Protective Barrier Program: Test Plan for Plant Community Dynamics

Prepared for the U.S. Department of Energy
Assistant Secretary for Environment,
Safety and Health

Westinghouse
Hanford Company Richland, Washington

Hanford Operations and Engineering Contractor for the
U.S. Department of Energy under Contract DE-AC06-87RL10930

Copyright License By acceptance of this article, the publisher and/or recipient acknowledges the U.S. Government's right to retain a nonexclusive, royalty-free license in and to any copyright covering this paper.

Approved for Public Release

LEGAL DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party's use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

This report has been reproduced from the best available copy. Available in paper copy and microfiche.

The U.S. Department of Energy and its contractors can obtain copies of this report from:
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831
(615) 576-8401

This report is publicly available from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

Printed in the United States of America

DISCLM-1.CHP (10-90)

0012338

WHC-EP-0380
UC-702

Protective Barrier Program: Test Plan for Plant Community Dynamics

M. R. Sackschewsky
Westinghouse Hanford Company

J. C. Chatters
S. O. Link
C. A. Brandt
Pacific Northwest Laboratory

Date Published
January 1991

JAN 1991
RECEIVED
EDMC

Prepared for the U.S. Department of Energy
Assistant Secretary for Environment,
Safety and Health

Westinghouse Hanford Company
P.O. Box 1970
Richland, Washington 99352

Hanford Operations and Engineering Contractor for the
U.S. Department of Energy under Contract DE-AC06-87RL10930

Copyright License By acceptance of this article, the publisher and/or recipient acknowledges the U.S. Government's right to retain a nonexclusive, royalty-free license in and to any copyright covering this paper.

Approved for Public Release

EXECUTIVE SUMMARY

The Westinghouse Hanford Company and Pacific Northwest Laboratory are jointly developing protective barriers for the long-term isolation of low-level radioactive and hazardous waste for the U.S. Department of Energy at arid sites. The present conceptual design of the arid sites protective barrier is a multilayer, earthen structure that will minimize water infiltration into and through the underlying waste, and will limit intrusion into the waste by plant roots, animals, and humans. Water infiltration will be minimized by using a layering structure of fine soil over sand. The textural break between these two layers will allow the water to be held in the upper layer until it can be recycled to the atmosphere through the processes of evaporation and plant transpiration.

Plants perform several crucial functions in the protective barrier. Through transpiration, plants are capable of removing, from a given volume of soil, considerably more moisture than evaporation alone. This becomes especially important during times of increased precipitation when the possibility of infiltration though the textural break and leaching of the waste is increased. Plants also significantly reduce the amount of wind and water erosion expected to occur on the barrier surface. In addition, the local plant community will greatly influence the species of animals that could inhabit the protective barrier; the burrowing activities of some species could have a serious influence on the infiltration and erosional characteristics of a protective barrier.

Different plant species and different plant community types will affect the moisture retention and erosional characteristics of a protective barrier in diverse ways. For instance, a sagebrush-bunchgrass community uses significantly more soil water than a cheatgrass community. Additionally, the plant community present on a protective barrier will change over time because of the natural processes of disturbance and succession and in response to climatic changes. The ability to predict what types of plant communities will be present in the future, the length and proportion of time a particular community remains in a climax state, and how these different communities and

successional stages will effect the performance of the protective barrier is necessary for proper and defensible barrier design decisions.

The work described in this test plan is directed at making these predictions. The first task is to identify native communities that are analogous to possible future climatic states. The second task is to characterize these climax communities, as well as successional stages of these communities, in terms of species composition, plant density, and overall spatial patterns. Once completed, sites will be selected that correspond to bounding states of possible future conditions. These sites will be intensively studied in terms of community level evapotranspiration, and smaller scale patterns of evapotranspiration and soil moisture within each of these communities. Finally, the process of succession will be analyzed and modeled using a Markov chain approach. This modelling approach will allow for the determination of the proportion of time a community spends in various successional stages as well as in the climax condition. This point is important because the evapotranspiration potential of a successional state may be significantly different from that of a climax stand, thus infiltration may be most likely to occur during the period following disturbances that result in early successional communities.

The result of these studies will be an understanding of what types of communities will be present on a protective barrier in the future, how these communities will affect the protective barrier, and the lengths of time that the communities will be in various climax and successional states. This information then can be used by other protective barrier development tasks such as the modelling of soil water movement and erosion. This information can be readily incorporated into changes in the specifications and design of the protective barrier.

CONTENTS

1.0 INTRODUCTION 1-1
1.1 PLANT COMMUNITY DYNAMICS 1-2
1.1.1 Present-Day Climax Vegetation 1-2
1.1.2 Succession 1-5
1.1.3 Climatically Induced Vegetational Changes 1-7
1.2 SOIL WATER SPATIAL PATTERNS 1-8

2.0 CLIMATIC STATES AND THE CHOICE OF ANALOG SITES 2-1
2.1 PURPOSE 2-1
2.2 METHODS 2-1

3.0 PLANT COMMUNITY CHARACTERIZATION 3-1
3.1 PURPOSE 3-1
3.2 METHODS 3-1

4.0 COMMUNITY EVAPOTRANSPIRATION STUDIES 4-1
4.1 PURPOSE 4-1
4.2 METHODS 4-1
4.2.1 Supplemental Precipitation 4-1
4.2.2 Neutron Probe Installation and Soil Analysis 4-2
4.2.3 Plant Growth Characteristics 4-2
4.2.4 Gas Exchange Measurements 4-2
4.2.5 Meteorological Data 4-3

5.0 MODELLING OF PLANT COMMUNITY DYNAMICS 5-1
5.1 PURPOSE 5-1
5.2 TECHNICAL CONSIDERATIONS 5-1
5.2.1 Scale of Disturbance 5-1
5.2.2 Modelling Options 5-2
5.3 METHODS 5-4
5.3.1 Selection of Plant Communities 5-4
5.3.2 Definition of Community States 5-5
5.3.3 Development of a Digraph 5-5
5.3.4 Determination of State Mortality Rates 5-6
5.3.5 Determination of Recruitment to States 5-7
5.3.6 Markovian Modelling 5-7

6.0 INTERACTION WITH OTHER BARRIER TASKS 6-1
6.1 BIOINTRUSION TASKS 6-1
6.2 WATER INFILTRATION TASKS 6-1
6.3 EROSION CONTROL TASKS 6-1
6.4 MODELLING TASKS 6-1
6.5 NATURAL ANALOG STUDIES 6-1
6.6 CLIMATE 6-1

7.0 PROJECTED COSTS (IN THOUSANDS) 7-1

8.0 REFERENCES 8-1

FIGURES

1-1 Major Central and Eastern Washington Vegetation Zones (from Daubenmire 1970) 1-3

1-2 Major Arid Sites Climax Vegetation Zones (from Cline et al. 1975) 1-4

ABBREVIATIONS AND ACRONYMS

ALE	Arid Land Ecology
DOE	U.S. Department of Energy
ET	evapotranspiration
GCM	Global Climate Model
PNL	Pacific Northwest Laboratory
VAM	vesicular-arbuscular mycorrhizae
Westinghouse Hanford	Westinghouse Hanford Company

1.0 INTRODUCTION

The Westinghouse Hanford Company (Westinghouse Hanford) and Pacific Northwest Laboratory (PNL) are jointly developing protective barriers for the long term isolation of low-level radioactive defense waste for the U.S. Department of Energy (DOE) at the Arid Sites. Protective barriers have been identified as an integral part of the overall final disposal strategy for low-level defense waste at the Arid Sites (DOE 1987).

At present, the conceptual design of the Arid Site protective barrier is a multilayer structure that will minimize water infiltration into and through the underlying waste, and will prevent intrusion into the waste by plant roots, animals, and humans. This multilayer system consists of a fine soil layer overlying a coarse sand and/or gravel geo-filter overlying a layer of large cobbles or basalt riprap. The textural difference between the fine soil and the coarser materials functions as a capillary break that prevents water from flowing into the coarser material; this allows the fine soil layer to hold more moisture. The water held at the textural interface can then be recycled to the atmosphere through the processes of evaporation and transpiration. The large cobbles or basalt riprap prevent plant root and animal intrusion, and because of the aggravation involved in excavating these materials, future intrusion by humans also may be minimized.

Plants contribute several crucial functions to the overall performance of the protective barrier. Through transpiration, plants are capable of removing considerably more moisture from a given volume of soil than the physical process of evaporation alone. This becomes especially important after periods of excessive precipitation when the possibility of saturation of the textural break and leeching to the buried waste is increased. Plants also function in significantly reducing the amount of wind and water erosion that would be expected to occur on the barrier surface. In addition to these physical functions, plants also influence other biotic effects on barrier performance. The type of plant community present on a protective barrier will directly influence the types of animals that will inhabit the barrier surface. Through burrowing activities, some animal species can have a serious influence on the water infiltration and erosional characteristics of a protective barrier.

Different plant species, plant forms, and community types (tree, shrub, or grass dominated) will affect the moisture retention and erosional characteristics of a protective barrier in diverse ways. Therefore, an understanding of what affects different plant species and community types will have on a protective barrier is necessary for proper and defensible design decisions. Additionally, even though the initial vegetation of a protective barrier may be carefully specified, the plant community that is present on a barrier will change over time because of the natural processes of disturbance and succession, as well as in response to long-term climatic change. Therefore, an ability to predict what types of plant communities will be present in the future and the characteristics of these communities is necessary for barrier design considerations.

1.1 PLANT COMMUNITY DYNAMICS

Plant community dynamics refers simply to changes in a plant community over time; this change may be attributed to the abundance of various species, the introduction and local extinction of species, the overall physiognomy of the community, or a combination of these factors. The subject area of plant community dynamics can be divided into two inter-related types of community change that are differentiated by the root cause and the temporal time scale of the change. Short-term changes of relatively small areal extent in response to a disturbance is termed succession. The second type of change is long-term, regionwide dynamics in a community structure that occurs in response to climatic changes. Succession can be thought of as occurring on an ecological time scale and can normally be documented within the life span of a single observer. Climatically driven community change occur on a much longer time scale and typically would not be particularly noticeable or documented within a typical human lifetime. These types of community change are important to the design of a protective barrier because of the relationship between the plant community and the potential for root intrusion into the buried waste, the amount and pattern of soil moisture removal from the system, and the amount of erosion protection supplied by the vegetation. The evapotranspiration characteristics, the erosion protection, and the probability of root intrusion into the buried waste will change simultaneously with the plant community on the protective barrier surface.

1.1.1 Present-Day Climax Vegetation

The climax vegetation community for an area is an assemblage of species that is self perpetuating, and shows very little change from year to year in species composition, stand biomass, and overall physiognomy (Ricklefs 1979). In other words, the climax community is one that is in dynamic equilibrium with its environment. The Hanford Site is identified as a case study or example of an arid environment. The Hanford Site occupies the center of what Daubenmire (1970) has described as the *Artemisia tridentata-Agropyron spicatum* vegetation zone. This is a large vegetation zone, which occurs in the drier central portion of the Columbia Basin (Figure 1-1). The vegetation is dominated by big sagebrush and bluebunch wheatgrass, with a large number of associated minor species. The Arid Sites itself has been divided into several sub-types of this general vegetation zone (Cline et al. 1975). These sub-types are the following:

- The sagebrush/wheatgrass/bluegrass type that occurs primarily on Rattlesnake Mountain and the Arid Lands Ecology (ALE) reserve

- The sagebrush/bitterbrush/bluegrass type that occurs along the Columbia River from the 300 Area to about the 100-F Area

- The sagebrush/cheatgrass/bluegrass type that occurs between these other two, and especially on the 200 Areas' plateau north to the Columbia River (Figure 1-2).

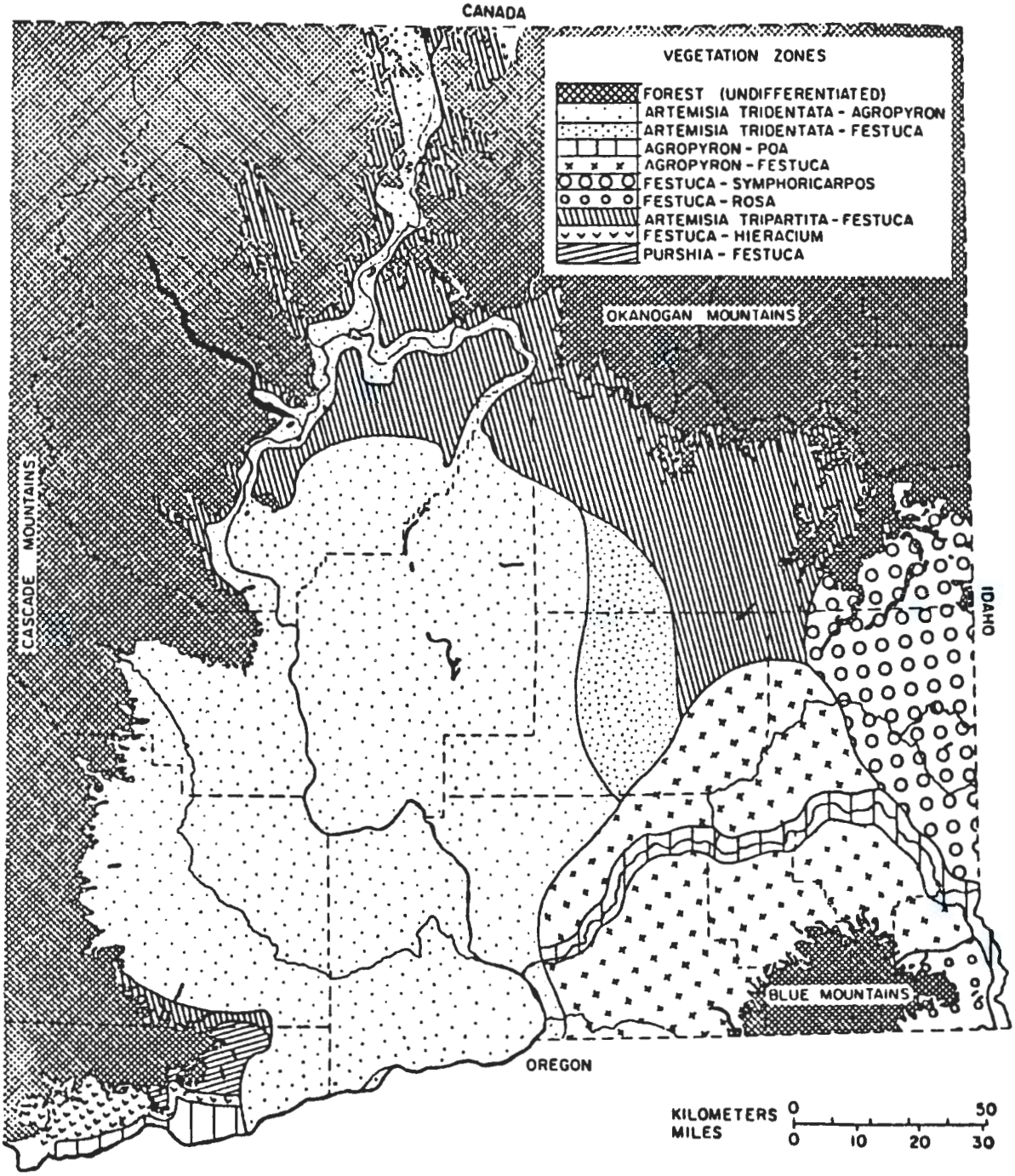

Figure 1-1. Major Central and Eastern Washington Vegetation Zones (from Daubenmire 1970).

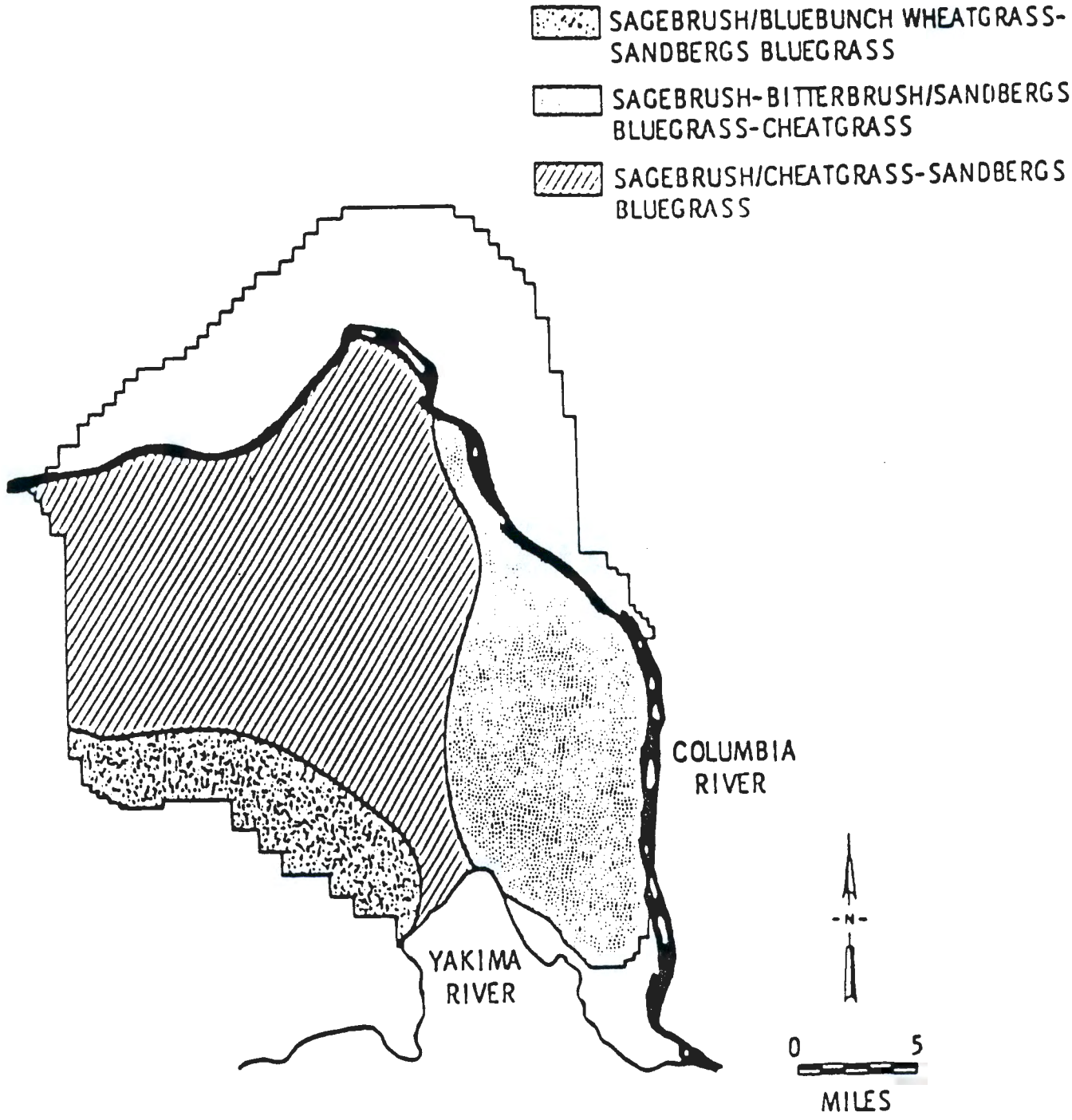

Figure 1-2. Major Arid Sites Climax Vegetation Zones (from Cline et al. 1975).

Several other minor zones, characterized by greasewood, hopsage, winterfat, or buckwheat, also have been described (Rogers and Rickard 1977). These different climax associations within the larger sagebrush - bluebunch wheatgrass vegetation zone primarily result from microclimatic and edaphic differences (Daubenmire 1970, Franklin and Dyrness 1973).

1.1.2 Succession

A useful definition of succession may be taken from Horn (1974):

> Succession is a pattern of changes in specific composition of a community after a radical disturbance or after the opening of a new patch in the physical environment for the colonization by plants and animals.

Ecologists recognize two general types of succession. Primary succession is the development of a community from some type of lifeless substrate to a mature community. Common examples of this is the development of plant communities on glacial moraines or newly deposited lava flows. This process often requires a considerable length of time because soil formation also is needed. More commonly occurring, and of much greater importance to the Arid Sites protective barrier program is secondary succession. This type of succession occurs when a community is subject to some type of disturbance (such as fire, overgrazing, or agricultural activities) that eliminates some or all of the dominant vegetation. The pattern and process of community recovery following a disturbance is secondary succession. The recovery typically involves a temporal sequence of communities or associations starting with a community dominated by weedy annuals and culminating with the climax community that is normally dominated by perennial species. Several factors can influence the rate and pattern of succession including the type, severity and duration of disturbance, the availability of propagules of different colonizing species, and the overall climatic conditions.

Several types of disturbance should be considered in protective barrier design, including fire, grazing, agricultural activities (especially repeated plowing) and small scale construction activities. These disturbances can have either a major affect on all aspects of community structure, or they can be minor, affecting only one or two understory species. Fire is an important type of disturbance in steppe regions such as the Columbia Basin. Big sagebrush is especially susceptible to fire because it is unable to resprout after burning (Daubenmire 1975). The other important shrub species of the Columbia Basin and the bunchgrasses that are capable of resprouting after fire, so burning functions as only a temporary set back to these species (Franklin and Dyrness 1973). Recolonization by sagebrush can be slow, because the process is a function of both the distance from propagule sources and the occurrence of favorable physical and climatic conditions for seedling development. Favorable conditions include the presence of safe sites for germination and growth, and adequate precipitation for seedling survival. Grazing has somewhat of an opposite affect as fire. Bluebunch wheatgrass and most of the other native perennial bunchgrasses are very sensitive to grazing,

while big sagebrush is fairly resistant (Franklin and Dyrness 1973). Several of the other species of wheatgrass (e.g., Siberian wheatgrass) are much more tolerant of grazing, and have been used successfully for revegetation on the Arid Sites. They have escaped from the cultivated areas to become established in the native stands (Waugh and Rountry 1983). A combination of fire and grazing results in the elimination of both big sagebrush and the native bunchgrasses, leaving a community dominated by cheatgrass with a few scattered rabbitbrush shrubs (Franklin and Dyrness 1973). The effects of mechanical disturbance of the soil resulting from cultivation or construction activities appear to depend on the duration of the disturbance. Abandoned agricultural fields often have very low soil concentrations of vesicular-arbuscular mycorrhizae (VAM) because of repeated plowing and disturbance to the soil. Loss of VAM resulting from other types of soil disturbance, especially strip mining, is very well documented (Williams and Allen 1984; Rives et al. 1980; Reeves et al. 1979). Mycorrhizae (literally fungus-root) are fungi that form a mutualistic association with plant roots. The fungus assists the plant in the uptake of water and nutrients and in return receives carbohydrates from the plant. The VAM are essential for the establishment of many native species, most notably big sagebrush, which is difficult to establish in old fields (Waugh 1988). Because of the lack of available VAM spores, abandoned agricultural fields in the Columbia Basin are typically near monoculture cheatgrass communities. Many annual, early successional species do not require VAM for establishment and/or survival and growth (Allen and Allen 1980). However, if the disturbance occurs as a single, brief event that does not significantly damage the mycorrhizal community, native species such as sagebrush may be capable of rapid recolonization. The specific role of VAM in community development on the Arid Sites has not been thoroughly studied.

Before the advent of European settlement of the Columbia Basin, fire was the only major disturbance factor experienced by the native plant communities. The native peoples did not engage in agricultural activities to any great extent, there were no large, congregating ungulates present (Mack and Thompson 1982), and there were relatively few annual species capable of dominating communities. Therefore, the original successional pattern following fire would have consisted of a temporary loss of sagebrush from the community, with the bunchgrasses and other shrubs resprouting from their basal crowns. This natural successional pattern in the Columbia Basin has been significantly altered by the introduction of several Eurasian annual weeds, and the introduction of the human mediated disturbances such as grazing and agricultural activities. The first colonizers of disturbed areas on the Arid Sites are usually the annual forbs Russian thistle, tumble mustard, and bursage. After several years these species usually relinquish their dominant role to cheatgrass (Waugh and Link 1987; Rogers and Rickard 1977). The only native shrub that appears to be able to recolonize stands dominated by cheatgrass is rabbitbrush. Cheatgrass was first documented in Washington State in 1893 and has spread rapidly throughout the Columbia Basin and most of the western United States (Klemmedson and Smith 1964). The phenology of cheatgrass is ideally suited to the climatic patterns of the Columbia Basin. The seeds germinate after autumn rains and, in early summer, the life cycle is complete at the time that soil moisture becomes limited. The roots grow rapidly following germination and continue to grow at low temperatures (Harris 1967). When cheatgrass seedlings grow in competition with seedlings

of bluebunch wheatgrass, the cheatgrass roots grow faster and extract the available soil moisture before the wheatgrass roots, depriving the wheatgrass of moisture needed for growth (Harris 1967, Harris and Wilson 1970). This is certainly one of the primary factors in the failure of bluebunch wheatgrass to become re-established in cheatgrass dominated communities. Once cheatgrass becomes dominant on a site, it may never relinquish its position, thus arresting the normal successional pattern at what would be considered an early stage in most other communities (Daubenmire 1975, Rickard and Sauer 1982).

Other alien species that are capable of dominating communities in some parts of the Columbia Basin include medusahead rye (*Elymus caput-medusae)*, Russian knapweed (*Centaurea repens*), and Yellow Star thistle (*Centaurea solstitialis*). Medusahead rye functions similarly to cheatgrass when in competition with wheatgrass, although it is a somewhat weaker competitor compared to cheatgrass (Harris and Wilson 1970). Russian knapweed and yellow star thistle are relatively recent additions to the regional flora and little is known about their ecology.

1.1.3 Climatically Induced Vegetational Changes

Assuming that the seasonal patterns of precipitation do not change (i.e., dry summers, wet winters), the best analogs for future plant communities on the Arid Sites following an increase in annual precipitation are areas toward the perimeters of the Columbia Basin and perhaps the Palouse region of Eastern Washington State. At the present time, the annual precipitation in Central and Eastern Washington ranges from less than 20 cm/yr at the Arid Sites to as much as 50 cm/yr at the Idaho border (Franklin and Dyrness 1973). Perhaps the most dramatic change associated with the increase in precipitation is the loss of big sagebrush from the native communities (Figure 1-1). Big sagebrush is replaced by three-tip sage (*Artemisia tripartita*) in the northern basin regions, and by wild rose (*Rosa* sp.) and snowberry (*Symphorocaros albus*) to the east. In these areas bluebunch wheatgrass is replaced by Idaho Fescue (*Festuca idahoensis*). There also is a large wheatgrass/fescue zone that is lacking in any dominant shrub (Daubenmire 1970). It should be noted that these changes in species composition are not solely in response to an increase in annual precipitation, there also are measurable soil differences associated with the different vegetation zones that may be as important as climate in determining species distributions (Daubenmire 1970). In other parts of its range, big sagebrush dominates regions that receive considerably greater amounts of precipitation than the central Columbia Basin, such as areas of Colorado, Wyoming, and Idaho, which receive some 50 cm/yr (Sturgis 1979). The dominance of big sagebrush in these communities and the complete absence in the portions of the Columbia Basin that receive comparable amounts of annual precipitation could be explained by the following:

- Genetic/subspecific differences among the populations
- Edaphic or soil differences
- Differences in the seasonality of the precipitation.

Throughout much of the big sagebrush range the seasonal precipitation patterns are characterized by a fairly even distribution during the year, or by predominately summer precipitation, which is the opposite of that experienced in the Columbia Basin (Ruffner and Bair 1977).

Because the Arid Sites occupies part of the driest area within the Columbia Basin, if the amount of annual precipitation on the Arid Sites decreases, there are few representative analogs for what the vegetation type would become. Several shrub/Sandberg bluegrass associations have been described to occupy the "warmest and driest portions of the Columbia basin" (Franklin and Dyrness 1973). The shrub components of these associations are big sagebrush, spiney hopsage [*Atriplex (or Grayia) spinosa*], or winterfat (*Eurotia lanata*). There appears to be no climate-related differences among these and the big sagebrush/bluebunch wheatgrass zones, as they form sharp ecotones with each other for reasons undetermined at this time (Franklin and Dyrness 1973).

Throughout most of the Columbia Basin steppe, the successional patterns following a disturbance have been drastically altered by the introduction of cheatgrass. The productivity of cheatgrass depends heavily on the amount of precipitation during the growing season (Rickard et al. 1977, Cline and Uresk 1979), while the productivity of bluebunch wheatgrass is not significantly affected by the amount of precipitation (Rickard et al. 1977). This means that cheatgrass is better able to take full advantage of unusually wet years, while blue-bunch wheatgrass is not. Dropseed (*Sporobolus cryptendrus*), another native bunchgrass, and rabbitbrush are among the few native species that are capable of recolonizing cheatgrass dominated stands in far Eastern Washington (Daubenmire 1975).

Successful prediction of future plant communities on protective barriers will depend on properly calibrating simulation models of community dynamics with information derived from field investigations and measurements. Needed variables would include factors such as the present vegetation, climate parameters, soil characteristics, soil moisture, and disturbance history. These measurements should be made over a range of climatic regimens throughout the Columbia Basin, especially in extreme community types that bound possible future vegetation states, and within different successional stages of community development at these different locations. Predictions of future climatic conditions are being made within the framework of the climate tasks of the protective barrier program (Adams and Wing 1986). Determining the specific characteristics of the resultant communities falls within the plant community dynamic task.

1.2 SOIL WATER SPATIAL PATTERNS

When evaluating protective barrier design, the primary importance of predicting plant community dynamics lies in the ET characteristics and the associated soil moisture patterns of the predicted successional and climax communities. The probability of water infiltration to the buried waste is greater in communities with low ET potentials. Low ET rates may occur year round in a community, or only at critical time periods during the year when

there is little live biomass. The ET characteristics of a plant community depend on the species present; the density of individual species; total plant density; soil characteristics; and physical factors such as temperature, solar radiation, wind, and precipitation. For the entire 10,000-yr functional life of the Arid Sites protective barrier, none of these factors can be completely predetermined. Within a particular community, the small scale variability in water use is also important. Unless there is complete plant coverage, which is rare in the Columbia Basin, the possibility exists that pockets of unused soil moisture that could lead to localized infiltration pathways may develop. These may result as a consequence of the spatial distribution of certain plant species (e.g., sagebrush) or from micro-relief patterns at the soil surface.

Small-scale, soil moisture content patterns within communities have not been well documented. Using an array of 25 access tubes within an area of about 600 m^2, Gee et al. (1988) reported that the soil water storage in the upper 3.5 m of soil in a cheatgrass/bluegrass community varied from about 2 to 10 cm depending on the season. However, the actual spatial patterns of this variation were not examined. At the McGee Ranch fine soil site, Link et al. (1988) found that the soil water content around spiny hopsage shrubs was less at shallow depths and greater at deeper depths than around sagebrush shrubs. The average water content at several randomly placed access tubes were within the same range as around the shrubs, but the vertical profiles and temporal changes were different.

Differences in the soil moisture patterns among different community types are better documented. Gee et al. (1988) found that the water storage in a sagebrush stand was much lower than in a nearby grass dominated stand. Link et al. (1990) found that the water storage below a depth of 1.25 m was greater in a bluebunch wheatgrass community than in an adjacent sagebrush/wheatgrass community. There was no difference in the water storage in the upper 1.25 m. Similarly, Cline et al. (1977) found that a sagebrush/wheatgrass community used nearly twice as much soil water as a cheatgrass dominated community.

Needed information regarding soil-moisture spatial patterns includes a detailed examination of plant communities in terms of small-scale soil-moisture spatial variability, and determinations of the causal factors involved in any variation found. The causal factors may be inferred from correlations of the soil moisture patterns with the spatial distributions of shrubs, hummocks, or other environmental or biological variables. This type of examination needs to be performed at both present day climax and successional communities on the Arid Sites and at potential future analog communities throughout the Columbia Basin. The proper determination of the extent and importance of soil water spatial patterns is needed for validation of the UNSAT-H (Fayer et al. 1986) model used to predict water movement through the barrier (Fayer 1990). If the spatial patterns are found to be relatively unimportant, then the present one-dimensional model is sufficient for design considerations; if, however, spatial patterns are found to be important, then two or three dimensional models must be developed.

The work described in this test plan is divided into four inter-related subject or task groups. In Section 2.0, the procedure for determining

possible future analog climatic states is provided, including the determination of the location of natural analog communities fitting the different climatic scenarios. Section 3.0 describes the methods that will be used in the description and characterization of these analog state climax communities, and various successional stages of these possible future climax communities. These characterizations will be used as a basic starting point for the work described in Sections 4.0 and 5.0. The determination of surface and below ground processes is described in Section 4.0, tasks in this section include determinations of soil characteristics, rooting distributions, and community scale evapotranspirational characteristics. The procedure for modelling community change and development is described in Section 5.0. Included are the needed input parameters for this model and the methods that will be applied to determine the appropriate values of these parameters.

2.0 CLIMATIC STATES AND THE CHOICE OF ANALOG SITES

2.1 PURPOSE

The long-term climate change task (Adams and Wing 1986) will generate seven climatic scenarios that are expected to include two Global Climate Model (GCM) projections and five paleoclimatic extremes. The past scenarios will be accompanied by reconstructions of plant communities, some of which have modern analogs. Thus the long-term climate change task will provide the criteria for both climatic conditions and plant community composition that will be used to select vegetation analog sites. This subtask uses those criteria to select modern vegetation analogs, which will be studied intensively to determine the effects of different plant communities on soil water balance, rooting distributions, and burrowing animal populations, all of which are important to the performance of protective barriers.

2.2 METHODS

Two approaches will be used to select spatial analogs of possible future vegetation communities. In the greatest possible detail, the climatic change studies will identify the vegetation communities and climatic patterns for five past periods. Future climate scenarios based on GCMs, no vegetation community data will be available. For past scenarios that include vegetation communities with known modern analog communities, analog sites will be chosen using maps of modern steppe vegetation types in the northwest (as in Daubenmire 1970). An effort will be made to select analog sites with climates most closely approximating those that have been reconstructed by paleoclimate tasks. For all other climate scenarios, location will be sought that have the same or similar climate to those that are reconstructed or modeled. Climate statistics from the U.S. Weather Service will be used in this endeavor. At least four alternative sites will be identified for each climate scenario, from which study sites can be selected.

3.0 PLANT COMMUNITY CHARACTERIZATION

3.1 PURPOSE

After the analog state climatic conditions and natural analog communities have been identified, some basic information must be obtained before the more complex tasks can be initiated. The tasks described in sections 4.0 and 5.0 are labor intensive, and it will not be possible to perform complete analyses of community scale ET, soil water patterns, or developmental modelling at all of the possible future analog sites. Therefore, the analog sites corresponding to the different climatic scenarios must be prescreened so that only sites that are likely to be significantly different from the present conditions at the Arid Sites (in overall community structure) will receive intensive analysis. In other words, some types of climatic change may result in communities that are fairly similar to present day Arid Sites plant communities in terms of overall physiognomy, dominant plant type, and rooting depths. In order to conserve the available resources, this type of community would probably be bypassed in favor of a community with significantly different dominant plant species, physiognomy, or evapotranspirational potential. The initial plant community characterizations described in this section will allow for more well informed decisions about which analog communities will receive intensive study and analysis.

3.2 METHODS

Plant community characterization will commence with a general survey of the site to determine what species are present and to identify any obvious spatial patterns and heterogeneity within the community. If large-scale spatial patterns are apparent, such as obvious interdigitation of community types, the site may be designated as two separate communities; or if the differences are not so dramatic, but still obvious, the sampling design will be devised so that the total area will be split into homogeneous sub-areas and the samples will be allocated in proportion to the size of each sub-area (Green 1979). Following the initial survey, a site-specific sampling design will be devised, grid coordinates will be determined, and an analysis of the community will be performed to provide data on plant coverage, density, frequency, spatial patterns, biomass, and leaf area within the stand.

Coverage is normally considered to be the best measure of species importance, because it relates to the amount of ground surface area dominated by each species, and it is not particularly affected by species size. Coverage also is more closely related to biomass than are frequency or density (Mueller-Dombois and Ellensberg 1974). Typically, the greater the coverage of a species the greater the importance, and the species with the highest coverage are usually the community dominants. Plant coverage at selected sites will be determined using a 50 by 100 cm ocular point intercept frame (Floydd and Anderson 1983a, 1983b,) which has been shown to be more effective for measuring coverage in sagebrush steppe vegetation than other commonly used techniques such as line interception (Canfield 1941) or coverage-class estimation (Daubenmire 1959). Sampling at each site will be performed using a

stratified random sampling design. The site will be divided into 10 by 10-m quadrants, and the frame positions within each quadrant will be randomly located. This sampling design will ensure that the entire site will be evenly sampled while maintaining the randomness necessary for statistical evaluations, and will allow for comparisons between quadrants within a site (Mueller-Dombois and Ellensberg 1974). The exact sampling design and number of quadrants for each site will be will be determined on a site specific basis. At this point it is envisioned that a minimum of 25 quadrats (in a 5 by 5 grid) and two sampling positions for each quadrat will be used for each site. Preliminary testing of this method will be performed to determine minimum number of quadrants and sample positions needed for adequate community characterization.

Plant density and frequency are useful measures for the analysis of spatial patterns and distributions, the calculation of diversity indices, and community classification (Ludwig and Reynolds 1988). Frequency is the proportion of examined plots that contain at least one individual of the species of interest to those that contain none. This will be measured by scoring the presence or absence of each species in the same plots used for coverage measurements. Density is defined as the number of individuals per unit area. This will be calculated for important herbaceous species by counting the number of individuals in each of the plots used for the canopy coverage measurements. For species that are relatively small and have a high density (such as cheatgrass) density will be determined by counting the number of individuals in several 10 by 10-cm subplots of the plots used for the coverage measurements. This will be done because there could potentially be several thousand individuals in the entire 50 by 100-cm plot. Shrub density will be determined by counting the number of live individuals within replicate 10 by 50-m plots in each community. Density also may be used for plant spatial pattern analysis and for determining the degree of clumping individuals within a population. Sampling will be performed by locating several randomly placed strip transects within a particular community. Plot frames (either 20 by 50-cm or 50 by 100-cm, depending on species size) will be sequentially placed along each transect, and the number of individuals of each species of interest in each plot will be determined. The data from this procedure can be used in any of several quadrat-variance procedures for determining the presence of a clumping pattern, the size and spacing of clumps, and the strength of the pattern.

Biomass and leaf area of herbaceous material will be determined by harvesting all plant material within randomly located subplots of the plots used for the coverage measurements. The vegetation will be clipped at ground level, sorted by species, placed in plastic bags, and stored in a cooler. The leaf area and oven-dried biomass will be determined in the laboratory as soon after harvesting as feasibly possible. Shrub biomass and leaf area will be determined by measuring the canopy. The height, the longest horizontal axis, and the axis perpendicular to the longest axis will be measured for a sample of shrubs within the 10 by 50-m plots used for shrub density estimation. Equations are available (i.e. Kirkham et al. 1986) that can be used to estimate shrub biomass and leaf area based on these canopy measurements. If an equation is not available for a particular species, or if

the available equations prove inadequate for the shrubs at a particular location, new equations will be derived by harvesting several shrubs, measuring the biomass and leaf area, and then determining the relationship between these variables and the measurements of the shrub canopy dimensions.

4.0 COMMUNITY EVAPOTRANSPIRATION STUDIES

4.1 PURPOSE

An important aspect of the plant community dynamics subtask is to provide estimates of the amount of water that could drain below the root zone of the various plant communities that are likely to exist on a protective barrier. Accurate drainage estimates require a detailed understanding of the evapotranspiration characteristics of the system under consideration. Investigations of the evapotranspiration characteristics of certain important species, such as cheatgrass, have already been initiated (Link and Waugh 1989). However, landscape scale studies are required to determine the evapotranspiration potential of whole communities, as well as the spatial variation of soil moisture and water use within these communities. Current models of soil-water dynamics assume spatial homogeneity at the surface. If significant soil-water patterns exist, then it may be necessary to develop two or three dimensional soil-water models that can take into account surface heterogeneity.

Community scale studies will be conducted at McGee Ranch and at a minimum of two other locations either on or off of the Hanford Site. The selection of these locations will depend on the results of the work described in Sections 2.0 and 3.0 of this test plan. The McGee Ranch site is considered ideal for the initial investigations because it is the location of the proposed fine soil borrow site for the protective barrier program, it contains both climax and old field plant communities, and the present climatic conditions are typical of the 200 areas waste management facilities. The McGee Ranch native stand is dominated by the shrubs *Artemisia tridentata* and *Grayia spinosa* and is characterized by a hummock / swale microtopography. The hummocks or mounds range from 0.2 to 0.5 meters in height and are found at the base of *Grayia* individuals, no such mounds are found around *Artemisia* shrubs. The hypothesis is that the soil-water patterns with depth will differ beneath the hummocks and swales and also will depend on the proximity to the shrubs. It is proposed that the soil-water patterns in this community be documented to determine whether heterogeneous patterns exist. The methods for this documentation are described below. The analyses conducted at additional sites will depend on the results of the McGee Ranch studies and on specific site characteristics.

4.2 METHODS

4.2.1 Supplemental Precipitation

Ten, circular, 50-m2-plots will be randomly located in each study area with seven plots assigned to the supplemental precipitation treatment and seven plots assigned to the ambient precipitation control treatment. Irrigation will be applied in November at two to four times normal winter precipitation. This will be performed using drip irrigation.

4.2.2 Neutron Probe Installation and Soil Analysis

Neutron probe ports will be located within each precipitation treatment plot in a manner that reflects surface topography. If there are no obvious patterns, the ports will be randomly located with a minimum of seven ports in any condition for replication. Ports will be placed to a depth of 3 m. When the ports are installed, soil-water, soil particle size, and root biomass and length will be measured. Soil samples will be retained in 30-cm depth increments for a total of ten cores per port. These samples will be used to calibrate the neutron probe. Soil-water contents will be determined gravimetrically. As each 30-cm core is removed, the soil will be double bagged in plastic and placed in a cooler. The cores will be weighed to determine wet weight. The soil will then be dried at 55 °C to constant weight. The core will be cut in half after it is dried. One half will be used to determine the soil particle size distribution and the other half will be processed to determine root biomass and length. Root processing will entail separating the roots from the soil in an automated root washing machine. After the roots are separated from the soil, roots will be measured to determine root length and weight on a soil volume basis. Alternatively, if sufficient funding is not available, root biomass will be measured as the ashed weight of the samples ashed in a muffle furnace. All root processing and analysis will be performed using equipment currently available at the Arid Lands Ecology Laboratory.

4.2.3 Plant Growth Characteristics

To identify plant factors that may influence soil-water patterns, it is necessary to characterize the phenological patterns for at least one year on a monthly basis. Growth patterns will be characterized by monthly measurements of leaf area, stem diameter, and root length. The leaf area of five individuals of each species will be measured within each treatment. Leaf area will be estimated by double sampling. Stem diameter measurements will be made with Ceres devises (Beedlow et al. 1986). Because it is automated, five individuals of each species within each treatment (20 plants total) will be monitored. Equipment requirements for this task include Ceres construction, and a datalogger for each site. Root dynamics will be monitored by examining roots in acrylic root observation ports. A trench also will be dug to obtain data on the spatial characteristics of five individuals of the important species.

4.2.4 Gas Exchange Measurements

Gas exchange measurements will be collected to correlate the plant growth parameters with the observed changes in soil moisture. This will give qualitative indications of the relative contributions of the important species to the overall community evapotranspiration and the relative effects of the different species on the soil moisture patterns. Gas exchange measurements will be recorded monthly on five individuals of each of the important species.

The measurements can be made using a portable gas exchange system that is currently available but would be more useful if the system can be upgraded for whole plant measurements. Operating conditions will be standardized for all observations and will be conducted at midday.

4.2.5 Meteorological Data

A data logging system will be employed to collect basic meteorological data at each of the research sites. The datalogger for each site will be shared with the Ceres devises used for stem diameter measurements. Basic meteorological data to be collected include precipitation, air temperature, soil temperature, solar radiation, photosynthetically active radiation, wind speed, and relative humidity. This information is needed for the estimation of the amount of evaporation, storage, and drainage that is occurring within the soil column.

5.0 MODELLING OF PLANT COMMUNITY DYNAMICS

Plant communities undergo change as a consequence of both disturbance and the introduction of new species. Dynamic change may be relatively slow, as in eastern deciduous forests, or rapid, as in the shrub-steppe region of the intermountain basin. Large-scale dynamics as a result of frequent fires or grazing may produce plant communities that are continually undergoing rapid change without ever producing a classic climatic community (e.g., Evans and Young 1978). An understanding of the temporal and spatial scales of dynamic processes of the vegetative communities on and around engineered barriers is essential for accurate, long-term barrier performance predictions.

5.1 PURPOSE

The purpose of this task is to predict the spatial and temporal patterns of variability of the dominant vegetation types within climatic regimes predicted for the barrier during its performance lifetime. These excersies are not meant to model the temporal transitions between the different climatically determined community types. Predictions of vegetation dynamics will include estimates of transition times from one plant cover type to another. Emphasis will be placed on species replacement over time (succession) rather than on system properties such as energy flows, because variation in species composition is one of the key elements in modelling evapotranspiration from the barrier over time. Community dynamics also will be estimated as a function of the disturbances characteristic of the climatic regime and the estimated anthropogenic uses of the area over the performance lifetime of the barriers. This information will allow comparisons of plant community resilience to disturbance.

5.2 TECHNICAL CONSIDERATIONS

5.2.1 Scale of Disturbance

Disturbance regimes cover a wide range of spatial and temporal scales. Because many physiological and ecological processes are scale-dependent, it is likely that plant dynamic processes are likewise a function of scale. Studies of succession in the forest and steppe regions of North America have focused primarily on large-scale disturbances, such as result from fire or abandonment of agricultural fields. A common finding of such studies in shortgrass and shrub-steppe regions is that the dominant native plant species recover very slowly or not at all. Yet, disturbance is a common feature of plant communities, and native dominants, by definition, must recover from disturbances that are normal for the area.

Disturbances that may be expected during the performance lifetime of the barriers range from small, patch-producing disturbances such as ungulate fecal pats and mounds and small animal burrows to large-scale disturbances such as wildfires, grazing, and severe weather events. Although individually of minor

importance, small-scale disturbances often occur at relatively high frequencies within a given landscape. Consequently, such disturbances can affect large portions of a given landscape. Successional dynamics and recovery times on these disturbed areas can be quite different than on larger disturbed areas (Coffin and Lauenroth 1990).

5.2.2 Modelling Options

5.2.2.1 Gap Phase Dynamics Models. The theory of gap-phase dynamics has been employed as the basis for simulation models of successional dynamics in mesic forests (e.g., Shugart 1984) and shortgrass steppe (Coffin and Lauenroth 1990). These gap dynamics models have proved valuable in predicting long-term dynamics of plants in response to small, frequently occurring disturbances. These models perform well when typical disturbance regimes are on a small scale, such as those that arise from treefalls, rodent burrowing, and plant senescence. They perform poorly when large-scale disturbances are addressed. Because large-scale disturbance, especially wildfire, is the norm in the sagebrush-steppe region (e.g. Evans and Young 1978), the current state of development of gap phase dynamic models is not adequate to address the needs of the protective barrier program.

5.2.2.2 Mechanistic Models. Mechanistic models drive predictions of larger-scale phenomena from analysis of the mechanisms driving smaller-scale behavior. Such models require thorough understanding of the interconnectedness of the community subunits to produce reasonable predictions of behavior. Such understanding does not come without intensive, long-term research. Few such models have been developed for the shrub-steppe region and none perform well. Because of the time and effort involved in producing mechanistic models of plant community dynamics, they are unlikely to be useful to the protective barrier program.

5.2.2.3 Markovian Process Models. In Markovian representations of community dynamics, the canopy (or cover) of various dominant species occupying a given area are usually designated as different states. The dynamics of this system are then depicted as a species-by-species replacement process in which the probability that species "i" will be replaced by species "j" is a function solely of the relative frequency of young individuals of species "j" beneath the canopy (or within a short distance of) species "i" (Horn 1975). This requirement shows that modeling community dynamics using Markovian state transition models require a definition of the discrete states of the community of interest, determination of non-zero transitional possibilities between states, and estimation of transition probabilities based on local patterns of state abundance and rates of recruitment, death, and decay within each state.

These data are then used to formulate a matrix **P** =

		Future state j (j = 1 → k)				
		1	2	3	--	k
present state i (i = 1 → k)	1	p_{11}	p_{12}	p_{13}	--	p1k
	2	p_{21}	p_{22}	p_{32}	--	p2k
	3	p_{31}	p_{23}	p_{33}	--	p3k
	--	--	--	--	--	--
	--	--	--	--	--	--
	k	pk1	pk2	pk3	--	pkk

where k is the total number of states in the community of interest and p_{ij} is the probability of moving from present state i to future state j during the time period of assessment.

Projections of community change over time are derived from measures or hypotheses regarding initial conditions, such as those subsequent to a wildfire or severe grazing event. These conditions are summarized as a state vector in the following manner:

$$\mathbf{N}_{(t = 0)} = (n_1, n_2, n_3, \ldots n_k)$$

where n_i is the relative proportion of state i in the starting community (i.e., at time t = 0).

The following shows subsequent state vectors at time t + 1 are derived from the post-multiplication of **N** by **P**:

$$\mathbf{N}_{(t)}\mathbf{P} = \mathbf{N}_{(t + 1)}$$

For regular Markov chains, iteration of the matrix multiplication will eventually produce a stable distribution of **N**, which is independent of the initial state vector.

Transition probabilities may be constant over time, or they may be functions of the values of $\mathbf{N}_{(t)}$, or they may vary with the type of disturbance. For example, the transition probabilities for *Artemisia*

tridentata → *A. tridentata* and *Chrysothamnus nauseosus* → *C. nauseosus*, depend on whether mortality is induced by disease and/or predation, or fire: *A. tridentata* can be destroyed by fire; *C. nauseosus* will often resprout after being burned; especially if the fire is not intense. Such changes in transition probabilities can be incorporated in nonhomogeneous Markov-chain models (e.g. Acevedo 1981).

5.2.2.4 Sources of Uncertainty and Validation of Predictions. Sources of uncertainty for predictions of environmental change or response include model error, natural stochasticity in space and time, and parameter uncertainty. Parameter uncertainty generally takes the form of a statistical distribution, rather than a biased estimate. Such uncertainty is a consequence of the protocol used to obtain the basic field data or results from the methods used to estimate the parameter from basic data, such as extrapolation from a regression estimate. Parameter uncertainty can be quantified at each step (field data collection and mathematical projections). Model errors can be assessed in one of two ways: (1) by comparing the performance of models using different sets of assumptions, and (2) by testing the predictions of a given model against independent field data. Uncertainty in the veracity of predictions as a consequence of natural stochasticity may be estimated from historic data, though this analysis introduces its own uncertainty (Suter et al. 1987).

5.3 METHODS

5.3.1 Selection of Plant Communities

A set of climatic conditions likely to occur in the Pasco Basin over the next 10,000 yrs will be identified in other tasks. Plant communities representative of these conditions will be identified and described (see Section 3.0). Within these representative communities, at least two study sites will be identified. These will be chosen on the basis of the following criteria:

- Representativeness of the climate/community type
- Representativeness of disturbance regimes to be expected in the barriers area
- Accessibility to research teams.

Similar data will be collected at both sites within each climate and/or community type. Data from one site will be used to define and parameterize the plant community dynamics models, and data from the other site will be used to validate the model and serve as a reference point for adjustment, as needed.

5.3.2 Definition of Community States

Discrete community states will be defined on the basis of cover dominance for each successional (seral) stage within a given climate and/or community regime. Standard references, such as Franklin and Dyrness (1980) shall be consulted for definition of seral communities and species dominants within those communities. Daubenmire (1970) is considered the primary reference for defining community states within the shrub-steppe province of Washington State.

Where data for seral communities are lacking, it will be necessary to generate community type assessments based on plant cover data obtained at the analogue site. These assessments will be based on stratified random field samples of species cover within standard-sized plots. Determination of suitable assessment plot size must account for the scale of the plants involved. Numbers of strata and plots within each strata will be determined using standard procedures (e.g., Cochran 1977). Resulting cover data will be subjected to standardized classification procedures (Pielou 1984). Because plant community composition is strongly affected by soil type, care must be taken to match plant community seres at analogue study sites with the loessal silt-loam soil types characteristic of the McGee Ranch area.

Potential community states to be considered should account for growth form, so that dominant species of forbs, grasses, shrubs, and trees are identified, where appropriate. Open space will be a state possible in all climate and community regimes. The primary criteria for inclusion as a discrete state within a seral stage are cover dominance and ubiquity for each growth form.

5.3.3 Development of a Digraph

The relevant literature shall be consulted to define a conceptual model (i.e., digraph) of the possible transitions among states within a climate sere. Attention should be paid to species replacement patterns, seed germination requirements, growth form, and life history. For example, in the Columbia Basin province, *Salsola kali* is the dominant species in early secondary succession, but *Bromus tectorum* dominates in late succession (Brandt et al. 1990). Both species are alien annuals, however, *Salsola* seeds are dispersed widely and require only the most ephemeral wetting to germinate (Allen 1984). *Bromus* seeds are less readily dispersed and require a litter cover or disrupted microtopography to germinate (Evans and Young 1972). Once established, *Bromus* is resistant to invasion by *Salsola*. Therefore, the digraph for this portion of the community would show a transition from open space to *Salsola* to *Bromus*, but not the reverse.

Once the first-phase conceptual model has been completed, a field examination at the analogue site shall be instigated to verify the model. The field examination shall focus on assessing the completeness of the digraph with regard to definition of community states and verifying the potential transitions among states. Transitions between states may be verified by examining the locations where seral dominant plants reach reproductive

maturity within the canopy range of other seral dominants. Thus, plant a germinating beneath the canopy of species b is not sufficient evidence to indicate the capability of species a to replace species b. Seed set by species a is required.

5.3.4 Determination of State Mortality Rates

State mortality (or loss) rates will be estimated from data obtained in the field under the identified disturbance regimes, which for a shrub-steppe would include fire, grazing, and no disturbance. Field data necessary to determine mortality rates of shrubs in a sagebrush and rabbitbrush habitat would thus include estimates for the following variables:

Variable	Definition
A	Number of dead sagebrush/ha
B	Number of live sagebrush/ha
C	Estimated number of years for sagebrush to decay beyond recognition.
D	Number of dead green rabbitbrush/ha
E	Number of live green rabbitbrush/ha
F	Estimated number of years for green rabbitbrush to decay beyond recognition.
G	Number of dead grey rabbitbrush/ha
H	Number of live grey rabbitbrush/ha
I	Estimated number of years for grey rabbitbrush to decay beyond recognition.

Mortality rates for sagebrush (m_s), for example, would then be computed from the relationship:

$$B\ m_s\ C = A.$$

Mortality rates for the other species would be computed by similar substitution of variables into this equation.

5.3.5 Determination of Recruitment to States

Recruitment to or generation of states will be estimated from data obtained in the field under the identified disturbance regimes. Field data necessary to determine recruitment rates of cheatgrass and Sandberg bluegrass into sagebrush states would include estimates for the following variables:

Variable	Definition
J	Recruitment of cheatgrass beneath sagebrush (No./ha/yr)
K	Recruitment of bluegrass beneath sagebrush (No./ha/yr)
L	Recruitment of bluegrass in cheatgrass stands (No./ha/yr)
M	Recruitment of bluegrass in open areas (No./ha/yr)
N	Recruitment of cheatgrass in open areas (No./ha/yr)
O	Recruitment of cheatgrass in bluegrass stands (No./ha/yr)
P	Area covered by sagebrush canopy
Q	Area covered by bluegrass canopy

5.3.6 Markovian Modelling

Transition properties for states will be computed as the product of state-specific mortality and state specific recruitment rates, with density and scale variables included where necessary. For example, the following depicts the transition probability for sagebrush to cheatgrass (P_{sc}):

$$J\ m_s\ /\ B = p_{sc}.$$

Markovian modelling would proceed using transition probabilities estimated for each state. Probabilities for each state transition will be compared across disturbance conditions to determine whether probabilities are constant across disturbance regimes. If they are found to be relatively constant, the method given previously will be used to model the progression of the plant community over time, given some hypothetical set of initial

conditions. If transition probabilities are found to be non-constant, nonhomogeneous Markov-chain modelling will be employed following standard methods (e.g. Acevedo 1981).

Model outputs will be compared to field data on state numbers from sites not used to develop the model to assess validity and refine the model's parameters. Model performance will be compared to actual state values using appropriate statistical tests. For example, predictions of dynamic performance over time will be compared to actual states over time (where such data are available) using a runs test. Static predictions can be assessed for bias by comparing predicted values to observed values using a binomial test. Evidence of bias will be a cause for reassessing the transition probabilities or assumptions of homogeneity, and refining values where necessary using field data from the model-testing sites.

5.3.6.1 Data Input Requirements and Expected Outputs. The following are required inputs:

- Definition/delineation of community space states based on focal (Dominant) species as well as vacant land surface
- Diagram of principal transitions among states
- Likely conditions of disturbance
- Mortality rates of species in state i under normal and disturbance conditions
- Recruitment rates of species i into state j, and into all other states
- Recruitment rates of species i as a function of spatial density of state j.

Required Outputs.

Minimal output from a Markovian modelling exercise will be a k-dimensional plot of the spatial density of the k species (or states) as a function of time, given some presumed initial conditions. These initial conditions will be determined from a field analysis of disturbance consequences (e.g. the number of species or states i present in an area within one year of a burn). Analysis of the model using the initial state conditions will identify the time-stable community composition as well as the time (in years) to reach that stable composition given an initial set of conditions. Disturbances may be entered into the model on a given recurrence interval, in which case time-stable compositions may never be reached. In this case, the model will identify the community composition change as a cyclic phenomenon with state density as a function of time. Output from the models may then be used as a basis for predicting barrier performance over time as a function of the change in plant community composition over time.

6.0 INTERACTION WITH OTHER BARRIER TASKS

The work performed within the plant community dynamics task will directly interface with and provide important data to a number of other task groups as defined by the barrier development plan (Adams and Wing 1986). Brief descriptions of some of these interactions are provided in the following sections.

6.1 BIOINTRUSION TASKS

Plant community type and state will have a direct affect on the types of burrowing animals present on a barrier, and directly will affect the probability of intrusion into the waste by either plants or animals.

6.2 WATER INFILTRATION TASKS

Water balance of the fine-soil surface layer will be directly dependant on the plant community characteristics (i.e., community-scale seasonal and annual ET patterns).

6.3 EROSION CONTROL TASKS

The magnitude of wind and water erosion will be effected by plant coverage, distributions, canopy architectures; and rooting characteristics of the plant community; these variables are dependant on the disturbance history, and successional stage and climatic conditions.

6.4 MODELLING TASKS

Model development, validation, and derived predictions require representative values for various plant community parameters (e.g., rooting depths, ET, water uptake patterns).

6.5 NATURAL ANALOG STUDIES

Plant community dynamics is a principle part of the overall natural analogs task group.

6.6 CLIMATE

The determination of plant community structure and change is the natural extension of the climate prediction tasks. The work described in this test plan ties the climate predictions to all of the other task groups previously listed.

7.0 PROJECTED COSTS (IN THOUSANDS)

TASK GROUP	FY1991	FY1992	FY1993	FY1994	TOTAL
Analog identification	$ 10	$ 5	$ 10	$10	$ 35
Community scale evaporation	150	100	100	100	450
Successional modelling	20	50	50	30	150
Total Pacific Northwest Laboratory Contribution	180	155	160	140	635
Community Characterization (Westinghouse Hanford Company)	50	30	50	20	150
Total	$230	$185	$210	$160	$785

8.0 REFERENCES

Acevedo, M. F., 1981, *On Horn's Markovian Model of Forest Dynamics With Particular Reference To Tropical Forests*, Theoretical Population Biology, 19:230-250.

Adams, M. R. and N. R. Wing, 1986, *Protective Barrier and Warning Marker System Development Plant*, RHO-RE-35P. Rockwell Hanford Operations, Richland, Washington.

Allen, E. B. and M. F. Allen, 1980, *Natural Re-establishment of Vesicular-Arbuscular Mychorrhizae Following Stripmine Reclamation in Wyoming*, Journal of Applied Ecology, 17:139-147.

Allen, E. B and D. H. Knight, 1984, "The Effects of Introduced Annuals on Secondary Succession in Sagebrush-Grassland, Wyoming," *Southwestern Naturalist*, 29:407-421.

Beedlow, P. A., D. S. Daly, and M. R. Thiede, 1986, *A New Device For Measuring Fluctuations in Plant Steam Diameter: Implementations For Monitoring Plant Response*, Environmental Monitoring and Assessment 6:277-282.

Brandt, C. A., W. H. Rickard, and M. G. Hefty, 1990 *Interim Reclamation Report Basalt Waste Isolation Project Boreholes 1989*. PNL-7280, Pacific Northwest Laboratory, Richland, Washington.

Canfield, R., 1941, "Application of the Line Intercept Method in Sampling Range Vegetation," *Journal of Forestry*, 39:388-394.

Cline, J. F. and V. A. Uresk, 1979, "Revegetation of Disturbed Grounds in the Semi-Arid Climate of Southcentral Washington," *Health Physics*, 36:289-294.

Cline, J. F., D. W. Uresk, and W.H. Rickard, 1975, *Characterization of Plant Communities Adjacent to the B-C Controlled Area and REDOX Pond Areas on the 200 Area Plateau*, BNWL-1916, UC-70, Pacific Northwest Laboratory, Richland, Washington.

Cline, J. F., D. W. Uresk, and W. H. Rickard, 1977, "Comparison of Soil Water Used by a Sagebrush-Bunchgrass and a Cheatgrass Community," *Journal of Range Management*, 30:199-201.

Cochran, W. G., 1977, *Sampling Techniques, 3rd Ed.*, John Wiley and Sons, New York.

Coffin, D. P. and W. K. Lauenroth, 1990, "A Gap Dynamics Simulation Model of Succession in a Semiarid Grassland," *Ecological Modelling*, 49:229-266.

Daubenmire, R. F., 1959, "Canopy Coverage Method of Vegetation Analysis," *Northwest Science*, 33:43-064.

Daubenmire, R. F., 1970, "Steppe Vegetation of Washington," *Washington Agricultural Experimental Station Technical Bulletin 62*, pp 131.

Daubenmire, R. F., 1975a, "Ecology of Artemisia Tridentata Subsp, Tridentata in the State of Washington," *Northwest Science*, 49:24-35.

Daubenmire, R., 1975b, "Plant Succession on Abandoned Fields, and Fire Influences, in a Steppe Area in Southeastern Washington," *Northwest Science*, 49:36-48.

Evans, J. A. and R. A. Young, 1972, "Population Dynamics After Wildfires in Sagebrush Grasslands," *Journal of Range Management*, 31:283-289.

Fayer, M. J., 1990, *Test Plan for Hydrologic Modeling of Protective Barriers*, PNL-7152, UC-702 Pacific Northwest Laboratory, Richland, Washington.

Franklin, J. F and C. T. Dyrness, 1973, *Natural Vegetation of Oregon and Washington*, Pacific Northwest Forest and Range Experiment Station, USDA Forest Service General Technical Report, PNW-8.

Franklin, J. F. and C. T. Dyrness, 1988, *Natural Vegetation of Oregon and Washington*, Oregon State University Press, Corvallis, Oregon.

Floydd, D. A. and J. E. Anderson, 1983, "A Comparison of Three Methods for Estimating Vegetal Cover," *Idaho National Engineering Laboratory Radioecology and Ecology Programs, 1983 Progress Report*, DOE/ID-12098, U.S. Department of Energy, Idaho Falls, Idaho, pp. 114-126.

Gee, G. W., M. L., Rockhold, and J. L. Downs, 1989, *Status of FY 1988 Soil-Water Balance Studies on the Hanford Site*, PNL-6750, Pacific Northwest Laboratory, Richland, Washington.

Green, R. H., 1979, *Sampling Design and Statistical Methods for Environmental Biologists*, John Wiley and Sons, New York, New York.

Harris, G. A. and A. M. Wilson, 1970, *Competition for Moisture Among Seedlings of Annual and Perennial Grasses as Influenced by Root Elongation at Low Temperature*, Ecology, 51:530-534.

Harris, G. A., 1967, "Some Competitive Relationships Between Agropyron Spicatum and Bromus Tectorum," *Ecological Monographs*, 37:89-111.

Horn, H. S., 1974, "The Ecology of Secondary Succession," *Annual Review of Ecology and Systematics*, 5:25-37.

Horn, H. S., 1975, "Markovian Properties of Forest Succession," *Ecology and Evolution of Communities*, M. L. Cody and J. M. Diamond, eds. pp. 196-211, Belknap Press, Cambridge, Massachusetts.

Klemmedson, J. O. and J. G. Smith, 1964, "Cheatgrass, Bromus tectorum L.," *Botanical Review*, 30:226-262.

Link, S. O., G. W. Gee, M. E. Thiede, and P. A. Beedlow, 1990a, *Response of a Shrub-Steppe Ecosystem to Fire: Soil Water and Vegetational Change*, Arid Soil Research and Rehabilitation 3:163-172.

Link, S. O., M. E. Thiede, R. D. Evans, J. L. Downs, and W. J. Waugh, 1990b, *Evapotranspiration Studies for Protective Barriers: FY 1987 Status Report*, PNL-6985, Pacific Northwest Laboratory, Richland, Washington.

Link, S. O., and W. J. Waugh, 1989, *Evapotranspiration Studies for Protective Barriers: Experimental Plans*, PNL-6899, Pacific Northwest Laboratory, Richland, Washington.

Ludwig, J. A. and J. F. Reynolds, 1988, *Statistical Ecology*, John Wiley and Sons, New York, New York.

Mack, R. N. and J. N., Thompson, 1982, "Evolution in Steppe with Few Large, Hooved Mammals," *American Naturalist*, 119:757-773.

Mueller-Dombois, D. and H. Ellenberg, 1974, *Aims and Methods of Vegetation Ecology*, John Wiley and Sons, New York, New York.

Pielou, E. C., 1984, *The Interpretation of Ecological Data*, John Wiley and Sons, New York.

Reeves, F. B., D. Wagner, T. Moorman, and J. Kiel, 1979, "The Role of Endomychorrhizae in Revegetation Practices in the Semi-Arid West, (I) A Comparison of Incidence of Mychorrhizae in Severely Disturbed vs. Natural Environments," *American Journal of Botany*, 66:6-13.

Rickard, W. H. and R. H. Sauer, 1982, "Self-Revegetation of Disturbed Ground in the Deserts of Nevada and Washington," *Northwest Science*, 56:41-47.

Rickard, W. D., D. W. Uresk, and J. F. Cline, 1977, *Productivity Response to Precipitation by Native and Alien Plant Communities*, In: *Proceedings of the Symposium on Terrestrial and Aquatic Ecological Studies of the Northwest*. March 26-27, 1976. Ed. by R. D. Andrews III, R. L. Carr, F. Gibson, B. Z. Lang, R. A. Soltero, and K. C. Swedberg. EWSC Press, Eastern Washington State College, Cheney, Washington.

Ricklefs, R. E., 1979, *Ecology*, 2nd Ed., Chiron Press, New York & Concord.

Rives, C. S., M. I. Bajwa, A. E. Liberta and R. M. Miller, 1980, "Effects of Topsoil Storage During Surface Mining on the Viability of VA Mychorrhiza," *Soil Science*, 129:253-257.

Rogers, L. E. and W. H. Rickard, 1977, *Ecology of the 200 Area Plateau Waste Management Environs: A Status Report*, PNL-2253, Pacific Northwest Laboratory, Richland, Washington.

Ruffner, J. A. and F. E. Bair, 1977, *The Weather Almanac*, 2nd Ed., Gale Research Company, Book Tower, Detroit, Michigan.

Sturgis, D. L., 1979, *Hydraulic Relations of Sagebrush Lands. In: The Sagebrush Ecosystem: A Symposium*, Utah State University, Logan, Utah.

Shugart, H. H., 1984, *A Theory of Forest Dynamics*, Springer-Verlag, New York.

Suter, G. W. III, L. W. Barnthouse, and R. V. O'Neill, 1987, *Treatment of Risk in Environmental Impact Assessment*, Environmental Management 11:295-303.

U.S. Department Of Energy, 1987, *Final Environmental Impact Statement - Disposal of Hanford Defense High Level, Transuranic and Tank Wastes*, DOE/EIS-0113, Richland, Washington.

Waugh, W. J., 1988, *Field Study of Gravel Admix, Vegetation, and Soil Water Interactions: A 1987 Status Report*, Pacific Northwest Laboratory, Richland, Washington.

Waugh, W. J. and S. O. Link, 1987, *Barrier Erosion Control Test Plan: Gravel Mulch, Vegetation And Soil Water Interactions*, SD-WM-TP-024, Rockwell Hanford Operations, Richland, Washington.

Waugh, W. J. and D. D. Rountry, 1983, *Evaluation of Vegetation Management on Outdoor Radiation Areas*, RHO-RE-EV-32, Rockwell Hanford Operations, Richland, Washington.

Williams, S. E and M. F. Allen, 1984, *VA Mychorrizae and Reclamation of Arid and Semi-Arid Lands*, Conference proceedings, Wyoming Agricultural Experiment Station, University of Wyoming, Scientific Report Number SA1261.

DISTRIBUTION

Number of copies		
OFFSITE	UNC Geo-Tech. P.O. Box 14000 Grand Junction, Colorado	
1	W. J. Waugh	
ONSITE	U.S. Department of Energy- Richland Operations Office	
5	P. K. Clark	A6-80
	R. D. Freeburg	A6-95
	M. J. Furman	A6-80
	G. W. Rosenwald	A6-80
	DOE-RL Reading Room	A1-65
16	Pacific Northwest Laboratory	
	L. L. Cadwell	P7-50
	M. D. Campbell	K6-77
	J. C. Chatters	P7-50
	M. J. Fayer	K6-77
	H. D. Freeman	K2-12
	G. W. Gee (2)	K6-77
	K. A. Hoover	K6-77
	C. T. Kincaid	K6-77
	M. W. Ligotke	K4-06
	S. O. Link	P7-50
	M. R. Rockhold	K6-77
	D. L. Stewart	K6-01
	T. L. Stewart	K6-27
	W. H. Walters	K6-77
	Technical Library	P8-55
35	Westinghouse Hanford Company	
	M. R. Adams	H4-55
	D. C. Board	H4-16
	L. C. Brown	H4-51
	J. W. Cammann	H4-14
	V. W. Hall	B2-15
	D. H. Jones	H4-16
	K. N. Jordan	B2-15
	C. J. Kemp	H4-14
	D. S. Landeen	H4-14
	D. R. Myers	H4-14

DISTRIBUTION (cont)

Number of Copies

ONSITE

Westinghouse Hanford Company - Cont

K. L. Petersen	H4-14
S. J. Phillips	H4-14
J. F. Relyea	H4-14
M. R. Sackschewsky (10)	H4-14
J. L. Scott	R2-87
D. R. Speer	R2-77
N. R. Wing	H4-14
T. M. Wintczak	B2-15
D. D. Wodrich	R2-23
R. D. Wojtasek	B2-15
J. C. Womack	R2-18
Publication Services (3)	H4-17
Environmental Data Management Center (2)	H4-22