Bureau of Environmental Services
1120 S.W. Fifth Avenue, Room 613, Portland, OR 97204-3713
503-823-7740 • BESStormManual@portlandoregon.gov
portland.gov/bes/SWMM

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By: Peter Bryant, Jason Law; Monitoring Coordination and Analysis team

To: Adrienne Aiona

104B Soil Moisture Study/Phase 1 – Results By Underdrain Type

Background

In 2018 BES constructed 53 green street facilities in the Argay Terrace neighborhood as part of the Slough 104B Green Streets project (BES Project E10638). The facilities were built to treat runoff draining to the Columbia Slough. All of the facilities are vegetated biofilters with underdrains, and about half are fully lined to protect groundwater along the busiest streets. The project allowed for an experimental design to test facility design modification with potential to improve summer soil moisture conditions and plant health in fully-lined biofilters. Fully-lined systems have been a particular maintenance concern for BES: staff have observed higher plant mortality rates in systems with liners where plant roots don't have access to the native soil. The experimental design allowed comparison of moisture results in lined facilities with a short underdrain vs. lined facilities with a full underdrain, and comparison of results in lined facilities with a trial soil blend vs. lined facilities with the city's 2008 standard soil blend.

The results for Phase I of the soil moisture study, which are the subject of this report, compare moisture by underdrain type using data recorded during summer 2021. The results for Phase 2, which compare soil moisture by soil type using data from summer 2022, are presented in a companion report. A separate report summarizing plant health monitoring results for the Slough 104B project summarizes both plant health results and soil moisture data.

Study Design

The primary focus of the study was to compare the effect of the different underdrain configurations on soil moisture. BES staff installed Stevens Water Hydra Probe continuous soil moisture loggers in six Green Street facilities constructed as part of the Slough 104B Green Streets project. Each soil moisture logger was connected to three soil moisture sensors that were equally distributed across the facility and placed at the same depth below the surface (7-8"). Staff positioned loggers in three facilities with the Portland Underdrain (also referred to as the Standard underdrain) and in three facilities with the Western Washington Underdrain (also referred to as the Seattle underdrain). The six facilities contain the high fines Special Soil Mix so the soil type isn't a variable in the comparison. Staff assessed each candidate facility for sun exposure and determined them to be in medium to high sun exposure locations.

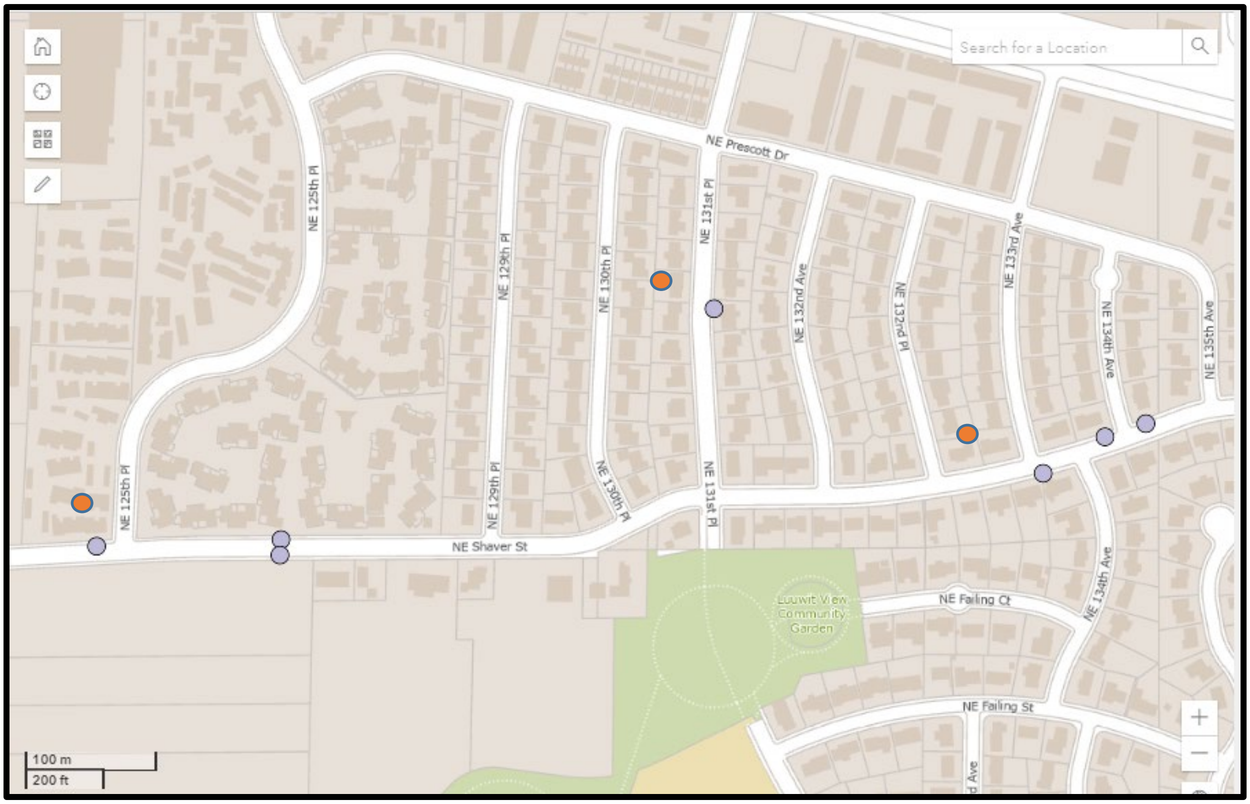

Figure 1. Monitoring locations. Orange dots are the Standard underdrain and purple dots are the Seattle underdrain.

On September 21, 2020, the monitoring equipment at one of the Seattle underdrain configuration facilities was stolen. A replacement was installed in a facility of the same underdrain type on March 15, 2021. The location of each of the seven facilities selected for monitoring is shown in Figure 1.

Analysis

To investigate the effect of the underdrain configuration on soil moisture staff calculated facility averages by averaging the data from the 3 sensors within each facility at each 15-minute timestamp. Drying events were identified in the facility average for each data logger. A drying event, for the purposes of this study, is defined as the period between field capacity to the next occurrence of saturation (see Figure 2). Field capacity was defined as the data point 24 hours after a peak in soil moisture values.

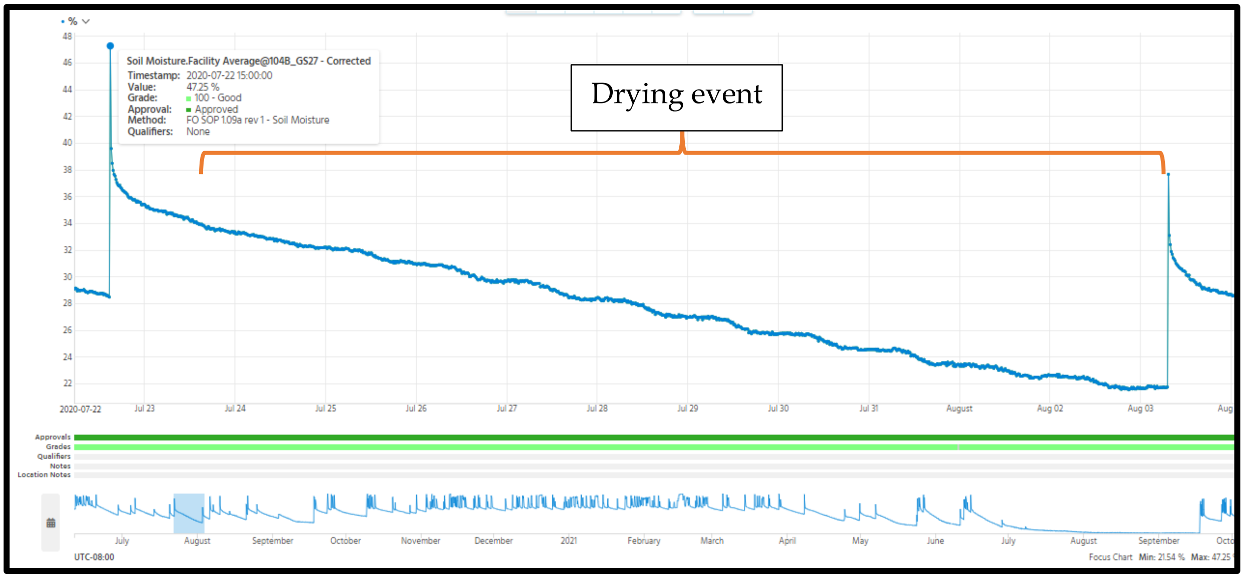

Figure 2. Drying event example. The authors assumed field capacity occurred 24 hours after a peak in soil moisture. In this example, the peak was at 15:00 on 2020-07-22 so the drying event was identified to start at 15:00 on 2020-07-23. The event occurred until the next peak in soil moisture. In this example, that was 2020-08-03 at 07:15.

Staff identified 100 drying events across all seven facilities where data loggers were deployed. No distinction was made between drying events following irrigation versus rainfall. The shortest drying event was two days, and the longest drying event was 93 days. Figure 3 displays the distribution of drying event lengths. Because there were only a few drying events longer than 21 days, only the drying events less than 21 days were included in the comparison analysis. All the drying curves included in the analysis are shown in Figure 4 and colored by underdrain type.

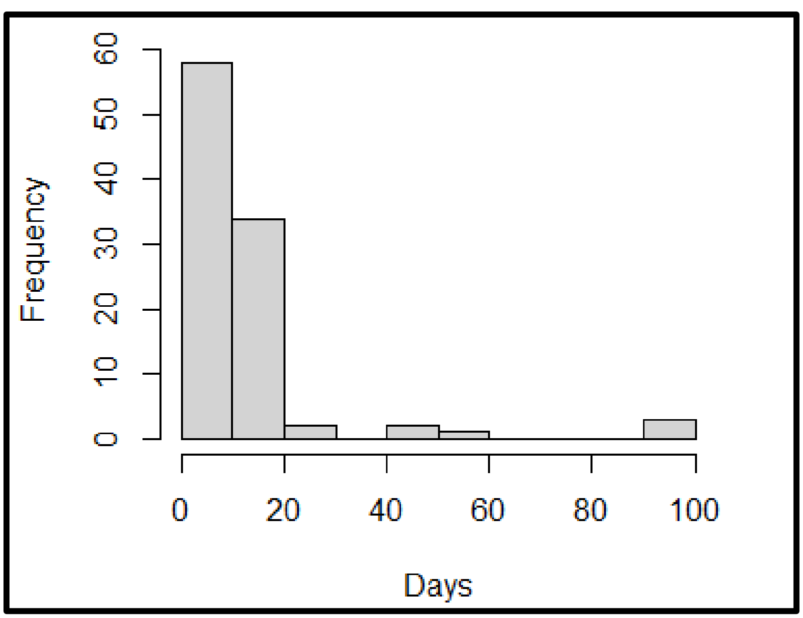

Figure 3. Distribution of drying event lengths.

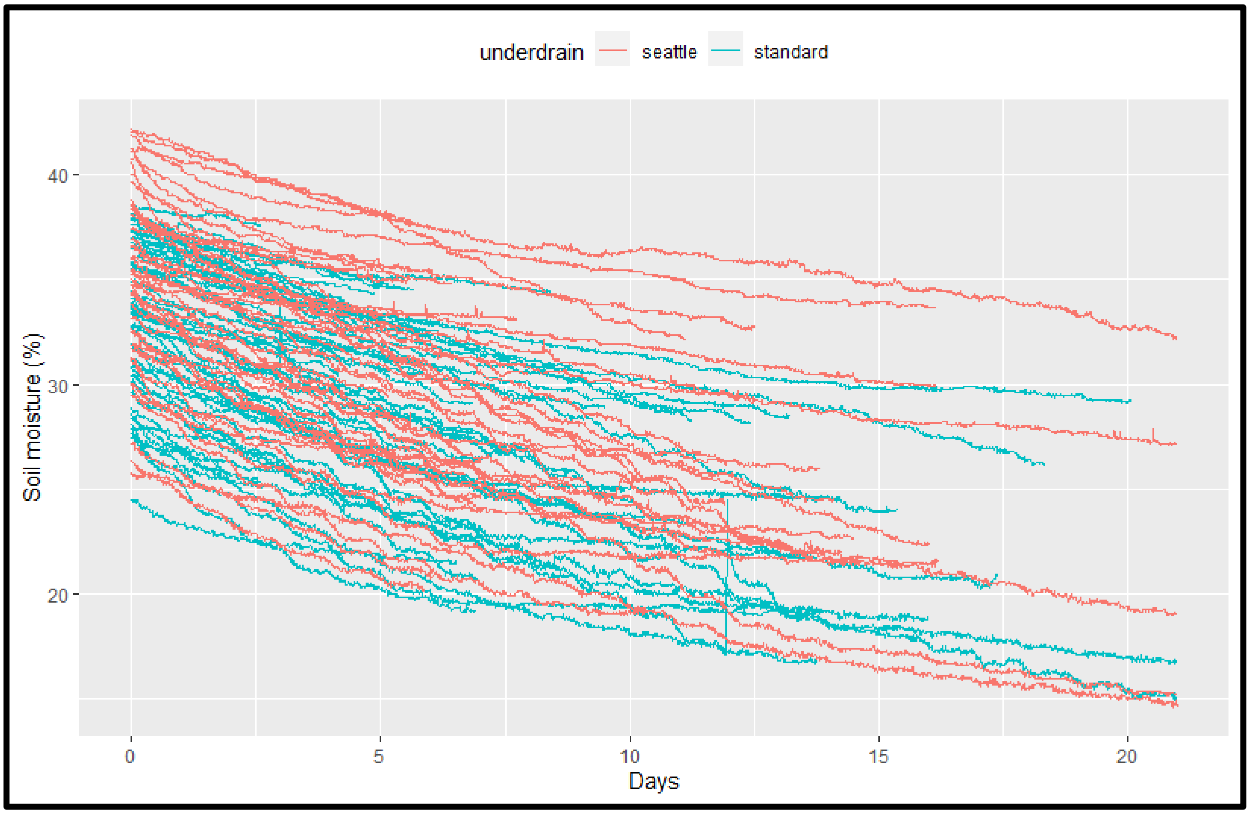

Figure 4. Drying events across all seven sites. The red lines are drying events at facilities with the Seattle underdrain and the blue lines are drying events at facilities with the Standard underdrain.

Generalized additive models (GAM) were fit to the drying events with an intercept and smooth term for each of the underdrain types. The intercept term represents the starting point for each of the underdrain types while the smooth term represents the drying rate like the slope term would in a simple linear regression. The model also allowed for different intercepts for each event to accommodate different soil moisture conditions at the beginning of each drying event. With the fitted model, predictions were generated over 21 days and compared. The comparison of the estimated predictions is in Figure 5. Using an Analysis of Variance (ANOVA) to test both the intercept and the smooth for the two different underdrains, the Seattle underdrain is significantly different (p-value < 0.001) than the Standard underdrain for both the intercept and smooth terms. However, the magnitude of the difference between the smooth terms is small enough there is effectively no difference between the Standard underdrain and the Seattle underdrain types regarding the drying trend. The differences are no greater than 1% of soil moisture between modeled results for the Seattle and the Standard underdrain types.

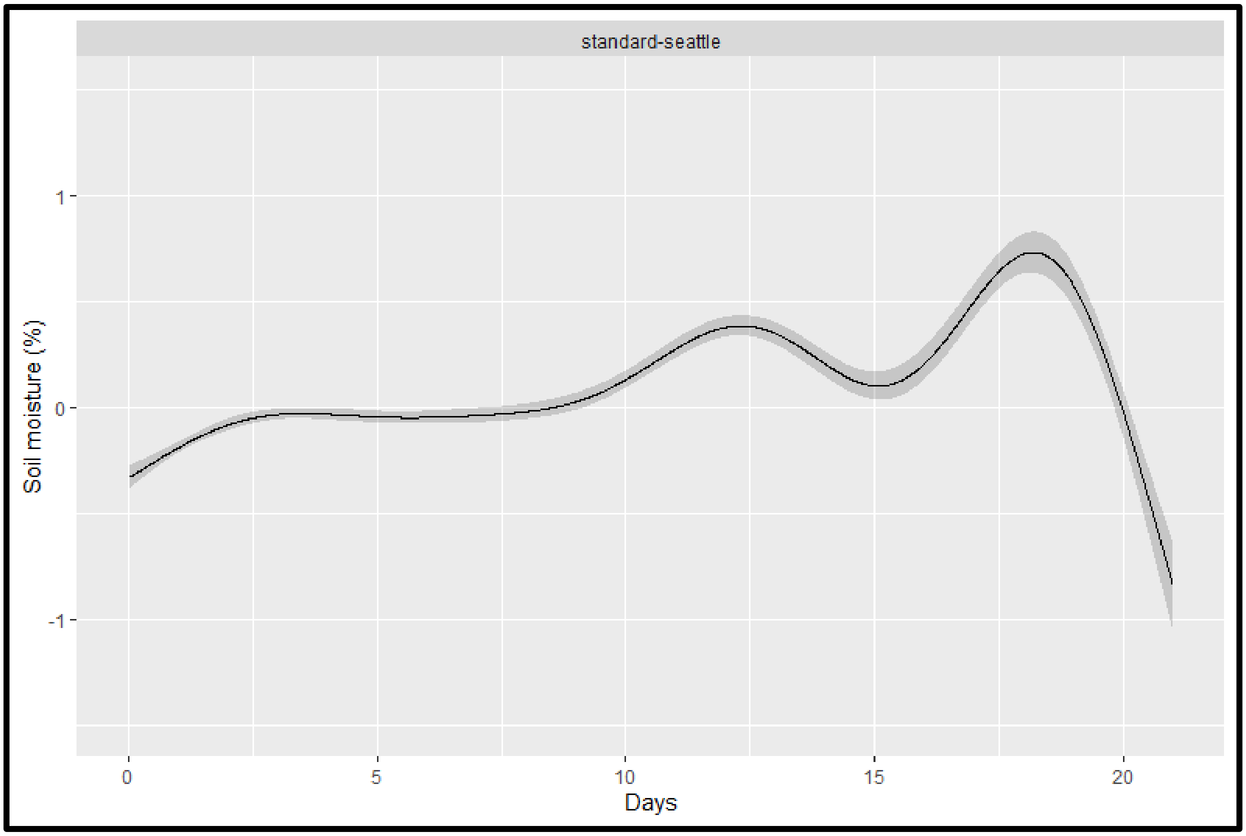

Figure 5. Difference in drying trend between estimated results of the Standard underdrain and Seattle underdrain types. The differences are no greater than 1% of soil moisture between modeled results.

The Seattle underdrain intercept appears to be about 1.3% higher in soil moisture at field capacity. Based on the similar drying trends between the underdrain types, it was observed that on day 10, the Seattle underdrain soil moisture is 1.3% higher than the standard underdrain. Figure 6 suggests that with the higher starting point, it takes the Seattle underdrain 2.5 days longer to reach 25% soil moisture compared with the Standard underdrain.

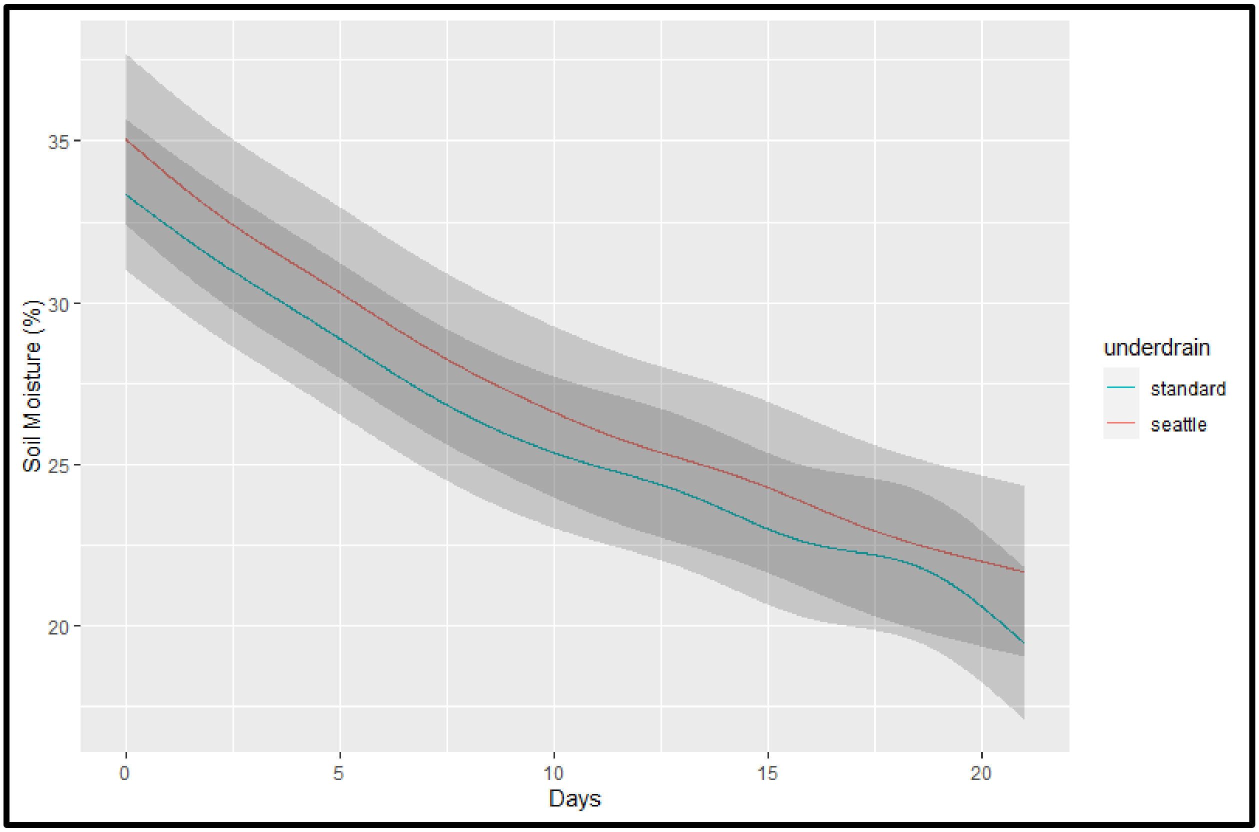

Figure 6. Estimated soil moisture drying trends with 95% confidence intervals for the Seattle and Standard underdrain types.

After observing the overlapping confidence intervals in Figure 6, staff explored the impact of air temperature on the soil moisture as a potential explanation for the variation in slope observed across the drying curves. An average air temperature was calculated across 6 air temperature loggers in southwest and southeast Portland. The resulting time series is in Figure 7. A generalized additive model (GAM) was fit to the drying events where the drying trend could vary as a smooth function of temperature. The model allowed for different intercepts and drying curves for each underdrain type as well as different intercepts for event specific changes.

The story is that temperature explains some of the overlap that we see in the error bars overlapping for Seattle and Standard underdrain types. The rate of drying is more in the beginning of the drying event and less as the event progresses, but the influence of temperature can increase the drying rate by up to about 1% per day at 40 deg C.

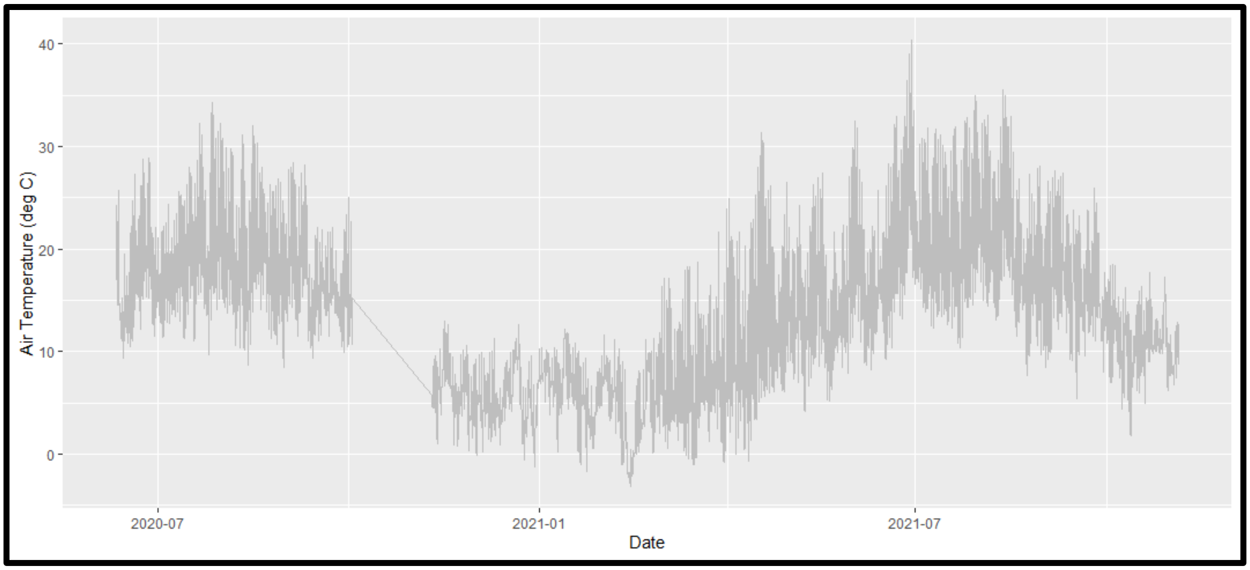

Figure 7. Air temperature calculated as a mean across 6 air temperature loggers in southwest and southeast Portland.

Conclusion

Staff set up the study to ascertain any observable difference in soil moisture drying trends between the Standard and Seattle underdrain types. Models were fit that allowed for varying slopes across the drying curves so as not to enforce a linearity assumption across the entire drying trend. Based on the comparison of model outputs, we observed no difference in drying trends.

Additionally, it was observed that field capacity in the Seattle underdrain was approximately 1.3% higher than the Standard underdrain. Putting together the similar drying trend with the higher starting point equates to a longer period to reach the same soil moisture. This supports the assumption that the Seattle underdrain would lead to improved soil moisture conditions for plants.

There is considerable uncertainty in the drying trend estimates between the underdrain types. The researchers explored whether considering air temperature would help to explain that uncertainty. It was found that higher air temperatures resulted in increased drying trends up to 1% more per day at 40 deg C. The air temperature helps to explain the uncertainty expressed in the overlapping confidence intervals on the predictions based on the underdrain types. This supports the conclusion that the Seattle underdrain results in improved soil moisture conditions relative to the Standard underdrain. When the air temperature increases, we see more rapid drying in both underdrain types. There are other factors besides air temperature including difference in soil composition, relative humidity, solar insolation of each facility, wind speed, and time of year that could also influence drying trends that were not explored in this study.