Subsurface Drainage of Modern Putting Greens

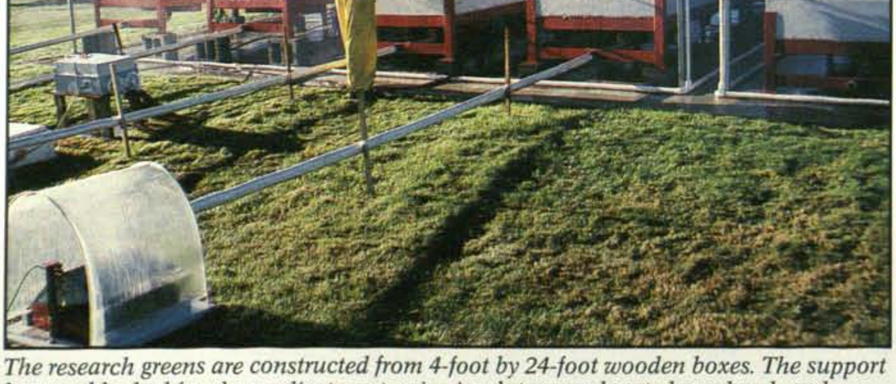
There's a lot going on below the surface.

by GUY PRETTYMAN and ED McCOY, Ph.D.

SUBSURFACE drainage involves both intensity and capacity attributes. Intensity of subsurface drainage refers to how rapidly a root zone drains. Capacity, on the other hand, refers to the extent of excess (gravitational) water removal from the root zone. Consequently, discussions of putting green drainage often become confused since the expression *improved drainage* can imply improved drainage intensity, improved drainage capacity, or both. This confusion most often occurs with modern, high sand content greens where subsurface drainage performance is emphasized.

The two most prevalent modern putting green construction methods are the California Method (Davis et al., 1990) and the USGA (USGA Green Section staff, 1993) green construction technique. The principal differences between these two construction methods are a higher recommended root zone permeability in a California (CA) green (relative to a USGA green) and the presence of a gravel blanket in a USGA green. With all other factors being equal, a higher root zone permeability should lead to higher drainage rates, and for most sandy root zones, a drier soil profile. Correspondingly, the gravel blanket should help drainage water move rapidly to drain pipes, but it also is shown to increase water retention in the root zone (reviewed by Hummel, 1993; Taylor, 1993). The key to comparing subsurface drainage in CA and USGA greens is understanding the interaction between root zone permeability and the presence of a gravel blanket.

Also, the natural contours or slopes that exist on putting greens may influence both the intensity and capacity of subsurface drainage. Even though these slopes are typically slight, they do represent a driving force for lateral, downslope water movement within the greens profile. The supposition here is that soil water retained in the profile after initial drainage may migrate downslope to yield spatially nonuniform soil moistures across a green. To our knowledge, however, no previously reported research on greens drainage has examined green slope effects.



The research greens are constructed from 4-foot by 24-foot wooden boxes. The support legs are blocked for slope adjustment, rain simulators are located overhead, and tipping bucket rain gauges are attached to the drainage outflow lines to allow for the measurement of water output.

This article reports research findings to address modern putting green drainage issues. The green construction methods under investigation are the USGA and California specifications. Other factors investigated include the effect of green slope on water drainage and redistribution.

The Research Approach

This study employed four green construction approaches consisting of:

1. A CA-style soil profile containing a 9:1 sand:sphagnum root zone.
2. A CA-style profile containing a 6:2:2 sand:biosolids compost:topsoil root zone.
3. A USGA layered profile (no intermediate layer) containing the 9:1 sand:sphagnum mix.
4. A USGA layered profile (no intermediate layer) containing the 6:2:2 sand:compost:topsoil mix.

Based upon independent testing by an accredited laboratory, both root zone mixes met the particle size and performance criteria for a USGA root zone. Additionally, the sand:sphagnum mix, although not entirely pure sand, met the recently proposed performance criteria of a CA root zone (Hummel, 1998). The sand:sphagnum root zone had a permeability of 20.8 in. $hr.^{-1}$ and is referred to as the high-permeability mix, while the sand:compost:topsoil blend had a permeability of 12.6 in. $hr.^{-1}$ and is referred to as the low-permeability mix. Gravel selection for the drainage blanket of the USGA profiles and for the drain line trenches of the CA profiles were based on the particle sizes of the respective root zones corresponding to USGA specifications for two-tier greens construction (USGA Green Section staff, 1993). The four treatments were replicated three times for a total of 12 experimental greens. At the time of the study, the greens contained a 15-month-old Penncross creeping bentgrass turf maintained at a mowing height of 3/16 inch.

The greens were built above ground in 4 ft. by 24 ft. wooden boxes supported by a legged, metal framework. Six-inch-wide by 8-inch-deep drain line trenches extended below the profiles, with each containing an outlet. The drain line trenches (perpendicular to the long axis) were constructed into each green at 2 ft., 12 ft., 17 ft., and 22 ft. from the downslope end. PVC pipes were connected to the outlet of each drain line trench, with each fitted with a valve for selective closure. The present study was conducted with only the 2 ft. and 17 ft. drain lines open, effectively yielding a drain spacing of 15 ft. The 12 research greens were placed in a randomized complete block design on an 80 ft. by 28 ft. concrete pad. This allowed 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 zones of each experimental green were instrumented with soil moisture probes at three depths (3 in., 6 in., and 9 in.) and five locations (2 ft., 7 ft., 12 ft., 17 ft., and 22 ft. from the downslope end of the green) for a total of 15 positions per green. The probes were connected to a measurement system that allowed frequent monitoring of soil moistures. Additionally, tipping bucket rain gauges were connected to the drainage outflow pipe of the furthest downslope drain line to monitor drainage outflow rate.

This experimental setup 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 experimental runs. During an experimental run, individual greens were configured to a predetermined slope of 0%, 2%, or 4%. Additionally, each green received rainfall from an overhead rain simulator set to deliver either a high (ca. 4.4 in. $hr.^{-1}$) or low (ca. 1.9 in. $hr.^{-1}$) rainfall rate. Rainfall was applied for 3 hours to ensure a constant drainage rate. At the end of the rainfall period, the rain device was turned off.

Drainage outflow was measured every 5 minutes for both the 3-hour rainfall period and for a 48-hour drainage period. Soil water contents were measured every 20 minutes for the 3-hour rainfall period and for the first 24 hours of the drainage period. Soil moisture levels were measured hourly for the remaining 24 hours. This resulted in about 44,000 total drainage outflow measurements 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.

Results

Due to space limitations, only a portion of the data collected in the study will be presented in this article. Specifically, we will present only the high rainfall rate data since, after the first two hours of the drainage period, rainfall rate had little effect on the experimental results.

Drainage rates between the two rootzone profiles differed significantly. The USGA profile greens (right) had a higher drainage rate than the California greens (left).

During rainfall, drainage rates from the research greens exhibited a significant interaction between profile design (either with or without a gravel blanket) and root zone permeability. The USGA profile greens, containing the gravel blanket, had higher drainage rates than the CA profile greens. Additionally, drainage rates from the USGA greens were essentially the same regardless of root zone permeability. This result differed from that of the CA greens, where the drainage rate during rainfall was substantially reduced for the low-permeability root zone compared to the high-permeability root zone. Finally, drainage rates in the USGA greens consistently increased with increasing green slope, while this was not the case for the CA greens.

Although drainage rates were much lower after 27 hours without rainfall, outflow was still observed from all research greens. The CA style greens had higher overall drainage rates than the USGA greens, due principally to differences between the high-permeability root zone treatments. Also, reversed from that observed during rainfall was the effect of green slope, where drainage rates of the CA greens exhibited a larger increase with increasing slope than the USGA greens.

Just as drainage rates showed an interaction between profile design and root zone permeability, the pattern of soil moistures through a cross-section of the root zone yielded a similar interaction. This pattern is illustrated by Figures 1 and 2, where isobands of soil moisture are shown as a function of distance upslope and root zone depth for each of the profile design:root zone permeability combinations. Also, the individual figures correspond to green slopes of 0%, 2%, and 4%.

After 48 hours drainage at 0% slope, both CA profiles showed an effect due to drain spacing. Lower soil moistures were observed over the drain lines at 2 ft. and 17 ft., and higher moistures were observed between the drains. This contrasts with the USGA profiles where soil water contents were more uniform laterally across the soil profile. As expected, root zone permeability yielded higher soil moisture levels for the low-permeability root zone for both profiles. It was interesting, however, that the levels of near-surface soil moistures were similar in the CA high-permeability and the USGA low-permeability greens.

All research greens exhibited increased water contents with root zone depth. In both permeability rates in the CA profiles, water contents increased by about 15% to 20% from the 2 in. to the 10 in. depths. The USGA low-permeability greens yielded about a 10% increase and, while not readily apparent from the figures, the USGA high-permeability greens had a 4% increase in water content with depth.

The patterns of soil moisture for greens sloped at 2% were somewhat similar to those observed at 0% slope. This small slope applied to the greens, however, generated some downslope accumulation of soil moisture for all systems. Consequently, the soil mois-

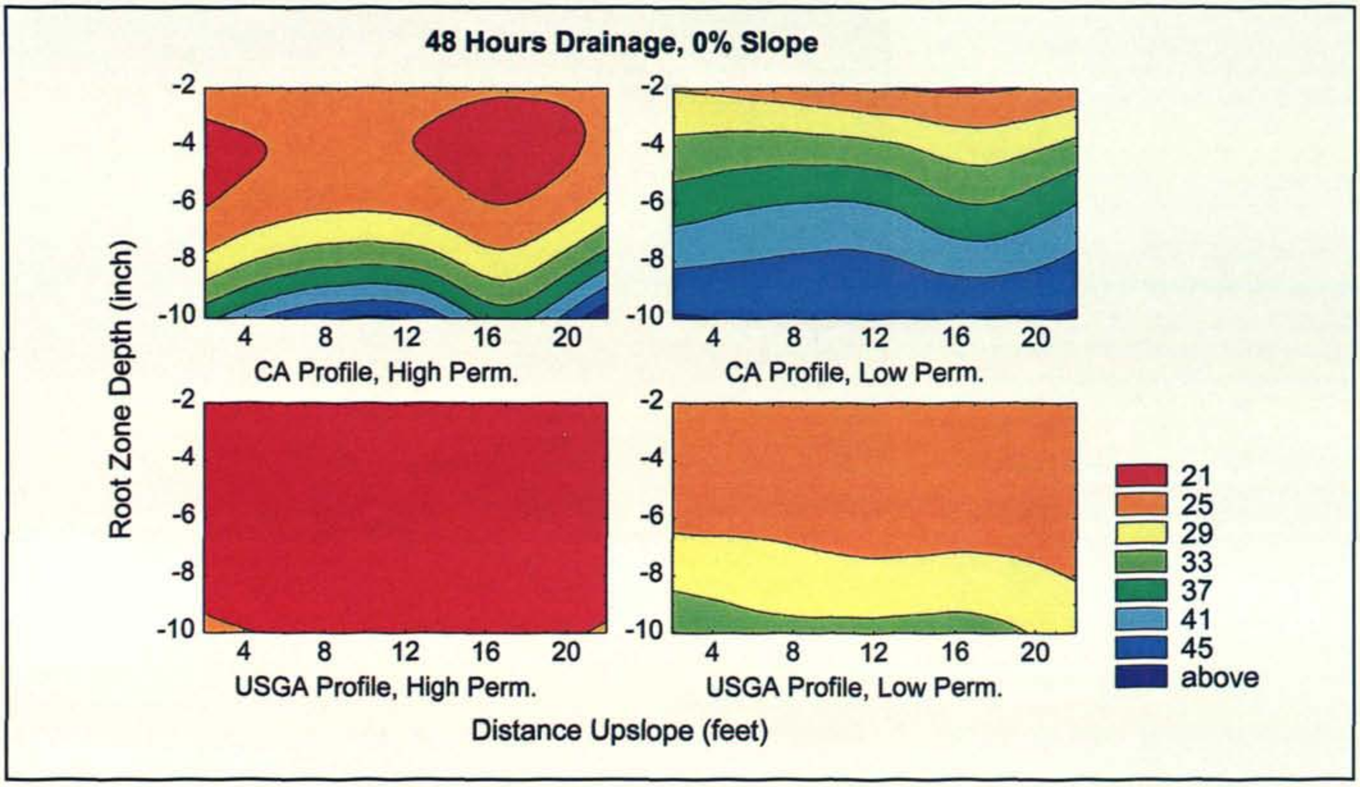


Figure 1. These contour plots demonstrate the soil moisture (% by volume) after 48 hours of drainage for research greens sloped at 0%. Individual plots show results for the California profile with a high permeability root zone, the California profile with a low permeability root zone, the USGA profile with a high permeability root zone, and the USGA profile with a low permeability root zone. Each plot shows moistures in a cross-section of the root zone with the horizontal axis given as distance upslope (feet) and the vertical axis given as root zone depth (inch). The plots are shown with the vertical axis expanded 16.7 times true scale.

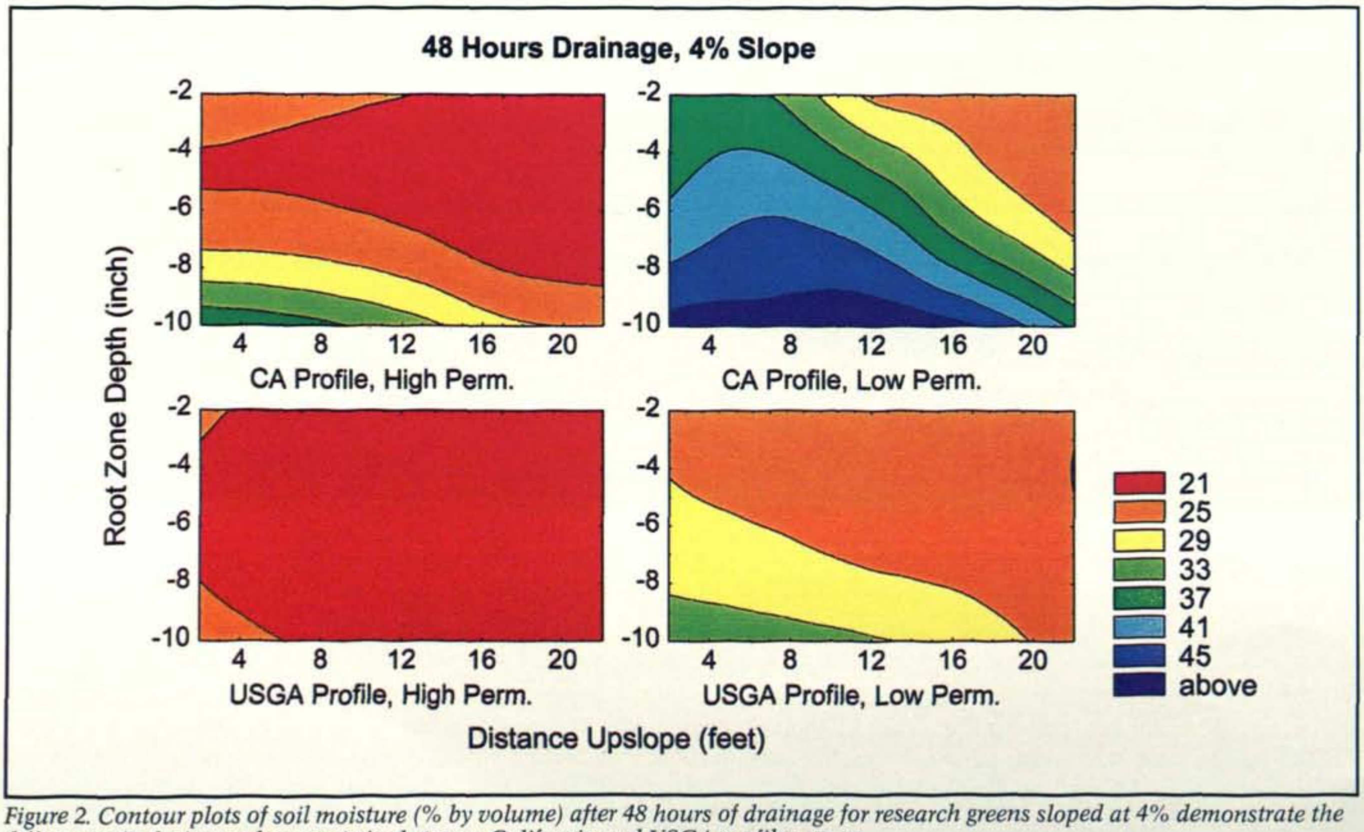


Figure 2. Contour plots of soil moisture (% by volume) after 48 hours of drainage for research greens sloped at 4% demonstrate the differences in drainage characteristics between California and USGA profile greens.

ture pattern due to drain spacing in the CA profile greens was skewed in the downslope direction, and downslope water accumulation, particularly at depth, was observed in the USGA greens. This downslope soil water accumulation was accentuated in all greens after 48 hours at 4% slope. Drain spacing effects disappeared for the CA greens and evidence of water perching in the USGA greens was absent near the upslope end. Finally, the 4% slope had the greatest influence on near-surface soil moistures in the CA low-permeability greens, where water contents ranged from 37% to 25% within a distance of about 18 ft.

It is important to point out that whereas results of Figures 1 and 2 are for 48 hours of drainage, similar soil moisture patterns were observed at earlier sampling times. The exception was that overall water contents were higher at earlier sampling times and slope effects did not become apparent until about 12 hours after rainfall stopped.

Table 1
Mean drainage rates during rainfall application and after 27-hour drainage for the experimental putting greens.

Green Profile	Root Zone Permeability	Green Slope	Drainage Rate During Rainfall	27 Hours
		%	---------- gal. hr.$^{-1}$	----------
California	High	0	59	0.22
		2	67	0.51
		4	52	0.52
	Low	0	10	0.08
		2	6	0.22
		4	3	0.46
USGA	High	0	82	0.13
		2	130	0.21
		4	140	0.24
	Low	0	81	0.17
		2	98	0.29
		4	146	0.30
LSD (0.05)			11	0.14

Implications

This research illustrates that when it comes to greens drainage, we need to go beyond considering just the root zone permeability or the profile design and consider the interaction of these two factors. Given equal root zone permeability, the USGA profile yielded more rapid drainage. Indeed, even rainfall rates of about 4.4 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. Consequently, it appears that CA profiles need a root zone permeability about 20 in. hr.$^{-1}$ greater than USGA profiles to yield similar drainage rates. Of course, greens built to CA specifications may be reasonably expected to have these higher permeabilities since the root zones frequently contain pure sand.

Drainage rate represents an intensity attribute. The capacity attribute of subsurface drainage, 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 formation of a perched water table in a USGA green would result in a less completely drained root zone than a CA green. Our results show that for equal root zone permeabilities the experimental USGA greens are drier after 48 hours (interpreted as having an increased drainage capacity) than the experimental CA greens. Also, the CA greens exhibited higher soil moistures midway between the drain lines. Both of these soil moisture features result from the need for water to move laterally through the root zone in a CA green before reaching a drain line. This rather slow route for water to exit the root zone, as compared with flow into and through the gravel of a USGA green, resulted in wetter soil conditions even after 48 hours of drainage. Again, for more complete drainage, a CA green appears to need a higher root zone permeability than a USGA green.

This research also illustrates that we need to consider how a putting green, either a CA or USGA construction method, fits into the landscape; that is, the green slope and direction. Green slope clearly had an effect on water redistribution following rainfall, and did so for both putting green construction methods. Within each profile design, however, the lower permeability root zone yielded enhanced downslope accumulation simply because there was more moisture retained and accessible for migration in this root zone. Interestingly, increasing slope in the CA profiles resulted in higher drainage rates at 27 hours and slightly drier root zones after 48 hours. Thus, green slope may be beneficial for continued drainage of a CA green.

On the other hand, the slope-induced, lateral differences in soil moisture observed for both the CA and USGA greens appears to be analogous to spatially non-uniform soil moistures observed within greens on golf courses. This spatial non-uniformity may result in the formation of localized drying or "hot spots" at upslope locations and excessive soil wetness in downslope locations. Both green construction methods apparently face this dilemma.

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