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WATER EROSION FIELD TESTS
FOR HANFORD PROTECTIVE BARRIERS:
FY 1992 STATUS REPORT

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MASTER

SUMMARY

Pacific Northwest Laboratory (PNL) conducted this study for the Office of Technology Development and the Office of Environmental Restoration of the U.S. Department of Energy. The purpose of the study was to investigate the erosion potential of barrier soil covers from high-intensity rainfall events and to propose erosion mitigation criteria for the soil cover.

Two sets of field plots were used in the testing program. Small plots (1 m^2) were used initially for scoping studies and larger plots (32.5 m^2) were used for a more comprehensive study of soil cover erosion. The study investigated the use of pea gravel admix and naturally established vegetation to reduce erosion of barrier soil covers.

Tests were conducted, initially on small 1-m^2 plots, to evaluate the erosion characteristics of Warden silt-loam under intense rainfall conditions and to provide information for the design of larger test plots. Tests were conducted on Warden silt-loam with and without gravel admix. Analysis of the water-sediment samples indicated that soil erosion was reduced by the gravel admix but continued to occur throughout the tests. The decision was made to include vegetation cover in future testing. Other information assisted in simplifying the sampling and measurement procedures.

The large plot tests focused primarily on testing the effects of gravel admix and vegetation cover on reducing erosion. Two percentages of admix were tested. The initial tests used 39% (dry weight) added to the silt-loam and follow-up tests used 22% admix. From the large plot tests the following conclusions and recommendations were identified:

- The dominant factor in reducing erosion was the presence of vegetation. Vegetation cover on the plots varied from 82% to 96% and was established under natural seasonal conditions.
- The presence of gravel admix reduced erosion but not nearly as much as the establishment of vegetation which reduces rainsplash erosion.
- Dry soil conditions significantly reduces the volume of runoff. The opposite is true for a high antecedent moisture, where runoff is increased.

- Tests on the 22% gravel admix plot were initiated but not completed. Further testing is recommended for FY 1993.

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1.0 INTRODUCTION

Radioactive and other hazardous wastes from Hanford operations were released to the ground or buried at the site over about 40 years of onsite nuclear materials production. A significant amount of the waste sites are either in shallow burial areas or held in near-surface soils at former disposal sites. Aboveground, mounded earth and rock material structures have been proposed as one method of capping the waste to prevent precipitation, plants, and animals from reaching the waste and transporting contaminants to the surface or ground water. The barrier will be expected to remain effective for up to 1000 years without long-term maintenance.

Concern over the potential erosion of the top surface soil cover, formalized in Wing (1989), led to the establishment of the water erosion task under the Hanford Protective Barriers Program at Pacific Northwest Laboratory (PNL). To obtain data and information on potential erosion of the barrier soil surface, PNL developed a field test plan to be conducted at Hanford over a period of 3 to 4 years. The results will be used to provide erosion mitigation criteria for the basic barrier design.

The field tests involved two separate sets of soil plots and the application of high-intensity rainfall with a mobile rainfall simulator. Initial tests were conducted on small 1-m² plots for a preliminary evaluation of the soil under intense rainfall conditions. The results were used to plan field tests with larger plots (32.5 m²) for the purpose of developing barrier design criteria. Data and information collected from the plots include applied rainfall, runoff, sediment yield, soil properties, and vegetation establishment.

The plot study data will be used to develop 1) recommendations regarding the use of gravel admix (percent by weight) in the cover soil, 2) information on the potential amount of long-term erosion and erosional characteristics, and 3) the effect of vegetation cover.

This report contains six sections. In Section 2, an overview of the field testing conducted in FY 1989, FY 1990, and FY 1992 is presented. The test facility and field plot design are described in Section 3. Section 4 discusses the results of small plot testing conducted in FY 1989. Prelimi-

nary conclusions regarding the erosion characteristics of Warden silt-loam and design recommendations for the large plot tests are included. Section 5 discusses the results of the FY 1990 and FY 1992 large-plot tests. Conclusions and recommendations regarding the use of gravel admix and the presence of vegetation in reducing barrier soil erosion are presented in Section 6.

2.0 FIELD TESTING OVERVIEW 1989 - 1992

Protective barriers will be used to isolate shallow-buried wastes by inhibiting the transport of radionuclides and other contaminants to the environment by water infiltration, intrusion by plants and burrowing animals, wind and water erosion, human intrusion, and release of noxious gases. The barriers, including a warning marker system, are being considered for the Hanford Site as part of an overall waste management strategy. The barriers will be expected to remain functional and maintenance free for up to 1000 years.

The purpose of the water erosion task is to test the performance of barrier components subject to water erosion from extreme rainfall-runoff processes expected during the design life of the barrier. The barrier component to be tested is the soil cover composed of Warden silt-loam which is found on the Hanford Site. The silt-loam will be placed on the barrier's top surface to intercept and temporarily store precipitation, not removed by runoff, that infiltrates into the soil until it can be removed through evapotranspiration.

Initial tests with small plots (1 m²) were conducted during September 1989. The objectives of these tests were to investigate the behavior of Warden silt-loam under intense rainfall conditions and to gain experience with the rainfall simulator and other field equipment. Important behavior variables considered were the amount of rainsplash erosion on bare soil, the effect of gravel admix on rainsplash erosion, the depth of infiltration, and changes in soil surface conditions and properties. The test results were used to design larger plot studies more representative of barrier conditions.

The plots were constructed with a 5% slope because early opinions regarding barrier design considered a 5% slope to be the most likely slope for the soil cover. Soils of three different size-class distributions were included in the tests: 1) native soil (Warden silt-loam) of 67-74% silt or finer, 2) native soil composed of 55-60% silt or finer, and 3) native soil with gravel admix.

The test results indicated that rainsplash was a significant erosional process for all test plot surfaces. The plots with gravel admix resisted rainsplash more effectively, although it continued to occur throughout the series of tests. This indicated a need for vegetation cover on the barrier surface including vegetation in future testing. Also, future tests need only to consider plots of native soil (no admix) and native soil with gravel admix. The results and evaluation of the small plot tests are presented in Section 4.0.

During FY 1990, discussions among the Barrier Technical Advisory Board (BTAB) members indicated that a 2% slope may be preferable to a 5% slope. Because of these discussions, one set of large plots was constructed to a 5% slope and the other set to a 2% slope. Each set included a plot of native soil and a plot of native soil with gravel admix. The purpose was to test both conditions initially and make a determination regarding the preference of one slope over the other. Two tests were conducted during September 1990 on the 2% plots with two tests scheduled for the 5% plots early in October 1990. The October tests were cancelled because funds to this task were cut during FY 1991.

Funding for the water erosion studies was reinstated about the midpoint of FY 1992 and testing was resumed. By this time, the BTAB had selected the 2% slope as the design criteria for the barrier top surface; therefore, tests on the 5% plots were omitted from the FY 1992 testing. By the spring of 1992, vegetation had become well established on both the 2% and 5% plots. Before testing was resumed, the vegetation on all plots was characterized and percent coverages determined in April and June (Appendix A). Two rainfall simulation tests were conducted in August 1992 with vegetation cover. Following those tests, vegetation was removed from the native soil plot (2% slope) and gravel admix was rototilled into the soil at about one-half the percentage (22%) of the other plot. The purpose was to test the use of less gravel admix based on recent BTAB discussions. A concern existed that significant quantities of admix could reduce moisture capacity of the silt-loam but that less admix may

not be sufficient for surface armoring over the life of the barrier. Testing of this particular plot began in late FY 1992 and is scheduled for completion in FY 1993.

3.0 TEST FACILITY AND PLOT DESIGN

3.1 SMALL TEST PLOTS

During the spring of 1989, four sets of small erosion plots were constructed at McGee Ranch, which is located near the western boundary of the Hanford Site (Figure 3.1). Twelve galvanized sheet-metal flumes, enclosing a 1-m² surface area, were placed over plots of three different soil treatments for each of the four sets of plots. Each flume was connected to a runoff collection system for water and sediment (Figure 3.2). The three soil treatments were as follows: 1) native soil with an average pea gravel admix of 42%, 2) native soil with 67-74% silt, and 3) native soil with 55-60% silt. The percent clay is included in the silt percentages but was less than 1% of the total. All percentages are in dry weights. The grain-size distribution curves for the three soils are shown in Figure 3.3.

Before placement of the flumes, the plot areas had been excavated to about a 1-m depth and then refilled with the three different soil treatments (one treatment per excavation). The soil was placed in the excavations in 10-cm lifts with each lift hand compacted. The top surfaces were groomed to a 5% slope. Each flume was connected to a vertical section of 20-cm (8-in.) polyvinyl chloride (PVC) pipe, which served as a collector for water and sediment during rainfall simulation events. The data collection and results of the small test plots are presented in Section 4.0.

3.2 LARGE TEST PLOTS

Using the results obtained from the FY 1989 small plot tests, two sets of larger plots were designed and constructed at McGee Ranch in FY 1990. Each set consisted of two plots 3 m by 10.7 m (10 ft by 35 ft) constructed of timber plank for plot boundaries with galvanized metal collectors at the down-slope end. Collector access pits were dug at each end to provide space for grab sampling during rainfall simulation tests (Figure 3.4).

The original intent was to test both a 2% and a 5% slope. Ground surface areas closely matching the two slopes were located with a surveying level

FIGURE 3.1. Location of McGee Ranch Field Test Plots

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FIGURE 3.2. Configuration of Small Erosion Test Plots

FIGURE 3.3. Grain-Size Distribution Curves for Small Test Plots

and then rototilled before placing the flume and collector system. Before the flumes were in place, pea gravel admix (39% dry weight) was added to one plot in each set and rototilled into the soil. The other plots used the native soil. The plots were then groomed to the desired slopes and galvanized sheet metal collectors were mounted on timbers at the downslope ends.

As mentioned previously, the decision not to use the 5% plots was made after their construction; therefore, grain-size distribution curves were developed for only the 2% plots (Figure 3.5). The silt-loam in the native soil plot averages 66% silt. The grain-size curve for the gravel admix plot was developed up to a maximum size of 2 mm, which is the upper limit for sand. The maximum gravel size used in the admix was 4 mm. The data collection and results of the large test plots are presented in Section 5.0.

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FIGURE 3.4. Configuration of Large Erosion Test Plots

FIGURE 3.5. Grain-Size Distribution Curves for Large Test Plots

3.3 RAINFALL SIMULATOR

Rainfall was applied to the plots with a rotating-boom rainfall simulator. The simulator, which is mobile, has ten 7.6 m (25 ft) arms in a radial configuration that supports a total of 30 V-Jet 80100 nozzles. The nozzles are positioned on radii of 1.52, 3.05, 4.57, 6.10, and 7.6 m with 2, 4, 6, 8, 10 nozzles on concentric circles. Fifteen of the nozzles are electrically operated and can be switched either on or off at any time during testing. The nozzles spray directly downward from an average height of 2.4 m, producing drop-size distributions similar to those of natural rainfall with near terminal velocity. Simulator energies are about 77% of those of natural rainfall (Simanton et al. 1985; Meyer 1965).

3.4 RAINFALL APPLICATION

Initial hydrologic design consideration for the barrier was based on the maximum amount of rainfall occurring in a 24-hour period with a recurrence interval of 1000 years. The initial targeted value was 68.07 mm (2.68 in.) for a 24-hour period based on extreme value analysis by Stone et al. (1983). This value was based on 23 years of information (1947-1969). However, with the addition of records from the Hanford Meteorological Station for 1970 through June 1991, and using the same method of analysis as in Stone et al. (1983), the 24-hour value was calculated to be 57.78 mm (2.27 in.). According to Ponce (1989), the maximum incremental rainfall occurs during a period of 11.5 to 12 hours for the Hanford Site, based on the Soil Conservation Service 24-hour rainfall table (Type II curve). During this period, the rainfall intensity is 43.91 mm/hr for a 24-hour period with a 1000-year recurrence interval. This intensity corresponds to a simulator intensity of 57.02 mm/hr.

4.0 SMALL PLOT FIELD TESTS

4.1 DATA COLLECTION

Four 20-min storm events were applied to the plots on September 8, 13, 20, and 27, 1989 (Table 4.1). The rainfall intensity for the second and third events was changed at specific points to test the effect on runoff and sediment yield. Before testing, a soil sample was collected from each plot to determine the soil particle-size distribution. A nuclear density gauge was used before and after each rainfall event to measure percent moisture, and wet and dry density of the plots. The changes in plot surface elevation, relative to initial conditions, were measured using a point gauging technique. The objective was to determine if the combined effects of soil loss, compaction, and settlement could be realistically interpreted and to document any rill development. During each event, total rainfall for each 20-min event was measured using rain gauges placed beneath the simulator (Table 4.2). The runoff (water and sediment) was collected in wells and the rate of accumulation monitored with pressure transducers. Grab samples were collected at the flume outlet for analysis of sediment yield and particle sizes.

4.2 RESULTS

Runoff and sediment yield were generated from all plots during rainfall events 2, 3, and 4, but not during event 1. Only a trace of water was

TABLE 4.1. Event Durations and Intensities

<u>Event</u>	<u>Intensity (mm/hr)</u>	<u>Duration (min)</u>
1	55	20
2	140	10
	70	10
3	60	5
	120	10
	60	5
4	120	20

TABLE 4.2. Average Total Rainfall per Plot Group

<u>Run</u>	<u>Plot Group</u>	<u>Average Total Rainfall (mm)</u>
1	1	20.57
	2	18.79
	3	17.53
	4	17.27
2	1	34.68
	2	31.37
	3	31.75
	4	30.63
3	1	30.39
	2	28.07
	3	30.48
	4	30.33
4	1	39.49
	2	38.61
	3	39.83
	4	39.49

collected in the wells as a result of water running down the protective metal hood covering the flume mouth. Therefore, no runoff and sediment yield data were available for event 1. During the other three events, problems occurred with the data logger system. The system failed to properly store the measured data for the events within the data logger. As a backup procedure, runoff data was obtained by visually reading and recording the automatic digital readout of the data logger on field data sheets as a backup procedure.

4.2.1 Reliability of Test Results

The lack of runoff data during the first rainfall event was caused by low antecedent moisture conditions, a short event time of 20 min, the lowest intensity tested (55 mm/hr), and post-construction conditions of loosely-packed soil. For subsequent rainfall events, the time at which runoff commenced was visually noted. Runoff began almost immediately for the gravel admix plots but required from 1 to 4 min for the native soil plots.

An evaluation of the rainfall rates for events 2 and 3 indicated that the desired intensities may not have been reached. The rate of 140 mm/hr may be beyond the physical limit for the simulator. Rainfall intensities of 120 mm/hr (all nozzles operating) and 60 mm/hr (half the nozzles operating) are probably reasonable physical limits of the simulator. For event 2, 140 mm/hr @ 10 min and 70 mm/hr @ 10 min should have produced a total rainfall of 35 mm. An average of the four plots indicated a total rainfall of 32 mm. The rates for the other events were close to the expected totals. Therefore, there was some question about the application of rainfall intensity for event 2. The total amounts of rainfall for event 3 indicated that the application rate was probably what was attempted. However, the number of data points for runoff did not provide a reliable basis for computing mass flow rates. The only reliable information that can be obtained from events 2 and 3 were total runoff and sediment yield. Rainfall event 4 produced the only consistent results for all four plots and the total rainfall indicated that the desired intensity was reached.

4.2.2 Results for Rainfall Event 4

For rainfall event 4 (120 mm/hr for 20 min), runoff hydrographs were plotted for each soil type to compare runoff characteristics between the three soil treatments. The runoff hydrographs for plots with gravel admix are shown in Figure 4.1. Similarly, hydrographs for plots with 55-60% silt are shown in Figure 4.2 and for 67-74% silt in Figure 4.3. Comparison of the trends in the three figures indicated that the gravel admix plots had less hydrograph variation between plots and a slightly larger runoff volume than the silt plots. Both groups of silt plots indicated a wider variation between individual plot hydrographs with the 55-60% silt group indicating less runoff than the other silt or gravel admix groups. In general, all hydrographs were of the same basic shape and appeared to have reached near equilibrium conditions within the first 10 min of the event.

Graphs of sediment concentration versus time were plotted for the three soil types in Figures 4.4 (gravel admix), 4.5 (55-60% silt), and 4.6 (67-74% silt). All plots indicated a wide variation with no well-defined trends

FIGURE 4.1. Runoff Hydrographs (Rainfall Event 4) for Gravel Admix Plots

FIGURE 4.2. Runoff Hydrographs (Rainfall Event 4) for Plots of 55-60% Silt

FIGURE 4.3. Runoff Hydrographs (Rainfall Event 4) for Plots of 67-74% Silt

FIGURE 4.4. Sediment Concentrations in Runoff from Gravel Admix Plots

FIGURE 4.5. Sediment Concentrations in Runoff from Plots of 55-60% Silt

FIGURE 4.6. Sediment Concentrations in Runoff from Plots of 67-74% Silt

except that sample concentrations for the gravel admix plots were considerably less than those for silt even though more runoff occurred. Sediment concentrations from the gravel plots did not exceed a concentration of about 14 g/L for any sample except for one concentration of about 17 g/L (Figure 4.4). Sediment concentrations for the silt plots varied from about 9 g/L up to about 60 g/L (Figures 4.5 and 4.6). Because of the wide variation in plotted points, it was difficult to determine whether any of the individual sediment concentration curves reached equilibrium conditions. The significant trend was that concentrations were much less for the gravel admix plots.

4.2.3 Rainsplash Erosion Observations

Raindrops striking a soil surface detaches soil particles and produces a net downslope transport of sediment. The effectiveness of this detachment depends significantly on rainfall intensity. The more intense the rainfall, the larger the soil particles that are detached. High-intensity rainstorms, typical of those that occur in arid and semi-arid regions, produce large raindrops of high velocity that can be magnified by wind speed and direction. Kirkby (1971) states that on a level surface, rainsplash has moved 4-mm rock particles for distances up to 20 cm; 2-mm particles up to 40 cm; and small particles up to 150 cm. The maximum particle size for the gravel admix used in these tests was approximately 4 mm.

Rainsplash was observed to occur about the time a pitted soil surface was observed. Rainsplash was more noticeable during the early minutes of the tests but was less visible when surface depression storage and runoff were occurring. Accumulation of water on the surface may reduce the upward movement of particles even though erosion by rainsplash can still occur within the surface stored water. Particles splashed onto the flume sides varied in size from silt up to fine sand sizes based on visual inspection. Coarse sand and gravel admix were found in the flume outlets on completion of the tests.

4.2.4 Sediment-Size Distributions

The distributions of particle sizes of eroded sediment (sediment yield) collected in plot runoff were determined for comparison with the plot soil

size distribution. The purpose was to determine which particle sizes tend to remain on the plots. The 15-ml water and sediment samples collected at intervals during each rainfall event were too small to analyze without incurring large weighing errors. Therefore, samples collected from specific plots were combined to provide enough sediment for particle-size analysis. The particle sizes were determined using the sieve and pipette method (Folk 1974).

Combined sample sets were analyzed only for the two types of silt plots because the plots with gravel admix did not yield enough sediment for analysis. Only rainfall events 3 and 4 were considered. For plots composed of 55-60% silt, plots 1.3 (events 3 and 4) and 2.2 (event 3) were analyzed (Table 4.3). For plots with 67-74% silt, plots 2.3 (events 3 and 4) and 4.3 (event 4) were analyzed (Table 4.4).

The maximum particle size of eroded sediment was less than 0.35 mm for all plots analyzed. About 4-8% of the particles were between 0.25-0.35 mm, which is in the medium sand size class (Simons and Senturk 1977). The percent silt and clay varied from 57 to 61% (55 to 60% silt plots) and from 68 to 73% (67 to 74% silt plots). The coarser fractions, 0.35 mm or larger, were presumed to have mostly remained on the plots, which caused the percent by weight of clay to increase to 9-14%. Comparison of the eroded sediment size distribution to that of the respective plot soil indicated at least 95% of the sediment will probably continue to erode under high-intensity rainfall conditions.

The low sediment yield from the gravel admix plots implies that armoring against erosion occurred; however, erosion may continue at a reduced rate. Table 4.5 lists the size distributions for gravel plots 1.2, 3.3, and 4.2. With the addition of gravel admix, about 54-58% of the particles are less than 0.35 mm, indicating that the sand sizes greater than 0.35 mm together with the added gravel may provide enough coarse material to significantly reduce the long-term erosion of the soil covers.

4.2.5 Changes in Soil Characteristics

Before testing, the high-intensity rainfall was expected to modify the plot surfaces. The development of small rills and surface irregularities was

TABLE 4.3. Particle-Size Distribution of Sediment Yield from Silt-Loam Plots with 55-60% Silt

Particle Size (mm)	Plot 1.3			Plot 2.2	
	Soil	Sediment Yield		Soil	Sediment
		Event 3	Event 4		Yield
Event 4					
<u>Gravel</u>					
4.0	--			--	
2.83	100			100	
2.0	99.91			99.77	
<u>Sand</u>					
1.41	99.60			99.38	
1.0	99.31			98.91	
0.71	98.91			98.37	
0.50	98.31			97.79	
0.35	97.59	100	100	96.95	100
0.25	96.14	93.7	91.61	95.48	95.25
0.177	93.83	89.98	86.50	93.12	92.03
0.125	89.64	85.86	81.69	88.60	88.12
0.088	73.54	76.62	71.18	72.74	78.79
0.063	59.38	60.77	57.42	60.00	63.05
<u>Silt</u>					
0.031	30.64	30.78	31.19	31.47	35.64
0.0156	15.45	19.93	21.15	16.44	23.04
0.0078	2.03	12.89	15.26	4.18	14.39
<u>Clay</u>					
0.0039	0.84	12.15	11.60	0.69	14.14
0.002	0	0	0	0	0

thought possible regardless of the relatively short length available for overland flow (1 m). With the gravel admix plots, the process of armoring was expected to develop during the rainfall events and become visually apparent following the test series. Also, some change in the consolidation and settlement of the soil was expected.

To quantify these expected changes, two types of measurements were made following each rainfall event: surface elevations and soil properties. The relative elevation of the plot surfaces was measured before and after each event using a point-gauging technique. Elevations relative to the metal flume

TABLE 4.4. Particle-Size Distribution of Sediment Yield from Silt-Loam Plots with 67-74% Silt

Particle Size (mm)	Plot 2.3			Plot 4.3	
	Soil	Sediment Yield		Soil	Sediment Yield Event 4
		Event 3	Event 4		
<u>Gravel</u>					
4.0				100	
2.83	100			98.86	
2.0	99.94			98.63	
<u>Sand</u>					
1.41	99.86			98.38	
1.0	99.65			98.10	
0.71	99.36			97.66	
0.50	98.96			97.15	
0.35	98.44	100	100	96.51	100
0.25	97.27	93.44	95.16	95.36	96.07
0.177	95.54	90.33	92.78	93.78	93.64
0.125	92.65	87.33	90.43	91.06	90.59
0.088	83.39	79.83	83.83	79.66	82.83
0.063	73.82	68.09	72.96	66.66	70.16
<u>Silt</u>					
0.031	41.13	40.05	42.61	35.77	41.72
0.0156	22.18	24.73	26.70	18.65	28.38
0.0078	9.63	13.65	16.10	2.87	16.68
<u>Clay</u>					
0.0039	2.38	11.07	9.42	0	9.60
0.002	0	0	0	0	0

perimeter were taken at 3-cm intervals along three cross sections for each plot. Comparison of the cross-sectional data provided a rough estimate of the depth of eroded sediment and also helped identify the development surface irregularities. Changes in soil properties were determined by measuring the wet and dry density and percent moisture of each soil plot with a nuclear density meter. The measurements were made before and after each event and used to compute soil porosity. Visual observations were made of all plot surfaces during and after each event.

TABLE 4.5. Particle-Size Distributions for the Native Soil Plots with Gravel Admix. Distributions were developed from samples collected from plot surfaces.

<u>Particle Size (mm)</u>	<u>Plot 1.2</u>	<u>Plot 3.3</u>	<u>Plot 4.2</u>
<u>Gravel</u>			
	100	100	100
4.0	86.60	85.20	79.81
2.83	65.70	60.31	60.29
2.0	61.94	56.19	56.96
<u>Sand</u>			
1.41	60.63	55.44	56.03
1.0	59.89	54.98	55.53
0.71	59.41	54.58	55.01
0.50	58.96	54.20	54.63
0.35	58.39	53.76	54.10
0.25	57.44	52.91	53.20
0.177	56.08	51.63	51.92
0.125	53.85	49.61	49.57
0.088	45.16	42.79	42.60
0.063	37.58	35.51	34.64
<u>Silt</u>			
0.031	19.89	17.27	17.35
0.0156	9.45	8.80	9.02
0.0078	1.77	3.16	2.47
<u>Clay</u>			
0.0039	0.45	0.75	0.49
0.002	0	0	0

The crusting of plot surfaces was apparent after the plots were allowed to dry out. Water penetration was uniform (8-10 cm) on all plots for all rainfall events. During the dry, warm weather conditions during September 1989 and the 1-wk interval between tests, crusts formed on all plots down to where the soil was still damp (1-2 cm). The strongest crusts developed on the 67-74% silt plots, which may have been a consequence of the higher silt content.

The point gauge measurements indicate that, collectively, the plots lost approximately 2-3.5 mm of soil from their surfaces after all four events were

applied (Table 4.6). The addition of gravel admix to the soil did not seem to make a difference between plots. This may have been partly because of the small plot size and the base level control by the flume border at the downslope end. The depth of soil loss was not significant and some error may have been introduced attempting to measure a depth of 2-3 mm since the gravel admix plots have sizes up to 4 mm.

The field measurements of soil density and moisture content are shown in Table 4.7. The measurements were made before rainfall event 1 and before rainfall event 4; therefore, the changes reflected in the data resulted from only the first three tests. The soil porosity and percent change in porosity were computed from the field measurements and included in Table 4.7. Examination of the results indicated an increase in density for all but two plots that involved gravel admix. The percent decrease in porosity varied from 0 to 27.6%.

4.3 RECOMMENDATIONS

The field tests conducted with the small plots provided data and information from which to plan and design the larger plot studies. Although the small plots were of insufficient length to test erosion from overland flow, the tests did provide comparative data between plot treatments regarding the effect of rainsplash erosion. Rainsplash was effective in removing soil from all plots; however, the sediment yield from the plots with gravel admix was much less than from plots without the admix. There was very little difference in sediment yield between the two types of silt plots.

The maximum particle size of the sediment yield from the plots was less than 0.35 mm. For McGee Ranch soil without gravel admix, erosion from high intensity rainfall events would continue to occur with little chance for armoring because about 95% of the particle sizes are less than 0.35 mm. With the gravel admix, some armoring would occur but erosion would probably continue at a reduced rate.

Changes in the plot soil characteristics, resulting from the testing, involved mainly the formation of crusts and a slight increase in bulk density. Corresponding to the increase in density, there was about an 8-28% decrease

TABLE 4.6. Depth of Cumulative Soil Loss from All Rainfall Events

Silt Loam (67-74% Silt) (mm)		Silt Loam (55-60% Silt) (mm)		Silt Loam with Gravel Admix (mm)	
Plot	Soil Loss	Plot	Soil Loss	Plot	Soil Loss
1.1	2.2	1.3	1.9	1.2	2.5
2.3	2.4	2.2	2.4	2.1	2.5
3.2	2.7	3.1	3.5	3.3	2.6
4.3	3.0	4.1	3.4	4.2	3.2

TABLE 4.7. Engineering Properties of Plot Soils

Plot	Rainfall Event	Dry Density (g/cm ³)	Wet Density (g/cm ³)	Moisture (%)	Porosity (%)	Change in Porosity (%)
<u>Silt Loam (67-74% Silt)</u>						
1.1	1	1.460	1.495	2.4	44.9	
	4	1.631	1.698	4.1	39.1	-12.9
2.3	1	1.296	1.353	4.4	51.6	
	4	1.648	1.701	3.7	38.5	-25.4
3.2	1	1.489	1.509	1.7	44.4	
	4	1.637	1.691	3.3	38.9	-12.4
4.3	1	1.456	1.493	2.5	46.0	
	4	1.789	1.864	4.2	33.3	-27.6
<u>Silt Loam (55-60% Silt)</u>						
1.3	1	1.364	1.396	2.3	48.6	
	4	1.531	1.587	3.6	42.9	-11.7
2.2	1	1.369	1.396	2.0	48.9	
	4	1.542	1.610	4.4	42.5	-13.1
3.1	1	1.412	1.436	1.7	47.3	
	4	1.583	1.644	3.8	40.9	-13.5
4.1	1	1.417	1.454	2.6	47.1	
	4	1.589	1.653	4.0	40.7	-13.6
<u>Silt Loam with Gravel Admix</u>						
1.2	1	1.580	1.612	1.6	37.2	
	4	1.761	1.807	2.6	34.3	-7.8
2.1	1	1.759	1.785	1.4	34.4	
	4	1.757	1.813	3.1	34.4	0
3.3	1	1.640	1.669	1.7	38.8	
	4	1.814	1.869	3.0	32.3	-16.8
4.2	1	1.833	1.863	1.6	31.6	
	4	1.758	1.814	3.2	34.4	+8.9

in soil porosity resulting from the testing. Based on the test results, the following recommendations were proposed for the large test plots:

- construct plot surfaces with a 1V:3H slope at the downslope end to test for the development of rills and gullies
- construct one plot with native soil and gravel admix and one with native soil only
- following the first year of testing, allow vegetation to establish naturally and test effects on erosion the following year
- replace the data logger system with a hand-sampling procedure
- collect water and sediment runoff in larger sample containers for laboratory analysis of individual samples for sediment yield and particle-size distribution
- omit the point gauge measurements of the plot surfaces as the data is of questionable value
- use the hydrometer method to determine sediment-size distributions in runoff samples.

5.0 LARGE PLOT FIELD TESTS

The large plots were designed to test the stabilizing effects of gravel admix and vegetation cover in reducing erosion of the Warden silt-loam when used as a barrier cover. The first two plots were constructed during the last quarter of FY 1990. One plot consisted of Warden silt-loam (native soil) and the other was native soil with 39% (dry weight) pea gravel admix. The plots were bare of vegetation and groomed to a 2% slope. The test plots constructed with a 5% slope were not tested as discussed in Section 2.0. Only two rainfall events were applied in late FY 1990 with plans to continue tests during the summer of FY 1991 after vegetation was established, however, testing did not resume until the summer of FY 1992. During the FY 1992 test sequence, a third plot was constructed to test a 22% gravel admix application. Two rainfall events were applied to this plot with plans to complete the series in FY 1993. A summary of rainfall intensity, duration, and application schedule for the FY 1990 and FY 1992 tests are listed in Table 5.1.

The large plot design included a collector system at the downslope end to allow sampling by hand because of the large volume of runoff expected. Grab samples of water and sediment runoff were collected and discharge measurements were made at timed intervals. The samples were collected in 1-L bottles about 1 to 2 min apart. Each sample was analyzed in the laboratory by sieve and hydrometer analysis to determine the variation in sediment concentration and particle-size distribution over each 30-min rainfall event. The discharge measurements were made with 2000-mL graduated cylinders about 1 to 2 min apart. Nuclear density meter measurements were obtained before and after each event to determine changes in soil density and moisture content.

5.1 FIELD TESTS - FY 1990

5.1.1 Runoff and Sediment Yield

Runoff rates for the native soil and gravel admix plots for events 1 and 2 are plotted in Figure 5.1. A comparison of the runoff rates for the two events shows much lower rates for event 1 because of the initial dry soil

TABLE 5.1. Simulated Rainfall Events and Application Schedule

<u>Rainfall Simulations</u>						
<u>Event</u>		<u>Intensity (mm/hr)</u>	<u>Duration (min)</u>			
1		58	30			
2		54	30			
3		64	58			
4		120	17			
		64	14			
5		63	45			
6		64	30			

<u>Application Schedule</u>						
<u>Plot Type</u>	<u>Event</u>					
	<u>1990</u>		<u>1992</u>			
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>
Gravel Admix (39%)	X	X	X	X	X	
Native Soil	X	X	X	X		
Gravel Admix (22%)					X	X

conditions. This is also indicated by the delay in the initiation of runoff (4-5 minutes) for event 1. Comparison of the native soil and gravel admix plots shows a higher rate of runoff for the gravel treatment. The difference can be upwards of 10 to 15 mm/hr for the same point in time for either event indicating a reduction in infiltration caused by the gravel armoring. Also, the runoff rate for the gravel plot approaches steady-state conditions about 3-5 min earlier, although it is difficult to determine if steady-state conditions were actually reached.

The variations in sediment concentration in the runoff for the native soil and gravel admix plots are shown in Figure 5.2. The plots show that

FIGURE 5.1. Runoff Hydrographs (Rainfall Events 1 and 2) for the Native Soil and Gravel Admix Plots

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FIGURE 5.2. Sediment Concentrations in Runoff from Rainfall Events 1 and 2 for the Native Soil and Gravel Admix Plots

average steady concentrations were reached about 10 min from the start of rainfall. The curve for the gravel admix plot (event 2) is missing the first three concentration values because the samples were lost in storage during the FY 1991 work stoppage. These three samples could have had much higher concentrations similar to the other three curves. The steady-state concentration for the gravel admix plot was about 6 g/L for event 1 and about 3 g/L for event 2. This indicated that most of the loose surface material was washed off and the surface had begun to develop an armor against rainsplash erosion. The development of armoring was also visually observed.

For the native soil plots, the results indicated that the plot began approaching average steady concentrations about 5 min later than the gravel plots during both events. The steady-state concentration for the first event is about 7-8 g/L and about 12-14 g/L for event 2. The increase in sediment concentration for event 2 may have resulted from a series of small parallel rills that were developing at the 1V:3H downslope end. The rills were visually observed as they developed late in the test. Also, with the rill development, the curve indicated a slight trend of increasing concentration (2-3 g/L) over the final 8-10 min of testing.

Total runoff volumes, average sediment concentrations, and total sediment yields from both plots were calculated for each event (Table 5.2). The significant data in the table are the values for the gravel admix plot for event 2. The total runoff (627.1 L) is the highest for the four combinations of data (event and plot). However, the average concentration (2.47 g/L) and sediment yield (0.222 ton/acre) was the lowest of the four combinations. This indicates that after the initial high-intensity event, the presence of gravel admix can measurably reduce erosion.

A nuclear density gauge was used to directly measure the wet and dry densities and percent moisture before and after the application of each rainfall event. The porosity and percent saturation were calculated using weight-volume relationships (Das 1985). The measured and calculated data are shown in Table 5.3.

TABLE 5.2. Runoff and Sediment Yield Measured During FY 1990 Tests Under Bare Plot Surface Conditions

Plot	Event	Rain Applied (L)	Total (L)	Runoff % of Applied	Sediment Concentration (g/L avg.)	Sediment Yield	
						(kg)	(tons/acre)
Gravel Admix (39%)	1	943.0	387.6	41.1	10.74	4.33	0.593
	2	894.2	627.1	70.1	2.47	1.62	0.222
Native Soil	1	943.0	313.8	33.3	11.76	3.69	0.505
	2	894.2	559.7	62.6	13.84	7.76	1.062

TABLE 5.3. Summary of Pre-Test and Post-Test Soil Properties Under Bare Plot Surface Conditions (in the sets of numbers, the first listed is the pre-test, the second listed is the post-test)

Plot	Event	Dry Density (g/cm ³)		Wet Density (g/cm ³)	Moisture Content (%)	Porosity (%)	Saturation
Gravel Admix (39%)	1	1.761	1.812	2.9	34.3	14.9	
		1.692	1.890	11.8	36.9	54.2	
	2	1.772	1.819	5.5	33.9	28.8	
		1.827	2.003	9.7	31.8	55.8	
Native Soil	1	1.575	1.646	4.5	41.2	17.2	
		1.493	1.774	19.1	44.3	64.5	
	2	1.566	1.717	9.6	41.6	36.2	
		1.590	1.879	18.2	40.7	71.3	

A comparison of the data in Table 5.3 indicated a higher density for the gravel admix plots, probably because of the presence of gravel in the soil (39% dry weight). The porosity of the gravel admix plot was lower with a correspondingly lower percent moisture and percent saturation. The difference in porosity between the native soil and gravel admix plots could have resulted from a closer packed granular structure with the addition of a range of small gravel sizes as compared to a more uniform grain-size distribution with the native soil. The reduced percent saturation for the gravel plot would be expected because of the greater total runoff and reduced porosity.

The increase in porosity during event 1 (both plots) indicated that water entered and filled the voids and a change in soil structure was occurring. The decrease in porosity for event 2 may indicate that surface sealing or crusting was occurring. According to McIntyre (1958), the formation of crusts is mainly because of the washing-in of fine particles and compaction of the immediate surface by raindrop impact. The compaction of the surface crust is supported by the increase in dry density from pre-event to post-event measurements.

5.2 FIELD TESTS - FY 1992

The field tests conducted in FY 1992 were a continuation of the FY 1990 tests except that an extensive vegetation cover was present on both plots. Before the FY 1992 testing, a vegetation survey was conducted on April 14 and June 5, 1992, to determine the percent cover and rooting depths. Both the 2% and 5% sloped plots were examined, although only the 2% sloped plots were being tested. For the 2% plots, the percent coverage for the gravel admix plot was 88% in April, which increased to 96% by June. The cover on the native soil plots increased from 58 to 82% between April and June. A discussion of the vegetation surveys and analysis is in Appendix A.

Rainfall events 3 and 4 were applied to both the gravel admix plot (39% gravel dry weight) and the native soil plot. Event 3 was applied at the rate of 64 mm/hr for 58 minutes. Original plans were to run for 30 min but the extremely dry conditions produced very little runoff and the decision was made

to continue the application for up to 60 min. Event 4 consisted of a rate of 120 mm/hr for about 17 min at which time the rate was reduced to 64 mm/hr. The purpose of the two different application rates was to evaluate any reduction in runoff and sediment concentration.

Upon completion of event 4, the decision was made to cease testing the native soil without gravel admix but continue further testing of the soil with gravel admix at a reduced percent based on a BTAB request as discussed in Section 2.0. The native soil plot was reworked by removing all vegetation and adding gravel admix at 22% dry weight. The purpose was to test a soil-gravel combination with about one half of the amount of gravel than previously tested. Rainfall events 5 and 6 were both about 64 mm/hr with durations of 45 min and 30 min, respectively. Event 5 was applied to both plots but event 6 was applied only to the 22% gravel plot because of problems with the collection system on the 39% gravel plot.

5.2.1 Native Soil Plot

Rainfall events 3 and 4 were the only events applied to the native soil plots. Event 3 was applied at the beginning of the test series with very dry soil conditions and extensive vegetation cover. Event 4 was applied several days later when much more soil moisture was present. The runoff hydrographs for events 3 and 4 (native soil plots) are shown in Figure 5.3. For event 3, runoff did not occur until about 9 min into the test. A rate of 1 mm/hr was reached about 43 min into the test. For event 4, runoff commenced about 2 to 3 min into the test and exceeded 30 mm/hr within 15 min. Runoff rates for the remainder of the event averaged about 33 mm/hr and, at times, approached 40 mm/hr. The reduction of the application rate during event 4 is not apparent in Figure 5.3 except for a tendency toward an average steady-state runoff condition. Another runoff characteristic indicated in Figure 5.3 involves the point at which runoff reaches about 25 mm/hr. Above this point, runoff varies cyclically between most measurements until the rate drops below about 25 mm/hr.

FIGURE 5.3. Runoff Hydrographs (Rainfall Events 3 and 4) for the Native Soil Plot

The only difference in plot conditions between the two events was the antecedent soil moisture. The first test of the year was under relatively dry soil conditions. Although event 4 used a higher application for the initial 17 min, the extreme contrast in runoff rate between the two events indicated that antecedent soil moisture had a significant effect on runoff.

Sediment concentrations in runoff from the native soil plots varied from a maximum of about 11 g/L to minimum of 3-4 g/L for both rainfall events (Figure 5.4). However, the extremely low runoff rate for event 3 indicated a much lower sediment yield. For the relatively dry initial conditions during event 3, the concentrations were low (less than 4 g/L) but increased rapidly to about 10 g/L within a few minutes and then gradually decreased to an average of about 6 g/L. The concentrations for event 4 increased rapidly during the first 5 min from about 8-11 g/L and then decreased rapidly to an average of about 4 g/L.

The plot soil properties for events 3 and 4 are in Table 5.4. Both the wet and dry soil densities were less than those measured during the FY 1990 tests (Table 5.3), probably as a result of the vegetation growth. A corresponding increase in percent porosity was calculated for the FY 1992 test conditions. These changes were also implied in the measured increase in percent moisture (post-test) for the FY 1992. After the FY 1990 tests, the percent moisture varied from 18 to 19%. For the FY 1992 tests, the moisture varied from 25 to 28% with vegetation present.

5.2.2 Gravel Admix Plot (39% gravel)

Rainfall events 3, 4, and 5 were applied to this plot. Testing was discontinued after problems developed with the collection system near the end of event 5. The runoff hydrographs for the events are plotted in Figure 5.5. For event 3, the hydrographs for the native soil and gravel admix plots were essentially identical with a minimum of about 2 mm/hr. For event 4, the hydrograph for the gravel plot reached a maximum runoff rate of about 35 mm/hr with an average of about 25 mm/hr for peak runoff conditions. Event 5 was basically the same rainfall rate as event 3 except the duration was 45 min. The maximum rate measured was 7 mm/hr at the end of the test and gradually

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FIGURE 5.4. Sediment Concentrations in Runoff from Rainfall Events 3 and 4 for the Native Soil Plot

TABLE 5.4. Pre-Test and Post-Test Soil Properties Under Vegetated Plot Surface Conditions (in the sets of numbers, the first listed is the pre-test, the second listed is the post-test)

Plot	Event	Dry Density (g/cm ³)	Wet Density (g/cm ³)	Moisture Content (%)	Porosity (%)	Saturation (%)
Gravel Admix with Vegetation (39%)	3	1.638	1.663	1.6	38.9	6.8
		1.477	1.732	17.5	44.9	57.7
	4	1.600	1.705	6.6	40.3	26.2
		1.584	1.836	16.0	40.9	62.1
	5	1.840	1.923	4.6	31.3	27.0
		1.763	2.020	14.7	34.2	75.9
Native Soil with Vegetation	3	1.350	1.375	5.6	49.6	15.3
		1.182	1.513	28.3	55.9	59.9
	4	1.301	1.415	8.8	51.5	22.3
		1.309	1.635	25.0	51.2	64.1

increasing which indicated that average steady-state conditions were not reached.

The sediment concentrations for the three events are plotted in Figure 5.6. For event 3 (dry soil conditions), the concentration averaged about 1 g/L for the entire test under relatively steady-state conditions. The initial concentrations for events 4 and 5 were in the range of 4.5-6 g/L and decreasing to about 2 g/L near the end of the events.

The measured and calculated soil properties for the FY 1992 tests are shown in Table 5.4. At the beginning of the FY 1992 tests, the densities had decreased, probably, in response to the establishment of vegetation. Porosity was also greater before to event 3 but decreased upon completion of event 5. The measured moisture content showed an increase over all three events, probably because of the presence of vegetation.

FIGURE 5.5. Runoff Hydrography (Rainfall Events 3,4, and 5) for the Gravel Admix Plot

A comparison of the runoff and sediment yield for both the gravel admix and native soil plots is presented in Table 5.5. The establishment of vegetation reduced the sediment yield from the native soil plots by more than half that of the FY 1990 tests (Table 5.2) even though the total FY 1992 rainfall application was about twice as much. The presence of vegetation both reduced the sediment concentration and the amount of runoff from the native soil plots. The gravel admix results were similar but the sediment concentration was close to that of test event 2 in FY 1990 after the armor layer began to form and loose material was removed by event 1. The significant reduction of sediment yield from the gravel admix plots is because of the reduction of runoff which could be attributed to the establishment of vegetation.

5.2.3 Gravel Admix Plot (22% Gravel)

After the removal of vegetation from the native soil plot and the addition of 22% (dry weight) gravel admix, rainfall events 5 and 6 were applied. These were initial tests for this admix weight and further testing after vegetation establishment is scheduled for FY 1993. The results of all tests conducted on the 22% gravel admix will be evaluated and reported during FY 1993.

TABLE 5.5. Runoff and Sediment Yield Measured During FY 1992 Tests

Plot	Event	Rain Applied (L)	Total (L)	Runoff % of Applied	Sediment Concentration (g/L avg.)	Sediment Yield	
						(kg)	(tons/ acre)
Gravel Admix (39%)	3	2011.9	19.6	0.97	0.93	0.019	0.003
	4	1556.4	270.3	17.4	4.24	1.14	0.157
	5	1546.7	84.3	5.45	3.22	0.271	0.037
Native Soil	3	2011.9	21.3	1.06	6.55	0.140	0.019
	4	1556.4	369.9	23.8	6.15	2.28	0.311

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FIGURE 5.6. Sediment Concentrations in Runoff from Rainfall Events 3, 4, and 5 for the Gravel Admix Plot

5.2.4 Observation of Surges in Runoff

Plots of runoff hydrographs for the FY 1992 rainfall events were characterized by significant intermittent surges after the runoff rate reached about 25 mm/hr (Figures 5.3 and 5.5). Some surging was indicated at slightly lower rates but was not as pronounced. Similar results were indicated during the FY 1990 events but were not as noticeable, possibly because of the plotting scale (Figure 5.1) and a slightly longer sampling interval.

An examination of the data indicated a systematic occurrence of these surges for the higher runoff rates. This phenomenon has been documented to occur in both open channel flow and overland flow (Chow 1959; Emmett 1978; and Mayer 1959). Emmett (1978) mentions that under certain conditions, overland flow may become unstable and cause the formation of roll waves, which are often called rain waves. The instability may be partly caused by the high-intensity rainfall application. Both Chow (1959) and Mayer (1959) discuss the possibility of two types of surging flow: 1) roll waves and 2) slug flow, with roll waves being described as a more uniform wave front. A further evaluation of roll waves (or slug flow) for the barrier study will be conducted during FY 1993 work.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The completed field testing work indicates that unprotected Warden silt-loam is very susceptible to rainsplash erosion and does not contain sufficient coarse material to eventually develop armoring. Some form of surface protection will be required for long-term stability of the soil cover.

The addition of 39% gravel admix (dry weight) did reduce the amount of sediment yield from the plots. Armoring did appear to form after the first application of rainfall and continued slightly during the following events. However, sediment yield continued to occur, although at a reduced rate. Whether armoring would improve beyond this point is difficult to say.

The most dominant factor in reducing runoff and sediment yield was the presence of vegetation cover. Vegetation was allowed to naturally establish on the plots from October 1990 to the summer of 1992. At that time, the vegetation cover on the gravel admix plot was 96% and 82% for the native soil plot. The vegetation survey discussion and results are in Appendix A.

Another factor that has significance is the amount of antecedent moisture in the soil. For very dry conditions representative of the Hanford summer climate, runoff is greatly reduced as demonstrated by the results of the first rainfall test conducted in FY 1992. The dry soil conditions coupled with the presence of vegetation can reduce surface runoff to a minimal amount, less than 1% of the applied rainfall, with very little sediment yield. Gravel admix with the natural vegetation cover and dry soil conditions reduced the sediment yield to the lowest observed levels for these tests. An established vegetation cover with gravel admix could possibly reduce sediment yield by 10-100 times for equivalent storms.

The tests on the 22% gravel admix plot were not conclusive and further testing is recommended. The initial tests indicated very little armoring with this percent of admix, which would make the establishment of vegetation more critical compared to the 39% amount of admix.

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APPENDIX A

PLANT GROWTH ON BARRIER TEST PLOTS: COLONIZATION AND ROOTING

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APPENDIX A

PLANT GROWTH ON BARRIER TEST PLOTS: COLONIZATION AND ROOTING

A.1 INTRODUCTION

Four experimental plots measuring approximately 4 by 10 m were established at the McGee Ranch site in 1990 as part of the engineered barriers research program. Plots were located on two different slopes (2% and 5% grades) and were tilled to an approximate depth of 10 cm. One plot in each slope category received a pea gravel admix during tilling. The 2% treatments received artificial watering in 1990 before all plots were temporarily abandoned.

The McGee Ranch site is a homestead that was abandoned in 1943. Before that time, part of the area had been under cultivation agriculture. The 2% slope plots were located in one of the old fields. The remaining plots were located outside of areas that had been tilled in the past.

In 1992, funding for the barriers research program was renewed, and a vegetative characterization of the plots was undertaken.

A.2 METHODS

Sites were visited on April 14 to remove dead Russian thistle (*Salsola kali*) and tumble mustard (*Sisymbrium altissimum*) from the plots. This material was removed without disturbing the soil or uprooting growing vegetation. Surrounding habitat was visually scanned for dominant species. The plots themselves were intensively searched to identify all species growing in the plots. Three transect lines were established along the length of each plot, and species point intercepts were obtained on each transect using an optical point sampling bar. Each transect contained approximately 110 points. These point intercept counts were converted to percentage cover for each species and bare ground by dividing the species intercept total by the total number of points on the transect. Point count data were obtained in April and again in June. Only two transects were run on the 5% slope plots in June.

After completing point intercept sampling in June, a rooting assessment hole was dug near the upslope end of each plot. Holes were dug beneath cheatgrass canopies to a depth below the last observed root. Rooting depths and profiles were derived from visual examination of the sides of the holes.

A.3 RESULTS

Habitat surrounding the 2% slope plots consisted almost entirely of cheatgrass (*Bromus tectorum*), with lesser amounts of tansy mustard (*Descurania sophia*) and globe mallow (*Sphaeralcea munroana*). The habitat surrounding the plots in the 5% slope area had all the above species plus big sagebrush (*Artemisia tridentata*), bulbous bluegrass (*Poa bulbosa*), starthistle (*Centaurea* sp.), white sweet-clover (*Melilotus alba*), and bracted verbena (*Verbena bracteata*). Each of these species was also found on the plots.

Vegetation covered 90% of the ground surface on the 2% slope gravel admix plot, and 72% of the ground surface on the unamended 2% slope plot in April (Table A.1 and Figures A.1 and A.2). By June, cover on these plots had increased to 96% and 82%, respectively. Vegetation occupied 79-80% of the 5% slope gravel admix plot on both survey dates, versus 71% of the unamended 5% slope plot.

Cheatgrass was the dominant cover on all plots. The other dominant species were tansy mustard and globe mallow. Globe mallow was the only perennial species common to all plots. Other perennial species that formed a small portion (<1%) of the cover on the 5% slope plots were big sagebrush, bulbous bluegrass (an alien), and starthistle (an alien noxious weed) (Figure A.1). Fewer species were identified on the plots in June than in April (Figure A.2), because of the senescence of most of the vegetation in June.

Cover data were further examined to determine the effects of sampling date, slope, and gravel amendment. Factorial analyses of variance were calculated using percentage cover of cheatgrass, tansy mustard, globe mallow, and bare ground as dependent variables (Table A.2). Percentage cover data were transformed to arcsine square roots to normalize distributions. Cover by annual plants differed significantly between April and June, increasing on all plots except the 2% slope gravel admix plot. Similarly, bare ground decreased

TABLE A.1. Average Percentage Cover of Vegetation on Barrier Test Plots

<u>Species</u>	<u>4/14/92</u>	<u>6/5/92</u>
2% grade, gravel admix		
Cheatgrass	88	96
Bare ground	10	3
Tansy mustard	3	1
Russian thistle	0	0
Tumble mustard	0	0
Globe mallow	0	1
2% grade, no gravel		
Cheatgrass	58	82
Bare ground	28	11
Tansy mustard	15	4
Tumble mustard	1	0
Globe mallow	1	1
Russian thistle	0	0
5% grade, gravel admix		
Cheatgrass	64	73
Bare ground	21	20
Tansy mustard	13	7
Globe mallow	5	5
Big sagebrush	1	0
Star thistle	0	0
White sweet-clover	0	0
Russian thistle	0	0
Tumble mustard	0	0
5% grade, no gravel		
Cheatgrass	59	62
Bare ground	29	29
Tansy mustard	9	5
Globe mallow	4	5
Tumble mustard	0	0
Russian thistle	0	0
Bulbous bluegrass	0	0
Bracted verbena	0	1
Big sagebrush	0	0

FIGURE A.1. Average Percentage Cover on Plots in April 1992

FIGURE A.2. Average Percentage Cover on Plots in June 1992

TABLE A.2. Analyses of Variance for Effects of Sampling Date, Slope, and Admix on Percentage Cover of Vegetation and Bare Ground

<u>Source</u>	<u>df</u>	<u>Mean Square</u>	<u>F</u>	<u>P</u>
Cheatgrass				
Date	1	0.100	13.283	0.0027
Slope	1	0.243	32.290	0.0001
Admix	1	0.187	24.858	0.0002
Slope x Admix	1	0.054	7.121	0.0184
Slope x Admix x Date	3	0.013	1.732	0.2062
Residual	14	0.008		
Tansy mustard				
Date	1	0.020	4.979	0.0425
Slope	1	0.003	0.805	0.3848
Admix	1	0.003	0.719	0.4108
Slope x Admix	1	0.018	4.464	0.0531
Slope x Admix x Date	3	0.003	0.669	0.5848
Residual	14	0.004		
Globe mallow				
Date	1	0.00013	0.158	0.6966
Slope	1	0.010	12.155	0.0036
Admix	1	0.00004	0.049	0.8276
Slope x Admix	1	0.00041	0.509	0.4874
Slope x Admix x Date	3	0.00005	0.067	0.9765
Residual	14	0.001		
Bare ground				
Date	1	0.027	11.879	0.0039
Slope	1	0.087	39.027	0.0001
Admix	1	0.078	34.934	0.0001
Slope x Admix	1	0.002	0.723	0.4093
Slope x Admix x Date	3	0.010	4.419	0.0220
Residual	14	0.002		

during the time period on three plots, but not on the 2% slope gravel admix plot. Total vegetative cover was significantly higher on the 2% slope plots than on the plots from steeper terrain. This effect was caused almost entirely by differences between sloped areas in cheatgrass cover: plots in the old fields had a much higher cover of cheatgrass than did plots in the unplowed habitat (Figure A.3). However, globe mallow cover in the two areas showed the opposite trend (Figure A.3). Overall, gravel admix plots supported more vegetation than did unamended sites.

FIGURE A.3. Mean and 95% Confidence Intervals for Percentage Cover by Treatment

The test holes in the plots showed strong differences between the old field (2% slope) and unplowed (5% slope) soil profiles. A strong plow layer was evident in the old fields at a depth of 19-23 cm. Root density was highest between 10 cm and the plow layer. A secondary rooting limit was seen at 44-45 cm on both 2% slope plots. Few roots were found below 65 cm on the gravel admix 2% slope plot; none were found below 45 cm on the unamended 2% slope plot. No plow layer was found in the 5% slope plots, and roots were more-or-less evenly distributed from 0-17 cm for the gravel admix and 13 cm for the unamended plot. Maximum rooting depth in the gravel admix plot was 46 cm, and 32 cm in the unamended 5% plot.

A.4 DISCUSSION

The level of vegetative cover on the plots 2 years after abandonment was remarkable. Vegetation covered as much as 97% of the plots, and included such late-successional species as big sagebrush and bulbous bluegrass. Aside from these two species, the only other perennial plant found in the plots was globe mallow. Cheatgrass and tansy mustard are winter-growing annuals that set seed and die in May. Bracted verbena, starthistle, tumble mustard, and Russian thistle are summer-growing annuals that set seed between July and September. As Figures A.2 and A.3 demonstrate, few of these summer-growing plants remained on the plots in June, probably because of the lack of soil moisture. Cheatgrass is an effective competitor for winter moisture; summer annuals generally are able to set seed only when late May and June rains occur (Daubenmire 1970). No rain fell on the Hanford Site between the vegetation sampling periods.

Cheatgrass cover was highest overall in the plots located in the old field habitat (2% slope). This habitat supports the highest density of cheatgrass outside the plots; thus, the seed source for the colonization of these plots was greater than in the 5% slope plots. Also, the 2% slope plots had received some additional water before recolonization, which would also have enhanced plant growth over the more dry plots.

Gravel admix plots had higher total vegetative cover than unamended sites; this was caused entirely by cheatgrass. Cheatgrass requires a mulch or broken soil to germinate (Evans and Young 1972). The effect of the gravel admix on vegetative growth was likely caused by the microsites the admix provided that enhance the germination of cheatgrass seeds.

Cheatgrass is usually a mid-successional species unable to establish on disturbed sites until the early successional Russian thistle and tumble mustard have provided sufficient litter to allow germination of cheatgrass seeds (Brandt et al. 1990). Large, dead Russian thistle plants found on the site in April were evidence that Russian thistle did colonize the site immediately after disturbance; however, cheatgrass growth was sufficient in 1992 to eliminate Russian thistle from the plots. The primary resource for competition is soil moisture. Residual soil moisture after April allowed

cheatgrass to grow between April and June, but too little moisture remained in June to allow significant growth of Russian thistle or tumble mustard.

A.5 REFERENCES

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