988). Mycorrhizae are essential to the growth of many native plants in arid regions, buffering the plant against water and nutrient stress (Allen and Allen 1980).

Following seeding, the area was sprayed with hydromulch. The hydromulch used was 100% virgin wood fiber with 3% tackifier added on a weight basis. The hydromulch was applied at a nominal rate of 1680 kg/ha.

At the trench site, weed-free straw was spread by hand and incorporated into the soil using hand rakes.

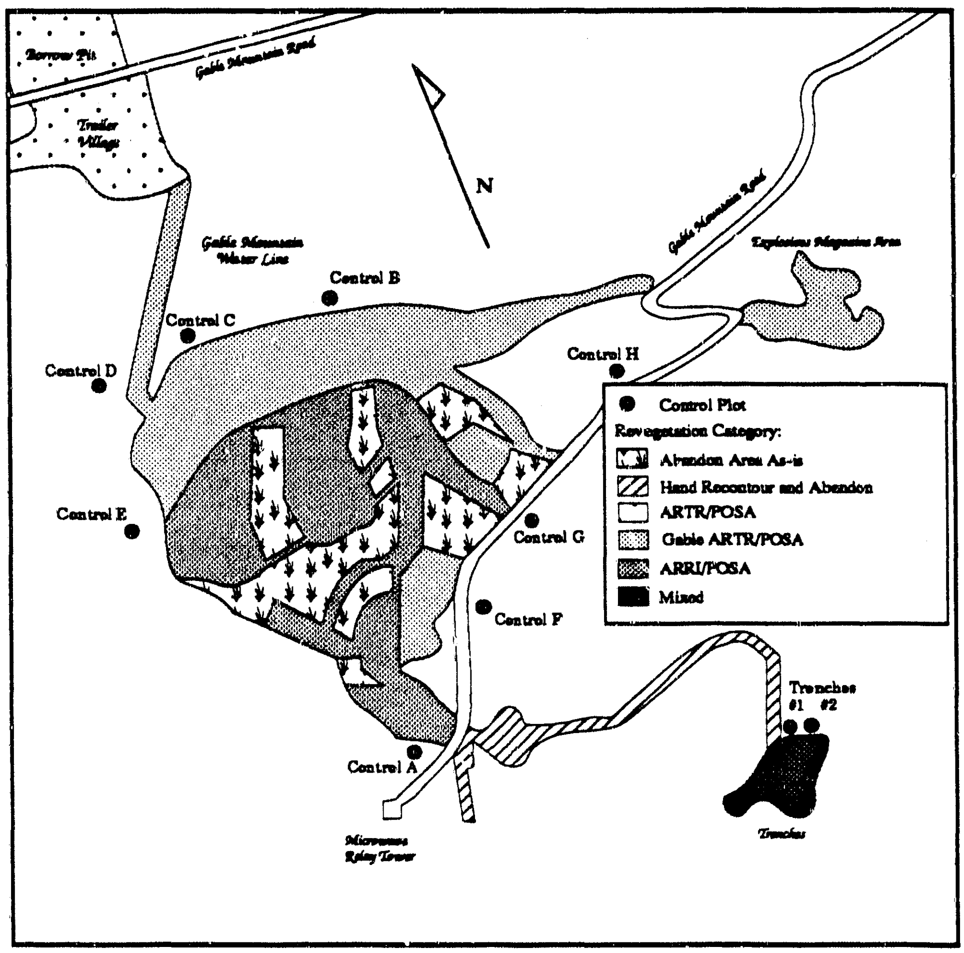

Figure 3.1. Revegetation Categories and Control Plot Locations on Gable Mountain

Table 3.3. Seeding Mixtures and Rates for the NSTF

Species	Seeding Rate
Gable Big sage-Sandberg's bluegrass (ARTR/POSA)	
Sandberg's bluegrass	6.7 kg PLS/ha
bottlebrush squirreltail	5.6 kg PLS/ha
bluebunch wheatgrass (Secar)	4.5 kg PLS/ha
needle-and-thread grass	2.2 kg PLS/ha
large-flowered desert parsley	0.28 kg PLS/ha
Carey's balsamroot	0.28 kg PLS/ha
Stiff sage-Sandberg's bluegrass (ARRI/POSA)	
Sandberg's bluegrass	6.7 kg PLS/ha
large-flowered desert parsley	0.28 kg PLS/ha
Carey's balsamroot	0.28 kg PLS/ha
Mixed (Trenches)	
Sandberg's bluegrass	6.7 kg PLS/ha
bluebunch wheatgrass (Secar)	5.6 kg PLS/ha
bottlebrush squirreltail	4.5 kg PLS/ha
round-headed buckwheat	0.6 kg PLS/ha
large-flowered desert parsley	0.28 kg PLS/ha
Carey's balsamroot	0.28 kg PLS/ha

Planting

After the areas were seeded and mulched, tubeling shrubs were planted. The rates and densities called for in the specifications are given in Table 3.4. The use of tubeling stock has proved much more successful than the seeding of shrubs on other sites (Cook 1988). Species to be planted and their component densities were determined using the same method as described previously. The boundaries of the area to be planted with the stiff sagebrush community were selected on the basis of likely soil depth. The stiff sagebrush community is adapted to shallow-soil, rocky areas (Daubenmire 1970).

Shrubs were planted in clumps of three at 2.5 cm below grade. Clumps consisted of three tubelings of the same species planted in a triangular configuration with approximately 35 cm between plants. Clumped plants have higher survival and growth rates than do plants set out in a more even pattern (MacMahon 1988) because of microclimatic changes and water harvesting by snow drifting. After planting each clump, each tubeling was surrounded with a handmade soil berm approximately 5 cm high with a radius of approximately 17 cm. Two liters of water were applied by hand to each tubeling shortly after planting. Clumps were more or less evenly distributed over each site. Planting was scheduled to begin immediately after mulching was completed and continue no later than March 15, 1990. Actual planting began on November 4 and was completed on November 11.

Table 3.4. Shrub Planting Rates for the NSTF

Species	Planting Rate
Gable Big sage-Sandberg's bluegrass (ARTR/POSA)	
big sagebrush	371 clumps/ha
stiff sagebrush	49 clumps/ha
winterfat (*Eurotia lanata*)	42 clumps/ha
Stiff sage-Sandberg's bluegrass (ARRI/POSA)	
big sagebrush	99 clumps/ha
stiff sagebrush	2471 clumps/ha
Mixed (Trenches)	
big sagebrush	1483 clumps/ha
stiff sagebrush	198 clumps/ha

Because of a supplier shortfall in delivering winterfat tubeling stock, winterfat was planted only on the eastern fourth of the bench area. Also, some tubelings of big sagebrush were grown in media containing a commercial water absorbent designed to retain supplemental moisture during periods of low moisture availability. These tubelings were planted on the bench area and the explosives magazine area.

3.2.2 Revegetation of the Waterline, Trailer Village, Borrow Pit, and Sand Pit

Revegetation of these areas was not constrained by shallow or rocky soils. Furthermore, financial constraints precluded the use of tubeling shrubs on these sites.

Cultivation and Site Stabilization

This activity reduced deep compaction of the seedbed and eliminated cheatgrass that was growing on the sites. The order of activity was to rip then disc the site, import soil to areas consisting mostly of gravels (the borrow pit and parts of the waterline), and apply a tacking agent to control erosion. This phase was conducted during late October and early November 1988. The area was then left to summer fallow.

The entire waterline was ripped to a minimum depth of 30 cm, followed by discing to a minimum depth of 15 cm. At this time, soil (see Section 3.1) was imported and distributed to an average depth of 7.5 cm over areas of heavy gravel content on the waterline as well as the recontoured borrow pit. Soil importation was required to produce a suitable medium for growth of plants, because parts of the waterline and all of the borrow pit comprised broken rock and gravel without sufficient soil to support growth of desired plants. Reclamation of coal mine spoils in semiarid regions of the western United States has found that topsoil depths of 7.5 cm allow plant growth indistinguishable from that established on deeper soil treatments (Biondini et al. 1985).

Following cultivation and soil importation, a tacking agent (J-Tac) was applied to all areas at a rate of 90 kg/ha. As an aid to monitoring application rates, 112 kg/ha of wood cellulose fiber was added to the tacking agent as a tracer. Tacking was completed on November 18, 1988.

Fallow and Seedbed Preparation

The order of activity for this phase was first to apply herbicide to designated areas and prepare a stable surface for seeding.

Fallowed areas were sprayed with a nonselective contact herbicide (glyphosate) to kill broad-leafed weeds and cheatgrass where such weeds had established on the seedbed. Spraying was done in May 1989.

Seedbed preparation was completed on the sand pit in November 1988. Seedbed preparation was scheduled to begin on the remaining sites on September 15, 1989; however delays in obtaining the necessary contractor postponed the start of this activity until October 19. Seedbed preparation consisted of texturing the soil using a spike tooth harrow to break up clods and provide a stable base for seeding. Following cultivation, all areas were compacted and pitted using a cultipacker.

Seeding

Seeding of the sand pit was recommended to occur between September 15 and October 15, 1988; seeding was not completed until November 8 because of a delay in obtaining a revegetation contractor. Seeding of the waterline and associated sites was scheduled to be done between September 15 and October 15, 1989. Seeding actually began October 24 and was completed October 26, 1989. The order of activities was first to broadcast shrub seeds, second to drill grasses, and third to apply a mulch of straw.

Seeds of rabbitbrush species and big sagebrush were broadcast at the rate specified in Table 3.5. Grass seed was then to be drilled into the seedbeds using a Truax drill calibrated to deliver seed at the rates and depths specified in Table 3.5. Seed mixes for each site were based on the quantitative assessments made of the vegetation in the habitats surrounding each site (see Table 2.1). Seeding rates were based on information provided in Wasser and Shoemaker (1982). Seeding depths were based on information in Fulbright et al. (1982) and Wasser and Shoemaker (1982).

Seeding of the sandpit was not done according to specifications and was conducted without informing PNL of the date or change. All seeds including the grass seed were broadcast rather than drilled into the seedbed. Consistent with standard practice, the actual seeding rate was over twice that recommended in the specification.

Seeding of the borrow pit and the waterline was performed with each grass species introduced into separate seed-hoppers on the drill. The seeding ports were then baffled such that each species was seeded into alternate drill furrows to limit interspecific competition among growing grasses. At the trailer village site, Indian ricegrass was seeded alone before seeding the remaining grasses. After seeding Indian ricegrass, the seed drill was be operated such that the furrows were oriented 90° to the furrows made when seeding Indian ricegrass. Soil openers were spaced between 20 and 30 cm. The drill was calibrated to deliver seed at the specified rates and adjustments double-checked before drilling a site. Depth bands were used to control seeding depths.

Although not called for in the revegetation specification, the trailer village and borrow pit areas were planted with tubeling shrubs at a rate approximating that used for the Gable Mountain big sagebrush-Sandberg's bluegrass community. This event came about as a result of overestimates of tubeling mortality at the greenhouse, resulting in excess shrubs being shipped to the site. Furthermore, the size of the areas needing planting were overestimated, and most were planted at less than the specified rate.

Table 3.5. Seeding Mixtures and Specifications for NSTF Reclamation Sites Other Than on Gable Mountain

Species	Seeding Rate	Seeding Depth (method)
West Waterline		
Sandberg's bluegrass	3.3 kg PLS/ha	0.6 - 1.25 cm
bottlebrush squirreltail	2.2 kg PLS/ha	0.6 - 1.25 cm
big sagebrush	0.28 kg clean seed/ha	(broadcast)
East Waterline		
Sandberg's bluegrass	4.5 kg PLS/ha	0.6 - 1.25 cm
needle-and-thread grass	1.1 kg PLS/ha	0.6 - 1.25 cm
bottlebrush squirreltail	1.1 kg PLS/ha	0.6 - 1.25 cm
big sagebrush	0.28 kg clean seed/ha	(broadcast)
grey rabbitbrush	0.14 kg clean seed/ha	(broadcast)
green rabbitbrush	0.14 kg clean seed/ha	(broadcast)
Trailer Village		
Sandberg's bluegrass	3.4 kg PLS/ha	0.6 - 1.25 cm
needle-and-thread grass	2.2 kg PLS/ha	0.6 - 1.25 cm
Indian ricegrass	3.4 kg PLS/ha	5 - 7.5 cm
big sagebrush	0.28 kg clean seed/ha	(broadcast)
grey rabbitbrush	0.14 kg clean seed/ha	(broadcast)
green rabbitbrush	0.14 kg clean seed/ha	(broadcast)
Sand Pit		
Sandberg's bluegrass	3.3 kg PLS/ha	0.6 - 1.25 cm
bottlebrush squirreltail	2.2 kg PLS/ha	0.6 - 1.25 cm
big sagebrush	0.56 kg clean seed/ha	(broadcast)
Borrow Pit		
Sandberg's bluegrass	4.5 kg PLS/ha	0.6 - 1.25 cm
big sagebrush	0.28 kg clean seed/ha	(broadcast)

Mulching

Following the drilling of seed, a mulch of certified weed-free straw was to be blown over all seedbeds at a rate of 4500 kg/ha, which is the rate specified by the Washington State Department of Transportation. Actual mulching rates were approximately twice the specified rate. The use of certified weed-free straw limits the introduction of weeds to the seedbed, which would otherwise lower revegetation success (Evans et al. 1970). The mulch was crimped into the seedbed. Mulching of the sand pit was completed on November 8, 1988; mulching of the other sites was completed by November 3.

Irrigation

The revegetated areas were irrigated each month from March to June following completion of planting. All sites except the sand pit were irrigated by means of hand-move sprinklers. The sand pit was irrigated in 1989 using sprinklers attached to hoses run from water trucks. Irrigation was performed at the end of each month sufficient to make the cumulative precipitation on the site reach 2.5 cm/mo. No irrigation was required during months experiencing 2.5 cm or more of precipitation. Final irrigation was completed in early July 1990.

4.0 RECLAMATION SUCCESS

The progress of the reclamation project at the NSTF was tracked by periodic checks as deconstruction and revegetation advanced. A qualitative examination of the germination and growth of plants on the sand pit was conducted during the spring of 1989 before the summer dormancy period of the native grasses, and all reclamation sites were examined in early spring and early summer of 1990. Quantitative surveys of control plots established in undisturbed habitat near each reclamation site were continued. These data provide a basis for assessing vegetative growth on revegetated sites relative to the reclamation goal for each site.

4.1 DECONSTRUCTION

Deconstruction was completed in early December 1988. By that date, all artificial materials had been removed from all areas, the trenches had been filled, and the bench material had been used to fill up the tunnels of the NSTF and to return the box cuts and borrow pit to grade. Broken rock was cleared from the natural rock outcrops beneath the bench, thereby exposing the original ground surface that had been covered since the site was constructed in 1978/1979. Artificial outcrops had been constructed on soil-importation (pit run) areas to restore a measure of relief to the otherwise unnatural homogeneity of the site, as well as to provide microhabitats for wildlife. At completion of deconstruction, the site appeared very much like it might have before its construction in 1978, except for the lack of vegetative cover.

Erosion of the area on Gable Mountain appeared to be minimal during the winter months. Some Russian thistle and bur ragweed (*Ambrosia acanthicarpa*) appeared on the cleared areas, but most of these plants were killed by herbicide in May 1989. Application of composted sludge appeared to be to specifications, though the material was incorporated quite deeply (25 cm) in the softer-soil areas of the explosives magazine and the trailer village areas. Deep incorporation will dilute the beneficial effects of the sludge.

4.2 VEGETATION CONTROL PLOTS

To track the development of vegetation in the target habitats, data on percentage cover and plant density were obtained from permanent plots located in each of the undisturbed plant communities near the reclamation sites. Markers for the plots used to develop revegetation specifications were inadvertantly removed by construction crews during the deconstruction phase of the project. New markers were placed in areas near to the previous plots (Figure 3.1). Plots were located in the Gable Mountain big sage/Sandberg's bluegrass community (plots B, C, D, and G), the stiff sage/Sandberg's bluegrass community (plots A, E, F, and two plots at the trenches), the big sage/ Sandberg's bluegrass community near the borrow pit (plot H), the big sage/Sandberg's bluegrass community along the water line (two plots), and the big sage/cheatgrass community along the water line (two plots). Vegetative cover and density in the control plots were assessed using the same methods described previously (Section 2.4). Plant cover was measured in April and again in June 1989 and 1990, as were species tallies. Shrub density was measured in June 1989 and June 1990.

Cheatgrass was present in all plots, ranging in cover from a low of 4% cover near the trenches to a high of nearly 40% cover in the borrow pit area. Native grasses were the predominant grasses in all habitats except the big sage/cheatgrass communities along the waterline and at the borrow pit. Sandberg's bluegrass was the most prevalent native grass, occurring in each of the habitat types. Shrubs include slender-bush buckwheat (*Eriogonum microthecum*).

Native forbs constitute a small portion of the total ground cover, but occur throughout the habitats. Common native forbs found on the plots included hoary aster (*Machaeranthera canescens*), large-flowered desert parsley, pale evening primrose (*Oenothera pallida*), threadleaf phacelia (*Phacelia linearis*), Carey's balsamroot, yarrow (*Achillea millefolium*), and yellow salsify (*Tragopogon dubius*).

The predominant alien annual species found in the control plots were cheatgrass, bur ragweed, and Russian thistle. All the alien species in the control plots are early succession colonizers and so are expected to invade the revegetated areas at some time. Because of their late seed-set, ragweed and Russian thistle are likely to be present before the other invasive species and in greater numbers during the first year. Because of the large amount of cheatgrass in the surrounding habitat, however, cheatgrass is expected to overtake the other annuals on the revegetated site within several years.

4.3 VEGETATION DEVELOPMENT ON REVEGETATED SITES

Growth of plants on revegetated sites was measured using a modified point frame system in which points cover 0.01 m^2 rather than a vanishingly small area. This method was chosen over the more standard point-intercept method as a means to compensate for the immaturity of the first-year plants and to allow statistically valid sampling of randomly spaced plants. In the modified point system, 0.01 m^2 is the average area covered by a mature Sandberg's bluegrass plant. Thus it is assumed that any first-year plant encompassed by the 0.01-m^2 point would, if it survived to maturity, fill the 0.01-m^2 space. This method underestimates cover at maturity of sparsely distributed immature plants other than bluegrass, because the other plants cover larger areas at maturity than does bluegrass. However, for densely distributed immature plants, cover estimates at maturity should approximate future cover.

The point frame used comprised 25 squares in a 0.25-m^2 frame. Each section of the NSTF revegetation area was subdivided into smaller units and sampled by tossing a stake haphazardly into the area and aligning the point frame with the long axis of the stake. Species occurring within the individual squares in the point frame were tallied and the stake tossed again into an unsampled region. Revegetated sites were sampled at a rate of approximately one sample per 200 m^2 of revegetated area. Results of sampling are discussed below.

No grasses have established on the sand pit or the reseeded portion of the trenches.

Sandberg's bluegrass was an element of all seeding mixes. Bluegrass grew on all revegetated sites except the sand pit, trenches, and borrow pit. Estimates of bluegrass cover in the remaining sites were approximately one fourth that found in the surrounding habitats (Figure 4.1). Bluebunch wheatgrass was broadcast in the Gable Mountain big sagebrush-Sandberg's bluegrass habitats and on the trenches. Bluebunch wheatgrass performed exceptionally well in all locations except the trenches, producing an estimated cover well in excess of that found in the neighboring control sites (Figure 4.1). Bottlebrush squirreltail also established well in all areas except the explosives magazine, where it failed to appear in any of the 37 samples taken on that area (Figure 4.1). Estimates of cover at maturity in most areas were well above that in the control areas. Indian ricegrass was found in the trailer village area, but stands were sparse and below the cover found in the control areas. Because the modified point frame systems underestimates cover of sparse stands, the actual cover when the revegetated plants reach maturity may be within the range of the control sites. Needle-and-thread grass performed well in most areas where it was seeded (Figure 4.1).

No shrubs were identified in any samples on areas where only shrub seed was used.

Densities of shrubs planted on the remaining areas were estimated within 1 week of completion of planting. Density counts in seven 100-m^2 assessment plots showed actual planting densities on the box cuts and generator pad areas to be below the specified density. The box cuts and generator pad densities as planted were 1200 clumps/ha versus the specified density of 5000 clumps/ha. The bench area was planted at a rate of 800 clumps/ha versus a specified density of 462 clumps/ha. Planting densities estimated from five 100-m^2 plots on the ventilation fan and explosives magazine areas were several times the specified density. Actual densities of all shrub species on these areas were 5000 and 1100 clumps/ha versus a specified density of 2570 and 462 clumps/ha, respectively. Plants on the trailer village and borrow pit areas were set at approximately the density specified for the Gable Mountain big sagebrush community (462 clumps/ha). Planting density on the trenches was approximately the specified rate (2100 clumps/ha versus 1681 clumps/ha).

Survival of planted shrubs was determined by transect sampling performed in May and June 1990. Transects were walked across revegetated areas with observers tallying both dead and living plants according to species. Transect sampling covered at least one third of each revegetated area.

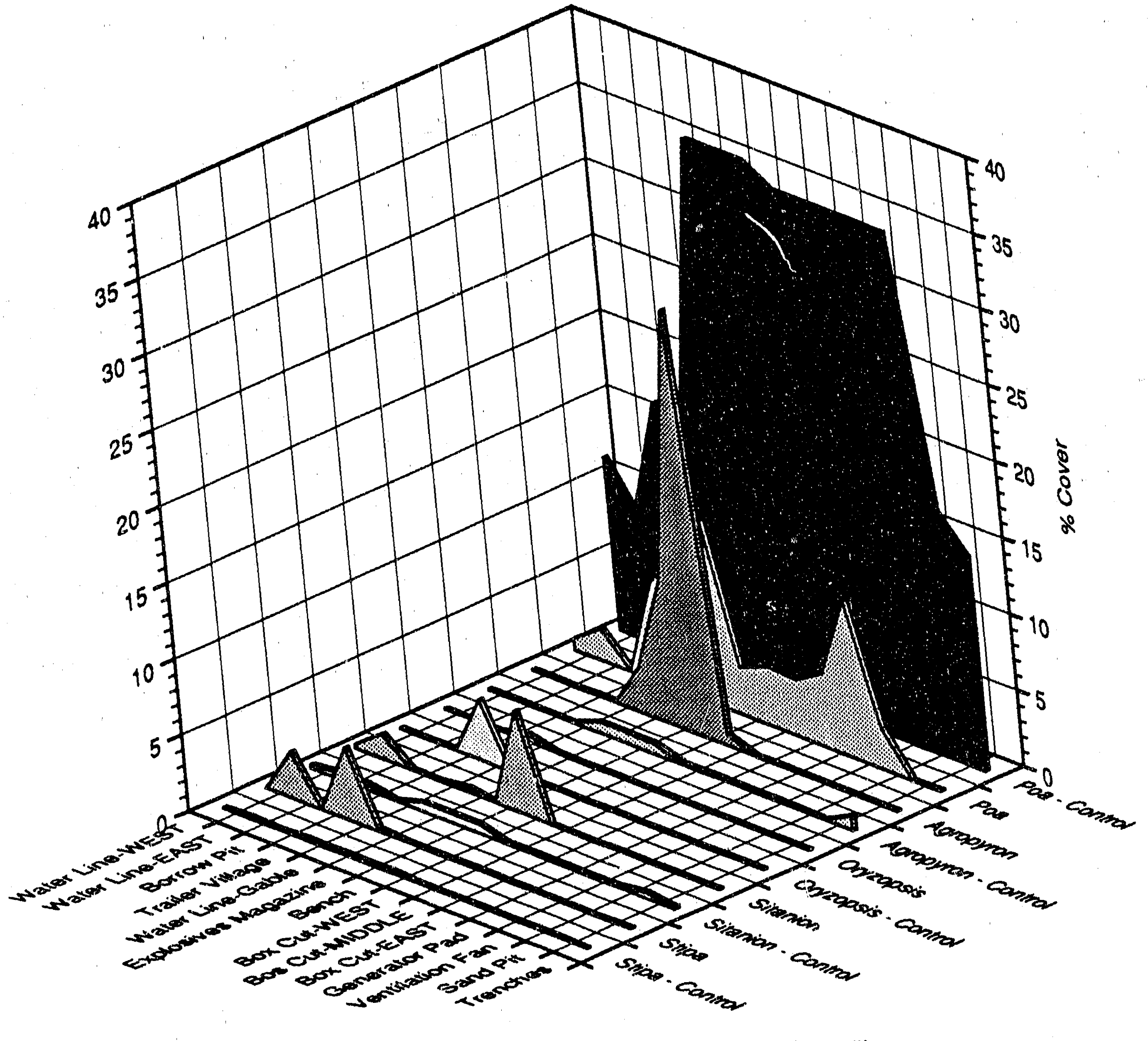

Figure 4.1. Grass Cover on Control and Revegetated NSTF Sites

Mortality of shrubs varied with species and location. Big sagebrush survival was poorest on the borrow pit and in the stiff sage communities (box cuts, generator pad, and ventilation pad areas), ranging as low as 6% on the borrow pit (Figure 4.2). Mortality rates on the bench area, explosives magazine, and Gable Mountain waterline ranged from 25% to nearly 40%. Mortality on the trenches was very low (1%). Stiff sage performance was similarly related to location, ranging from 0% to 92%. The 0% mortality estimate for the borrow pit was based on observation of a single clump, and so bears no statistical validity. No mortality was observed on the trenches. Winterfat mortality was 47% (Figure 4.2).

Plants of desert parsley, balsamroot, and buckwheat were found occasionally on the bench, Gable Mountain waterline, and explosives magazine areas. None were found on the imported pit run soils.

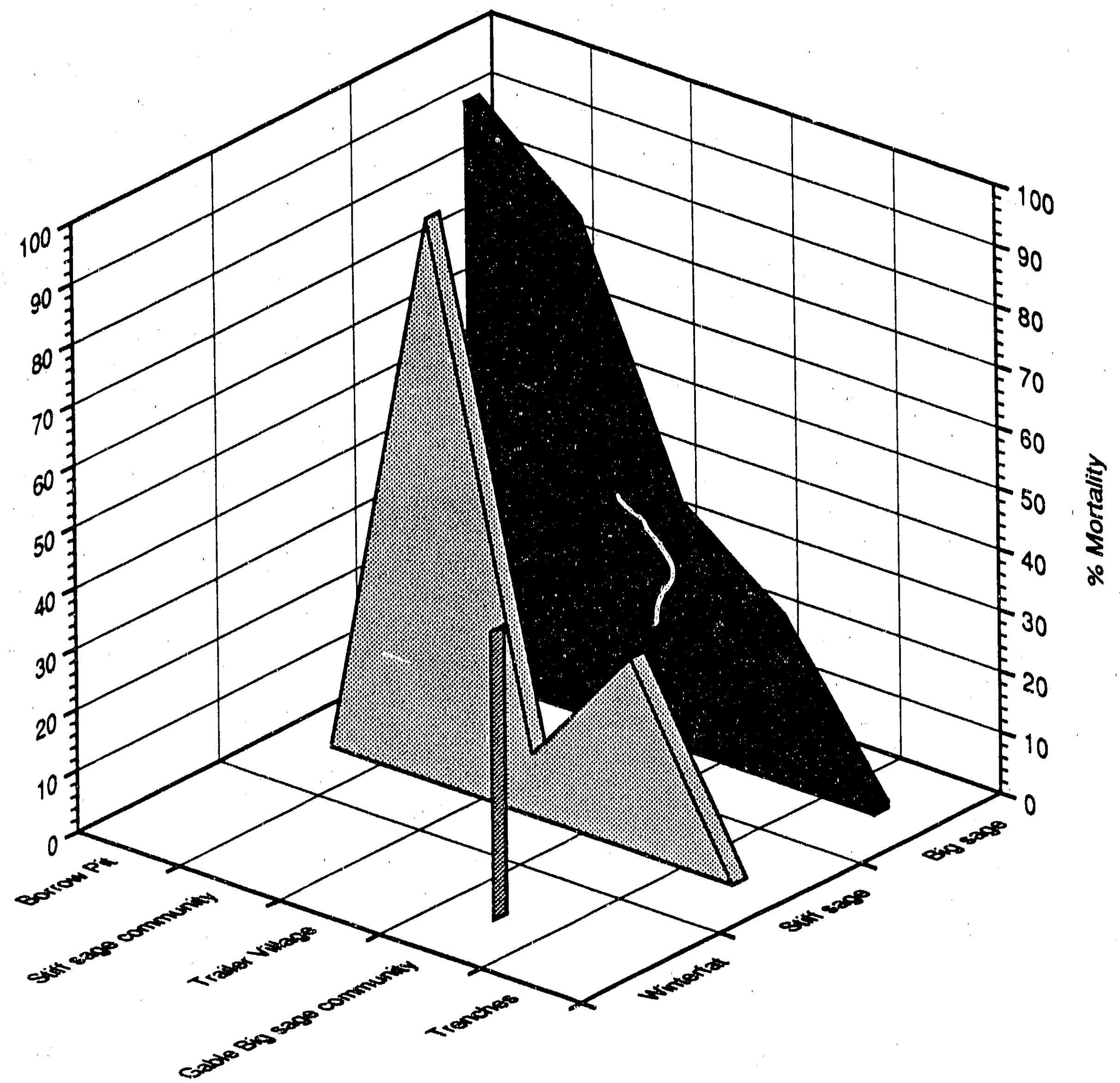

Figure 4.2. Mortality of Planted Shrubs After 7 Months

4.4 POTENTIAL CAUSES OF PERFORMANCE DIFFERENCES

Causes of performance differences can potentially be ascribed to differences in soil or soil treatment, seeding methods, plant treatments, or weather history. Where possible, analyses of causes are based on statistical comparisons of plant performance under different conditions. Parametric statistical comparisons use raw data transformed to meet the primary assumptions of the tests (i.e., normally distributed data and homogeneous variances). Rank transformations were applied to cover data, and the modified arcsine transformation was applied to percentage mortality data. Significant differences are assumed when the probability of obtaining the same result by chance alone is less than one chance in twenty. Multiple comparisons utilize the Games-Howell test, which retains the experiment-wise error rate of 1-in-20 and is robust to inhomogeneous variances (Day and Quinn 1989).

The poorest performing grass was Sandberg's bluegrass. The best performance was found on the explosives magazine, trailer village, Gable Mountain waterline, and the generator pad, in increasing order. The trailer village area was seeded by drilling; the remaining areas were broadcast-seeded. Similarly, the least successful areas were a mix of broadcast- and drill-seeded areas. There were no significant differences in bluegrass cover attributable to planting method.

Percentage cover of bluegrass differed significantly among soil types ($F_{3,791}$= 16.110, $p < 0.0001$), with the poorest growth on pit run material and the best on Kiona silt loam (Figure 4.3). Based on rank-transformed data, bluegrass cover on pit run was not significantly different from cover on Burbank loamy sand, but both supported lower cover than did Kiona silt loam or Rupert sand, which underlies the tr_iler village area (Games-Howell test, $p < 0.05$). Pit run material was applied to portions of the waterlines, borrow pit, the box cuts, generator pad area, and the ventilation fan area. Burbank loamy sand occurs in the east end of the waterline where the natural soil profile had been overturned, but no imported material had been applied.

Kiona silt loam is the soil type covering the whole of Gable Mountain. Disturbances in this soil type included loss of the A horizon and mixing of A and B horizons through discing. All soils had been treated with 7% composted sewage sludge before seeding; consequently there was no basis to assess the effectiveness of this treatment.

Mortality of planted big sagebrush shrubs was also significantly related to soil type ($F_{2,38}$=27.418, $p < 0.0001$). The greatest mortality occurred on the pit run soils on Gable Mountain, while the lowest mortality was found on the Kiona silt loam soils (Figure 4.4). The mortality difference between the two native soils was not significant, whereas the mortality on pit run material was lower than that on either of the native soils (Games-Howell test, $p < 0.05$). Although mortality differences among sites for stiff sage were less than for big sage, similar trends were evident (Figure 4.4). Overall, mortality differences among soil types for stiff sage were significant ($F_{2,12}$=6.752, $p = 0.019$). However, too few stiff sage were encountered in either

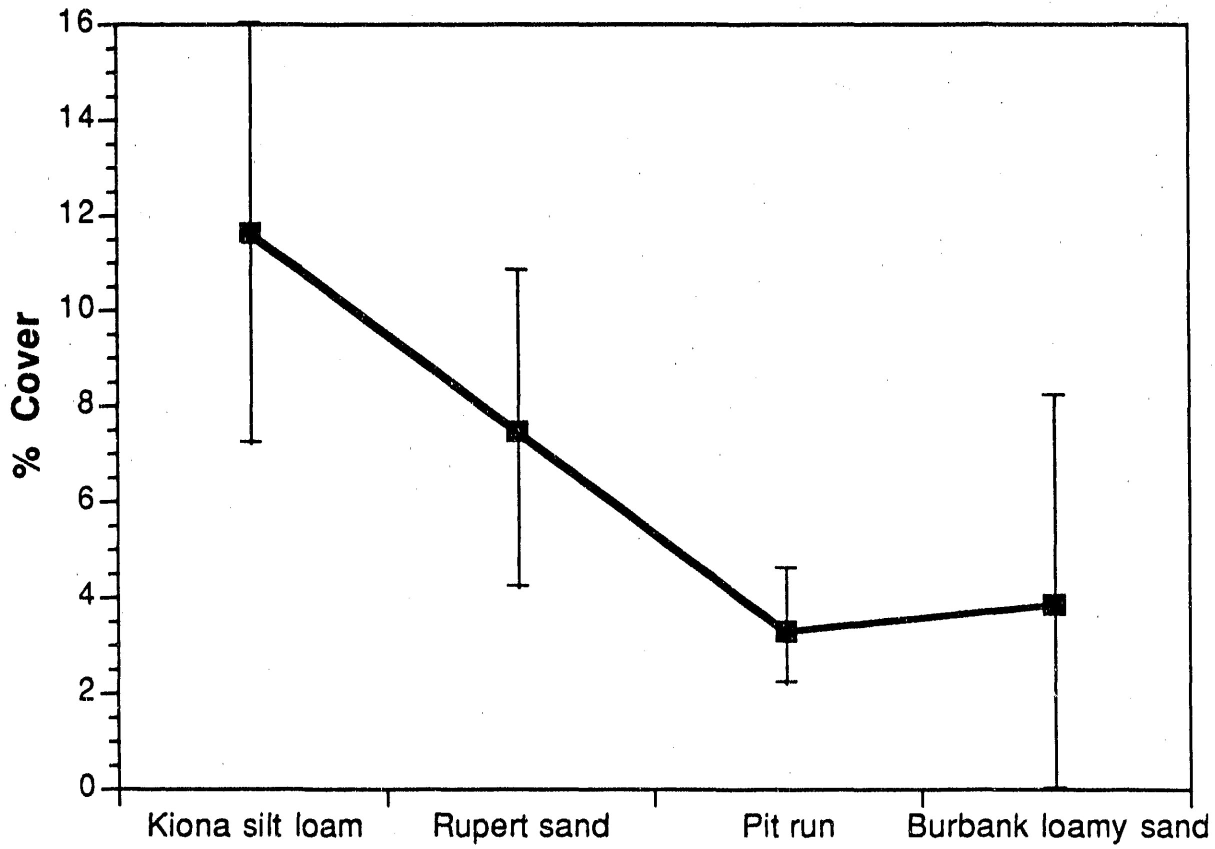

Figure 4.3. Bluegrass Cover on Different Soils at the NSTF (mean plus 95% CI)

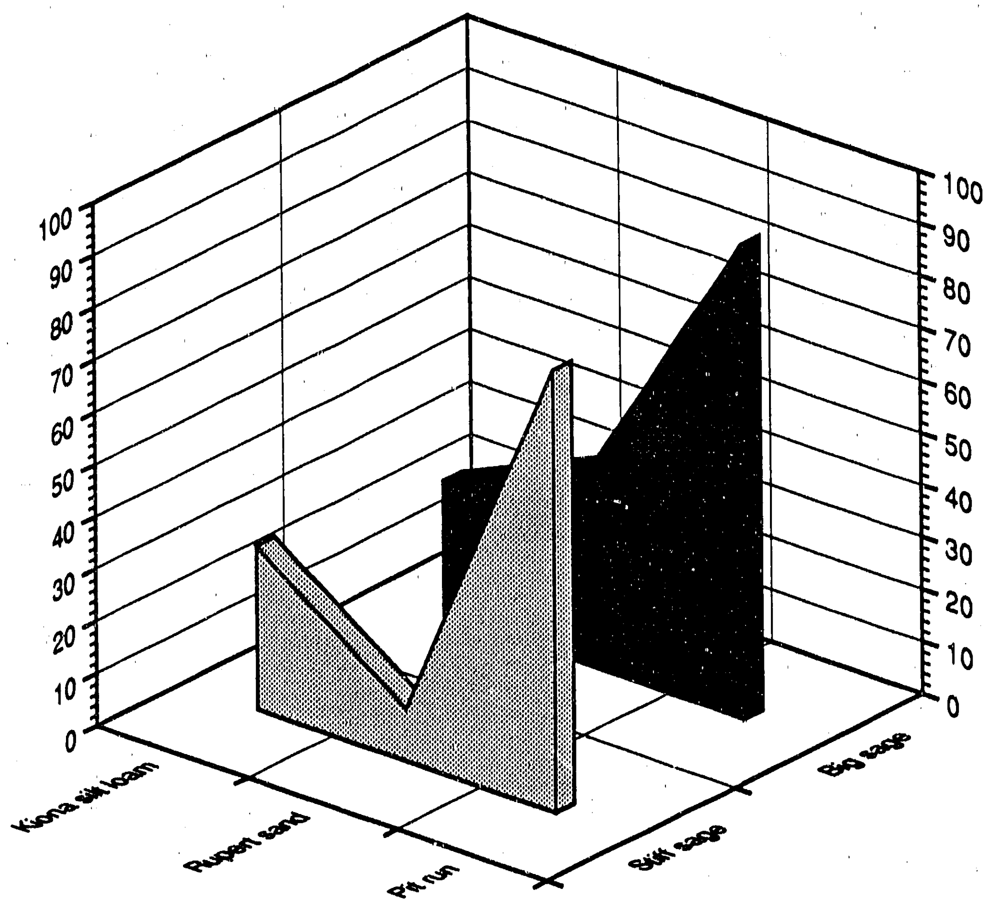

Figure 4.4. Tubeling Shrub Mortality by Soil Type

the Kiona silt loam or Rupert sand soil types to allow individual statistical comparisons. Mortality of stiff sage on pit run material averaged nearly 85%.

Water-retention additives were incorporated into the potting material of big sagebrush plants set into the bench area. Survival rates on the bench area were significantly higher than on the borrow pit, but not significantly different from untreated plants set on the trailer village or in the stiff sage community. Any potential beneficial effect of the additive was therefore not realized.

Weather during the 1988-1989 growing season was punctuated by an extremely cold period in February (Figure 4.5). Temperatures reached -20°C during this period without benefit of a snow cover to protect plants. Only the sand pit had been seeded late in 1988. However, the extremely cold period was not the cause of failure at this area because no plants ever germinated on the site. During the 1989-1990 growing season, moisture levels during the critical growth period from December 1989 to March 1990 were less than half of normal (Figure 4.5). Temperatures during this period were higher than normal, so plants were not in a dormant state. This lack of moisture produced an unusually low total ground cover even in undisturbed habitat. The stress on first-year plants was undoubtedly considerable.

No growth of vegetation was ever discovered on the sand pit. Because sandy soils such as occur at this area hold very little moisture, it is essential that seeds be planted in furrows or pits to maximize seed-water contact time. Such a seeding design was not implemented in this area, even though it was originally recommended. The failure of this area to meet its reclamation objective can probably be traced to this deviation from specifications.

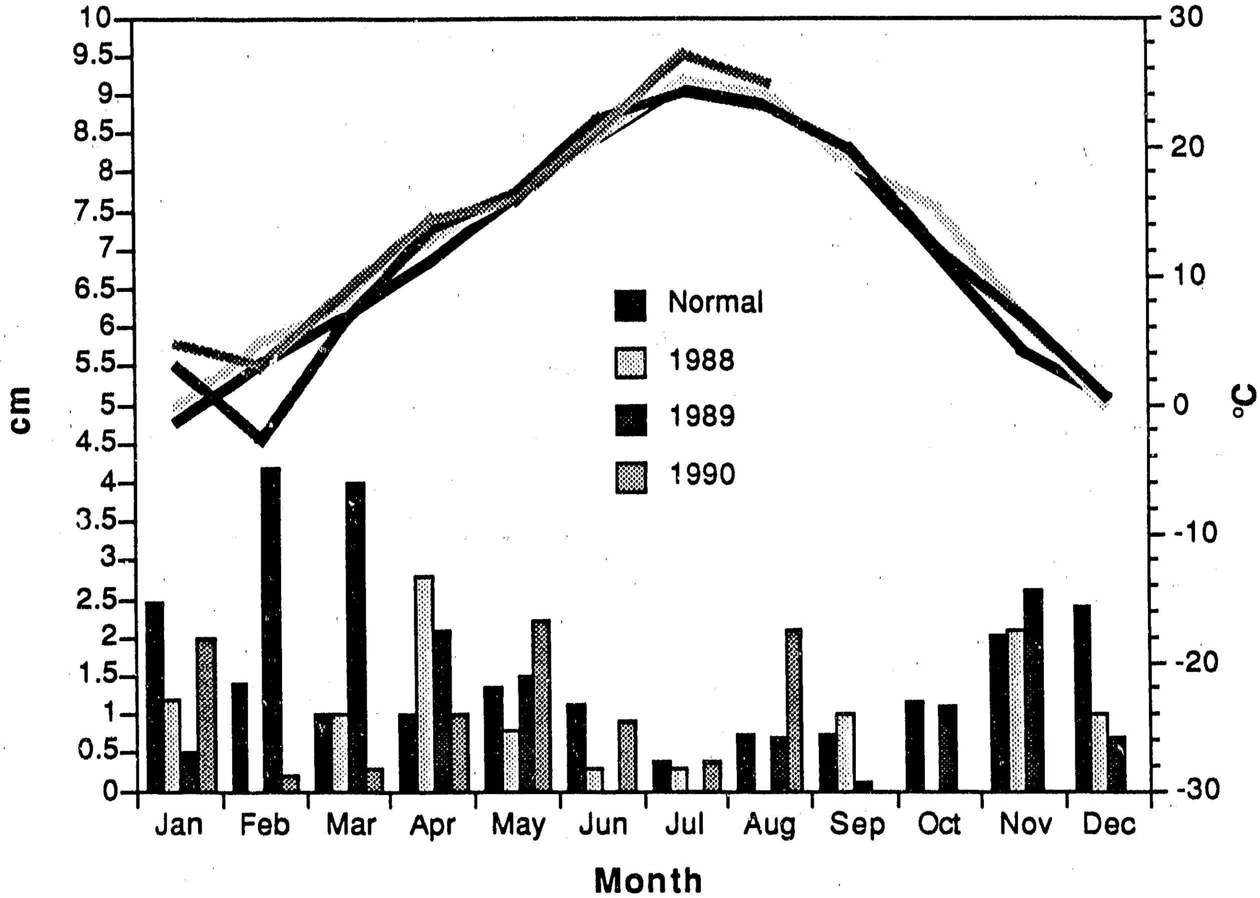

Figure 4.5. Monthly Mean Temperatures (lines) and Precipitation (bars) at the Hanford Meteorlogical Station

4.5 CONCLUSIONS REGARDING CURRENT STATUS

Vegetation growth on the NSTF during the first season yielded mixed results. The deconstruction phase of the reclamation task produced sites that resembled the surrounding areas at least in contour. However, soil conditions on some reclamation sites were greatly different than that in the surrounding native habitats. The greatest differences were between the imported borehole pad material (i.e., pit run soils) and the surrounding native soils. Native soils are fine textured, with a relatively high percentage of organic matter. The borehole material was extremely coarse, with no organic material other than the composted sludge that was incorporated after the soil was placed. The borehole material was removed from borehole sites before their revegetation because of the material's coarseness and low organic content, the resulting low water retention, and high levels of residual herbicide activity found in samples in 1988. The alternative materials available for use on the NSTF were limited to this material, pure sand, and a native silt loam that would have to be scalped from a fairly large area which would itself have required revegetation. DOE elected to use the borehole material, recognizing the risks involved.

Most revegetation work was performed within specifications, except for seeding of the sand pit. Failure to imprint seeds in the sand pit, with the subsequent lack of constant moisture at the seed is probably the prime cause for the total failure of this site to produce vegetation. Remediation is required if this site is to meet the reclamation objective.

Shrub seeds failed to produce plants on any of the areas despite irrigation. Establishing shrubs from seed has generally not been a successful endeavor on any of the BWIP reclamation sites (Brandt and Rickard 1990b). Constant moisture is probably key to allowing shrubs to establish from seed. Even though the NSTF areas were irrigated beginning at the end of March 1990, soil moisture was very low from December 1989 to that time (Figure 4.4). Consequently, seeds that might have germinated in response to the November 1989 rains were unable to continue growth during the following dry months.

Planted shrubs fared exceptionally poorly on the non-native soils. Currently, there are virtually no shrubs surviving on the box cuts, ventilation fan area, generator pad area, or the borrow pit. Remediation is required if these areas are to meet the reclamation objective. The range of mortality on the native soils was within the 30% level anticipated in the revegetation design. Because of the higher-than-specified density of planting on these areas, current shrub density on the native soils is within the range defined by the control areas. Furthermore, the additional shrubs planted on the trailer village area adequately compensated for the failure of seeded shrubs there.

Grass growth during the first year produced mixed results. Grass growth and survival on the areas where pit run material had been heavily applied was extremely poor. Many plants germinated in these areas, but few were alive in May 1990. No plants of any species, including early succession aliens such as Russian thistle, performed well on these sites. The combination of an exceptionally dry growing season, soil with poor water-holding characteristics, and possible residual herbicide activity probably interacted to produce the high level of failure on these sites.

Growth of Sandberg's bluegrass is currently below the reclamation objective everywhere on the NSTF. The dry growing season is likely the cause for this plant's limited performance. This species is the primary cover in the stiff sage community; its failure on the artificial soils in this community is a significant loss. Sandberg's bluegrass is a primary grass in the remaining communities, but others also occur there. Bluebunch wheatgrass, a component of the Gable Mountain big sagebrush community, produced surprising results on the revegetated sites, with estimates of cover after the first growing season in excess of that in the control areas. Indian ricegrass also produced well, though currently it is below the reclamation objective in terms of cover. Growth of bottlebrush squirreltail is at or above the reclamation objective on the bench, Gable Mountain waterline, and east waterline, but below in other areas. Finally, growth of needle-and-thread grass is above the objective on the east waterline and trailer village.

Species of concern to Native Peoples, such as buckwheat, parsley, and balsamroot, were found on the areas where seeds were broadcast, except on the pit run material. No quantitative reclamation goals have been set for these species because of their haphazard occurrence in undisturbed habitats. Consequently, growth of these species is acceptable on the bench, Gable Mountain waterline, and explosives magazine, but not elsewhere.

4.6 PROSPECTS FOR FUTURE GROWTH

Because monitoring data are available only for a single growing season, it is not possible to quantitatively predict performance of vegetation on the NSTF over the next few years. However, some generalizations can be made based on the current state of the area and the likely causes behind that state.

First, it is extremely unlikely that the sand pit, borrow pit, box cuts, generator pad area, or ventilation fan area will reach the reclamation objectives set for these areas within the next 50 years without further intervention. These areas currently support few living plants. If the primary cause of failure is poor moisture-holding capacity, heavy applications of organic amendments and/or incorporation of clays such as bentonite may greatly enhance future revegetation success. Plants likely to colonize these areas in wet years will be limited to Russian thistle, bur ragweed, and possibly Indian ricegrass. Only ricegrass is a native species, but it is a minor component of the natural vegetation of Gable Mountain. If the primary cause of failure is residual herbicide activity, only time and considerable moisture will allow successful introduction of vegetation to the area. Herbicides known to have been used on the borehole sites included soil sterilants (C. J. Haggerty, personal communication[a]) that have extremely long soil-residence times. Greenhouse growth tests in which the pit run material is kept at field water capacity would differentiate between the potential causes of failure and allow selection of an appropriate remediation alternative.

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[a] C. J. Haggerty, Operations and Site Services, Westinghouse Hanford Company; personal communication with C. A. Brandt, Pacific Northwest Laboratory; November 17, 1989.

Second, vegetation on relatively undisturbed native soils appears to be growing as expected. Cover by all species except Sandberg's bluegrass is within acceptable limits. It is not known whether bluegrass cover will increase over time, or whether the living shrubs will produce viable offspring. However, because the seed stock for the shrubs was collected from Gable Mountain and the surrounding area, the prospects for future production of viable seed from the tubelings is good.

Third, vegetation growth on the main waterline is well below the objective. To date, no shrubs have grown on the site, growth of native grasses is well below the objective, and much of the area has been covered with the pit run material. Without further treatments, the areas without the pit run material will likely revert to a nearly pure cheatgrass condition. Future conditions on the areas covered by pit run material will depend on whether the material retains soil sterilant activity or simply poor water-holding capacity. The former condition will not allow any vegetative growth for many years without remediation in the form of heavy irrigation or stripping. The latter condition will allow colonization by the alien annuals Russian thistle and bur ragweed. Cheatgrass fares poorly in low-moisture conditions, but Sandberg's bluegrass does even less well. Without remediation, the waterline is likely to stand out from its surroundings as an area comprising primarily alien species.

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