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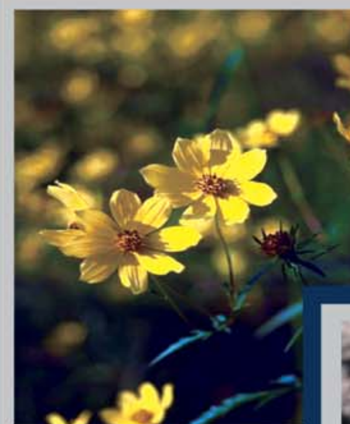

Sewage Wastewater Application Ecological Impact Study 2003

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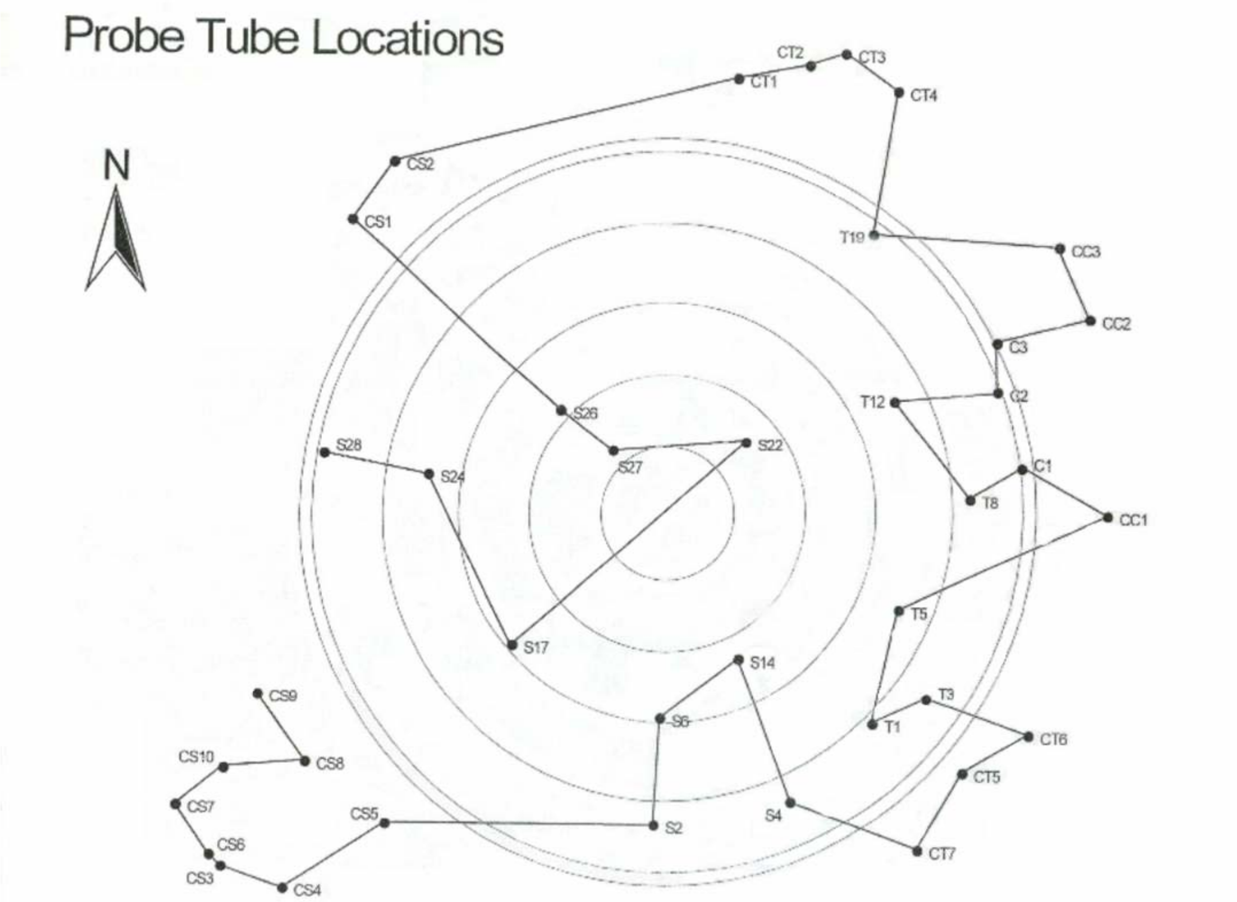
Probe Tube Locations
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INTRODUCTION

Sewage wastewater at the Central Facilities Area (CFA), Idaho National Laboratory (INL) is routinely treated and disposed of through a series of open lagoons. Treated wastewater from the lagoons is subsequently applied to adjacent rangeland using a center pivot irrigation system. The amount and timing of wastewater land application has been chosen such that wastewater will be quickly evaporated and/or transpired by local vegetation, so that neither the wastewater, nor contaminants from the water percolate through the rooting zone and eventually into the aquifer. Although land application of wastewater is common in agricultural systems and is being increasingly researched under those conditions, the application of sewage wastewater in non-cultivated systems is a more recent development and has received very little study. In fact, a national conference was recently sponsored by EPA to highlight research on sustainable land application of waste, and participants outlined the need for field-scale studies and the need for ecological studies as two of the most important directions for future research (O'Connor et al. 2005).

In 1996 an ecological impacts research study at the wastewater land application area was begun. The primary objective of the research study was to determine the ecological benefits or hazards of applying wastewater on rangelands in semiarid regions, and to determine whether wastewater application affects diverse native plant communities and crested wheatgrass monocultures similarly. Specific objectives were developed to determine the potential for impacts on rangeland quality, resident wildlife populations, soil water balance, and the potential for trace metal contamination of the environment. To address these objectives, the study would measure plant community characteristics, soil moisture, wildlife use, and plant and soil chemistry inside the application area and compare them to similar measurements made immediately outside the application area.

Research conducted on this disposal method at the INL provides an opportunity to determine the benefits and/or hazards of disposal of wastewater on native vegetation in arid and semi-arid regions. Results will be applicable to a wide range of municipal, industrial and agricultural wastewater disposal needs. Because permits to dispose of agricultural and industrial wastewater may have restriction on application to prevent deep percolation, this research may refine some of the models used to predict the maximum rate of wastewater application possible without percolation below the rooting zone.

METHODS

The present vegetation inside the application circle includes at least three distinct community types:

- Sagebrush steppe

- Crested wheatgrass planting

- Transitional zone between sagebrush steppe and crested wheatgrass.

Sampling locations were assigned such that each of these community types was adequately represented. Twenty sample plots were established inside the application area of the center pivot, and 20 control plots were established outside of, and adjacent to the application area. Within both the treatment and control areas, three sample plots were established within the crested wheatgrass vegetation type, seven plots were established within the transitional zone, and ten plots were established within the sagebrush steppe plant community. Since the time the plots were initially established, one plot within the irrigated transition zone vegetation type has been lost. Therefore, only six plots are sampled within that vegetation type/treatment combination, and 39 plots are sampled in total.

Plant species composition and cover were estimated at each sampling location. From 1996 through 2002, the vegetation sampling plot at each location consisted of five point frames along a 10 m transect. In 2003, the vegetation sampling design was modified to reduce sampling error and decrease statistical uncertainty. Five transects were established perpendicular to the 10 m base transect, and four point frames were located on each perpendicular transect, for a total of 20 point frames per vegetation sampling plot. Point frame sampling methods were consistent with those outlined by Floyd and Anderson (1982). Vegetation sampling began in mid-July and continued through the end of the month. Vegetation data were analyzed using t-tests (Zar 1996) for cover and Morisita's Similarity Index (Krebs 1999) for plant community composition. When vegetation cover data did not meet assumptions of normality and equal variance appropriate for parametric statistics, data were transformed using an arcsine square root transformation; when transformed data did not meet normality and equal variance assumptions, non-parametric Mann-Whitney rank sum tests (Zar 1996) were used instead of t-tests. The Simplified Morisita's Similarity Index was used to determine how similar the plant communities were between the irrigated and control plots for each community type in each year from 1996-2003. This index returns a value of 1.0 for two plant communities that are identical and 0.0 for two communities that have no similar elements. These values can be considered as a "percent similarity." Morisita's Similarity Index was calculated using relative cover because we were interested in assessing only the composition of the live plant community, rather than all measures of community structure (such as litter or bare ground) with this analysis. We evaluated community structure, including litter and bare ground, and dead shrub cover with t-tests as a component of absolute cover described above.

Transects were also established for small mammal trapping and breeding bird surveys both inside and outside the application area to determine species composition and abundance. The small mammal trapping transects are generally the same location as those used for the vegetation and soil moisture measurements. Small mammal trapping was not done in 2003. The sampling transect for a breeding bird survey was established at the center of, and around the periphery of application area in 1997; surveys have been conducted annually since that time. The 2003 breed bird survey was conducted on June 13, and sampling methods followed United States Geological Survey (USGS), Breeding Bird Survey (BBS) guidelines.

Access tubes for neutron moisture probes were installed at the same plot locations as those used for vegetation sampling. Soil moisture was estimated using neutron scattering (Schmugge et al. 1980) with a Model 503DR Hydroprobe. The Hydroprobe was calibrated to a silty clay loam soil common across the INEEL. Moisture measurements were collected at increments of 20 cm below the soil surface, and access tube depths ranged from 20 cm to 2 m.

Access tube depth was determined by the texture of the soil in the immediate vicinity of the access tube and the depth to basalt at that particular location. Soil moisture measurements were collected once every two weeks beginning on March 18, 2003, and ending on October 20, 2003. A complete set of soil moisture data was collected on a total of 17 sampling dates throughout the growing season. Data from only eight of those sampling dates were included in the soil moisture profiles presented in this report to facilitate interpretation of soil moisture dynamics throughout the growing season. The sampling dates used in the soil moisture profiles presented in this report were chosen such that the entire growing season is adequately represented and soil moisture dynamics in the spring are more heavily represented than soil moisture profiles in the fall. More detail is provided for spring sampling dates because changes in water distribution throughout the soil profile occur more rapidly in the spring, whereas, soil moisture changes very little from one sampling date to the next in the fall.

RESULTS AND DISCUSSION

Vegetation

Total vegetation cover was significantly higher on the irrigated plots within the crested wheatgrass vegetation type than on the control plots within the same vegetation type ($P = 0.04$) during the 2003 growing season. Nearly all of the plant cover on the plots within the crested wheatgrass vegetation type resulted from crested wheatgrass (*Agropyron cristatum*); grass cover on the irrigated plots was more than double grass cover on the control plots (Table 1). Shrubs were absent from plots sampled in the crested wheatgrass vegetation type regardless of irrigation treatment. Hood's phlox (*Phlox hoodii*), a native perennial forb, was present in the irrigated plots; however, it contributed a very small amount to total vegetative cover in those plots. Prickly pear cactus (*Opuntia polyacantha*) was present in the control plots of the crested wheatgrass vegetation type, but it contributed less than 0.1% of the total vegetative cover. Species richness averaged 1.3 for both irrigated and control plots. The average amount of litter within the crested wheatgrass vegetation type was 72% and the average amount of bare ground was 16%. The amount of litter and bare ground was not significantly different between irrigated and control plots.

Table 1. Percent absolute cover of vegetation in 2003 for irrigated and control plots in each community type within and surrounding the wastewater application area.

	Grass Cover	Shrub Cover	Forb Cover	Total Cover
Control Crested	5.8	0.0	0.0	5.8
Irrigated Crested	12.9	0.0	0.1	13.0
Control Transition	5.4	7.2	0.1	12.7
Irrigated Transition	8.2	1.9	0.0	10.1
Control Sagebrush	1.7	15.8	0.4	17.9
Irrigated Sagebrush	5.5	13.8	0.8	20.1

Within the transition zone vegetation plots, total vegetative cover on the control plots was slightly higher, but not significantly different from total vegetative cover on the irrigated plots.

Grass cover was slightly higher on the irrigated transition zone plots, but it did not differ significantly from grass cover on the control plots (Table 1). All of the grass cover on the control plots resulted from crested wheatgrass. Grass cover on the irrigated transition zone plots was primarily due to crested wheatgrass, although a small percentage (0.2%) resulted from Great Basin wildrye (*Leymus cinerus*). At 7.2%, shrub cover was substantially greater on the control plots, compared to 1.9% shrub cover on the irrigated plots within the transition zone (Table 1). Statistically, the difference was only marginally significant (P = 0.07). Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) cover on the control transition zone plots (3.7%) was more than double cover of the same species on the irrigated transition zone plots (1.8%). Green rabbitbrush (*Chrysothamnus viscidiflorus*) cover was also much higher on the control plots (2.6%) than on the irrigated plots (0.1%) within the transition zone vegetation type. In addition to Wyoming big sagebrush and green rabbitbrush, winter fat (*Krascheninnikovia lanata*), prickly pear (*Opuntia polyacantha*), and gray horsebrush (*Tetradymia canescens*) contributed to shrub cover on the transition zone control plots. Forb cover was a very small component of total vegetation cover in both the irrigated and control transition zone plots in 2003. Hood's phlox was present in the control plots with a total absolute cover of 0.1%; and cushion buckwheat (*Eriogonum ovalifolium*) was measured in the irrigated plots with a total absolute cover of 0.02%. Cover of dead shrubs averaged about 6% and was similar between the irrigated and control plots. Bare ground was nearly 7% higher in the control plots and litter was 10% higher in the irrigated plots; neither difference was statistically significant. Finally, mean species richness was 3.6 in the control transition zone plots and was 2.7 in the irrigated transition zone plots.

Total vegetative cover was similar between the irrigated and control plots within the sagebrush steppe community type and was higher on both irrigated and control plots within the sagebrush steppe community type than on either irrigation treatment in the crested wheatgrass and transition community types (Table 1). Grass cover in 2003 was significantly higher on the irrigated plots within the sagebrush steppe community type than it was on the control plots within the same community (Table 1, P = 0.009). Nearly half of the grass cover on the irrigated plots resulted from crested wheatgrass. Bottlebrush squirreltail (*Elymus elymoides*), a native, perennial bunchgrass also contributed substantially to total grass cover on the irrigated plots. On the control plots, six native, perennial grass species contributed nearly equally to total grass cover. Crested wheatgrass was also present on the control plots within the sagebrush steppe community type; however, at 0.4%, cover of this species was much lower on the control plots than on the irrigated plots. Mean shrub cover was similar between irrigated and control plots within the sagebrush steppe community type and was about double the shrub cover recorded in the transition community type (Table 1). Green rabbitbrush cover contributed the greatest amount to total shrub cover and was similar between the irrigation treatments. Gray horsebrush was also present in both irrigated and control sagebrush steppe community plots in nearly the same abundance. Sagebrush cover was slightly lower (1.8% lower) on the irrigated plots than on the control plots. Forb cover was twice as high on the irrigated plots as on the control plots within the sagebrush steppe community type; however, total forb cover was low in both irrigation treatments relative to total vegetative cover (Table 1). Hood's phlox was the most abundant forb in both irrigated and control plots. The amount of cover contributed by dead shrubs, bare ground and litter were similar between irrigated and control plots; dead shrub cover averaged about 7%, mean bare ground was 28%, and average litter cover was 44%. Average species richness was 5.2 in the control plots within the sagebrush steppe vegetation type and was

5.9 in the irrigated plots. Two invasive, annual species cheatgrass (*Bromus tectorum*) and Halogeton (*Halogeton glomeratus*) were recorded at less than 1% cover each on the irrigated plots, but were not present in the control plots.

In 2003, the Morisita's Similarity Index was quite high between the irrigated and control plots within the crested wheatgrass plant community. This result is similar to that of past years. The index value was lower between the irrigated and control plots within the transition zone community in 2003 than in 2002; in was also lower between the irrigation treatments within the transition zone than it was between irrigation treatments within the sagebrush steppe vegetation community in 2003 (Table 2). Thus, the structure and composition of plant communities differed the most between the irrigated and control plots in the transition zone vegetation type, and differed the least in the crested wheatgrass community type. The 2003 Morisita's Similarity Index values were well within the range of variation over the past eight years and were relatively high, indicating relatively small differences in species composition between control and irrigated plots within each vegetation type.

Table 2. Morisita's Similarity Index measuring similarity of vegetation community composition between irrigated a control plots for each community type from 1996 through 2003.

	Crested Wheatgrass	Transition	Sagebrush Steppe
1996	0.99	0.85	0.83
1997	0.91	0.78	0.93
1998	0.96	0.93	0.85
1999	0.94	0.89	0.61
2000	0.89	0.97	0.79
2001	>0.99	0.99	0.85
2002	0.99	0.98	0.83
2003	>0.99	0.88	0.94

In summary, the application of sewage wastewater had an important effect on grass cover in all three of the vegetation community types in 2003; the effect was statistically significant in the crested wheatgrass and sagebrush steppe community types. Because grasses were the primary component of the crested wheatgrass community, the increase in grass cover in the irrigated plots translated to greater total vegetation cover in irrigated plots within that community type. The increased grass cover in the irrigated plots of the transition zone community type was offset by higher shrub cover in the control plots, so that total vegetation cover was not statistically different in that vegetation type. Although grass cover was significantly higher in the irrigated plots within the sagebrush steppe vegetation community, total vegetation cover was similar between irrigated and control plots within the sagebrush steppe community type.

Differences in grass cover between irrigated and non-irrigated plots may be due to differences in water distribution. Because the wastewater is applied frequently, and in small quantities, the wetting front of the soil in the irrigated plots is very shallow (Forman et al. 2003). The irrigation pattern and associated shallow wetting front would be expected to favor species with shallow, fibrous root systems that can take advantage of those water pulses, such as grasses (Comstock and Ehleringer 1992). Conversely, shrubs are much more efficient at utilizing water from deeper in the soil profile (Chabot and Mooney 1985); thus, shrub cover is likely much more closely related to deeper infiltration events, such as large precipitation events and recharge resulting from spring snowmelt. Therefore, shrub cover would not be expected to be greatly affected directly by the application events. However, shrub cover may be affected indirectly through competitive exclusion (Anderson and Inouye 2001). For example, shrub seedlings may have a difficult time establishing when grass cover is high, because grasses are better able to utilize all of the available soil moisture in the top of the soil profile. Further multi-year data analysis will be required to determine whether differences in water distribution is playing a role in the difference in grass and shrub cover between the irrigated and control plots, or whether those differences are due to factors other than water balance such as the chemistry of the applied wastewater.

Although the irrigation treatment had the greatest affect on total cover within the crested wheatgrass vegetation type, it affected species composition within that vegetation type the least. The Morisita's Similarity Index value comparing species composition between irrigated and control plots in the crested wheatgrasses vegetation type was nearly 1.0, indicating that the same species were present in nearly the same proportions, regardless of absolute vegetative cover. Species composition was the least similar between the irrigated and control transition plots, largely because of the difference in the occurrence and relative abundance of shrub species within that vegetation type. Overall, the index values were relatively high, indicating that the major vegetation components of the plant community were similar between irrigated and control plots for each of the three vegetation community types in 2003.

The results of vegetation cover and community composition reported for 2003 differ slightly from results reported for the previous year. For example, results from 2002 indicated that irrigation had a very small effect on grass cover in all three community types; 2003 vegetation results indicate a much larger effect of irrigation on grass cover. Differences in results from 2002 to 2003 may be caused by multiple factors. First, differences in results are likely related to changes in the sampling design. The previous sampling design had little statistical power to detect true changes in the plant communities. Therefore vegetation data results from 2002 and previous years were quite variable, and that variability may have been due, in part, to the sampling design, rather than a real change in the plant community. Factors that affect soil moisture, such as amount and timing of ambient precipitation and the amount and timing of sewage wastewater application may also affect vegetation cover and community composition from year to year. Monitoring vegetation data collected with the modified sampling design for consistency in future years will clarify to what extent variation in annual vegetation analyses relates to sampling design and to what extent that variation is a real response to sewage wastewater irrigation.

Vertebrate Populations

In 2003, Western meadowlark (*Sturnella neglecta*) remained the most abundant species. Other common species included; horned lark (*Eremophila alpestris),* sage thrasher *(Oreoscoptes montanus)*, vesper sparrow (*Pooecetes gramineus*), and lark sparrow (*Chondestes grammacus*). One species, brown-headed cowbird (*Imolothrus ater*), which has been common in the past, was not observed during the 2003 survey. Two species, lark sparrow *(Chondestes grammacus)* and Say's phoebe *(Sayornis saya)* were observed for the first time on the application area this year, but are not uncommon in surrounding areas. Otherwise, results from the 2003 survey were comparable to previous years and similar to that found on the Central Facilities Area BBS route.

Table 3. Species abundance and percent composition for the sewage wastewater application area during the 2003 Breeding Bird Survey.

Species	Abundance	Percentage
Western Meadowlark	17	40.5
Horned Lark	8	19.0
Sage Thrasher	4	9.5
Vesper Sparrow	4	9.5
Lark Sparrow	3	7.1
Brewer's Sparrow	2	4.8
Sage Sparrow	2	4.8
Say's Phoebe	1	2.4
Brewer's Blackbird	1	2.4
Total Individuals = 42		
Total Species = 9		

Soil Moisture

During the 2003 growing season (mid-March through October), soil moisture dynamics were very similar between irrigated and control plots within the crested wheatgrass vegetation community. Figure 1 depicts soil moisture profiles typical of those within irrigated and control crested wheatgrass communities during the 2003 growing season. The wetting front resulting from snowmelt and spring recharge generally ranged from 0.4 to 0.6 m in depth. The majority of spring infiltration occurred prior to the first soil moisture sampling date, March 18, 2003. However, a very small amount of water redistribution throughout the soil profile occurred until the middle of May. Most of the plant available water resulting from the spring recharge event evaporated and was transpired back into the atmosphere between mid-May and mid-July. By the end of July, nearly all of the water available to plants had been transpired, and the soil moisture profiles of the plots within the crested wheatgrass plant community approached the lower limit of extraction. Soil moisture profiles remained at the lower limit of extraction from the end of July through the end of the growing season in October.

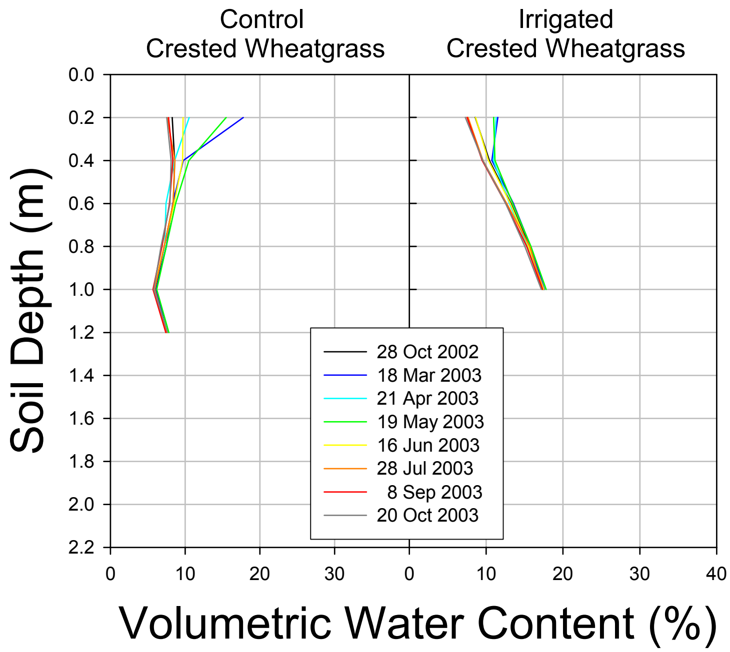

Figure 1. Soil moisture profiles during the 2003 growing season for two neutron hydroprobe access tube locations in crested wheatgrass vegetation. One access tube was located in an area receiving sewage wastewater application, and the other was located in a control area.

Soil moisture dynamics in the irrigated and control plots within the transition zone and sagebrush steppe vegetation types were similar to soil moisture dynamics in the irrigated and control plots within the crested wheatgrass vegetation community. Figure 2 depicts representative soil moisture profiles for irrigated and control plots within the transition zone vegetation type, and Figure 3 depicts soil representative soil moisture profiles for irrigated and control plots within the sagebrush steppe plant community during the 2003 growing season. As with the crested wheatgrass plant community, depth of the wetting front, timing of spring infiltration, timing of soil moisture extraction during the summer, and the date at which soil moisture profiles began to approach the lower limit of extraction did not differ substantially between irrigated and control plots in either the transition zone or sagebrush steppe plant community.

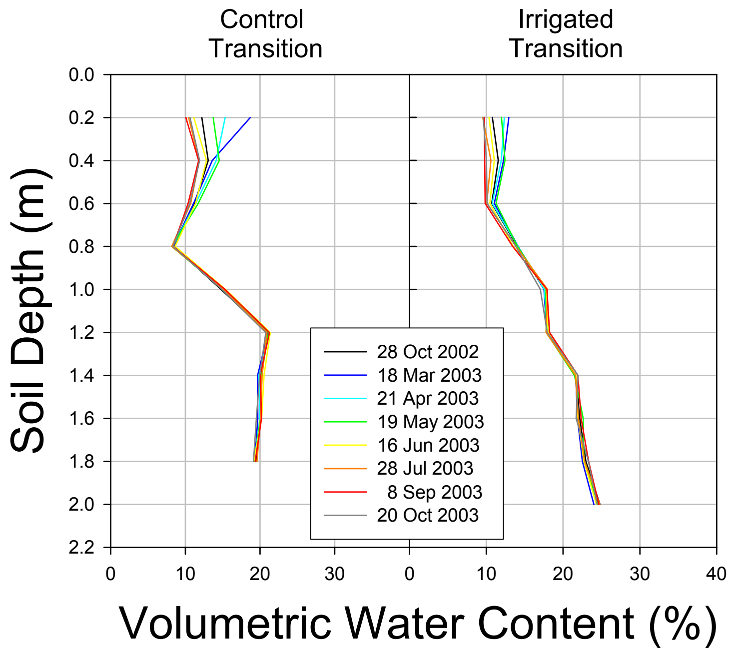

Figure 2. Soil moisture profiles during the 2003 growing season for two neutron hydroprobe access tube locations in vegetation representing a transition zone between sagebrush steppe and a crested wheatgrass monoculture. One access tube was located in an area receiving sewage wastewater application, and the other was located in a control area.

Out of the 39 plots for which soil moisture profiles were analyzed, percent volumetric water content did not change below the spring wetting front in 38 of those profiles. The relative stability of the soil moisture profiles below the spring wetting front indicates that the likelihood of water moving through the soil profile below the rooting zone due to saturated flow is very low. The plot in which changes occurred in volumetric water content below the spring wetting front is a control plot within the sagebrush steppe vegetation community and is depicted in Figure 3. The changes in volumetric water content below the spring wetting front in this plot are likely due to extraction and transpiration of water residual in the profile from the previous growing season.

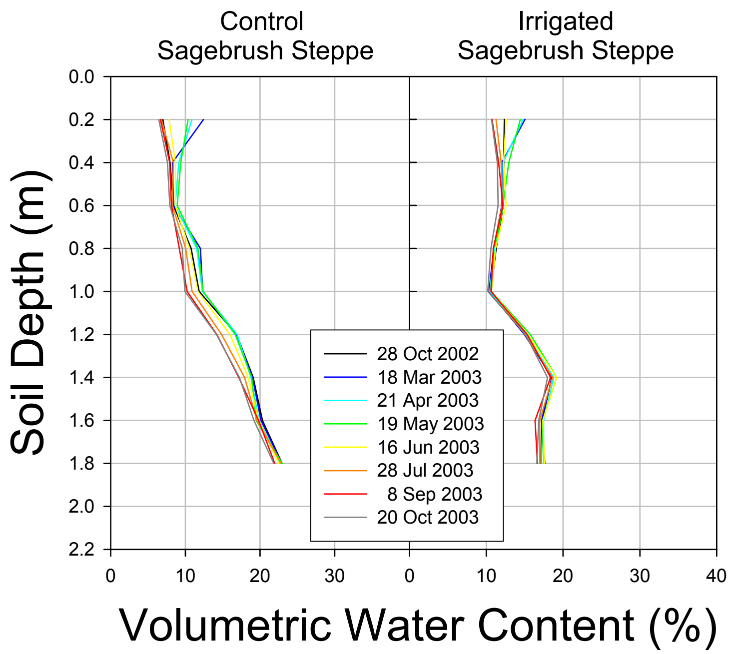

Figure 3. Soil moisture profiles during the 2003 growing season for two neutron hydroprobe access tube locations in sagebrush steppe vegetation. One access tube was located in an area receiving sewage wastewater application, and the other was located in a control area.

In all three of the vegetation types, the soil moisture profiles do not indicate an increase in soil moisture at 20 cm of depth or deeper due to wastewater application. In fact, irrigated plots within all three vegetation types have spring infiltration events similar to those of control plots, and irrigated plots have water extraction patterns throughout the summer that are similar to those of the control plots. If wastewater applied through the center pivot were to affect soil moisture in the irrigated plots, we would expect to see either small wetting fronts in the soil moisture profiles throughout the summer, or we would expect to see soil moisture to remain elevated near the top of the soil moisture profile throughout the application period. Because neither of these patterns is apparent in the 2003 soil moisture data, and because soil moisture profiles are similar between irrigated and control plots, the likelihood of flux through the measured soil moisture profile and past the rooting zone is no greater for irrigated plots than for control plots in all three of the vegetation types.

As noted above, the probability that water percolated through the rooting zone and into basalt due to saturated flow during the 2003 growing season is low and does not differ between irrigated and control plots. These conclusions are similar to those reported for the 2002 growing season. Although the probability of water flux past the rooting zone was minimal in both 2002 and 2003, some differences in soil moisture dynamics between the two growing seasons were apparent. For example, spring wetting fronts were slightly deeper on average, more plant-available water was stored in the top of the soil profile at the beginning of the growing season, and lower limit of extraction was reached later in the growing season in 2002 than in 2003. Figure 4 depicts typical differences in soil moisture dynamics between the 2002 and 2003 growing seasons. Differences in soil moisture dynamics were greater in individual plots between the 2002 and 2003 growing seasons than they were between irrigated and control plots in any single growing season. Thus, the amount and pattern of precipitation had a greater impact on soil moisture dynamics than did the application of treated wastewater during the 2002 and 2003 growing seasons.

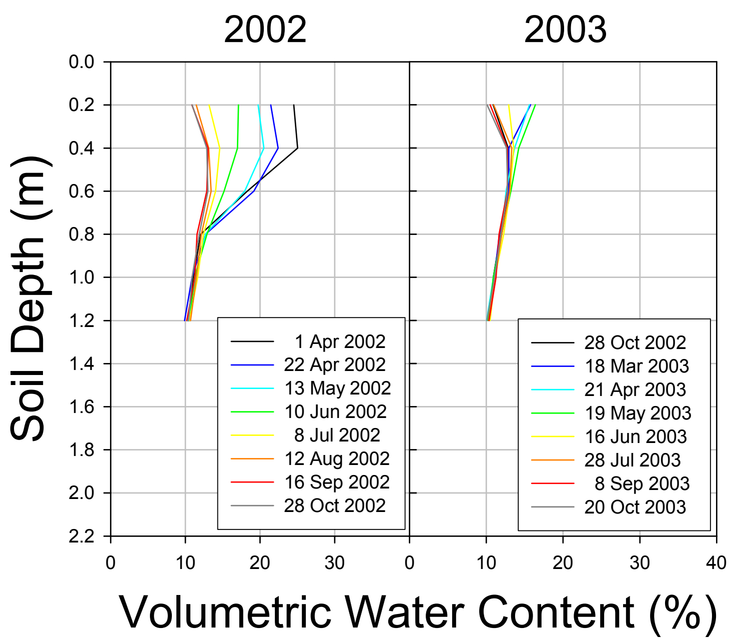

Figure 4. Soil moisture profiles in 2002 and 2003 for a neutron hydroprobe access tube located in a sagebrush steppe vegetation plot not receiving wastewater application.

Precipitation was well below normal in 2002 and 2003. Figure 5 depicts water season precipitation for three years. The water season is defined as the time period through which precipitation is expected to affect vegetation during the growing season. In the cold desert region of North America the water season is typically defined as the time period between October and the following September, because water received throughout the winter directly affects the amount of water available to plants the subsequent spring and summer (Anderson and Inouye 2001). The 1998 water season was similar to long-term averages in the total amount and timing of precipitation. Total precipitation during the 2002 and 2003 water seasons was only about half the precipitation received in an average year. Additionally, relatively little precipitation was received during May and June in 2003, typically two of the wettest months on the INL (Figure 5).

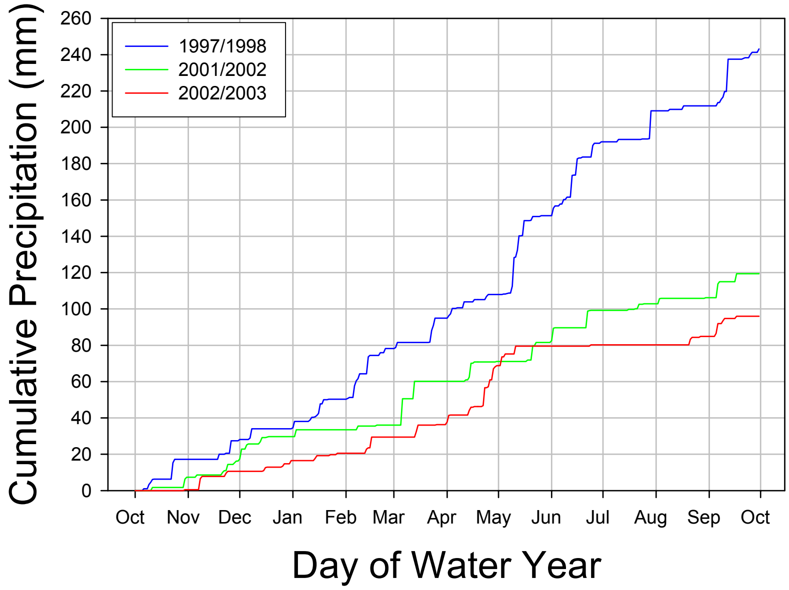

Figure 5. Cumulative water year precipitation at the Central Facilities Area for the 1998, 2002, and 2003 water years.

The difference in the timing of precipitation between the 2002 and 2003 water seasons is likely the primary factor driving differences in soil moisture dynamics between the two growing seasons. Furthermore, because total precipitation during the 2002 and 2003 water seasons were so far below average, conclusions about soil moisture dynamics in those two years cannot be extrapolated to years with average or above average precipitation. Thus, although water flux below the rooting zone was unlikely in 2002 and 2003, soil moisture dynamics will have to be analyzed in wetter years to be able to make a broad statement about the probability of water movement below the rooting zone through time. As discussed in the Sewage Wastewater Application Ecological Impact Study 2002 (Forman et al. 2003), the possibility of flux due to unsaturated flow or saturated flow in shallow soil profiles exists; however quantification of this risk is beyond the scope of the ecological impacts study as it is currently designed.

Because wastewater land application is a cost effective method for the disposal of treated sewage wastewater, the potential for use of this disposal method elsewhere on the INL exists. If this disposal method is to be used elsewhere on the INL and permits are to be granted by the relevant stakeholders, soil moisture dynamics and the related ecological effects of sewage wastewater application must me thoroughly understood and characterized.

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