Goliad County Recharge Evaluation

Summary of Field Data Collection for September 2022

Submitted by

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Submitted to

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September 2022

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Monitoring Sites

Rainwater and Coldren (2018a,b, 2019, 2020a,b, 2021a,b) previously reported the details of the instrumentation choices and site positions at the Landgrebe, Dohmann, and Fuller locations in Goliad County. Table 1 summarizes the details about the depths of the soil moisture sensor probes (P1-P5) at each of the datalogger sites (L1-L3, D1-D3, and F1-F3), as well as the coordinates of the datalogger sites and weather stations (WS). Aerial images (Google Earth) of the locations are shown in Figures 1, 2, and 3, respectively. Local soil conditions were presented in the previous reports. Table 1 also includes the current status of the soil moisture sensors and weather stations. Of the 45 soil moisture sensors initially installed, 29 are currently working (ok), 12 have failed (month/year of failure), and four are questionable (?, some erratic behavior in recent past followed by more stable recent values). Observed data graphs are provided in a later section of this report.

Table 1. Current Status of Installations and Instruments

Land Use, Location	Site	Latitude (DD)	Longitude (DD)	Sensor Depths (ft), Status (ok, ?, or month lost)				
				P1	P2	P3	P4	P5
Cultivated, Landgrebe	L1	28.88164	97.39657	1	3.3	4.9	4.9	5.9
				?	?	6/18	?	?
	L2*	28.88614	97.39632	1	3.3	4.9	4.9	5.9
				ok	1/20	ok	ok	8/20
	L3	28.88155	97.39714	1	3.3	4.9	4.9	9.5
				ok	9/21	ok	ok	7/21
	WS	28.88164	97.39657	Temp/RH sensor malfunction 6/21, replaced 7/21				
Ranch, Dohmann	D1	28.79439	97.42340	1	3.3	4.9	4.9	8.2
				ok	ok	ok	ok	2/22
	D2	28.79519	97.42325	1	3.3	4.9	4.9	8.2
				ok	2/20	ok	6/20	10/19
	D3	28.79480	97.42204	1	3.3	4.9	4.9	8.2
				ok	ok	ok	ok	ok
	WS	28.79410	97.42496	Temp/RH sensor malfunction 12/21, replace 11/22?				
Ranch, Fuller	F1	28.65360	97.61954	1	3.3	4.9	4.9	9
				ok	ok	ok	ok	ok
	F2#	28.65374	97.61944	1	3.3	4.9	4.9	9
				ok	1/20	ok	ok	ok
	F3	28.65392	97.61941	1	3.3	4.9	4.9	9
				11/21	4/22	ok	ok	ok
	WS	28.654	-97.619	Solar radiation sensor off 6/22, replace 11/22?				

* L2 datalogger failed 2/22, replaced 7/22, recording again 8/22
** F2 datalogger failed 2/22, replaced 7/22, recording 7/22

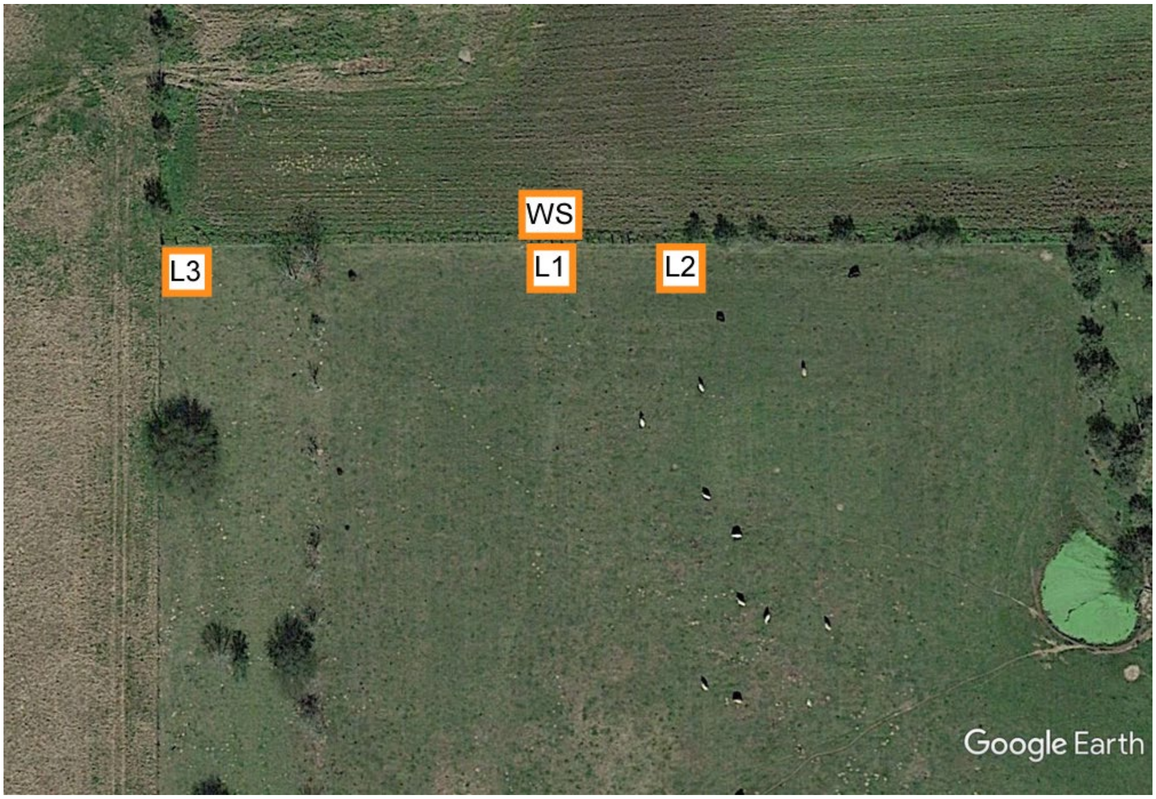

Figure 1. Approximate instrumentation sites at the Landgrebe cultivated location

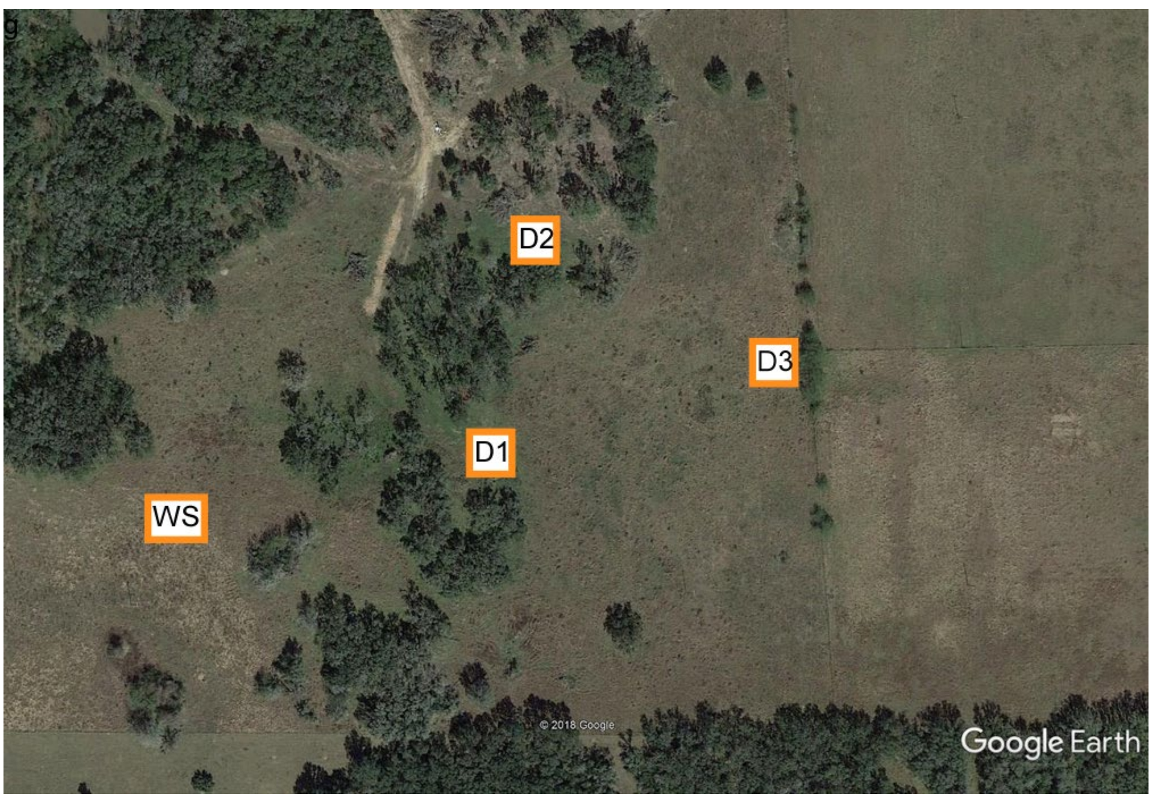

Figure 2. Approximate instrumentation sites at the Dohmann wooded location

Figure 3. Approximate instrumentation sites at the Fuller location

Data Collection

As reported by Rainwater and Coldren (2018b, 2019, 2020b, 2021b), data collection began in late June 2018 at the Landgrebe and Dohmann locations, and later at the Fuller location in January 2020. Table 2 provides the timing of the five data collection visits since the previous annual data summary. The TTU team is grateful for the data downloads and maintenance performed by the District staff who provided the datafiles as email attachments or as datafile transfers. All the data files were converted to Excel spreadsheets for analyses and plotting. All Excel files are available upon request, as the tables are too large for inclusion in this report. The data presented in this report were collected from 6/28/21 to 8/2/2022. It should be noted that the soil moisture sensors provide data on 30- or 60-min intervals, while the WSs report to their dataloggers on 30-min intervals.

Table 2. Site Visit Dates Since August 2021

Date	Data Collectors
8/30/2021	GCGCD
11/23/2021	GCGCD
2/11/2022	GCGCD
6/24/2022	GCGCD
8/2/2022	GCGCD

Most of the soil moisture sensors have performed well continuously, but there have been some problems. Table 1 identified the 29 sensors are still working (ok) and the 12 that have failed (month/year of failure). In addition, four of the sensors at L1 are still showing readings, but those readings were erratic in Year 4. It should be noted that that this field data collection project was purposely planned with three different locations, three sites at each location, and five soil moisture sensors at various depths at each site to allow for future uncertainties. Weather conditions and human error can affect the communication of each probe with its datalogger over time. In Year 4 we had to replace the dataloggers at L2 and F2 after both failed unexpectedly after the data downloads on 2/11/2022. Luckily, the TTU team had a replacement on hand for the older model Em5b datalogger at L2. A new replacement ZL6 datalogger had to be purchased to replace the newer datalogger at F2. While these two sites missed several months of soil moisture data, the other two sites at each location were still working, so our redundancy approach did maintain overall data collection.

As noted in the previous reports, the WS at each location has instruments for rainfall (RF), wind speed, temperature, humidity, and solar radiation. The last four observations allow calculation of evapotranspiration for a reference grass (ET ref). The SpecWare Pro software presents the daily RF and ET ref values. All three WSs were able to collect and report daily RF continuously through Year 4. Unfortunately, we encountered some WS sensor problems that interrupted the reporting of ET ref values at all three sites at various times. The first problem was noted at the Dohmann WS during the summer of 2021. The temperature/relative humidity sensor malfunctioned (very high temperature readings) starting 6/15/2021, so it was replaced by the TTU team on 7/14/2022 and returned to service. The temperature/relative humidity sensor at the Landgrebe WS apparently started malfunctioning (very high RH values on days without RF) about 12/1/2021, making its ET ref values untrustworthy. Replacement of that sensor is planned for 11/22 if the project continues. Finally, the solar radiation sensor at the Fuller WS stopped sending data to its datalogger on 6/22/2022, so ET ref cannot be calculated. The Spectrum Technologies tech support staff think it may be possible to restart that sensor, but the TTU team plans to be ready to replace it in 11/22 if the project continues.

Under these circumstances, the missing ET ref values for sites with malfunctioning WSs had to be estimated. It should be noted that that daily ET ref values at the three sites are typically much more similar that daily RF events, so the TTU team used data from the working WS(s) to fill in the missing data at the site(s) that were missing data. For three weeks in the summer of 2022 (6/22/2022 to 7/14/2022) all three WSs were not generating useful observations, so those date were filled in with ET ref data from the same three weeks in 2021. As of the date of this report, only the Dohmann ET ref values are being recorded, and those will be applied to the other two locations until the repairs are complete. Maintenance and repair of field equipment is expected and necessary in any outdoor weather application.

<u>Results and Observations</u>

With the start of data collection at the first two locations on 6/28/18, it was reasonable to see Year 1 of the dataset stretching from that date to 6/27/2019, Year 2 from 6/28/2019 to 6/27/2020, and Year 3 from 6/28/2020 to 6/27/2021. Year 4 began on 6/28/2021 and ended on 6/27/2022. Data collection at the Fuller location began on 1/10/2020, starting almost six months into Year 2 and continuing into the following years. Table 3 summarizes the RF and ET ref values for the three locations and the four years. It is notable that the Year 1 RF totals of 48.92 in and 41.39 in at the Dohmann and

Landgrebe locations, respectively, were well above the average annual RF of 36 to 37 in for Goliad. The Year 2 RF totals of 23.52 in and 27.77 in at the Dohmann and Landgrebe locations, respectively, were well below the Goliad annual average, as were the Year 3 values of 28.85 and 23.64 in, respectively, at the Landgrebe and Fuller sites. The RF values at all three locations were well below average in Year 4. While Year 4 included some long periods without RF, Table 4 summarizes the dates with daily RF depths equal to or greater than 1.0 in. The ET ref values for year 4 were the highest for all three locations for our project duration.

Table 3. Yearly Rainfall and ET ref

Location	6/28/18-6/27/19		6/28/19-6/27/20		6/28/20-6/27/21		6/28/21-6/27/22	
	RF (in)	ET ref (in)	RF (in)	ET ref (in)	RF (in)	ET ref (in)	RF (in)	ET ref (in)
Dohmann	48.92	43.41	23.52	50.45	9.34[1]	42.54	32.32	52.80
Landgrebe	41.39	45.52	27.77	49.13	28.86	46.42	28.29	52.09
Fuller	na	na	17.70	38.00	23.64	54.24	27.37	56.83

Table 4. Rainfall Events in Year 4 of 1 in/d or More

Date	Rainfall (in)		
	Dohmann WS	Landgrebe WS	Fuller WS
7/4/2021		1.04	
7/7/2021	2.45	1.86	
7/8/2021	2.45	2.70	2.67
7/9/2021	3.04	2.56	2.18
7/21/2021		2.45	
8/3/2021	3.51		
9/29/2021	2.34	3.99	2.09
10/14/2021	5.12	2.97	5.52
11/3/2021	1.13	1.06	
4/25/2022			1.08

Figures 4 to 13 display the Year 4 (6/28/21 to 6/27/2022) and early Year 5 (6/28/2022 to 8/2/2022) observations for the Landgrebe sites, aligned vertically on tabloid-sized pages to allow visual comparison of the graphs while keeping the horizontal time axes aligned. Figure 4 is a bar chart that shows the daily values of RF and ET ref in in/d provided by the Landgrebe WS data. ET ref is calculated for a hypothetical reference grass as used in the Penman-Monteith approach, based on one of the most popular evapotranspiration formulas (Shuttleworth 1993). Figures 5 to 7 provide the variations in moisture content for the sensor probes at sites L1, L2, and L3, respectively, during Year 4. Figure 5 for L1 is problematic, as the data appear somewhat noisy for P1, P2, and P4. The P2 readings appear to remain near saturation for most of the year, which could be possible after the significant RF events in July to November. Figure 6 shows the data from L2 for P1, P3, and P4. The soil moisture data show responses to the RF events were noted in all three sensors. Figure 7 shows that P2, P3, and P4 all started the year with relatively high soil moisture, then declined before the large RF event on 10/16/2021. Unfortunately P5 failed early in Year 4. The reason for the step changes in P3 and P4 in January and February 2022 is unknown, but the trends returned to their previous positions after the step changes and then declined more toward the summer months. Figure 8 shows the cumulative depths of RF and ET ref for Year 4. Coupled with the large deficit between ET ref and RF, this dataset indicates that both evaporation from the soil and transpiration through the plants were drying the upper soils and limited downward migration of water. Figures 9 to 13 display the data from the first two months of Year 5. The upper three probes responded to the July RF events, then the moisture contents began declining. Unfortunately, only L1 still had the lowest P5 operating, and its moisture content was stable after a small increase in July 2022. L2 had no data for this period due to operator error on setting the data collection time interval, but that error was fixed on 8/4/22.

Figures 14 to 23 summarize the Year 4 and early Year 5 data for the Dohmann sites. Responses to RF events in Figure 14 were clearer than those at the Landgrebe locations in Year 4. The moisture contents at D1's P5 showed some increase in moisture content at P5 in July of Year 4 then stabilized near its previous lower value before failing in February 2022. P5 at D3 had similar behavior and remained operational all Year 4. It is interesting that the RF event responses for the shallower sensors at the three sites were not exactly the same, but that result is not surprising based on the complex nature of infiltration of water through the soil near each sensor. Figure 18 compares the cumulative RF and ET ref for Year 4. The data for the short time period in Year 5 in Figures 19 to 23 shows some response at shallow sensors to the RF event in late June 2022.

Figures 24 to 33 display the Year 4 and early Year 5 data for the Fuller sites. In Year 4, the soil moisture sensor responses were somewhat similar at all three sites. The upper three probes responded to the rainfall events in both years, but the lowest P5 remained stable across both years. Cumulative ET ref greatly exceeded the cumulative rainfall in Year 4, again indicating little chance for deeper recharge. The Year 5 data showed responses to the early July rainfall events at P1 for F1 and F2, but no deeper response.

Other Analysis of Previous Data

The current year contract allowed for a limited amount of student worker time to prepare graphs of vertical distribution of soil moisture at the different locations and their sites over time. The student developed monthly figures for the 1st, 11th, and 21st day of each month showing the soil moisture content on the horizontal axis and depth on the vertical axis for all of the data from the summer of 2018 through the summer of 2021. Figure 34 shows an example from site D2 at the Dohmann location for the three dates across the month of December in 2018. The shapes for the three dates are similar, but the later two dates show small increases in soil moisture from the 12/1/2018 line. The Dohmann WS recorded 3.73 in on 12/7/2018. Figure 35 shows the vertical variations in soil moisture for 12/1/2018 before the rainfall event, then four dates 12/8-11/2018 after the rainy day, then 12/21/2018. Much larger changes in soil moisture are seen in the shallower sensor depths, and the slow increase in the soil moisture at the P5 depth is also visible. At this time, we have over 130 of these figures prepared, too many for inclusion in this brief report. We will find a way to present them in the coming year if the GCGCD chooses to continue this work.

Next Steps

Dr. Rainwater just retired from TTU effective August 31, 2022. As a retiree, Dr. Rainwater does not have access to the field equipment used to install the equipment at the three locations. He is happy to continue working the GCGCD to complete the field work and eventual data analyses to improve the estimates of potential groundwater recharge to the aquifers of interest. If the GCGCD wishes to continue this monitoring and reporting work with the GCGCD staff with occasional field visits by Dr. Rainwater for maintenance of the instrumentation, the next contract will have to be a simple consulting contract with Dr. Rainwater. Dr. Rainwater provided a proposal for that type of contract to the GCGCD in August 2022.

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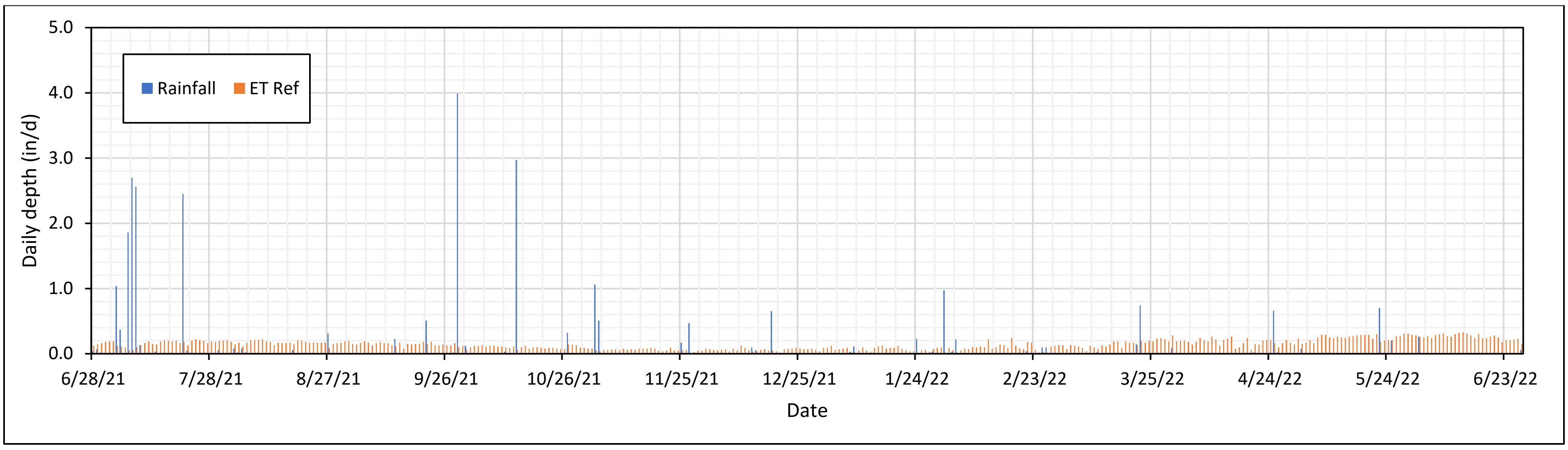


Figure 4. Landgrebe daily rainfall and ET ref June 28, 2021 to June 27, 2022

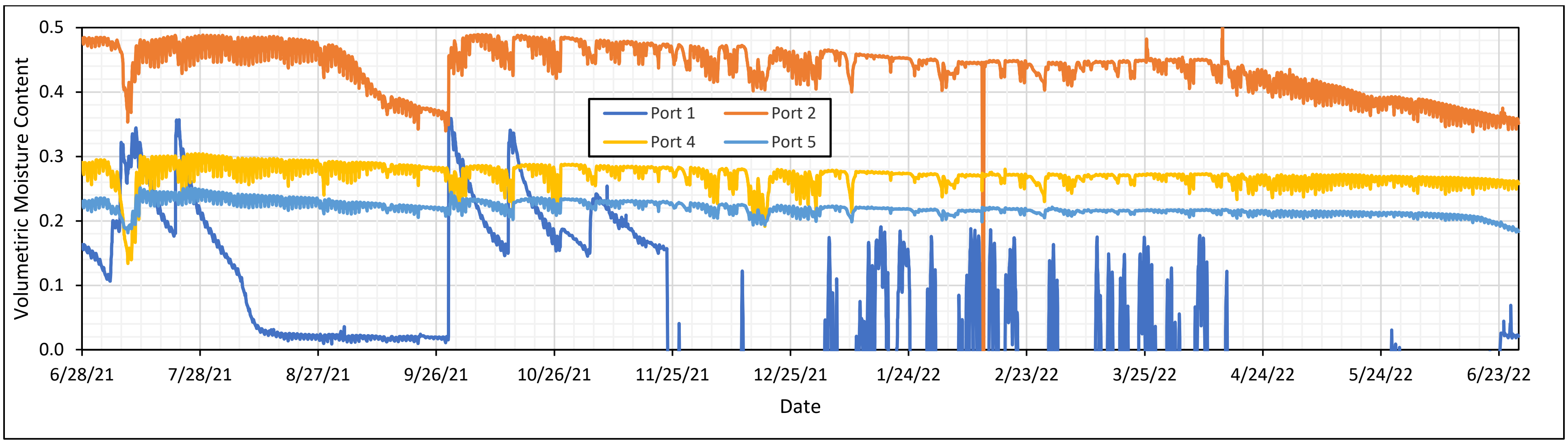


Figure 5. Landgrebe L1 soil moisture probes June 28, 2021 to June 27, 2022

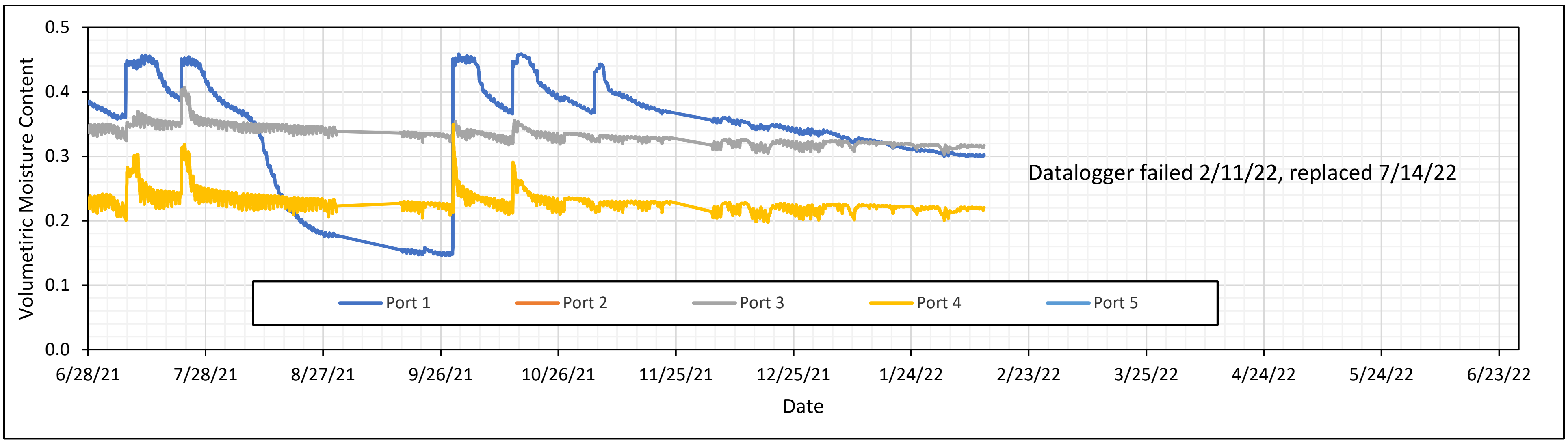


Figure 6. Landgrebe L2 soil moisture probes June 28, 2021 to June 27, 2022

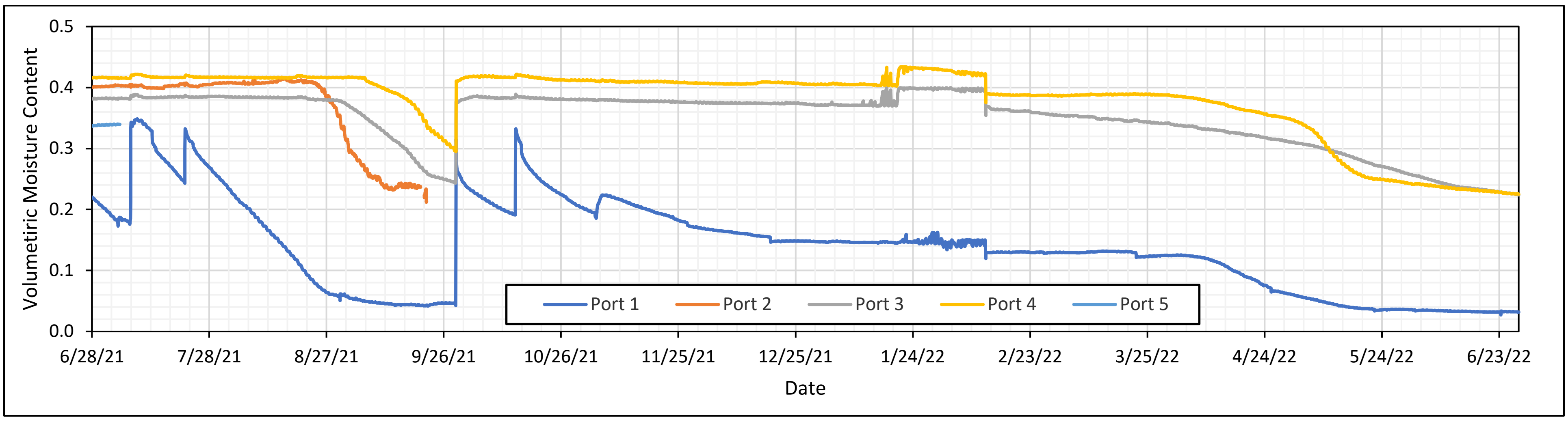


Figure 7. Landgrebe L3 soil moisture probes June 28, 2021 to June 27, 2022

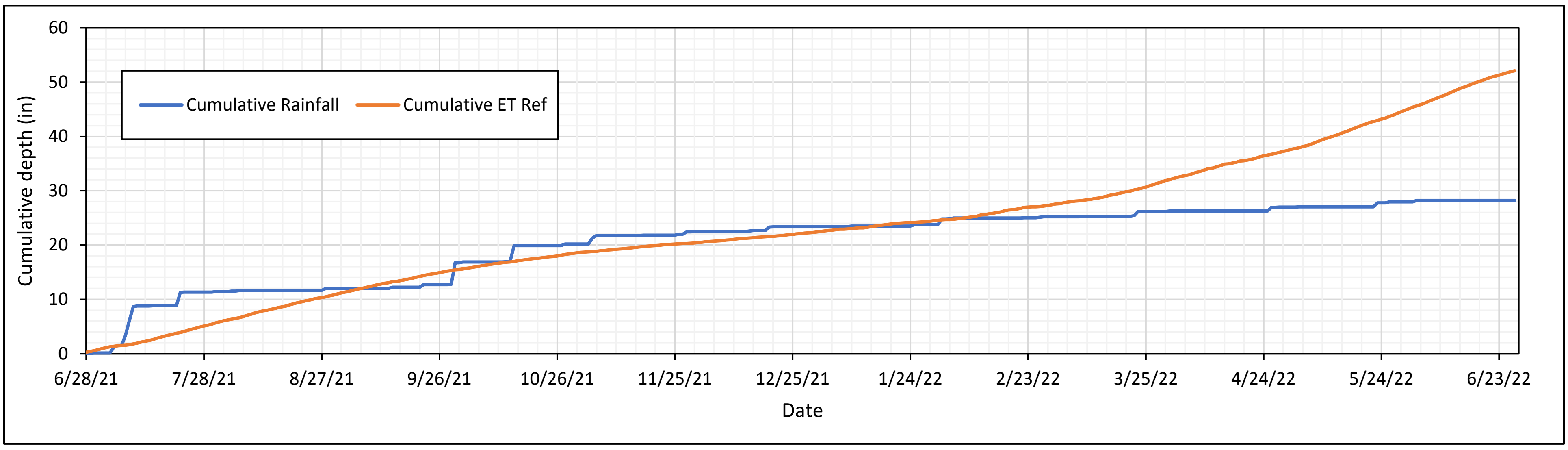


Figure 8. Landgrebe cumulative rainfall and ET ref June 28, 2021 to June 27, 2022

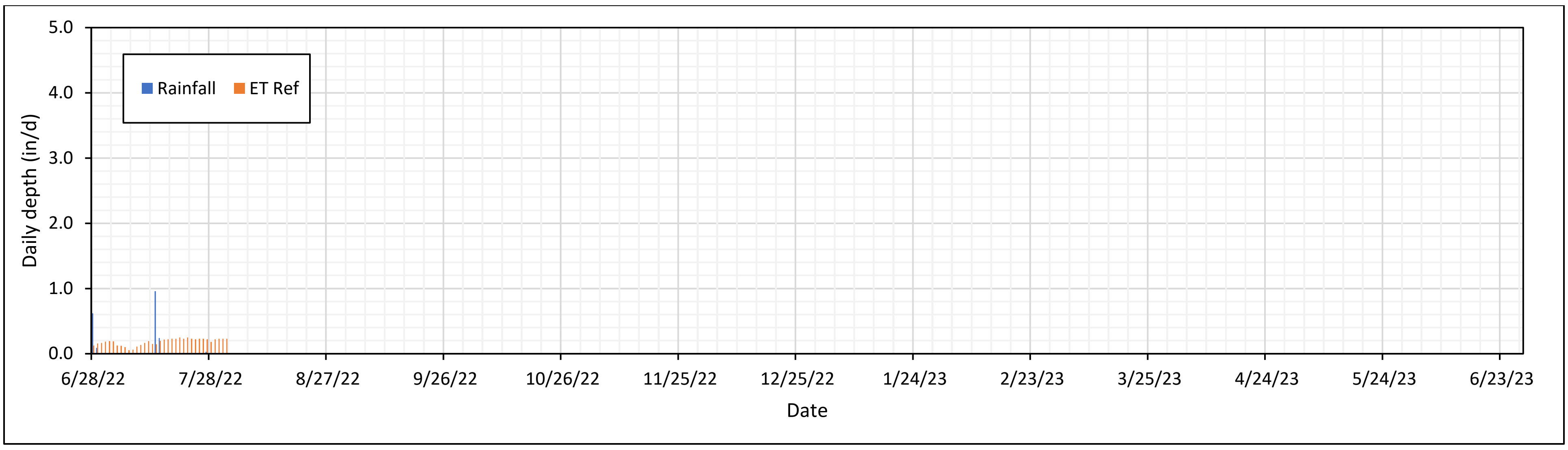


Figure 9. Landgrebe daily rainfall and ET ref June 28, 2022 to August 2, 2022

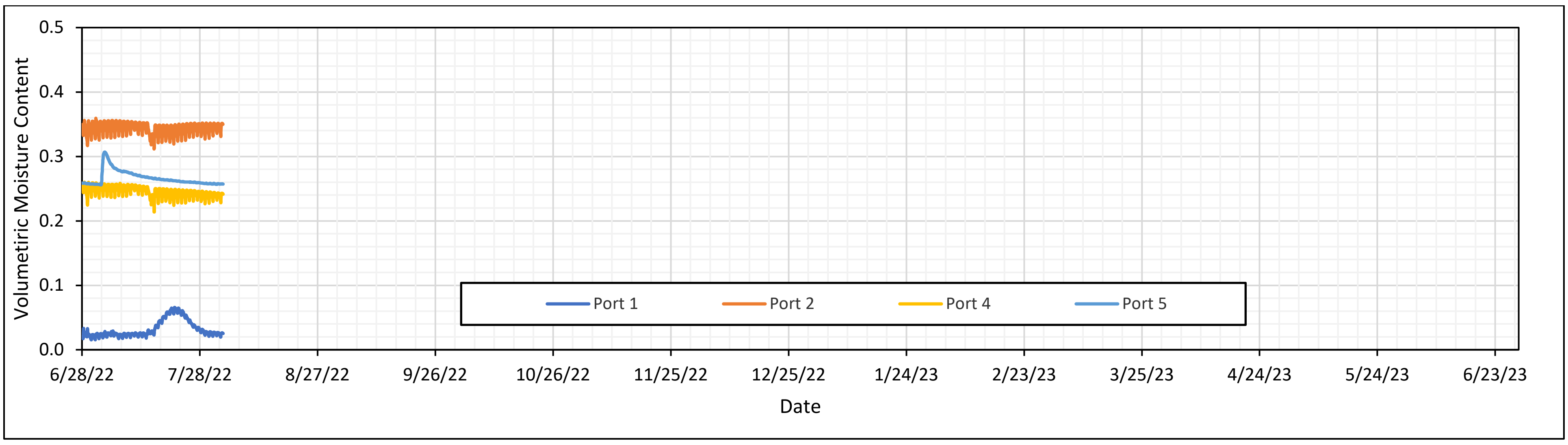


Figure 10. Landgrebe L1 soil moisture probes June 28, 2022 to August 2, 2022

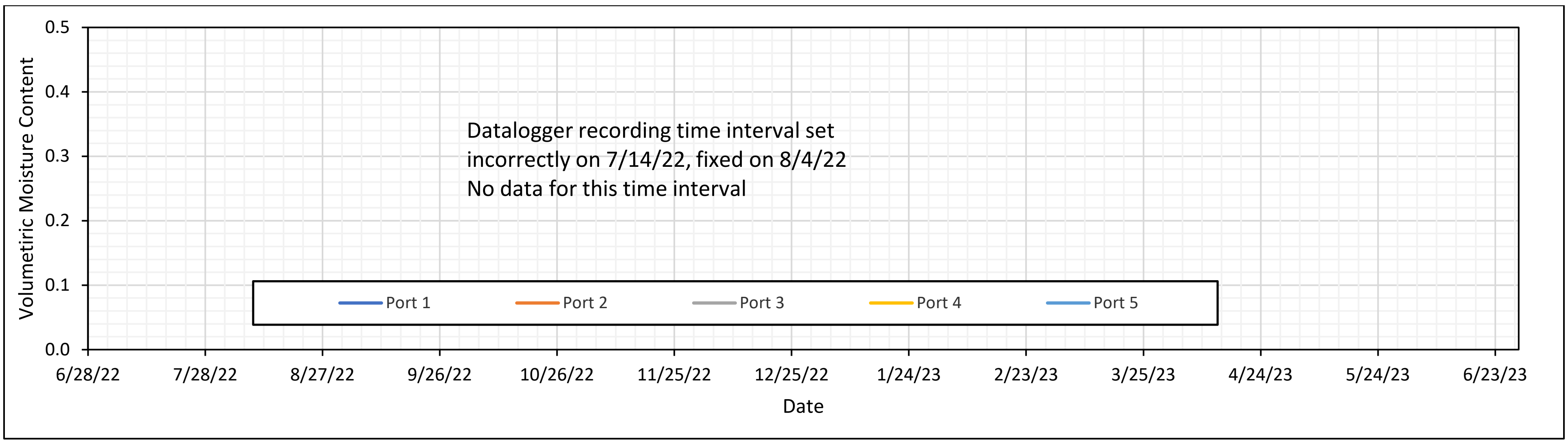


Figure 11. Landgrebe L2 soil moisture probes June 28, 2022 to August 2, 2022

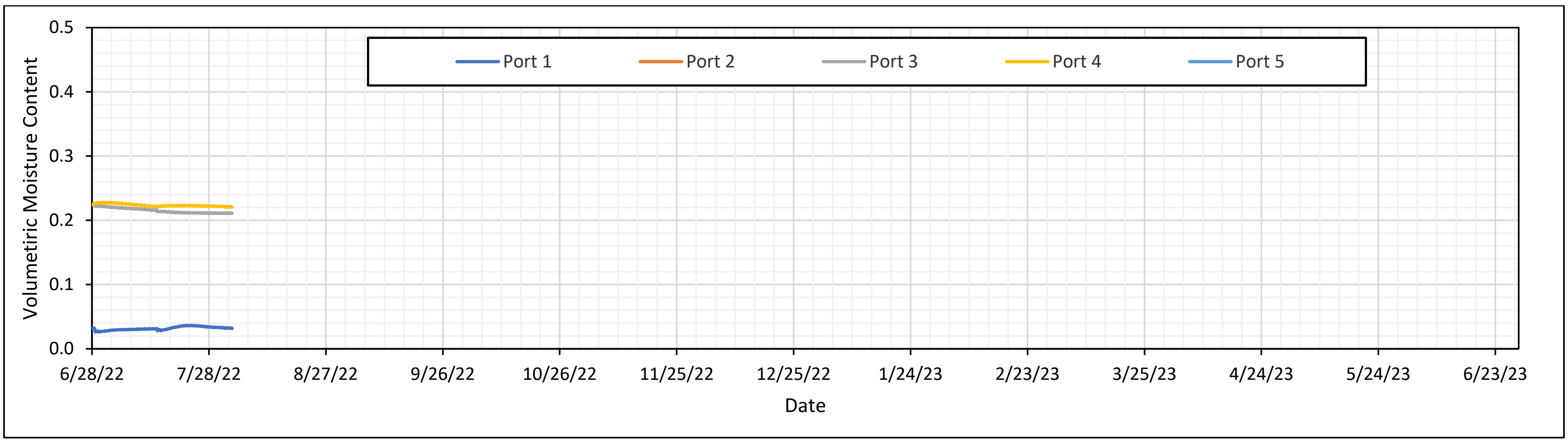


Figure 12. Landgrebe L3 soil moisture probes June 28, 2022 to August 2, 2022

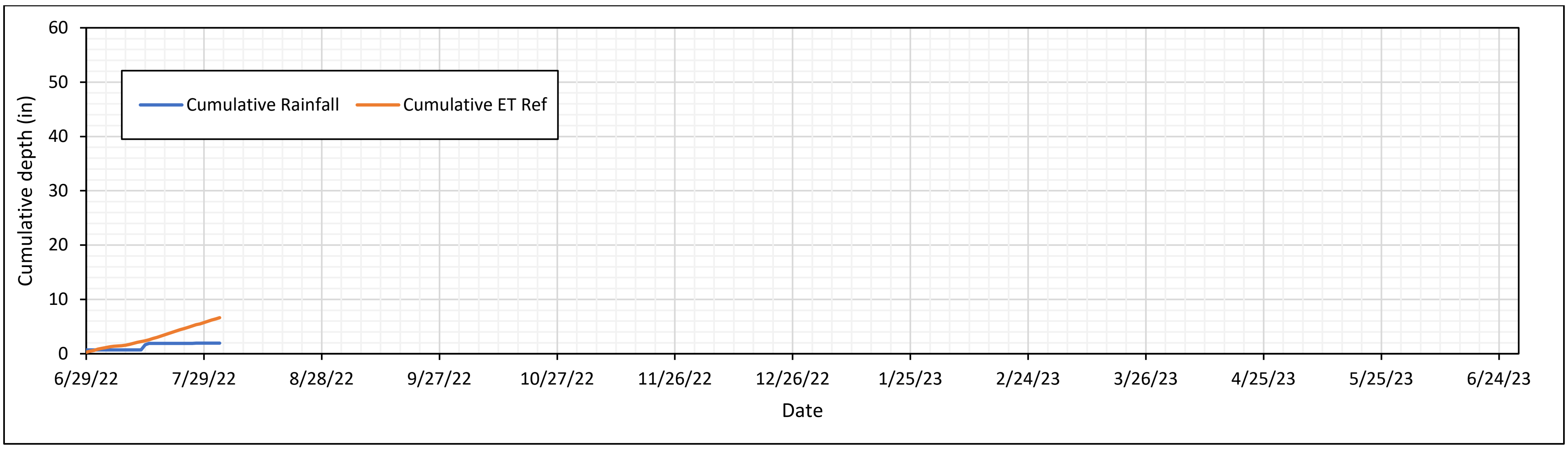


Figure 13. Landgrebe cumulative rainfall and ET ref June 28, 2022 to August 2, 2022

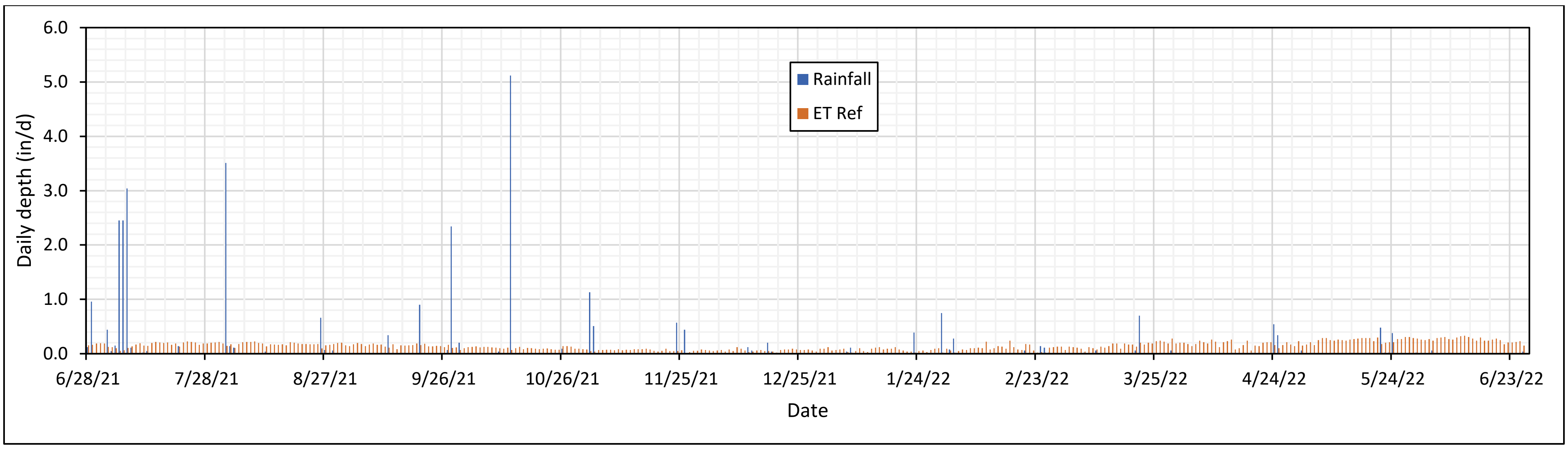
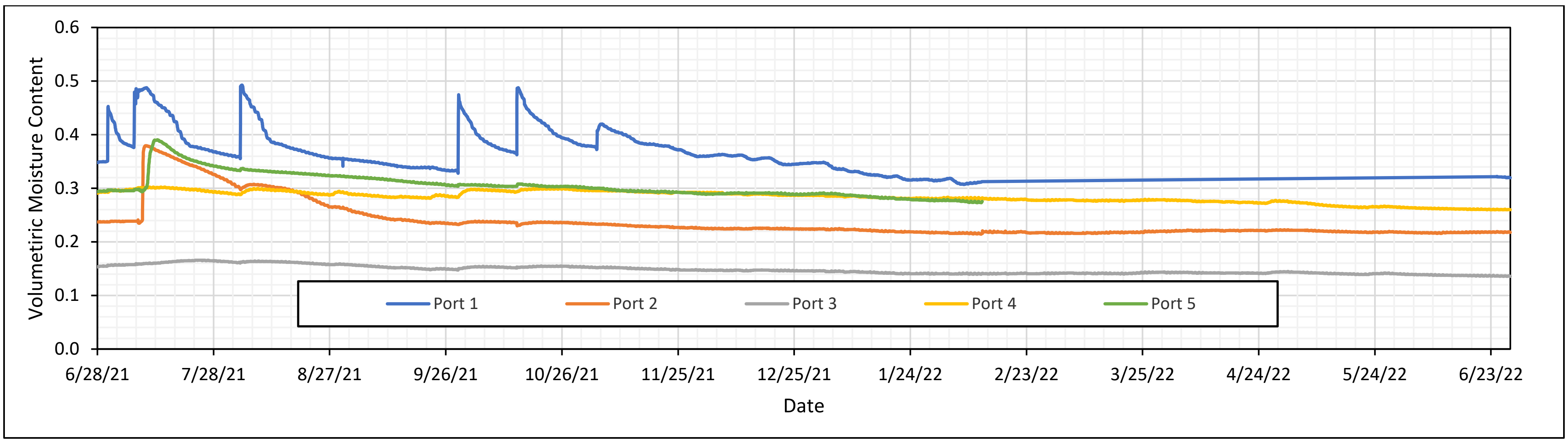


Figure 14. Dohmann daily rainfall and ET ref June 28, 2021 to June 27, 2022



15. Dohmann D1 soil moisture probes June 28, 2021 to June 27, 2022

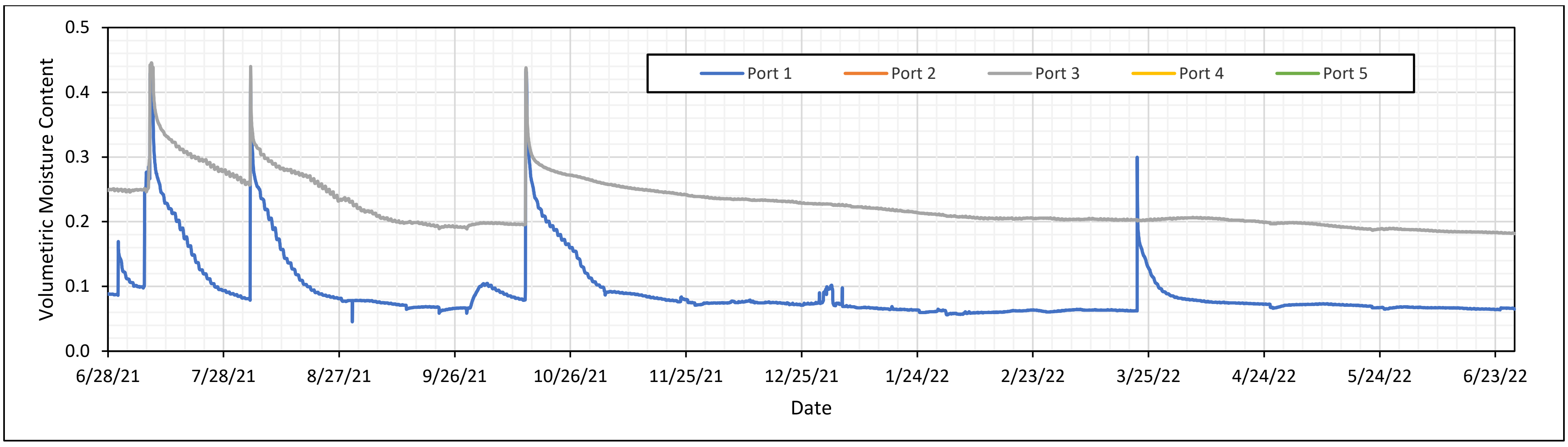


Figure 16. Dohmann D2 soil moisture probes June 28, 2021 to June 27, 2022

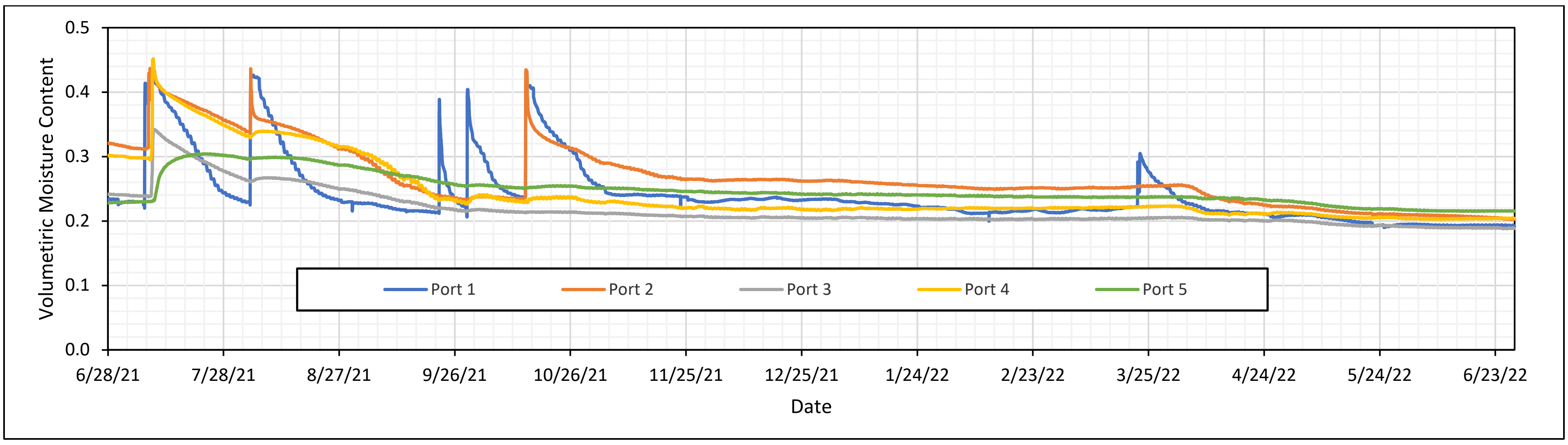


Figure 17. Dohmann D3 soil moisture probes June 28, 2021 to June 27, 2022

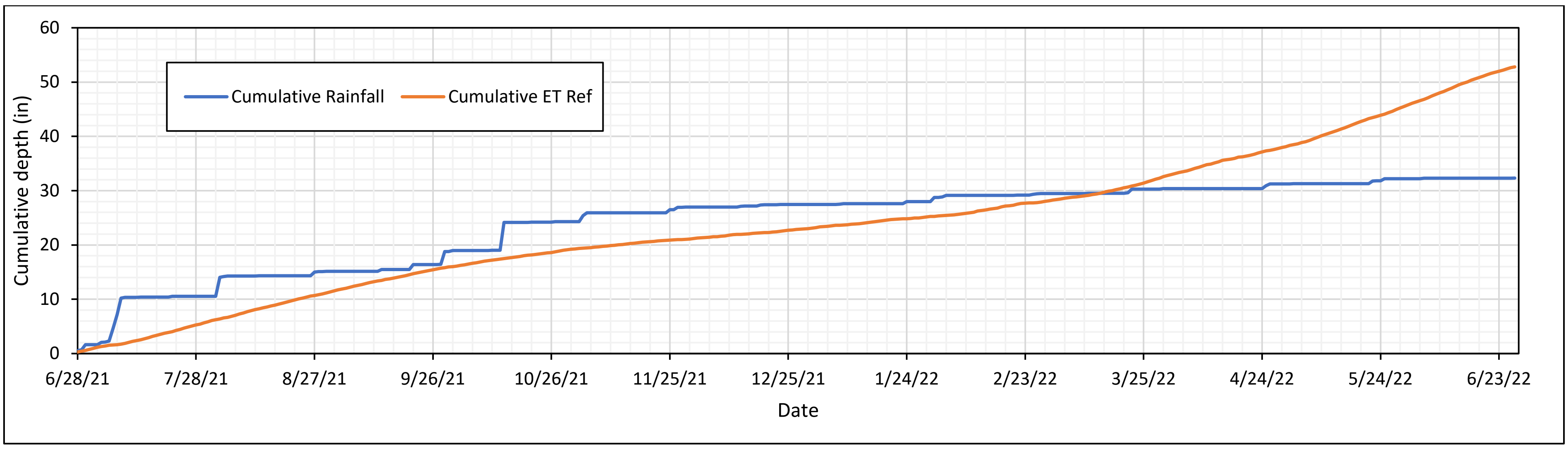


Figure 18. Dohmann cumulative rainfall and ET ref June 28, 2021 to June 27, 2022

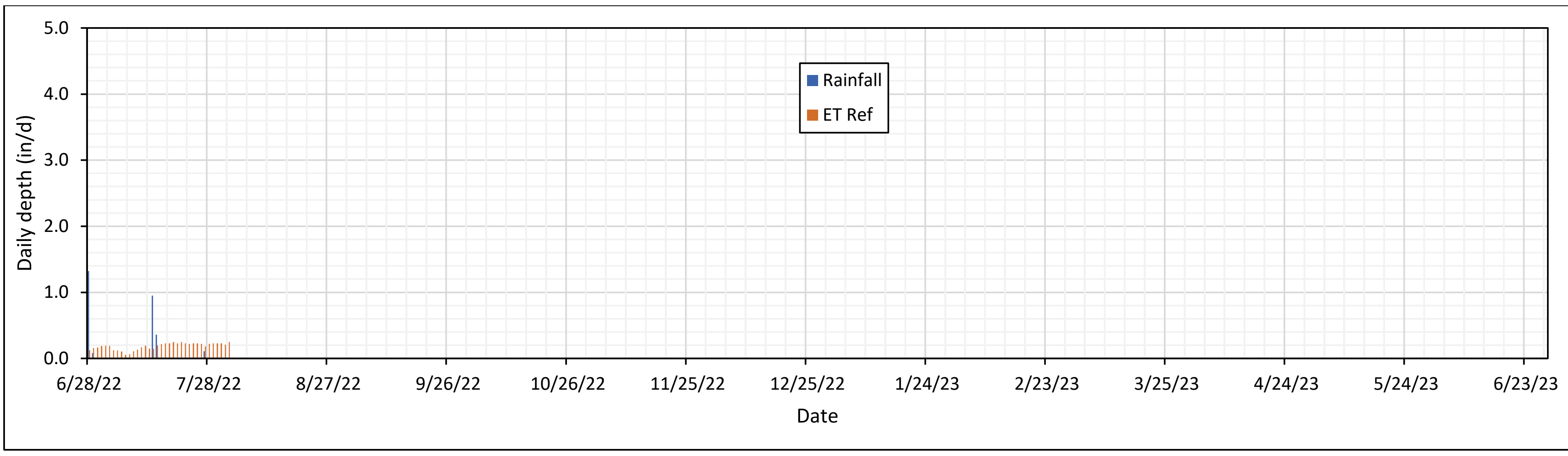
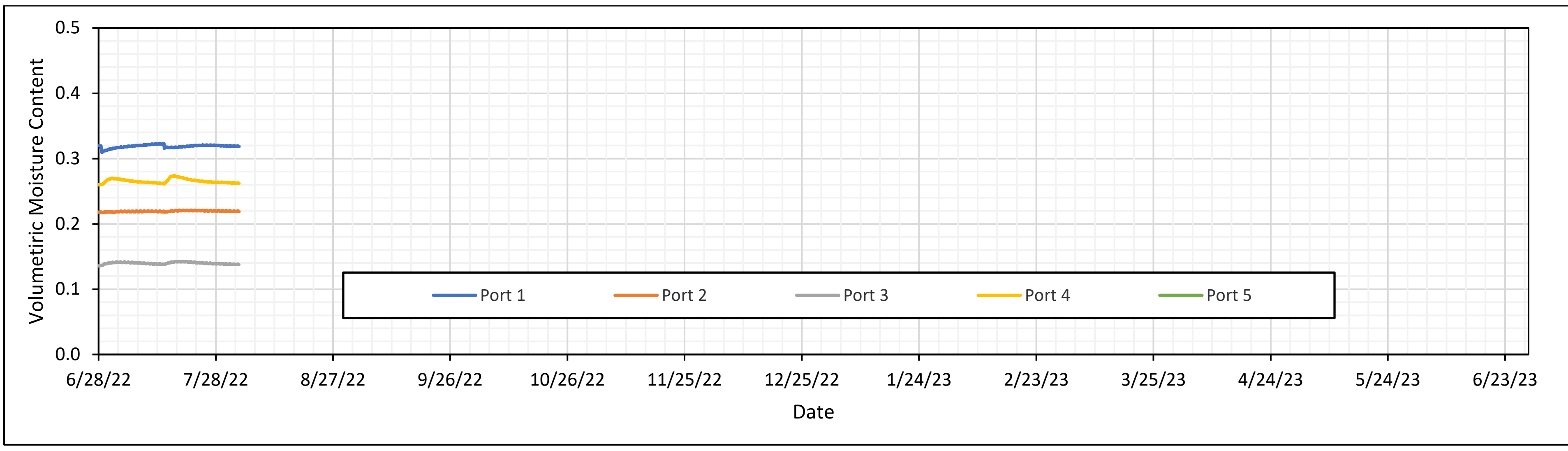


Figure 19. Dohmann daily rainfall and ET ref June 28, 2022 to August 2, 2022



20. Dohmann D1 soil moisture probes June 28, 2022 to August 2, 2023

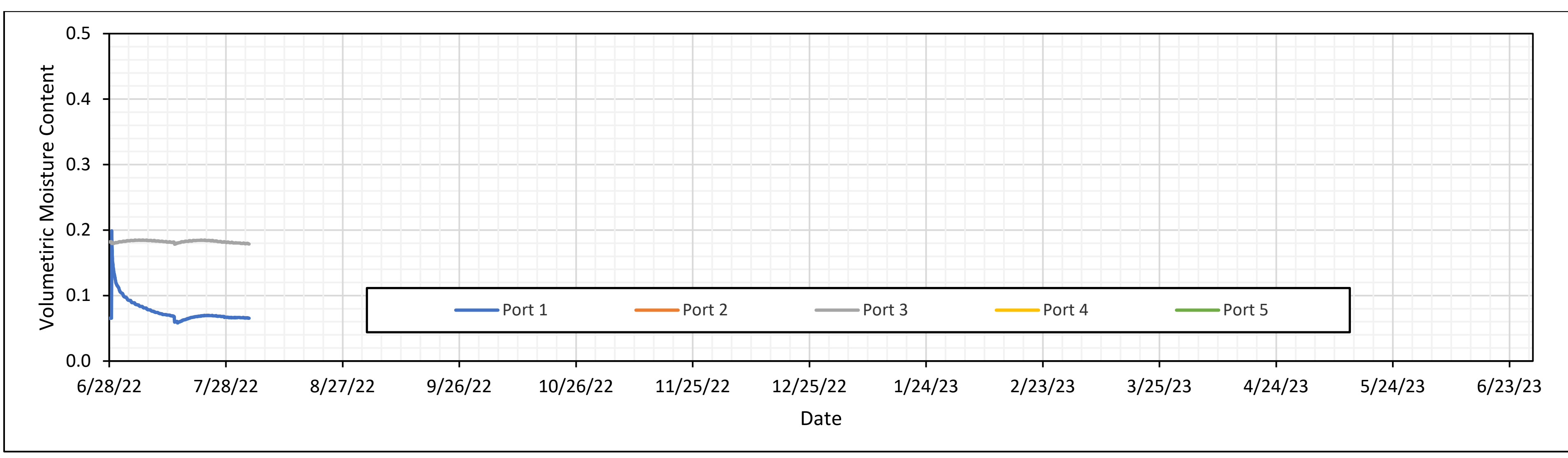


Figure 21. Dohmann D2 soil moisture probes June 28, 2022 to August 2, 2023

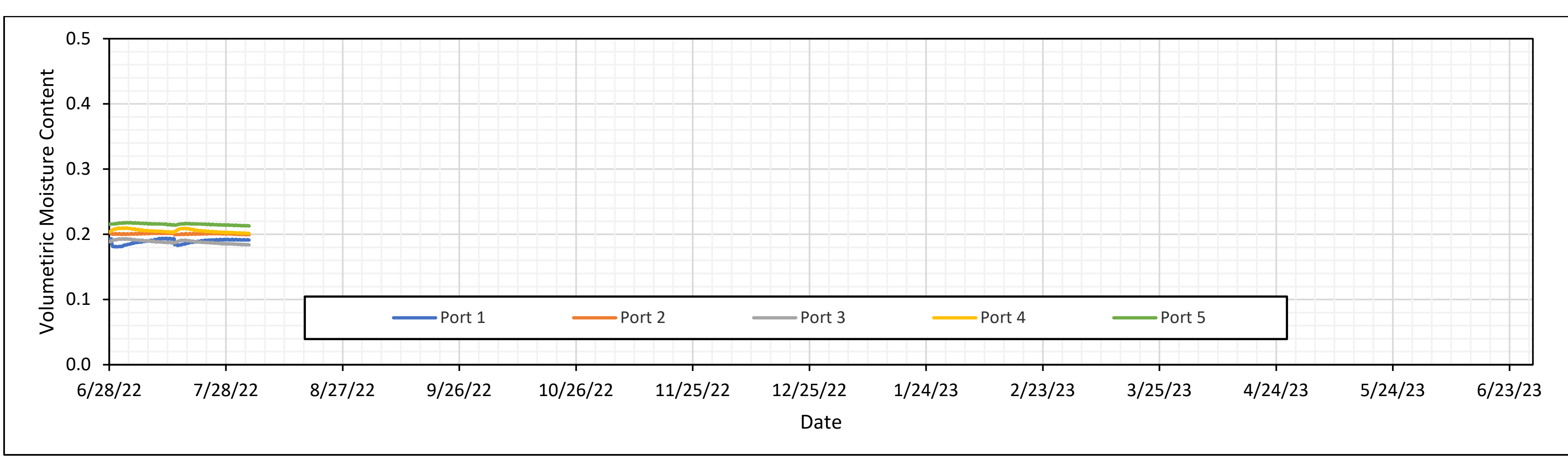


Figure 22. Dohmann D3 soil moisture probes June 28, 2022 to August 2, 2022

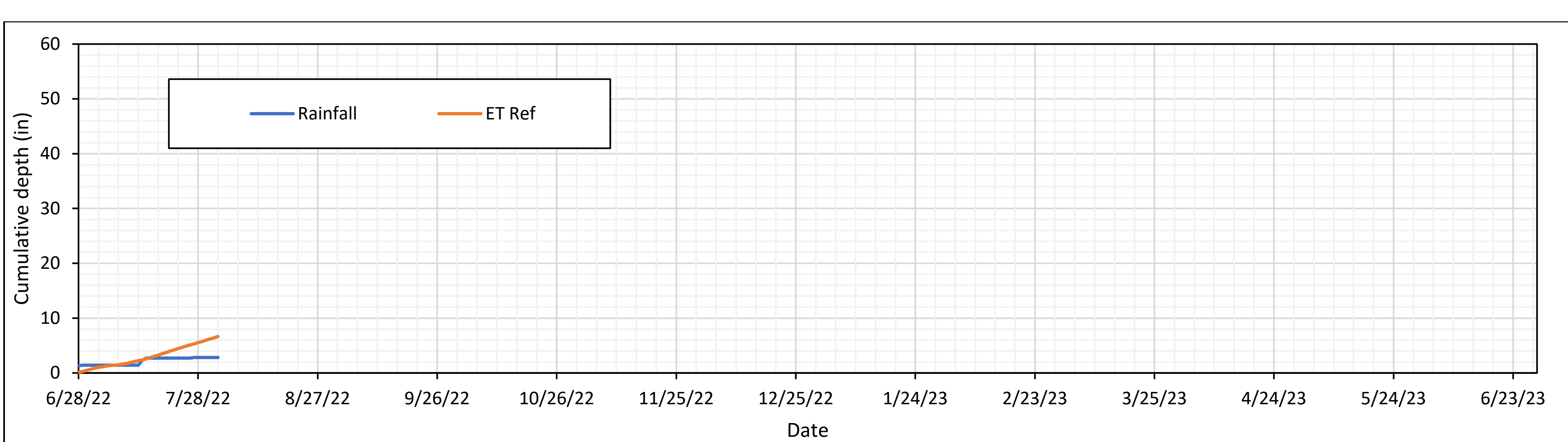


Figure 23. Dohmann cumulative rainfall and ET ref June 28, 2022 to August 2, 2022

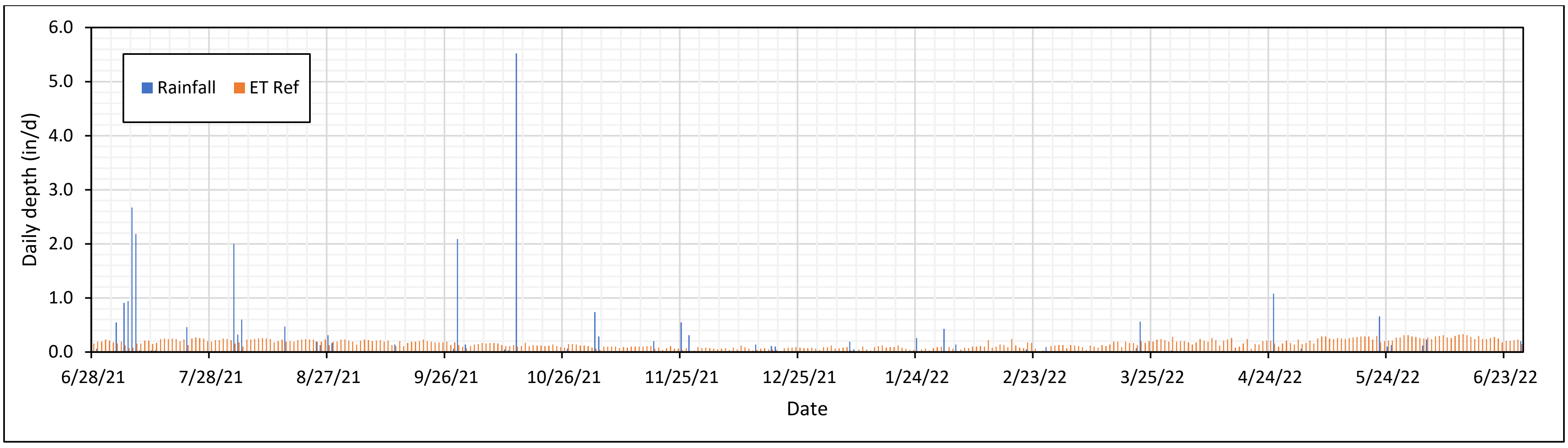


Figure 24. Fuller daily rainfall and ET ref June 28, 2021 to June 27, 2022

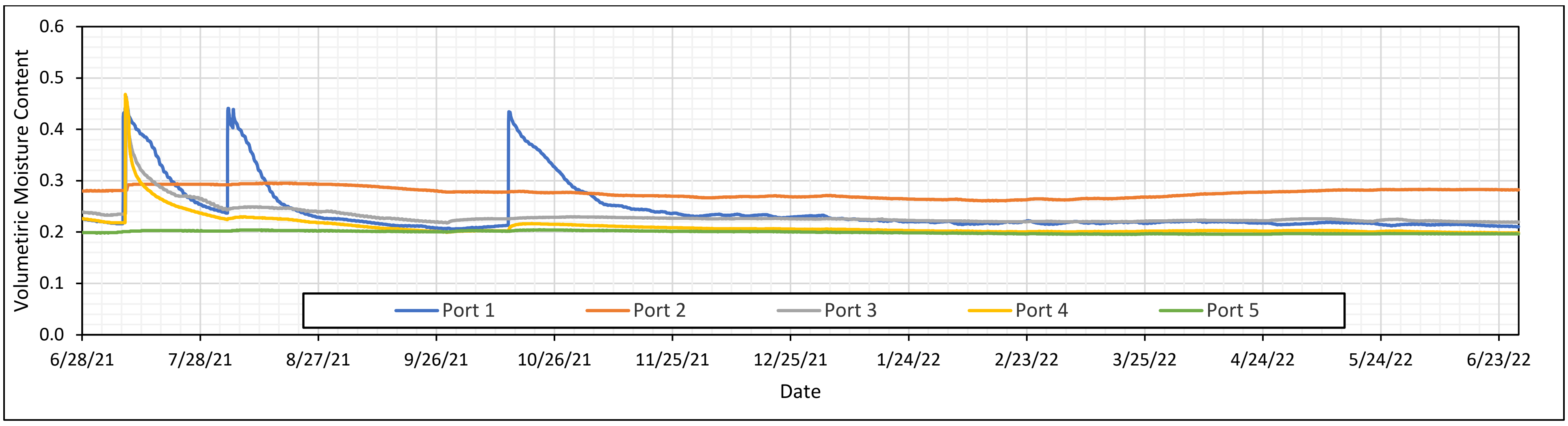


Figure 25. Fuller F1 soil moisture probes June 28, 2021 to June 27, 2022

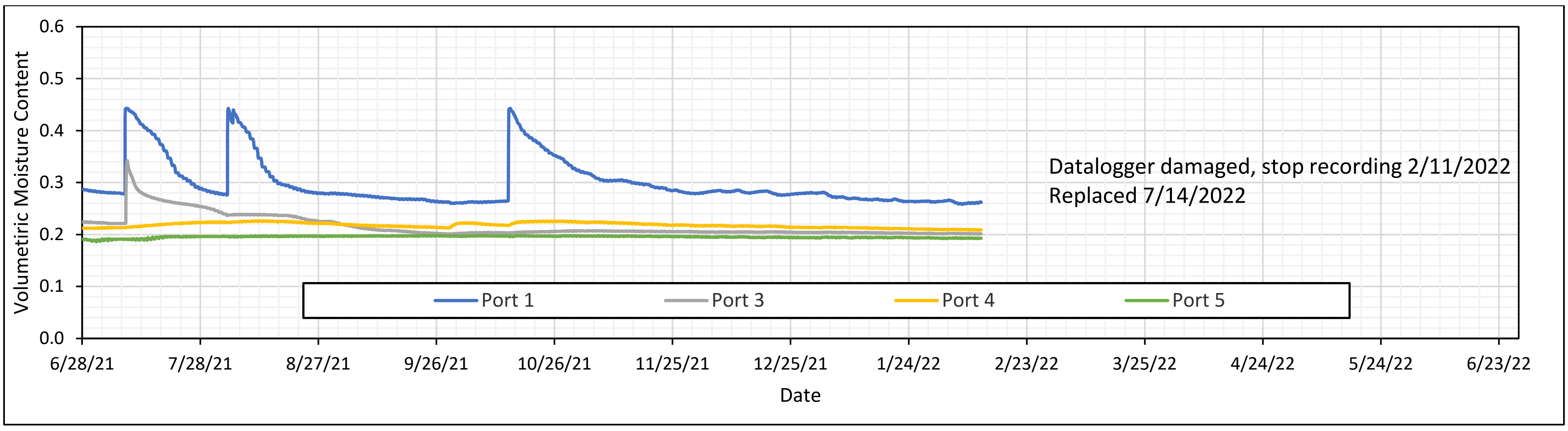


Figure 26. Fuller F2 soil moisture probes June 28, 2021 to June 27, 2022

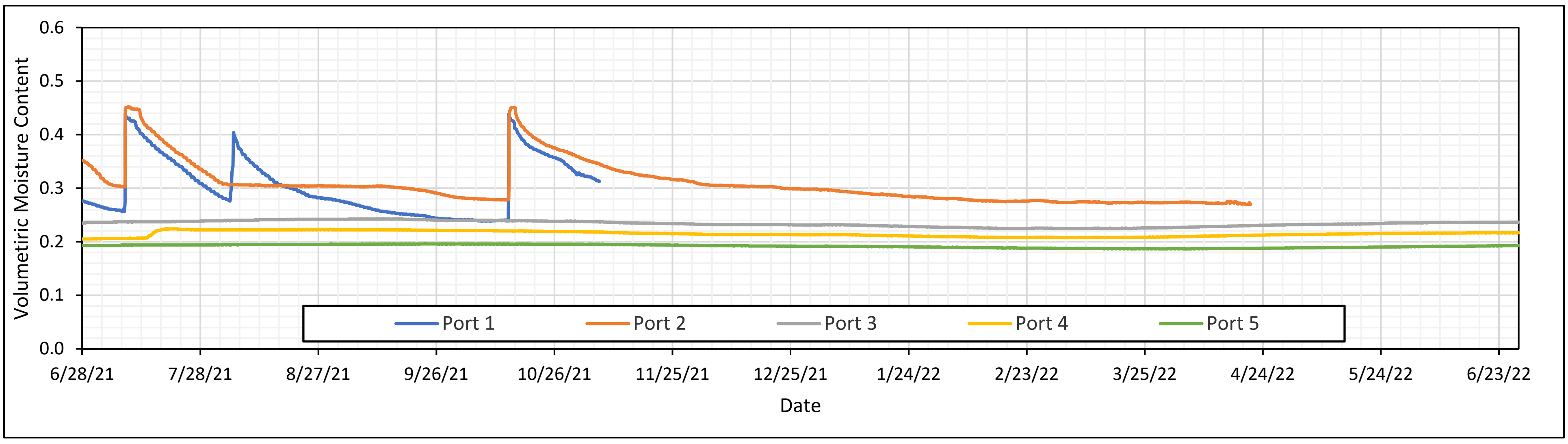


Figure 27. Fuller F3 soil moisture probes June 28, 2021 to June 27, 2022

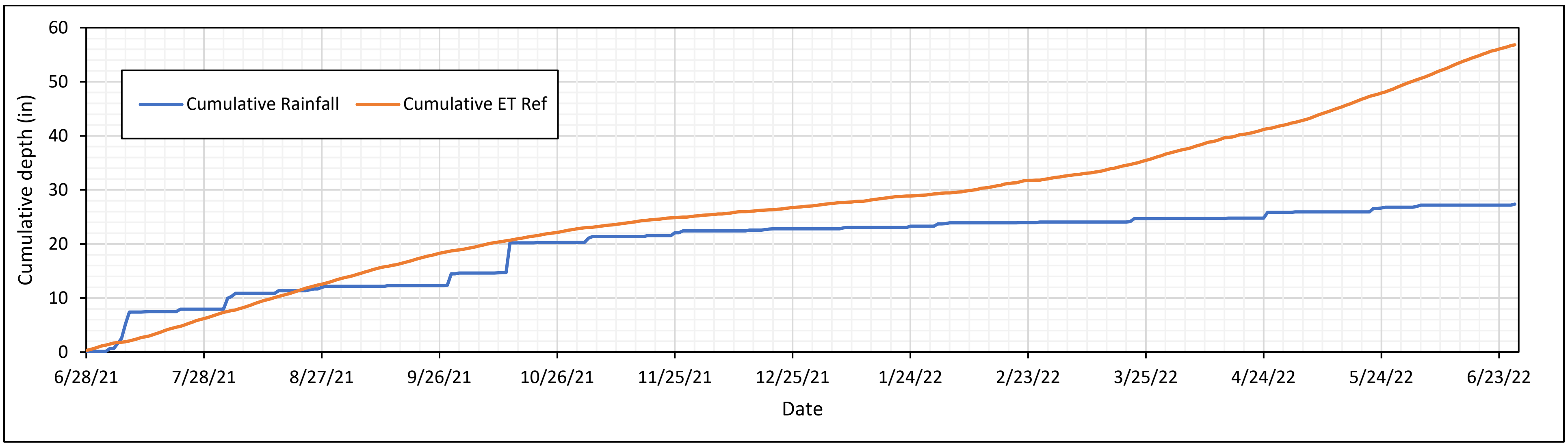


Figure 28. Fuller cumulative rainfall and ET ref June 28, 2021 to June 27, 2022

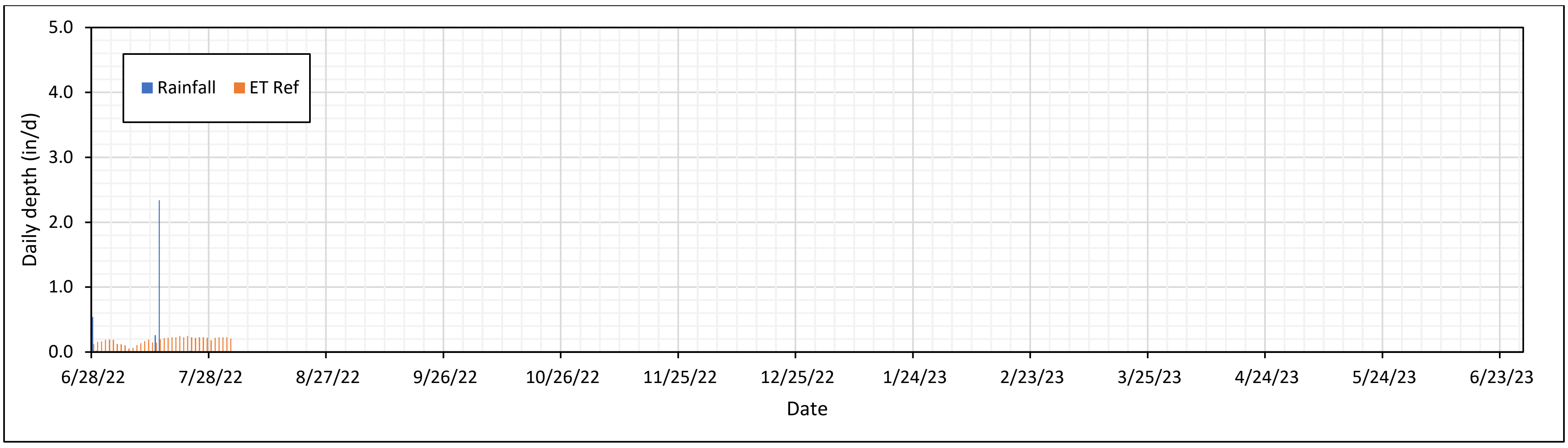


Figure 29. Fuller daily rainfall and ET ref June 28, 2022 to August 2, 2022

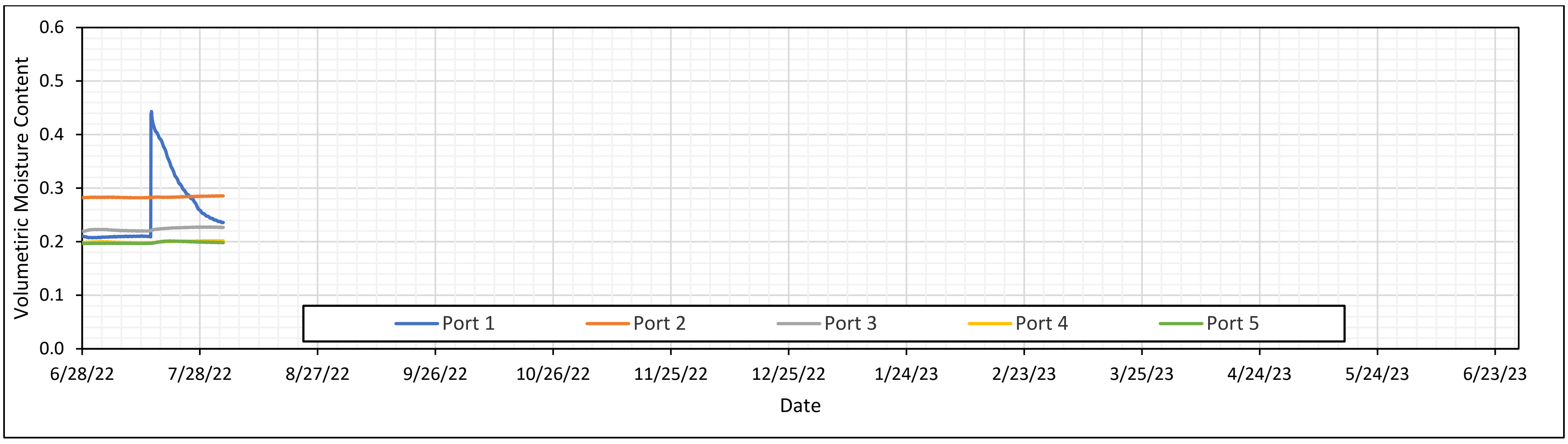


Figure 30. Fuller F1 soil moisture probes June 28, 2022 to August 2, 2022

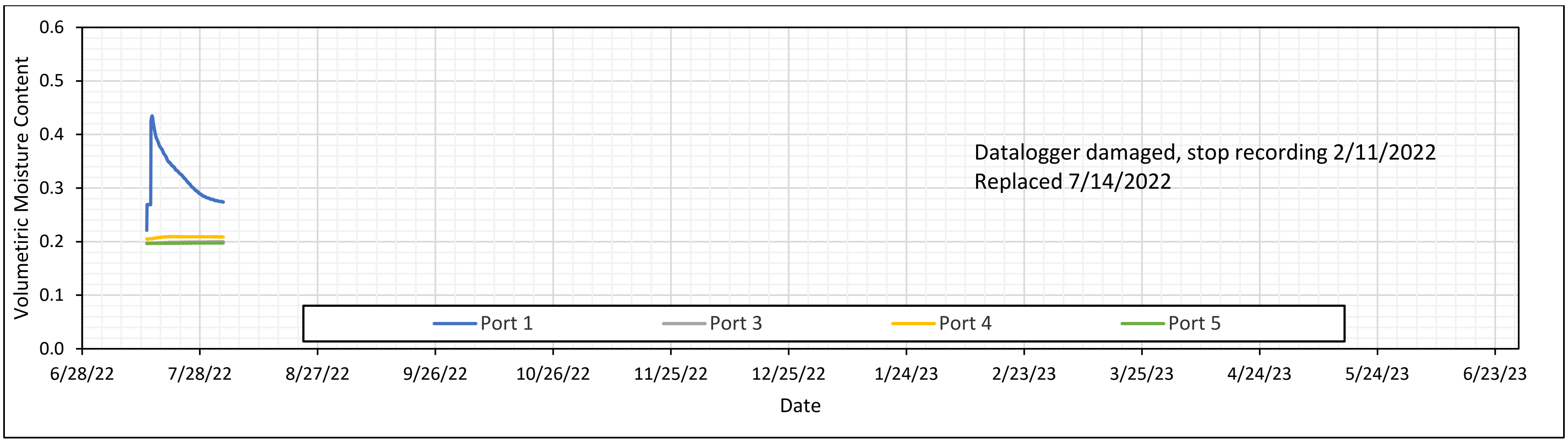


Figure 31. Fuller F2 soil moisture probes June 28, 2022 to August 2, 2022

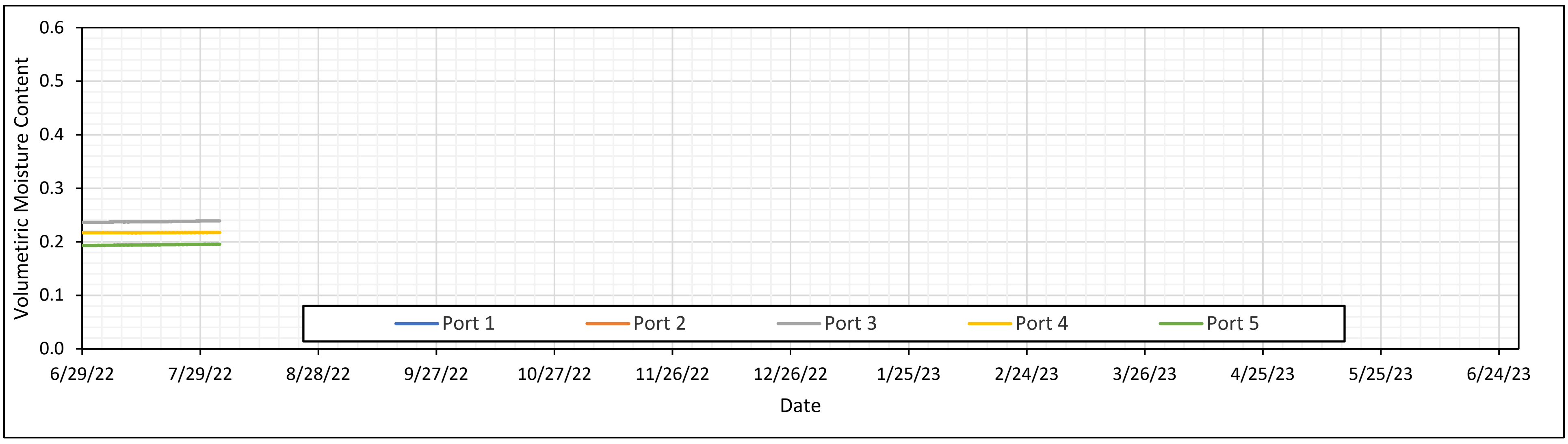


Figure 32. Fuller F3 soil moisture probes June 28, 2022 to August 2, 2022

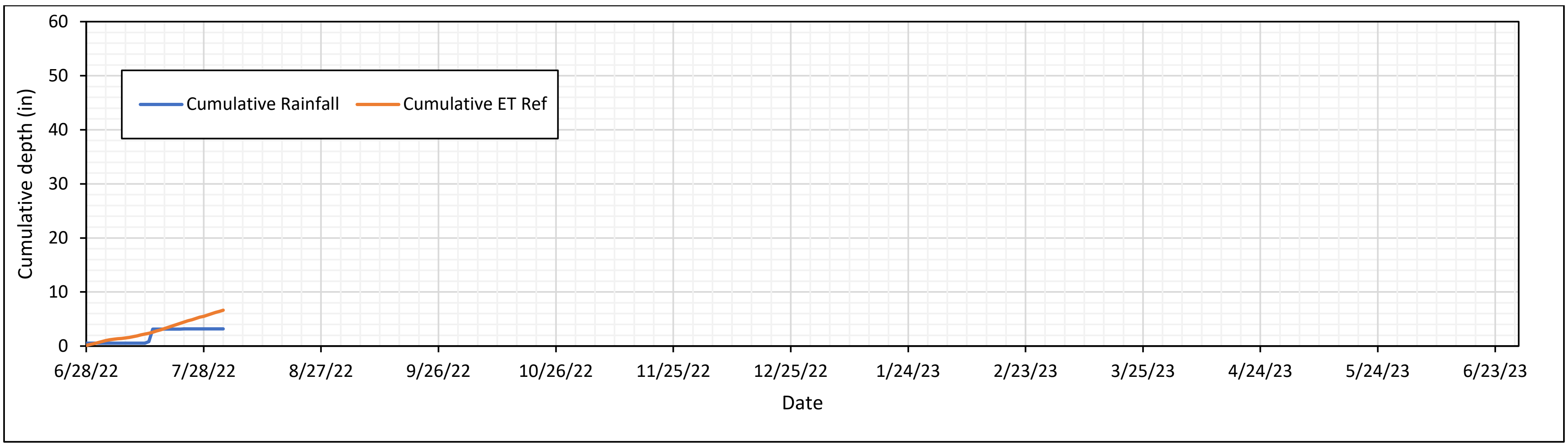


Figure 33. Fuller cumulative rainfall and ET ref June 28, 2022 to August 2, 2022

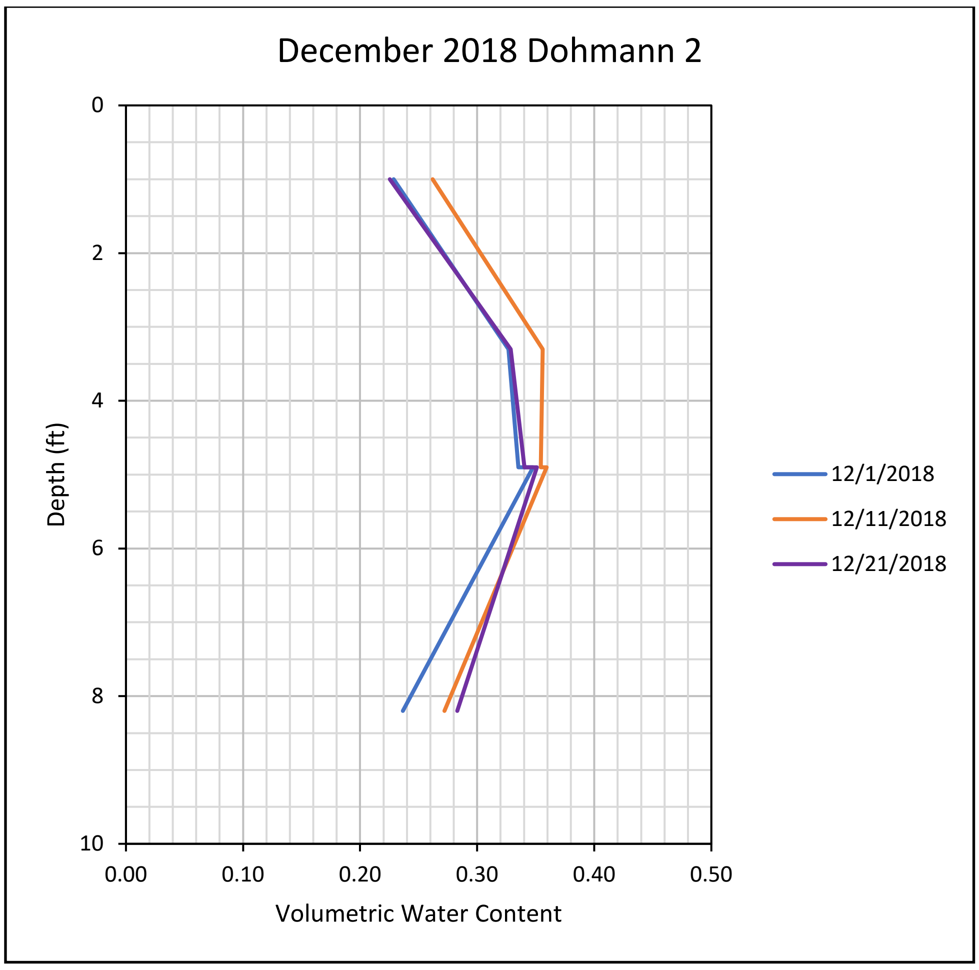


Figure 34. Vertical distribution of soil moisture as volumetric water content for D2 for three dates in December 2018

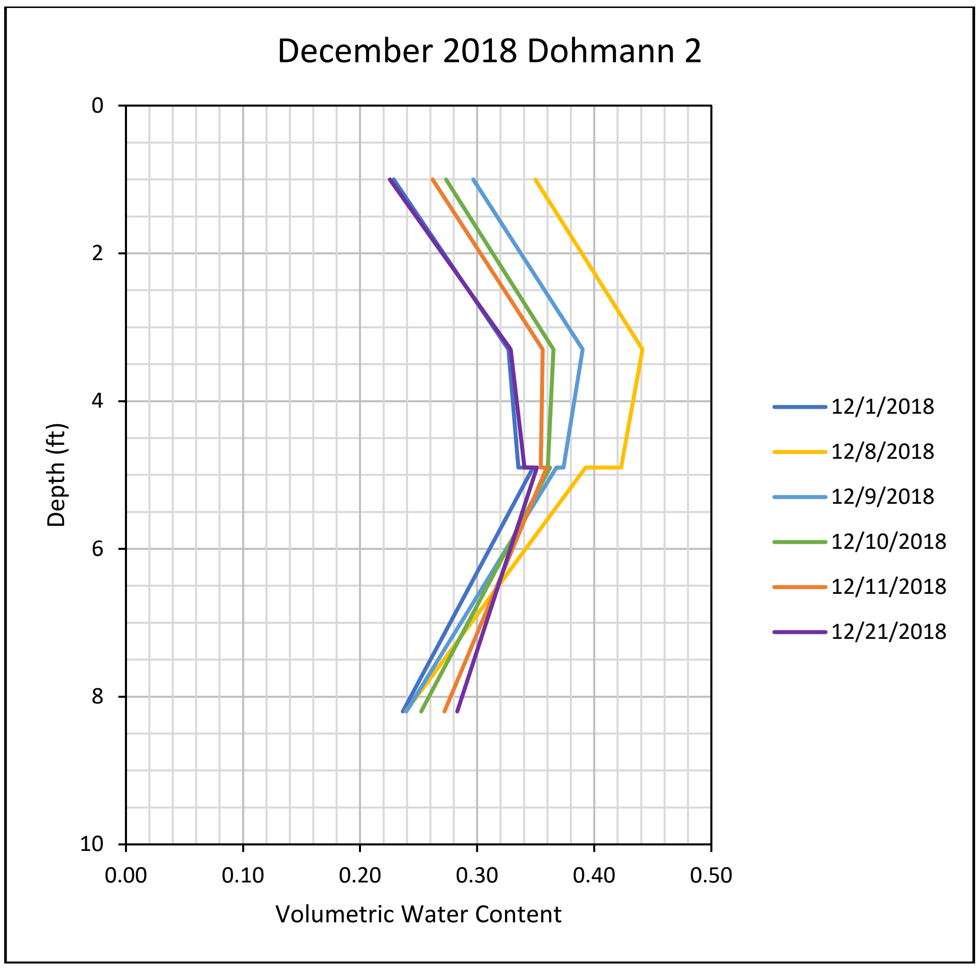


Figure 35. Vertical distribution of soil moisture as volumetric water content for D2 for selected dates in December 2018 near 12/7/18 rainfall event of 3.73 in