Understanding the Hydrology of Modern Putting Green Construction Methods

1997 Executive Summary

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This research investigates the influence of modern putting green construction method on hydrologic processes in the root zone, including water infiltration, redistribution, and drainage. The greens construction methods under investigation are the United States Golf Association (USGA) and California (CA) specifications. Additionally, each soil profile design contained either a high or low water permeability root zone, resulting in 4, soil profile/root zone composition treatments, each replicated 3 times. The experimental greens contained a creeping bentgrass turf maintained at a mowing height of 3/16th inch.

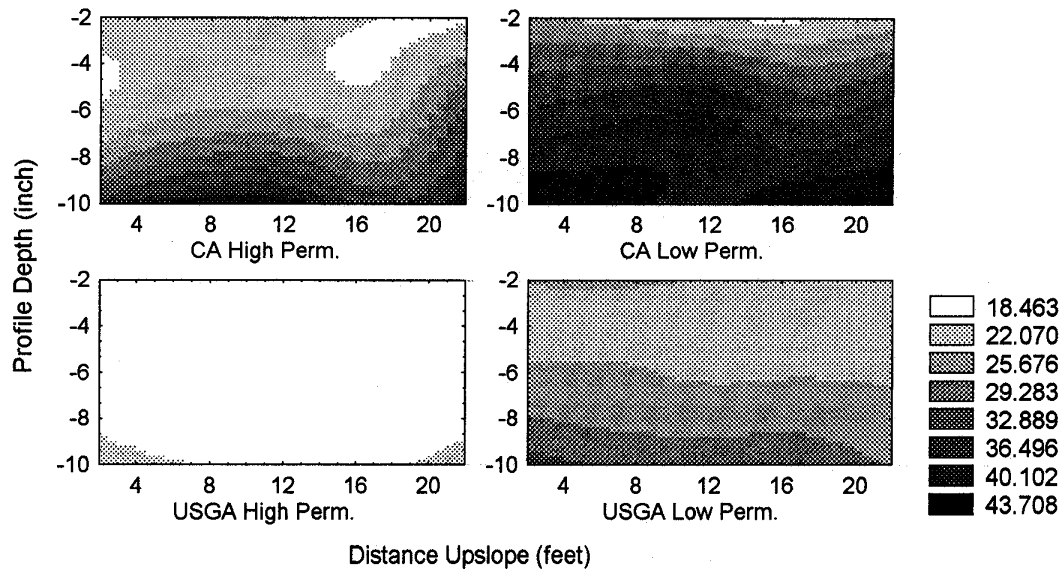
Of particular interest is the effect of green slope on hydrologic processes. The greens were built above ground in 4 by 24 ft boxes with slopes of 0, 2 and 4% adjusted by jacking and blocking the legs. The units also contained drain lines at 2 and 17 ft from the downslope end effectively yielding a 15 ft drain spacing. The root zone of each experimental green was instrumented with TDR soil moisture probes at 3 depths (3, 6 and 9 inches) and 5 locations (2, 7, 12, 17 and 22 ft from the downslope end). A tipping bucket rain gauge was connected to the outflow of the furthest downslope drain line to monitor drainage outflow rate.

Each green received simulated rainfall from a device delivering either 4.44 ±0.09 in hr^{-1} for the high rate or 1.89 ± 0.04 in hr^{-1} for the low rate treatment. Continuous measurements of drainage outflow and soil water contents were started at the beginning of the rainfall period. Rainfall was then applied for 3 hr to ensure a constant drainage rate. At the end of the rainfall period, the rain simulation device was turned off but drainage outflow and soil moisture measurements continued for an additional 48 hr.

While drainage rate is but one aspect of putting green hydrology, there is some confusion regarding which construction method should be the more rapidly drained and proponents of either system have claimed that theirs promotes faster drainage. The key understanding we demonstrated in this study is that both profile design and root zone mix permeability contribute to drainage rate. Given equal root zone mix permeability, the USGA profile yields more rapid drainage. Indeed, even rainfall rates of about 4.5 in hr^{-1} failed to overwhelm drainage of the USGA profiles as evidenced by equivalent drainage rates for both the low and high permeability root zones. Further, this same rainfall rate exceeded the drainage capacity of a CA profile containing a root zone mix initially tested to have a permeability of 20 in hr^{-1}. For equivalent drainage performance, therefore, it seems that a CA style green would need a root zone mix permeability 10 to 20 in hr^{-1} greater than a USGA green.

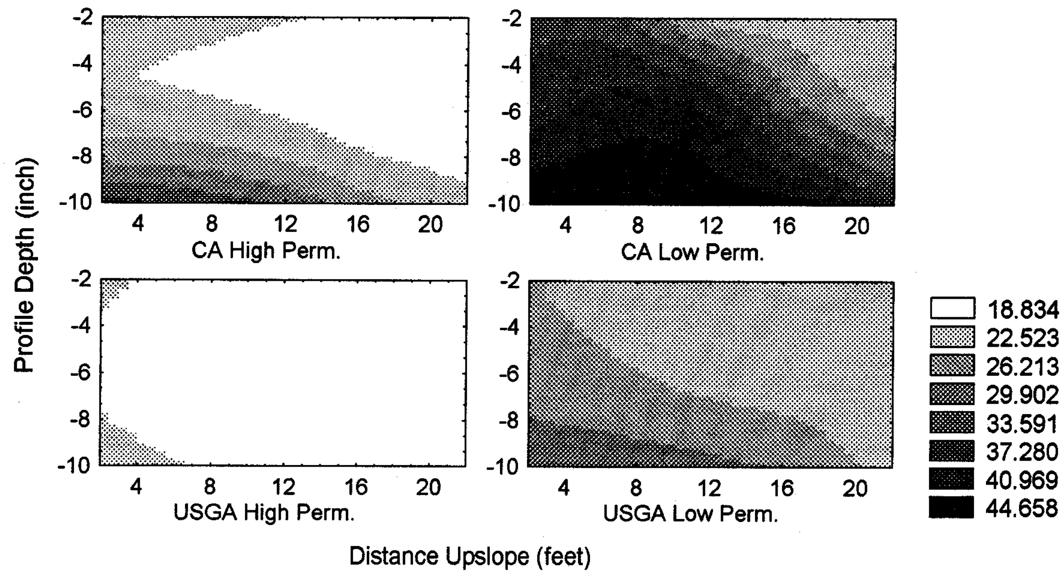
Drainage rate represents an intensity factor. The capacity factor of the drainage process, in the context of the present study, is the completeness of excess water removal from the respective root zones. Here, it is commonly thought that a USGA putting green profile would become less completely drained than a CA green. This belief results from the water perching effect in a USGA green. Our results showed that for equivalent root zone mix permeabilities the USGA green is drier after 48 hr (interpreted as more completely drained) than a CA system green (Fig. 1). This appears to be principally due to the need for water to move laterally through the root zone in a CA green before reaching a drainline. Again, for more complete drainage, a CA green would appear to need a higher root zone permeability as evidenced by the nearly equal soil water contents after 48 hr drainage in the CA high permeability profile and the USGA low permeability profile.

Fig. 1. Soil Water Content (% vol.), 48 hrs Drainage, 0% Slope, High Rain Rate.



All greens are contoured or sloped to some degree. This contouring may be slight in cupset areas but is more extreme between terraces or throughout links style greens. This sloping clearly has an effect on water redistribution following rainfall. Prior to this study we believed that the perched water table in a USGA green would lead to strong lateral movement of water to more downslope locations. This would suggest the possibility of 'hot spots' forming at higher elevations in a USGA green. We did not believe this would occur to a great extent in a CA green because this green construction method was thought to be more completely drained, having no perched water to migrate. The results from this study suggested that our prior beliefs were somewhat incorrect. While lateral water movement was observed in the USGA greens, it was also observed in the CA greens. Thus, for equal root zone permeabilities, there was a much greater lateral difference in water contents after 48 hr drainage in the CA greens than the USGA greens (Fig. 2).

Fig. 2. Soil Water Content (% vol.), 48 hrs Drainage, 4% Slope, High Rain Rate.



One caveat in the results of this study is that these constructions were just 1 year old and had not experienced foot traffic. Our future plans for these experimental greens is to simulate foot traffic and repeat this study under more natural conditions. We also have collected undisturbed soil cores in November 1996 and 1997. These cores are currently being employed for measurement of soil physical properties and to assess changes relative to the fresh mixes. These periodic sampling and measurements will continue throughout the study.

Understanding the Hydrology of Modern Putting Green Construction Methods

Progress Report
10 December, 1997

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The two most prevalent, modern putting green construction methods are the United States Golf Association (USGA) and the California (CA) green construction techniques. The principal differences between these construction methods are the presence of a gravel drainage blanket in the USGA design and a higher recommended root zone permeability in the CA design. These differences will, at least in theory, yield different hydraulic behaviors of these two greens construction methods. The vertical and lateral pathways of water movement during profile drainage in the CA method occur exclusively in the root zone sand layer. In the USGA system, vertical water movement occurs in the root zone while lateral water movement occurs in the gravel drainage blanket. Following complete profile drainage, the USGA design creates a perched water table extending into the root zone while no such water table is thought to occur in the CA system. Subsequently, this perched water table may act as a reservoir for water use by the turf.

Our current understanding of these systems, however, ignores the natural contours of a putting green that may promote lateral water flow within the soil profile. In this case, water perching in a USGA profile may be reduced at upslope locations and rapid profile drainage may be accomplished without a gravel drainage blanket. There is also insufficient evidence for the need of the perched water table as a reservoir for turf use given currently employed irrigation practices.

This research investigates the influence of modern putting green construction methods on hydrologic processes in the soil profile. These processes include water infiltration, redistribution within the rootzone, drainage, and uptake by the turf. The greens construction methods under investigation are the United States Golf Association (USGA) and California (CA) specifications. Of particular interest in this report is the effect of green slope on water infiltration, redistribution and drainage, referred to as Phase I of the overall research program. This report also includes progress on the turf water use study (Phase II), and progress on monitoring microbial populations in high sand content putting green root zones.

Phase I Methods

The study of water infiltration, drainage and redistribution employed 4 greens designs consisting of 1) a CA system soil profile containing a 9:1 sand:sphagnum root zone, 2) a CA profile containing a 6:2:2 sand:compost:topsoil mix, 3) a USGA design soil profile containing the 9:1 sand:sphagnum, and 4) a USGA profile containing the 6:2:2

sand:compost:topsoil mix. The sand:sphagnum blend had a lab permeability of 20.8 in hr^{-1} and is referred to as the high permeability mix while the sand:compost:topsoil blend had a lab permeability of 12.6 in hr^{-1} and is referred to as the low permeability mix. These 4 profile design/root zone mix treatments were replicated three times for a total of 12 experimental greens. The greens contained a Penncross creeping bentgrass turf maintained at a mowing height of 3/16th inch.

The greens were built above ground in 4 by 24 ft wooden boxes supported by a legged, metal framework. Six inch wide by 8 inch deep simulated drainline trenches were fabricated from sheet metal extending below the profiles with each containing an outlet in the center. For experimental units containing a USGA 2-tier profile, the sides of the wooden box was 16 inches whereas units containing a CA system profile were 12 inches. The drainline trenches (perpendicular to long axis) were constructed into each unit at 2, 12, 17 and 22 ft from the downslope end. Nominal 2 inch PVC drainpipes were connected to the outlet of each drainline trench with each fitted with a valve for selective closure. The present study was conducted with only the 2 and 17 ft drainlines open effectively yielding a drain spacing of 15 ft.

The 12 experimental units were placed, in a randomized complete block design, on an 80 by 28 foot concrete pad. This allowed for adjustment of the green slope by jacking and blocking the metal legs. Green slopes used in this study were 0, 2, and 4%.

The root zone of each experimental greens was instrumented with TDR soil moisture probes at 3 depths (3, 6 and 9 inches) and 5 locations (2, 7, 12, 17 and 22 ft from the downslope end of the green) for a total of 15 positions per green. The probes were connected to a multiplexed recording unit for continuous monitoring of soil moistures. Additionally, a tipping bucket rain gauge was connected to the drainage outflow pipe of the furthest downslope drainline to monitor drainage outflow rate.

This experimental set-up was used to monitor water drainage and redistribution within the root zone as influenced by green construction method, green slope and rainfall rate. The overall study was conducted as a series of 18 individual experimental runs. During an experimental run, one green from each replication was configured to a predetermined slope of either 0, 2, or 4%. Additionally each green received rainfall from a rain simulation device set to deliver either a high or low rainfall rate. Continuous measurements of drainage outflow rate and soil water contents were started at the beginning of the rainfall period. Rainfall was then applied for 3 hr to ensure we had achieved a constant drainage rate. Rainfall measurements were also collected during this 3 hr period. At the end of the rainfall period, the rain simulation device was turned off but drainage outflow and soil moisture measurements continued for an additional 48 hr. Subsequently, the next replication was configured for an experimental run.

Drainage outflow was measured every 5 min for the 51 hr duration of an experimental run. Soil water contents were measured every 20 min for the first 27 hr and hourly for the remaining 24 hours. This resulted in about 44,000 total drainage outflow and 113,000 total soil moisture measurements for the full 18 runs of the study. Data collection began on 6 August, 1997 and ended on 30 October, 1997.

Phase I Results

Mean (± s.e.) rainfall rates for the high rainfall treatment was 4.44 ±0.09 in hr^{-1} and for the low rainfall treatment was 1.89 ± 0.04 in hr^{-1}. Mean (± s.e.) surface slopes measured with a digital level were -0.05 ± 0.03%, 2.01 ± 0.02% and 4.00 ± 0.03% for the desired 0, 2 and 4% slope treatments, respectively. Drainage of the experimental greens was expressed as cumulative outflow vs. time after rain application was stopped (Figs. 1 to 4). The curves begin at 1.5 hr prior to rain ending and continue for the 48 hr drainage period. Data is shown for the 0 and 4% slope treatments under both high and low rainfall rate conditions. Error bars shown on the curves are the standard errors for 3 replications.

At 0% slope under the low rainfall rate condition (Fig. 1), both USGA profiles showed high drainage rates during rain application. This is given by the steep slope of the cumulative outflow curve prior to rain cessation. The CA low permeability profile had a much lower drainage rate during this same period, with the CA high permeability profile intermediate. After rainfall stopped, drainage from the USGA greens slowed substantially since the cumulative outflow curve quickly became almost flat. The CA greens, on the other hand, showed continued drainage although at a slower rate than during rain application. The much lower cumulative outflow after 48 hr from the CA low perm. profile was the result of the infiltration rate being less than the rainfall rate such that excess rainfall occurred as runoff and did not enter the soil profile.

Drainage rates during the low rainfall rate application for greens at 4% slope (Fig. 2) were very similar to that of the 0% slope treatment. Additionally, after rainfall stopped, drainage from the USGA greens slowed substantially. The CA greens at 4% slope, however, continued to drain throughout the 48 hr period at a higher rate than the 0% slope treatment. As before, the lower cumulative outflow after 48 hr from the CA low perm. profile resulted from runoff of excess rainfall.

While cumulative outflow was greater, the high rainfall rate applied to the greens at 0% slope (Fig. 3) yielded very similar results as compared to the low rainfall rate treatment. The major difference at the high compared to the low rainfall rate was the increased difference between the USGA and CA greens in terms of overall drainage. Both of the CA greens were unable to infiltrate all of the rainfall and the excess was subject to runoff although the high permeability CA green clearly had less runoff than the low permeability green. The USGA greens performed identically regardless of the permeability of the root zone mix. The 4% slope, high rainfall rate treatment (Fig. 4) yielded results very consistent with treatments discussed previously. The CA greens showed reduced drainage during rainfall, but continued to drain at a reasonable rate for the full 48 hr. The overall reduced cumulative drainage from these greens was due to excess runoff that was not apparent in the USGA profiles.

The remaining figures depict the progress of root zone drainage over 48 hr for each of the experimental greens. This is shown using contour graphs of soil water content (% by vol.) as a function of profile depth (inch), distance upslope (feet), and for times of 0, 1, 3, 9, 27, and 48 hours after rainfall stopped. Results for the low rainfall rate treatment were quite similar to that for the high rainfall rate and thus only the high rainfall rate treatments at 0 and 4% slope are shown here. Although each graph is roughly square, it is important to remember that the lateral distance is about 1/10th of the true scale. Also, an open drainline is located in each graph at 2 and 17 ft. upslope for a drain spacing of 15 ft.

The CA high perm. profile at 0% slope showed virtually a textbook example of soil drainage after rainfall (Fig. 5). As rainfall ended (0 hr) there was a lateral pattern of higher water contents between the drainlines and lower water contents above the drainlines and near the soil surface. As the soil drained, this pattern was maintained as overall water contents declined. An equilibrium condition developed at 27 hr with a vertical gradient of increasing moisture with depth and a lateral gradient of decreasing water contents over the drainlines. Little change in this situation was observed after 48 hr drainage. A very similar response was observed early in the drainage period when the CA high perm. profile was sloped at 4% (Fig. 6). At 27 hr, however, there was a trend of increasing soil water contents at the downslope locations. Further, additional drainage occurred from 27 to 48 hr. This led to a overall drier root zone at 48 hr and an accumulation of soil moisture at the furthest downslope location for the 4% slope as compared to the 0% slope condition. Mean standard errors for water content in the CA high perm. profile was 1.4% indicating a high degree of agreement between the replications.

The CA low perm. profile at 0% slope showed a slight lateral pattern of water contents as rainfall ended (0 hr, Fig. 7). This is expected due to the lower permeability of this root zone than the CA high perm. profile. A more pronounced lateral pattern of higher water contents between the drains developed, particularly near the soil surface, as this profile drained. Equilibrium conditions again appeared after 27 hr with little further drainage after 48 hr. Again, a very similar response was observed early in the drainage period when the CA low perm. profile was sloped at 4% (Fig. 8). At 9 hr a trend began to develop with increasing water contents at the downslope locations. This trend strengthened after 27 hr resulting in about a 10% difference in water content from the downslope to the furthest upslope locations. Unlike the CA high perm. profile at 4% slope, equilibrium conditions appeared to be established after 27 hr for the CA low perm. profile. Mean standard error water contents in the CA low perm. profile was 1.7% indicating again that the contour levels shown represent significant differences.

The USGA high perm. profile at 0% slope exhibited some characteristics that deviated from textbook examples of soil drainage after rainfall (Fig. 9). Principally, as rainfall ended (0 hr) water contents near the soil surface were higher than at depth. This is likely due to the gravel layer underlying the root zone and the high permeability of the mix resulting in more rapid drainage than rainfall. Further, the lateral distribution of water contents was quite uniform as compared with the CA profiles. Rapid drainage also resulted in water contents after 1 hr ranging from 20 to 23% as compared to a range of 27 to 30% at 0 hr. Although drainage slowed after 1 hr some continued drainage was observed for the full 48 hr period. This resulted in very uniform soil moistures ranging from 17 to 19% throughout most of the profile. Results for the USGA high perm. profile at 4% slope (Fig. 10) were quite similar to that observed at 0% slope. There was, however, a slight tendency for water accumulation near the base of the root zone at the downslope locations. This resulted in about a 2% increase in water content at the furthest downslope location and a 2% decrease in the furthest upslope location than that observed at 0% slope. Mean standard error water contents in the USGA high perm. profile was 0.5%.

The USGA low perm. profile at 0% slope (Fig. 11) yielded some unexpected results that were evident as rainfall ended and continued for the early drainage period. While (at 0 hr) water contents near the soil surface were generally higher than at depth there was also a trend of higher water contents in the downslope direction. This was unexpected since the green was set to a 0% slope and water contents should be more uniform laterally. Regardless of this initial moisture distribution, this profile also drained rapidly resulting in water contents after 1 hr ranging from 25 to 29% as compared to a range of 31 to 34% at 0 hr. Continued, although slower, drainage occurred throughout the 48 hr period. Interestingly, a rather uniform lateral distribution of water contents was observed after 48 hr drainage. This distribution also exhibited a more pronounced accumulation of water near the base of the root zone as compared with the USGA high perm. profile. Results for the USGA low perm. profile at 4% slope (Fig 12) agreed with expectations relative to the previously discussed treatments. Initial water contents (0 hr) were quite uniform throughout the profile and rapid drainage after 1 hr subsequently slowed. Continued drainage from 3 to 48 hr resulted in the accumulation of soil moisture at the downslope locations. Mean standard error water contents in the USGA low perm. profile was 1.1%.

The final two figures show data presented previously yet in a format that allows more direct comparison between construction methods. Figure 13 shows the 4 systems after 48 hr drainage at 0% slope. The CA profiles clearly show the effect of drain spacing on water contents whereas the USGA profiles are more uniform in the lateral direction. Expectedly, the low permeability root zone resulted in higher soil moistures throughout, yet surprisingly the CA profiles were substantially wetter than the USGA. These same systems after 48 hr at 4% slope (Fig. 14) clearly show the effect of slope on water accumulation at downslope locations. While this was expected to some degree in the USGA profiles, the strong response to slope in the CA method was surprising.

Implications of the Phase I Results

While drainage rate is but one aspect of putting green hydrology, there is some confusion regarding which construction method should be the more rapidly drained and proponents of either system have claimed that theirs promotes faster drainage. The key understanding we demonstrated in this study is that both profile design and root zone mix permeability contribute to drainage rate. Given equal root zone mix permeability, the USGA profile yields more rapid drainage. Indeed, even rainfall rates of about 4.5 in hr^{-1} failed to overwhelm drainage of the USGA profiles as evidenced by equivalent drainage rates for both the low and high permeability root zones. Further, this same rainfall rate exceeded the drainage capacity of a CA profile containing a root zone mix initially tested to have a permeability of 20 in hr^{-1}. For equivalent drainage performance, therefore, it seems that a CA style green would need a root zone mix permeability 10 to 20 in hr^{-1} greater than a USGA green.

Drainage rate represents an intensity factor. The capacity factor of the drainage process, in the context of the present study, is the completeness of excess water removal from the respective root zones. Here, it is commonly thought that a USGA putting green profile would become less completely drained than a CA green. This belief results from the water perching effect in a USGA green. Our results again show that for equivalent root zone mix permeability the USGA green is drier after 48 hr (interpreted as more completely drained) than a CA system green. This appears to be principally due to the need for water to move laterally through the root zone in a CA green before reaching a drainline. Again, for more complete drainage, a CA green would appear to need a higher root zone permeability as evidenced by the nearly equal soil water contents after 48 hr drainage in the CA high perm. profile and the USGA low perm. profile.

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Phase II Progress
This study examines turfgrass water use, the depth distribution of soil water uptake, and turf stress indices as influenced by root zone depth, composition, water perching and irrigation management. Consequently, to employ a water balance approach for turf evapotranspiration (ET), we have constructed 36, 6 ft diameter non-weighing lysimeters to be used as experimental plots. These lysimeters contain a hydraulically isolated root zone and gravel layer (simulating a 2-tier USGA profile). The bottom and sides of each lysimeter

are lined with plastic and a drainage port is fitted in the bottom. Each lysimeter drainage port is then connected to an individual drainline for collection and recording of water leaching.

The experimental plots contain 6 different root zone mixes and 2 profile depths. The root zone mixes are based upon 2 contrasting sand textures with one relatively fine (by USGA specifications) and the other relatively coarse. These 2 sands were used to create 100% sand, sand:peat and sand:soil:peat blends for a total of 6 root zones. Further, these same sand sources were employ in the Phase I experimentation. Profile depths are 9 and 12 inches where the 9 inch depth was accomplished by adding 3 inches to the gravel layer. There are 3 replications for each root zone composition:depth treatment combination, yielding 36 total plots. These treatments were arranged as a randomized block design.

Following Penncross creeping bentgrass establishment, 2 sets of TDR wave guides will vertically span the entire root zone to record soil moistures for ET measurement. In addition, horizontal, buriable TDR wave guides will record soil moistures at 3 and 6 inch depths in the shallow rootzone and 3, 6 and 9 inch depths in the deeper root zone. The turf water use experimentation will commence next summer.

Root Zone Microbiology
Finally, this project also includes research on the microbiology of the putting green root zones from the Phase I study. As reported earlier, this research has noted that prior to greens construction, the low permeability mix harbored larger bacterial populations than the high permeability mix. Both mixes had a relatively high number of fungal colony forming units (CFUs). Recall that the low permeability mix was a 6:2:2 sand:compost:topsoil blend and the high permeability mix contained 9:1 sand:sphagnum.

Root zone samples were also collected 3 months after turf establishment. Table 1 summarizes the microbial population data obtained from the rhizosphere of bentgrass in the California and USGA greens. Both the high and low permeability mixes, regardless of profile type, continue to harbor relatively high bacterial, fungal, and chitinolytic actinomycete populations. Although still relatively high, bacterial population densities in the low permeability mix significantly (P=0.05) decreased during the initial three months of the study. A significant decrease was also observed in fungal CFUs for all treatments. Chitinolytic actinomycete populations are slightly higher in the low permeability mixes irrespective of profile type.

Approximately 2000 bacteria and 800 actinomycetes have been isolated and stored from the pre-construction and 3 month sampling. These strains are in the process of being identified via gas chromatography-fatty acid methyl esterification analysis. About 1000 fungi have also been isolated, pure cultured, and stored for further identification. Currently, root zone samples collected 15 months after establishment are undergoing isolation and enumeration using the same protocols as earlier samplings. Microbial community structure analyses will commence pending identification.

Table 1. Bacterial, fungal and chitinolytic actinomycete population densities 3 months after greens establishment.

Sampling Unit	Population Density (log_{10} CFU/g dry weight)			
	TSA[1]	KB[2]	APDA[3]	Chitin[4]
Low permeability				
CA profile	8.99	8.84	5.16	6.87
USGA profile	8.98	8.88	5.27	6.88
High permeability				
CA profile	8.49	8.38	4.93	6.26
USGA profile	8.08	7.80	5.23	6.20
$LSD_{0.05}$	0.13	0.15	0.24	0.12

[1] 0.1 Trypticase soy (TSA) is a general medium used to enumerate soil bacteria.

[2] King's media B (KB) used to enumerate fluorescent pseudomonades.

[3] Acidified potato dextrose (APDA) medium used to enumerate fungi.

[4] Chitin agar is a selective medium used to enumerate chitinolytic actinomycetes.

Figure 1.

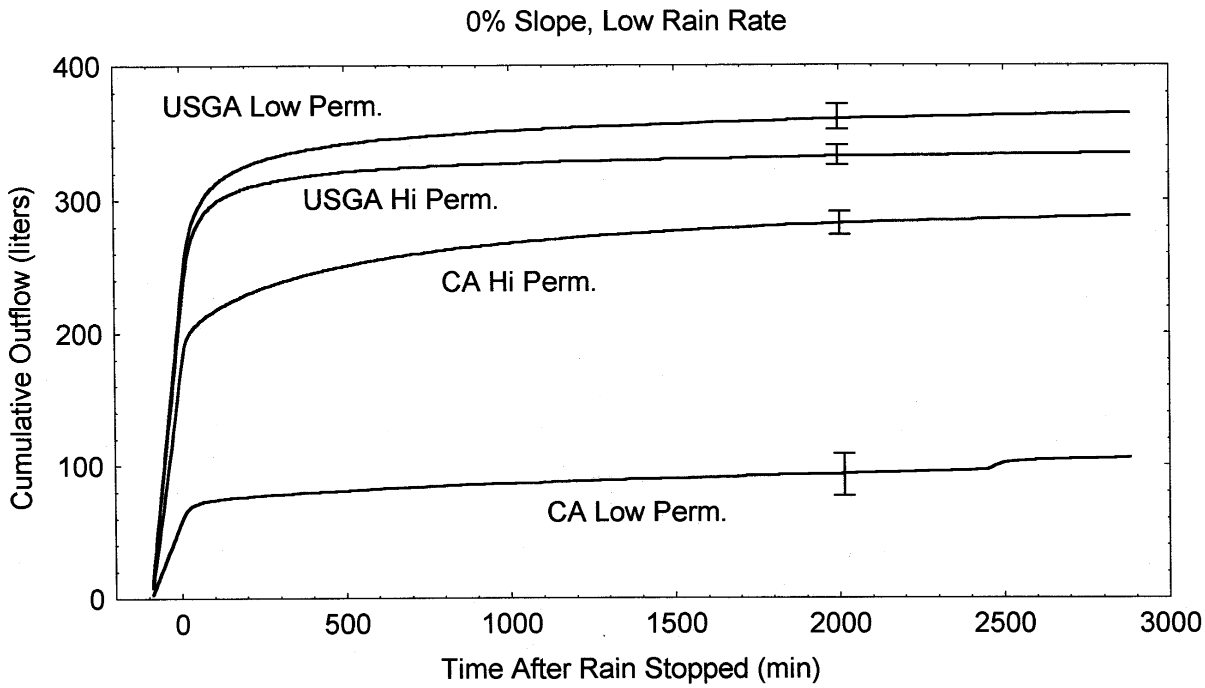

0% Slope, Low Rain Rate
USGA Low Perm.
USGA Hi Perm.
CA Hi Perm.
CA Low Perm.
Cumulative Outflow (liters)
0
100
200
300
400
Time After Rain Stopped (min)
0
500
1000
1500
2000
2500
3000

Figure 2.

4% Slope, Low Rain Rate

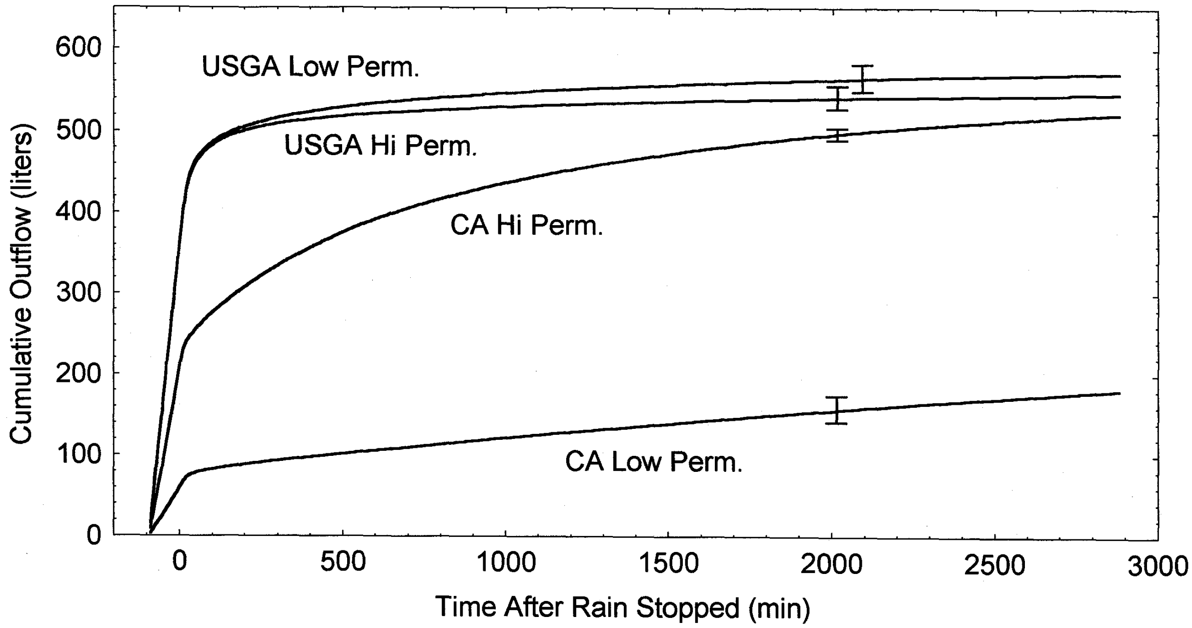


Figure 3.

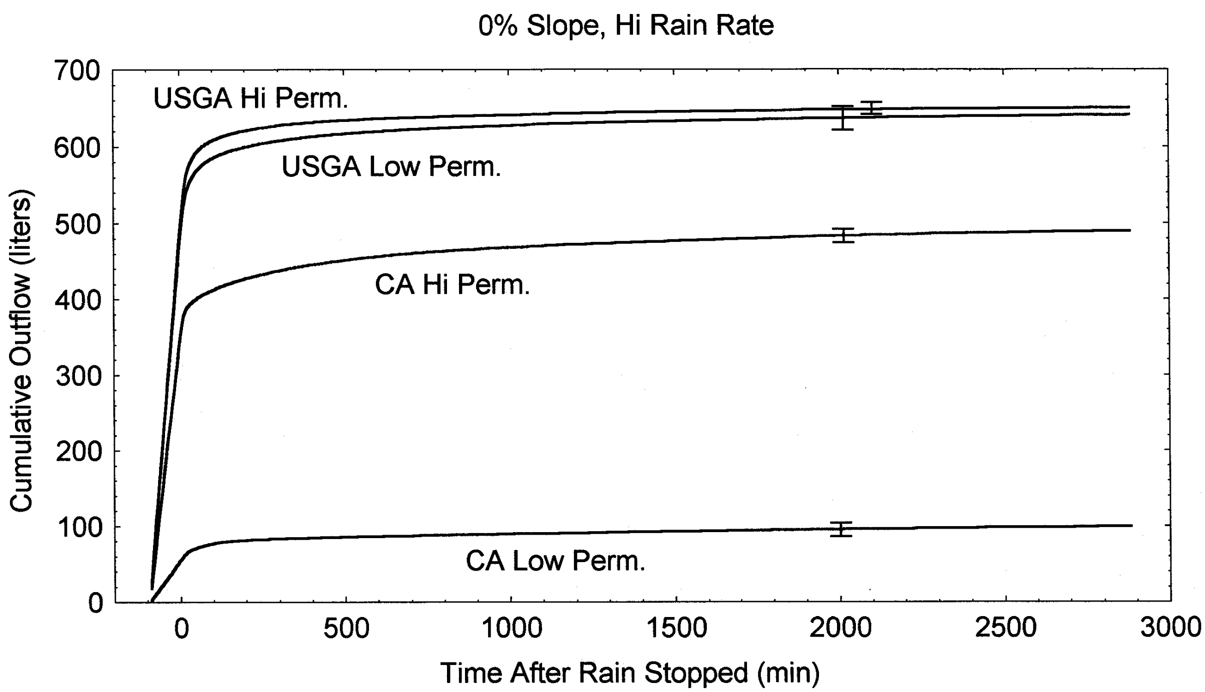

0% Slope, Hi Rain Rate
USGA Hi Perm.
USGA Low Perm.
CA Hi Perm.
CA Low Perm.
Cumulative Outflow (liters)
0
100
200
300
400
500
600
700
Time After Rain Stopped (min)
0
500
1000
1500
2000
2500
3000

Figure 4.

4% Slope, Hi Rain Rate

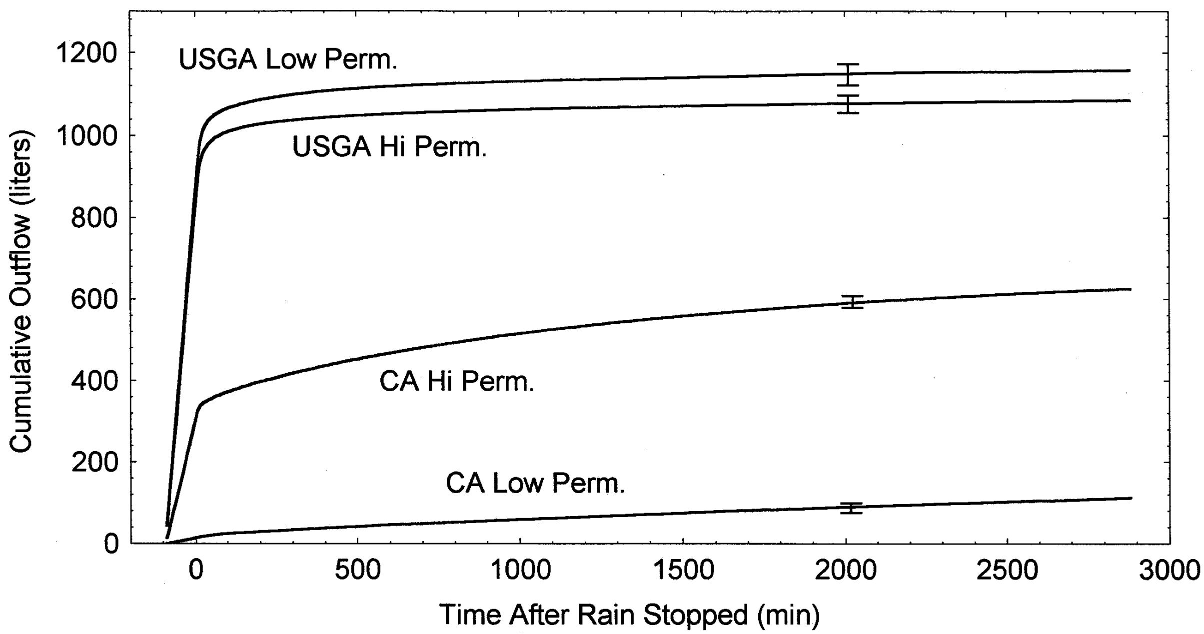
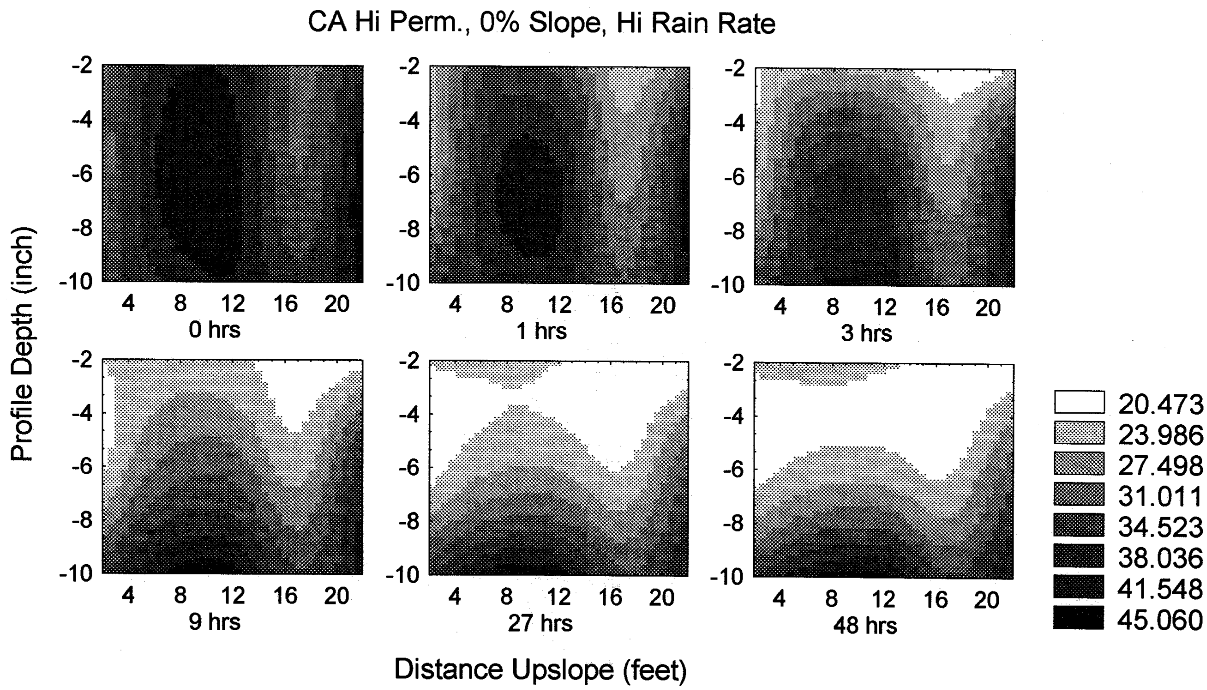


Figure 5.



CA Hi Perm., 0% Slope, Hi Rain Rate
Profile Depth (inch)
-2
-4
-6
-8
-10
4 8 12 16 20
0 hrs
1 hrs
3 hrs
9 hrs
27 hrs
48 hrs
Distance Upslope (feet)
20.473
23.986
27.498
31.011
34.523
38.036
41.548
45.060

Figure 6.

CA Hi Perm., 4% Slope, Hi Rain Rate

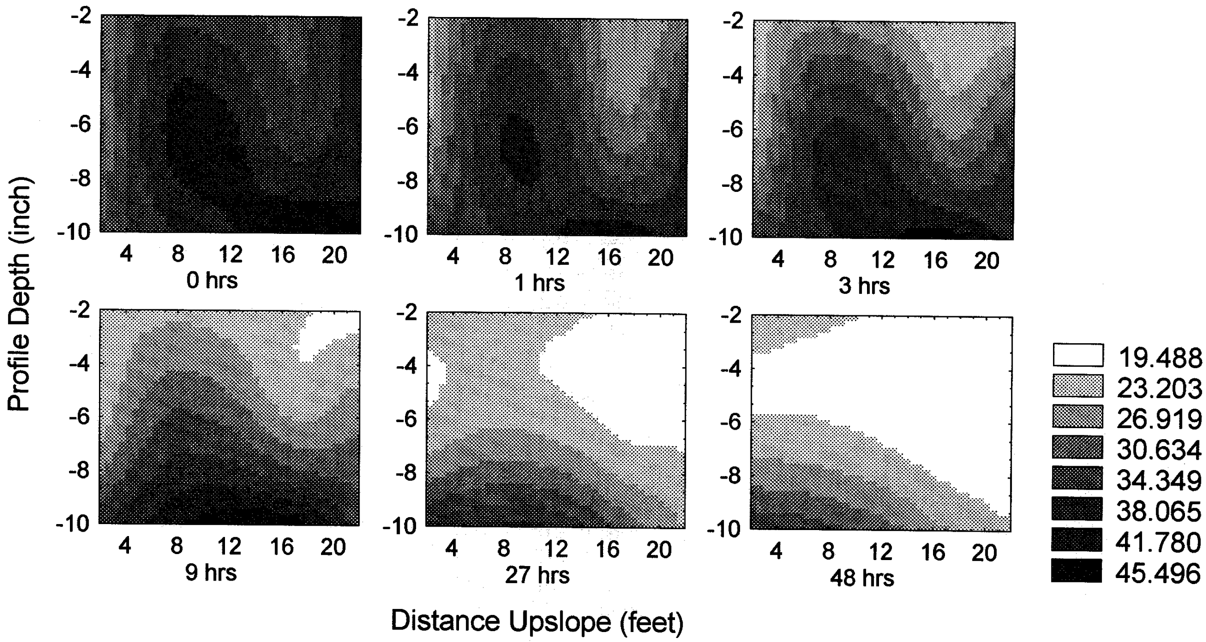
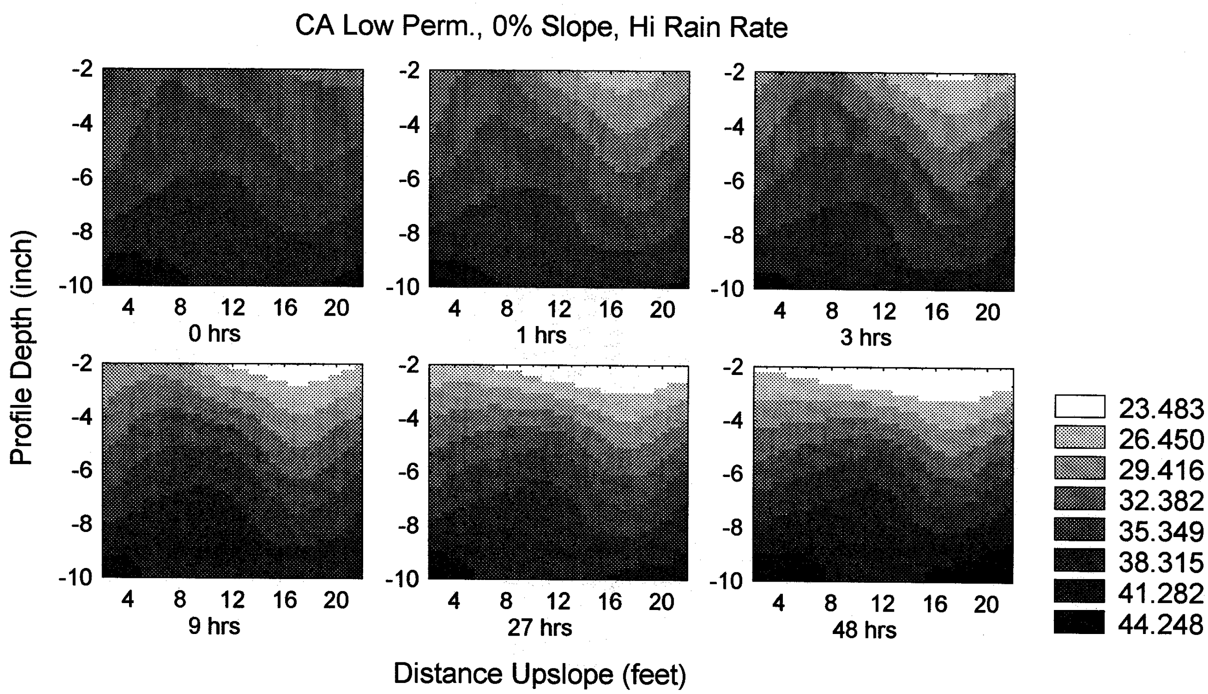
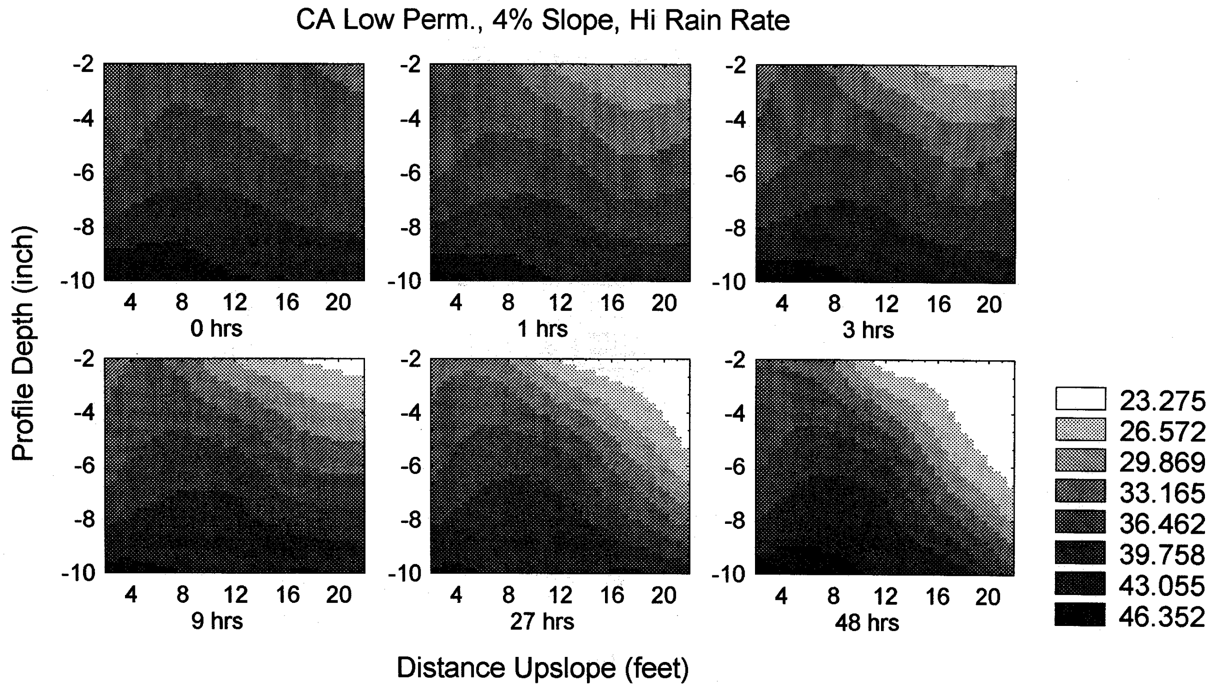


Figure 7.



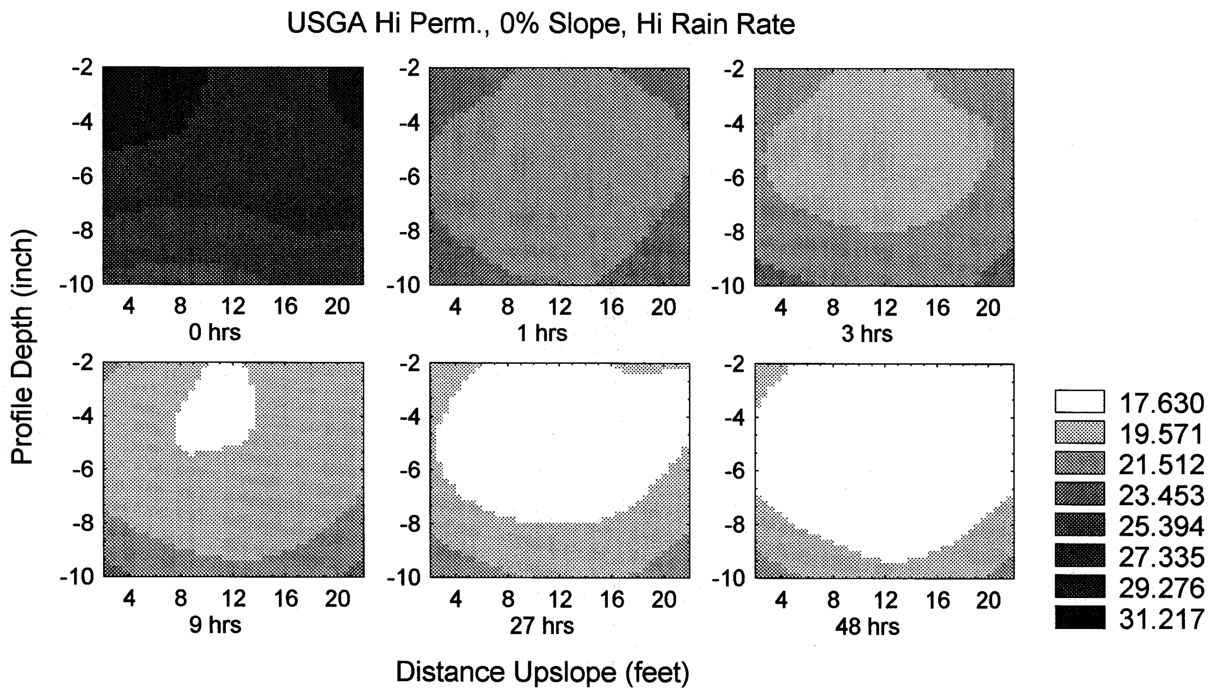
CA Low Perm., 0% Slope, Hi Rain Rate
Profile Depth (inch)
-2
-4
-6
-8
-10
4
8
12
16
20
0 hrs
1 hrs
3 hrs
9 hrs
27 hrs
48 hrs
Distance Upslope (feet)
23.483
26.450
29.416
32.382
35.349
38.315
41.282
44.248

Figure 8.



CA Low Perm., 4% Slope, Hi Rain Rate
Profile Depth (inch)
-2
-4
-6
-8
-10
4 8 12 16 20
0 hrs
1 hrs
3 hrs
9 hrs
27 hrs
48 hrs
Distance Upslope (feet)
23.275
26.572
29.869
33.165
36.462
39.758
43.055
46.352

Figure 9.



USGA Hi Perm., 0% Slope, Hi Rain Rate
Profile Depth (inch)
-2
-4
-6
-8
-10
4
8
12
16
20
0 hrs
1 hrs
3 hrs
9 hrs
27 hrs
48 hrs
Distance Upslope (feet)
17.630
19.571
21.512
23.453
25.394
27.335
29.276
31.217

Figure 10.

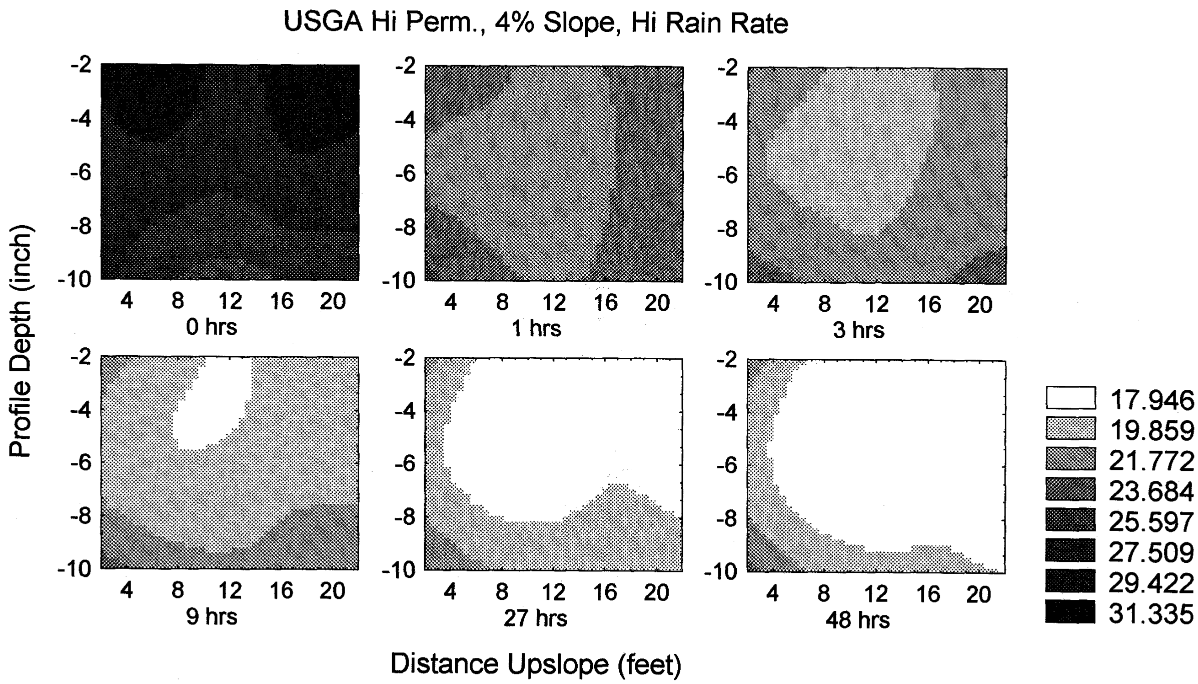
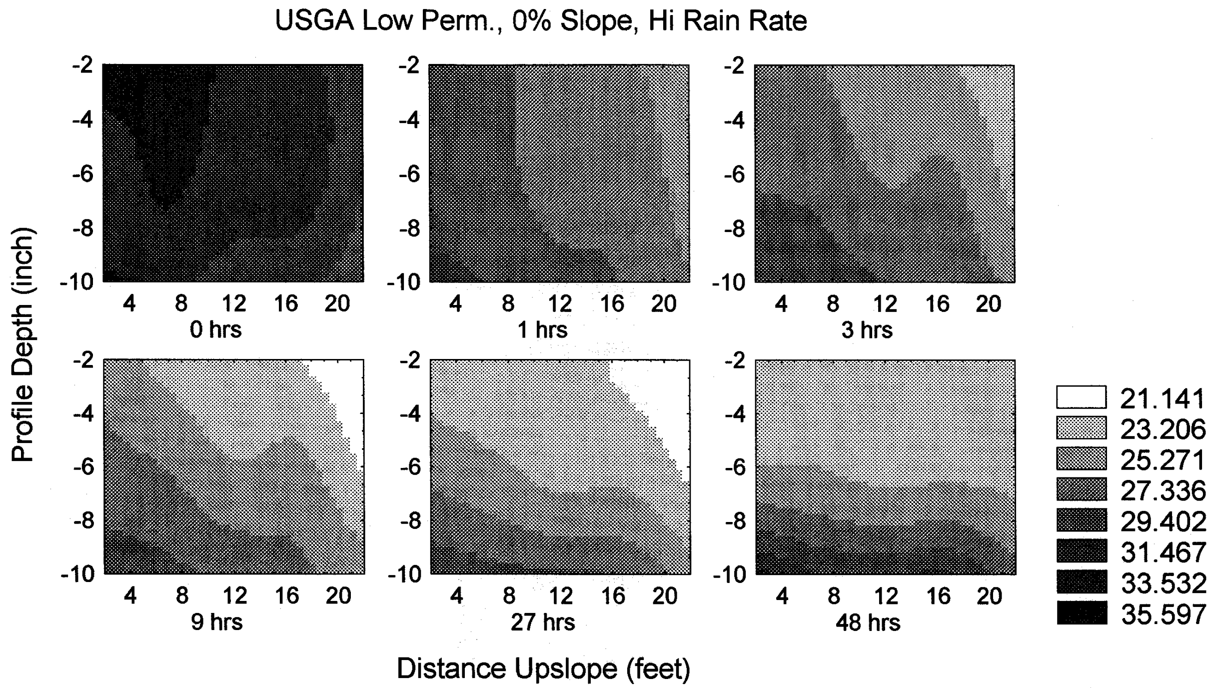
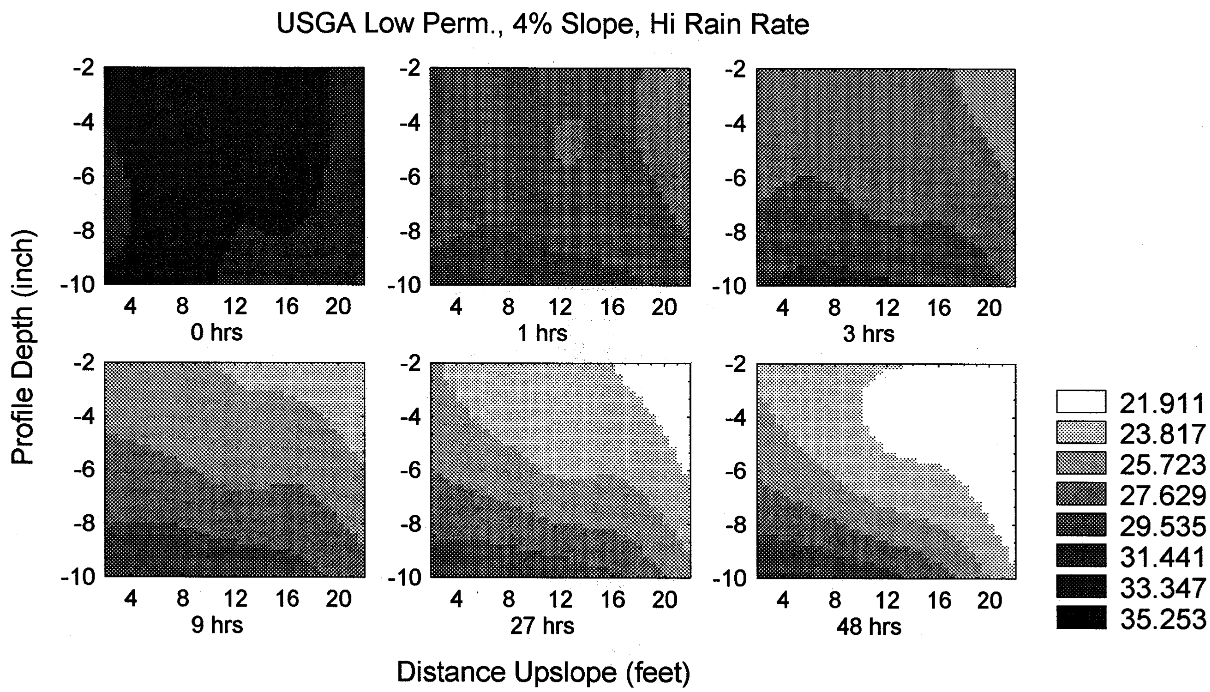

USGA Hi Perm., 4% Slope, Hi Rain Rate
Profile Depth (inch)
-2
-4
-6
-8
-10
4 8 12 16 20
0 hrs
1 hrs
3 hrs
9 hrs
27 hrs
48 hrs
Distance Upslope (feet)
17.946
19.859
21.772
23.684
25.597
27.509
29.422
31.335

Figure 11.



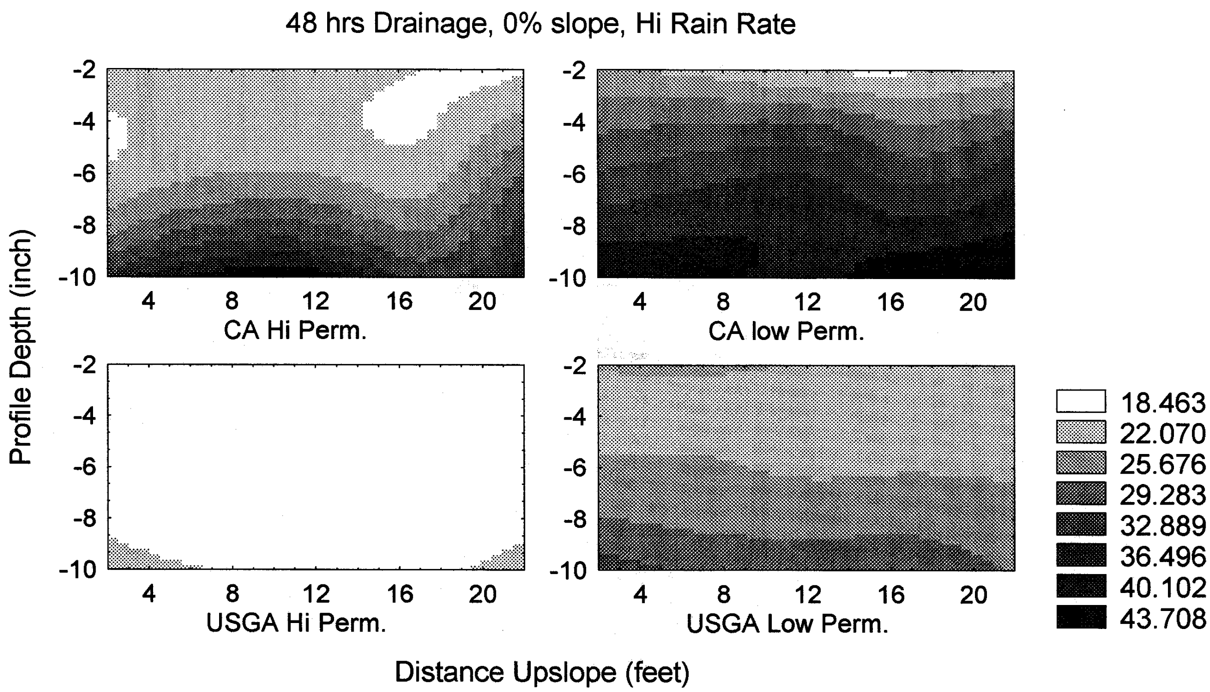
USGA Low Perm., 0% Slope, Hi Rain Rate
Profile Depth (inch)
-2
-4
-6
-8
-10
4 8 12 16 20
0 hrs
1 hrs
3 hrs
9 hrs
27 hrs
48 hrs
Distance Upslope (feet)
21.141
23.206
25.271
27.336
29.402
31.467
33.532
35.597

Figure 12.



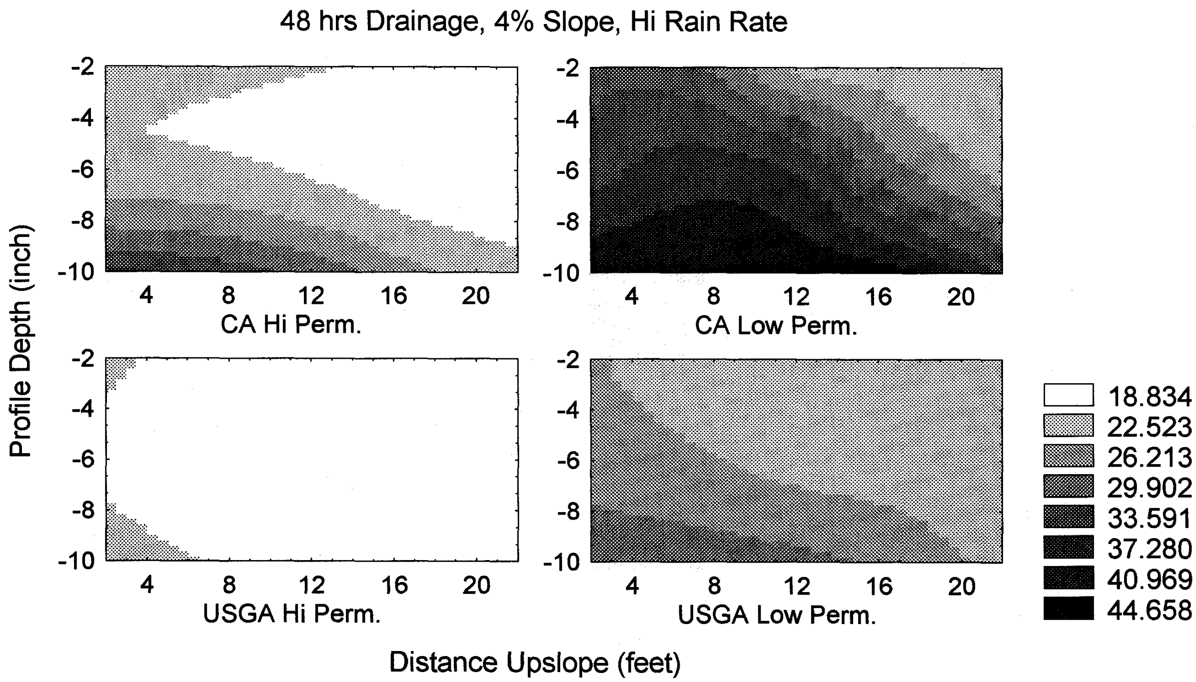
USGA Low Perm., 4% Slope, Hi Rain Rate
Profile Depth (inch)
-2
-4
-6
-8
-10
4
8
12
16
20
0 hrs
1 hrs
3 hrs
9 hrs
27 hrs
48 hrs
Distance Upslope (feet)
21.911
23.817
25.723
27.629
29.535
31.441
33.347
35.253

Figure 13.



48 hrs Drainage, 0% slope, Hi Rain Rate
Profile Depth (inch)
CA Hi Perm.
CA low Perm.
USGA Hi Perm.
USGA Low Perm.
Distance Upslope (feet)
-2
-4
-6
-8
-10
4
8
12
16
20
18.463
22.070
25.676
29.283
32.889
36.496
40.102
43.708

Figure 14.


48 hrs Drainage, 4% Slope, Hi Rain Rate
Profile Depth (inch)
-2
-4
-6
-8
-10
4
8
12
16
20
CA Hi Perm.
CA Low Perm.
USGA Hi Perm.
USGA Low Perm.
Distance Upslope (feet)
18.834
22.523
26.213
29.902
33.591
37.280
40.969
44.658