Cannington, Mandurah and Northam greyhound racing tracks: Report 3 – Track surface maintenance

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Executive summary

The purpose of this Report was to review the track surface maintenance of the Cannington, Mandurah and Northam greyhound tracks. The pre-race existing maintenance data was analysed and correlated with the harrowing depth and harrowing frequency.

The Mandurah greyhound track analyse of the surface moisture and firmness data confirmed that almost all of the readings fell outside the recommended range for producing an optimal racing surface. The moisture content range was lower than the recommended range indicating that the Mandurah greyhound track surface is dryer than optimum. The sand firmness range was also lower than the recommended range indicating the Mandurah greyhound track surface is harder than optimum. The fluctuations in the surface moisture and firmness data between the inside and middle of the track readings were high at several regions around the track.

High fluctuations between the inside and middle track, do not necessarily affect the leading dogs since the leading greyhounds do not experience the change in the surface condition as they tend to run an ideal trajectory around the track. However, the trailing dogs tend to jostle and change direction in a pack to avoid bumping and checking. They thus experience fluctuations in the track surface. This sudden change in the surface condition increases the probability of injuries and over time leads to a higher injury rate.

Harrowing at Mandurah greyhound track in was less than optimal. The sub-surface condition was *critical*, did not fall within the recommended range and had a number of regions with high fluctuations between the inside and middle regions of the track. All of these parameters can contribute to injuries.

The main observations were:

- The sand surface track at Mandurah is both dry and hard;
- The harrowing practice at Mandurah is infrequent;
- The watering management at Mandurah is inappropriate; and
- The *dig test* be replaced by a track profiler.

UTS recommends that:

- RWWA purchase a profiling tool for each track so they can identify and record fractures and/or layers within the track sand prior to racing and trialing;
- RWWA purchase a Clegg hammer for each track so they can measure and record the impact attenuation the track sand prior to racing and trialing;
- RWWA investigate the cause of the errors and take step to improve data collection at the Cannington greyhound track;
- RWWA initiate the collection and recording of relevant track maintenance data at the Northam greyhound track;
- The Mandurah greyhound track Harrowing be conducted every 2 to 3 weeks regardless of the season at the Mandurah greyhound track;
- The Mandurah greyhound track irrigation program to be adjusted to provide additional time for the track surface to absorb the applied water to establish consistent water absorption radially for the entire track;

It is expected that above recommendations led to a homogeneous surface condition, improve the quality of the running surface and therefore decrease the risk of track related injuries at the Mandurah greyhound track[1].

The Cannington greyhound track analysis of the surface moisture and firmness data confirmed that the moisture content readings were off range. Multiple errors in the data were noted suggesting that either the device was faulty, not properly used or there was an issue with data entry. Therefore, the Cannington greyhound track data was not analysed. For the Northam greyhound track there was no data for analysis.

[1]These recommendations were made specifically for the Mandurah greyhound track. Nevertheless they apply equally to the Cannington and Northam Mandurah greyhound tracks.

Contents

1 Injury contributing factors

1.1 Harrowing frequency and depth

Table 1 shows the date, frequency and depth of the harrowing[2] at the Mandurah greyhound track. On average harrowing is conducted every 8 weeks.

Table 1: Mandurah greyhound track harrowing dates, frequency and depths.

Date	Frequency	Depth (mm)
17 Apr 2019	N/A	50 to 70
26 Aug 2019	18 weeks	50 to 70
25 Sep 2019	4 weeks	50 to 70
14 Oct 2019	3 weeks	50 to 70
11 Dec 2019	8 weeks	50 to 70

1.2 Water management

There are three types of irrigation systems: the fixed irrigation system, water trucks/carts/trailers, and a manual irrigation system. Regardless of the irrigation system used, the irrigation management should apply water to the surface in a controlled, even and consistent manner.

Appropriate watering management, coupled with a frequent deep harrow would improve the quality of the surface, as it would allow the water to evenly penetrated into the deeper layers of the sand. The sand profile in this condition would be homogeneous, without fractures or layers.

1.3 Track surface profile inspection

The current method for inspecting the sand surface profile at WAGRA is referred to as the dig test which is performed as: if the curator could not reach a depth of 40 mm with 3 scratches of his index finger the track needed to be harrowed. The standard method, advised by other jurisdiction and recommended by UTS, is called the track surface profile inspection via a sand profiler, which is explained in the following.

Ideally, track surface shall be monitored daily using the sand profiler. The profiler should be inserted into the track in a vertical upright position to a minimum depth of 75 mm and ideally to 150 mm.

[2]Harrowing is also called a 'deep rake'.

Any visible fracture or layers withing the top 35 mm of the surface requires immediate attention. Visible fracture deeper than 50 mm is acceptable. However it is recommended that the suitable practice to be conducted in due time. Figure 1 shows an example of a sand profile which was considered a failure during a track surface profile inspection.

Figure 1: A sample of the track profile which is failed based on the sand profile inspection criteria. Due to the confidentiality purposed, the name of the track is not revealed.

The top 30-35 mm of the track is critical in terms of maintaining safety and performance of the greyhound and therefore, any visible fracture and layers in this region should be addressed. The fractures and layers suggest either shallow harrowing or inappropriate irrigation plan (or combination of both), which does not allow the water to penetrate into deeper layers and causes the observed surface condition.

Performing the so called dig-test at WAGRA, might give useful information on the firmness of the surface, but as the layers cannot be inspected, it cannot provide information about the underneath layers. Accordingly, its strongly recommended that the track surface profile inspection to be performed at WAGRA.

1.4 Sand characteristics

The following Table 2 shows the recommended track sand particle size distribution.

Table 2: Recommended sand particle sizes and percentage.

Fraction	Size (mm)	Percentage (%)
Fine gravel	2.00	0
Very coarse sand	1.00	$< 5\%$
Coarse sand	0.50	10% to 20%
Medium sand	0.25	30% to 40%
Fine sand	0.15	40% to 50%
Very fine sand	0.05	40% to 50%
Silt/clay	< 0.05	$< 5\%$

In the absence of any other information it is recommended that the surface sand particle size and distribution comply with the variable Table 2.

1.5 Review of surface moisture and firmness data

The safe range for surface water content and firmness recommended varies with sand type. The accepted safe range is 22.0% to 32.6%[3] and 270 mm to 535 mm[4], respectively.

In order to review whether the current maintenance practices, harrowing and water management, affect the quality of the surface, the surface condition data 'before' and 'after' each harrowing practice are compared with each other. The quality of the track surface, both in terms of the range of moisture content, the range of sand firmness data and the fluctuation between inside and middle readings are compared, before and after the harrowing practice.

The fluctuation between inside and middle track readings is calculated at different vicinity of the track. having high fluctuation between the inside and middle track surface properties, might not affect the leading dogs as they tend to run over the same lane all through the race. However, the trailing dogs tend to jostle and change direction to avoid bumping and checking. They experience different

[3]One recommendation for sand moisture content range is 22.0% to 28.6% while another recommends 26.0% to 32.6%. Track surface sand varies from jurisdiction to jurisdiction and the sand used by WAGRA is quite different to that used in the Eastern States and further analysis is required to determine its safe operating range.

[4]The instrument to measure track firmness in WAGRA is the FieldScout Turf Firmness Meter, where firmness is measured as the depth of travel.

running surface in the course of the stride and sudden change in the surface condition may contribute to injuries.

It is hypothesised that if the moisture content range, does not fall within the recommended range, the surface is not an optimal surface to race and may contribute to injuries.

It is also hypothesised that if the firmness data range does not fall within the recommended range, the surface is not an optimal surface to race and may contribute to injuries.

It is further hypothesised that the high fluctuations in both moisture content and firmness between the inside and middle track surface data may contribute to injuries.

2 Mandurah greyhound track

UTS was provided with a copy of the sand moisture and firmness data were recorded before each race event at Mandurah track from July 2018 to April 2020.

2.1 Harrow: 17 April 2019

The surface moisture and firmness data before (12 April 2019) and after (18 April 2019) the harrowing practice at Mandurah track, are compared with each other.

The surface moisture content range before the first harrow was 14.9% to 21.3%[5], which does not fall within the recommended range[6]. The data show that the surface is dry suggesting issue with the watering management.

The surface firmness range before the first harrow was 188 mm to 494 mm which does not fall within the recommended range[7]. The data show that the surface is harder than the recommended range. One reason that might have harden the sand surface is shallow and infrequent harrowing as well as insufficient moisture content, which is required to bond sand particles together.

Sand moisture content is plotted against different locations at the track and given below in Figure 2. Sand firmness data is plotted against different locations at the track and given below in Figure 3.

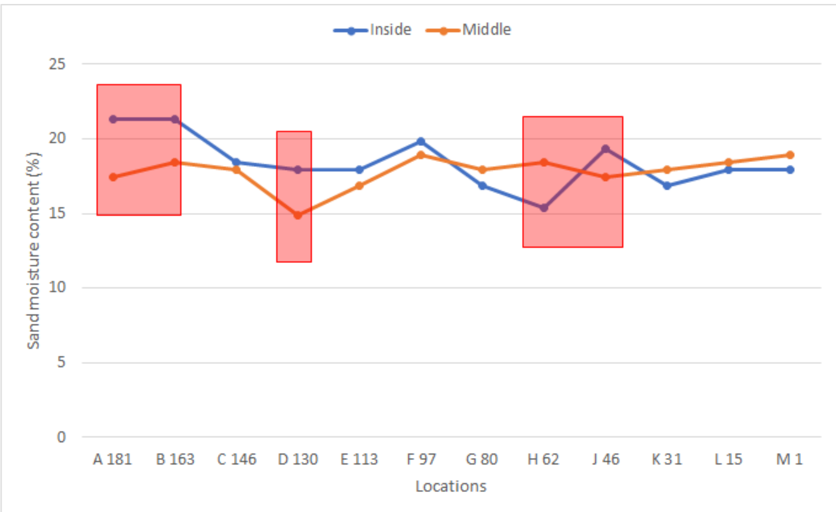


Figure 2: Sand moisture content versus different locations at the Mandurah track (12 April 2019).

[5]Text in red is used to indication test results which fall outside the accept safe range.
[6]The recommended moisture content range is 22.0% to 32.6%
[7]The recommended firmness range is 270 mm to 535 mm.

Figure 3: Sand firmness data versus different locations at the Mandurah track (12 April 2019).

The average of fluctuation between the inside and middle track moisture data is 10%. As it can be seen, the difference between the inside and middle moisture content at locations A and B (22% and 16%), D (20%), H and J (16% and 11%) are higher than the average.

The average of fluctuation between the inside and middle track moisture data is 25%. As it can be seen, the difference between the inside and middle firmness data at locations A and B (39% and 52%), G (33%), H and J (32% and 29%) are higher than the average.

Having high fluctuation between the inside and the middle track surface properties, would expose trailing greyhounds to a running surface with different properties as they tend to jostle and change direction to avoid bumping and checking. Any sudden change in the surface condition may contribute to injuries.

The surface moisture content range after the first harrow was 16.4% to 23.3%, which does not fall within the recommended range. The data show that there was a slight improvement in data after the harrowing[8]. However the surface is still dry suggesting possible issue with the watering management.

The surface firmness range after the first harrow was 312 mm to 576 mm, which does not fully fall within the recommended rang. The data show that there was a slight improvement in firmness data (the surface is slightly softer than before). However the surface is still harder than the recommended range. One reason that might have harden the sand surface is shallow and infrequent harrow as well as insufficient moisture content, which is required to bond sand particles together.

[8]Frequent and deep harrowing coupled with appropriate irrigation program, would improve the sand water retention.

Sand moisture content is plotted against different locations at the track and given below in Figure 4. Sand firmness data is plotted against different locations at the track and given below in Figure 5.

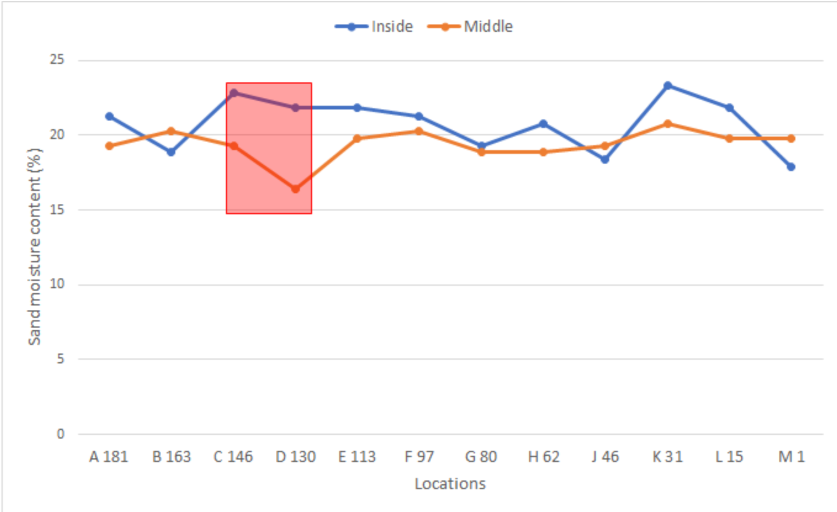


Figure 4: Sand moisture content versus different locations at the Mandurah track–18 April 2019.

Figure 5: Sand firmness data versus different locations at the Mandurah track–18 April 2019.

The average of fluctuation between the inside and middle track moisture data is 11%. As it can be seen, the difference between the inside and middle moisture content at locations C and D (18% and 33%) are higher than the average.

The average of fluctuation between the inside and middle track moisture data is 16%. As it can be seen, the difference between the inside and middle firmness data at locations C (17%), F and G (both 21%), J (34%) and M (44%) are higher than the average.

It seems that the harrowing was successful in terms of making the sand moisture content more homogeneous throughout the track. There are only two regions at the track with moisture content fluctuation higher than the average the harrow as opposed to three high fluctuations areas before the harrow. However, the moisture content range is still below the recommended range and can be considered 'very' dry.

It seems that the harrowing was not very successful in terms of making the sand firmness value more homogeneous throughout the track. However there was a slight improvement in sand firmness after the harrow, the sand firmness range is still below the recommended range and can be considered 'hard'.

2.2 Harrow: 26 August 2019

The surface moisture and firmness data before (23 August 2019) and after (27 August 2019) the harrowing practice at Mandurah track, are compared with each other.

The surface moisture content range before the first harrow was 13.5% to 17.4%, which does not fall within the recommended range. The data shows that the surface is dry suggesting a possible issue with the watering management.

The surface firmness range before the first harrow was 233 mm to 548 mm, which does not fall within the recommended range. The data shows that the surface at some locations is harder than the recommended range and at some locations is softer than the recommended range.

Sand moisture content is plotted against different locations at the track and given below in Figure 6. Sand firmness data is plotted against different locations at the track and given below in Figure 7.

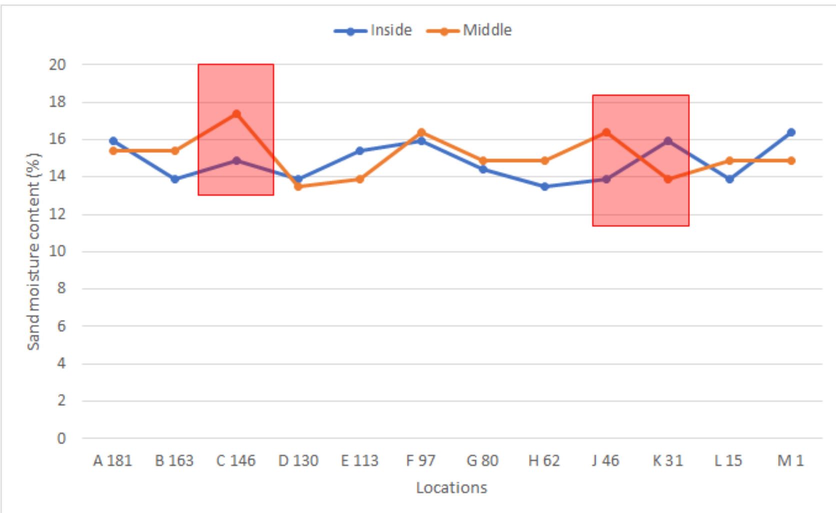


Figure 6: Sand moisture content versus different locations at the Mandurah track (23 August 2019).

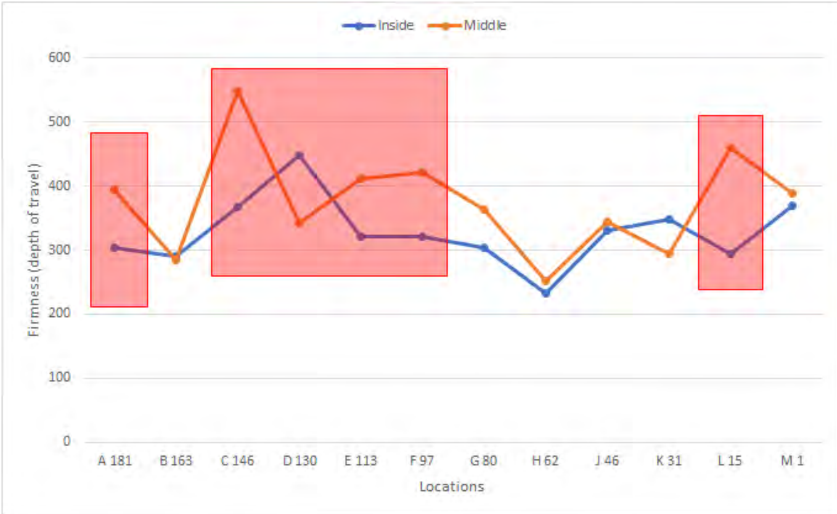


Figure 7: Sand firmness data versus different locations at the Mandurah track (23 August 2019).

The average of fluctuation between the inside and middle track moisture data is 9%. As it can be seen, the difference between the inside and middle moisture content at locations C (14%) and J and K (15% and 14%) are higher than the average.

The average of fluctuation between the inside and middle track moisture data is 19%. As it can be seen, the difference between the inside and middle firmness data at locations A (23%) and C, D, E and F (33%, 31%, 22%, and 24%) and L (36%) are higher than the average.

Having high fluctuation between the inside and the middle track surface properties, would expose trailing greyhounds to a running surface with different properties as they tend to jostle and change direction to avoid bumping and checking. Any sudden change in the surface condition may contribute to injuries.

The surface moisture content range after the second harrow was 13% to 16.4%, which does not fall within the recommended range. The data show that there was a no improvement in data after the harrowing[9]. The surface is still dry suggesting issue with the watering management.

The surface firmness range after the second harrow was 173 mm to 321 mm, which does not fall within the recommended range. The data show that there was a no improvement in data after the harrowing (the surface is harder than before the harrow). The surface is still harder than the recommended range. One reason that might have harden the surface is infrequent and shallow harrowing.

Sand moisture content is plotted against different locations at the track and given below in Figure 8.

[9]Frequent and deep harrowing coupled with appropriate irrigation program, would improve the sand water retention. In other words, the sand could retain additional water.

Sand firmness data is plotted against different locations at the track and given below in Figure 9.

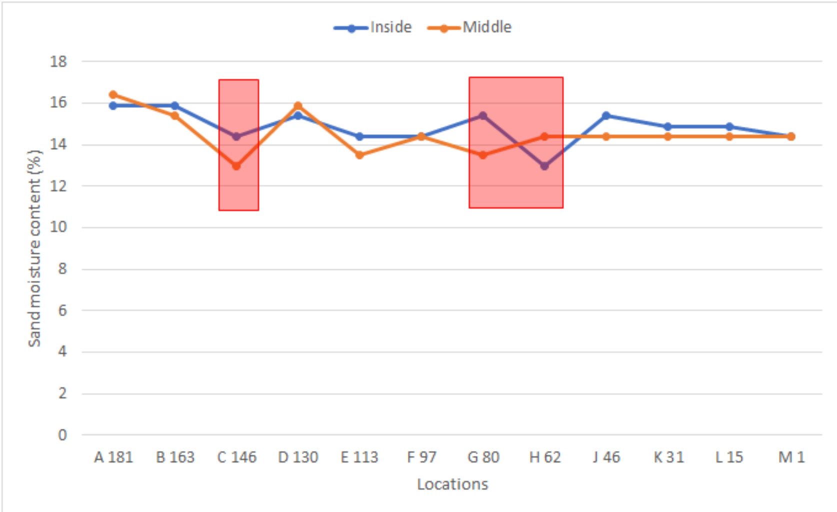


Figure 8: Sand moisture content versus different locations at the Mandurah track–28 August 2019.

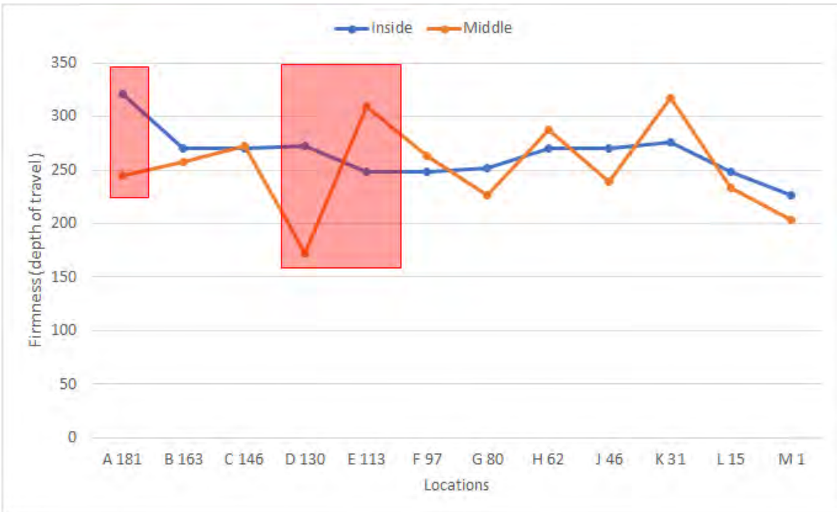


Figure 9: Sand firmness data versus different locations at the Mandurah track–28 August 2019.

The average of fluctuation between the inside and middle track moisture data is 5%. As it can be seen, the difference between the inside and middle moisture content at locations C (11%) and J and H (14% and 10%) are higher than the average.

The average of fluctuation between the inside and middle track moisture data is 15%. As it can be seen, the difference between the inside and middle firmness data at locations A (31%) and D and E (58% and 20%) are higher than the average.

It seems that the harrowing was successful in terms of making the sand moisture content more homogeneous throughout the track (less fluctuation percentage between the moisture content and firmness data). However, the moisture content range is still below the recommended range and can be considered 'very' dry.

It seems that the harrowing was not very successful in terms of making the sand firmness value more homogeneous throughout the track as there are still regions at the track with high fluctuation in firmness between the inside and middle track. The sand firmness range is still below the recommended range and can be considered 'hard'.

2.3 Harrow: 25 September 2019

The surface moisture and firmness data before (24 September 2019) and after (26 September 2019) the third harrowing practice at Mandurah track are compared with each other.

The surface moisture content range before the first harrow was 15.9% to 22.6%, which does not fully fall within the recommended range. The data show that the surface is dry suggesting possible issue with the watering management.

The surface firmness range before the first harrow was 291 mm to 445 mm, which fall within the recommended range.

Sand moisture content is plotted against different locations at the track and given below in Figure 10. Sand firmness data is plotted against different locations at the track and given below in Figure 11.

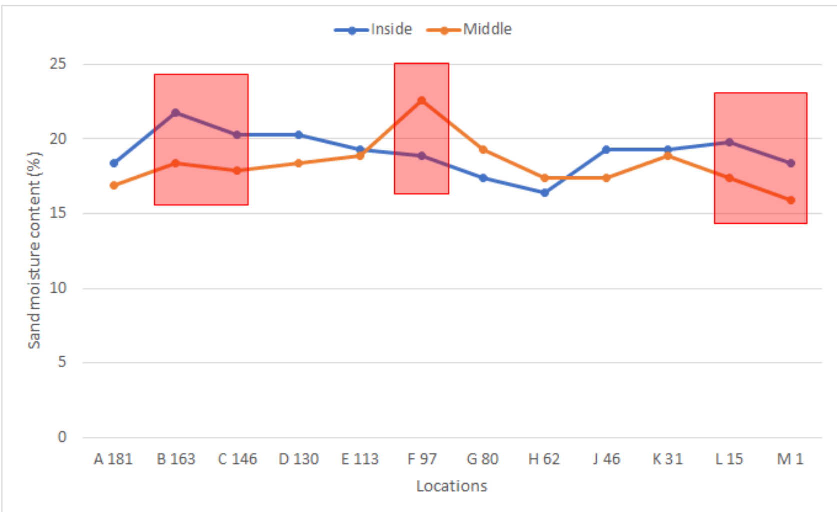


Figure 10: Sand moisture content versus different locations at the Mandurah track–24 September 2019.

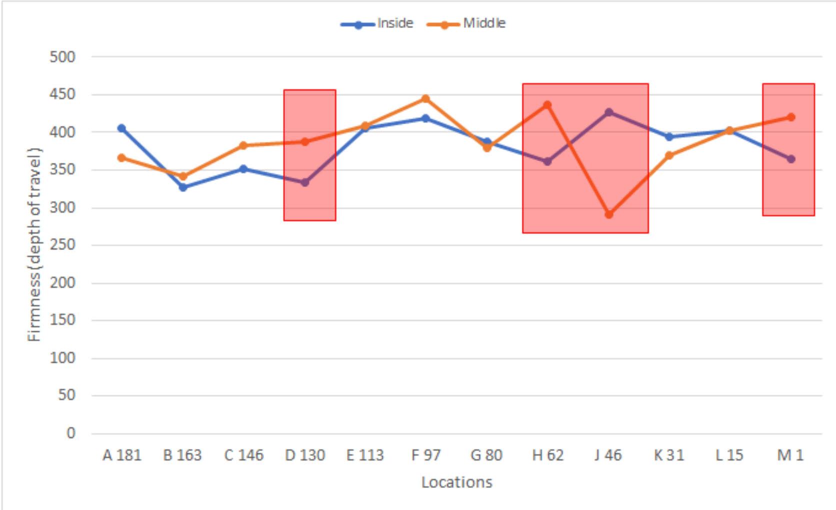


Figure 11: Sand firmness data versus different locations at the Mandurah track–24 September 2019.

The average of fluctuation between the inside and middle track moisture data is 11%. As it can be seen, the difference between the inside and middle moisture content at locations B and C (18% and 13%), F (16%) and L and M (14% and 16%) are higher than the average.

The average of fluctuation between the inside and middle track moisture data is 11%. As it can be seen, the difference between the inside and middle firmness data at locations D (14%) and H and J (17% and 47%) and M (14%) are higher than the average.

Having high fluctuation between the inside and the middle track surface properties, would expose trailing greyhounds to a running surface with different properties as they tend to jostle and change direction to avoid bumping and checking. Any sudden change in the surface condition may contribute to injuries.

The surface moisture content range after the third harrow was 15.4% to 23.3%, which does not fully fall within the recommended range. The data show that there was a slight increase in the moisture content after the harrowing[10]. The surface is still dry suggesting an issue with the watering management.

The surface firmness range after the third harrow was 321 mm to 479 mm, which fall within the recommended range. The data show that there was an improvement in data after the harrowing.

Apart from the fact that the sand moisture content and firmness should fall within the recommended range, the fluctuation between the inside and middle track reading should be minimum, suggesting a homogeneous surface and therefore lower risk of injuries. Therefore, the sand moisture content and

[10]Frequent and deep harrowing coupled with appropriate irrigation program, would improve the sand water retention. In other words, the sand could retain the water.

firmness after the third harrow are plotted against different locations at the track and given below in Figure 12 and Figure 13, respectively.

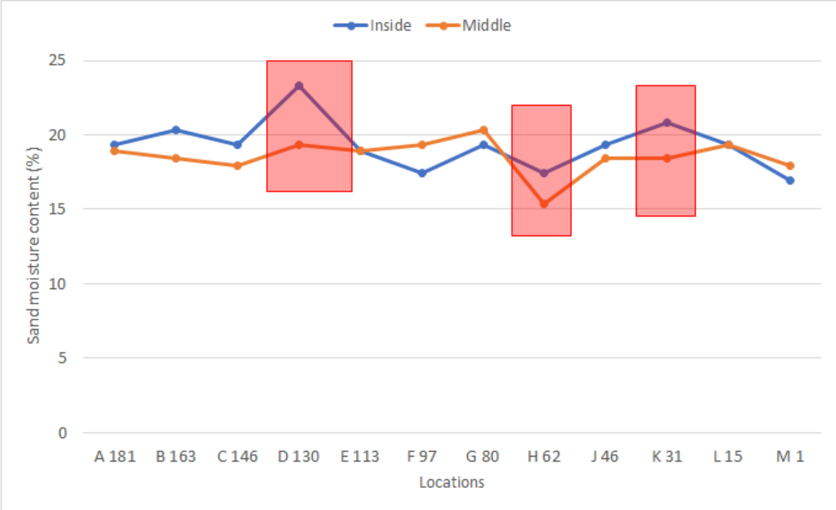


Figure 12: Sand moisture content versus different locations at the Mandurah track (26 September 2019).

Figure 13: Sand firmness data versus different locations at the Mandurah track (26 September 2019).

The average of fluctuation between the inside and middle track moisture data is 8%. As it can be seen, the difference between the inside and middle moisture content at locations D (21%), H (13%) and K (13%) are higher than the average.

The average of fluctuation between the inside and middle track moisture data is 16%. As it can be seen, the difference between the inside and middle firmness data at locations B, C and D (21%, 19% and 32%) and G and H (31% and 25%) are higher than the average.

It seems that the harrowing was successful in terms of making the sand moisture content more homogeneous throughout (less fluctuation percentage between the moisture content). However, the moisture content range is still below the recommended range and can be considered 'very' dry.

However the sand firmness range fall within the recommended range, it seems that the harrowing was not very successful in terms of making the sand firmness value more homogeneous throughout the track as the fluctuation between the middle and inside track has increased after the third harrow.

2.4 Harrow: 14 October 2019

The surface moisture and firmness data before (11 October 2019) and after (17 October 2019) the third harrowing practice at Mandurah track are compared with each other.

The surface moisture content range before the fourth harrow was 13.5% to 21.8%, which does not fall within the recommended range. The data show that the surface is dry suggesting possible issue with the watering management.

The surface firmness range before the fourth harrow was 206 mm to 324 mm, which does not fully fall within the recommended range. Based on the data, the surface is harder than the recommended range. One reason causing surface hardening is infrequent and shallow harrowing as well as inappropriate water management, which will cause the surface becoming hard and dry.

Sand moisture content is plotted against different locations at the track and given below in Figure 14. Sand firmness data is plotted against different locations at the track and given below in Figure 15.

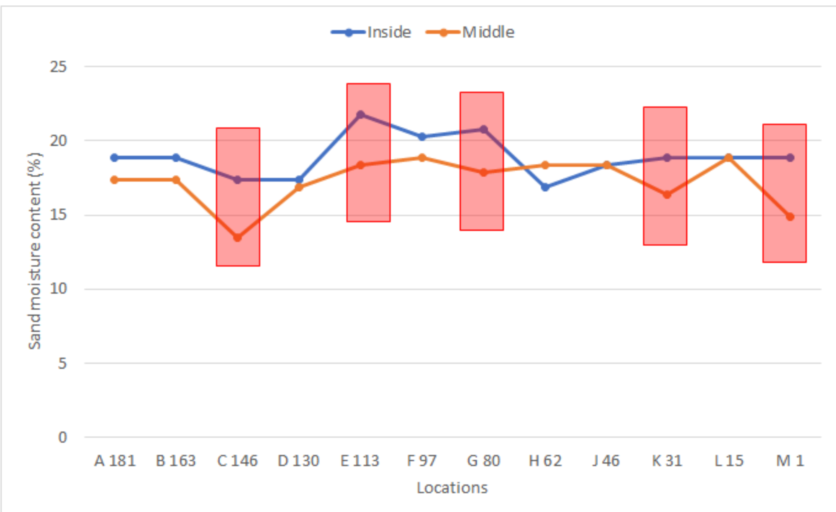


Figure 14: Sand moisture content versus different locations at the Mandurah track (11 October 2019).

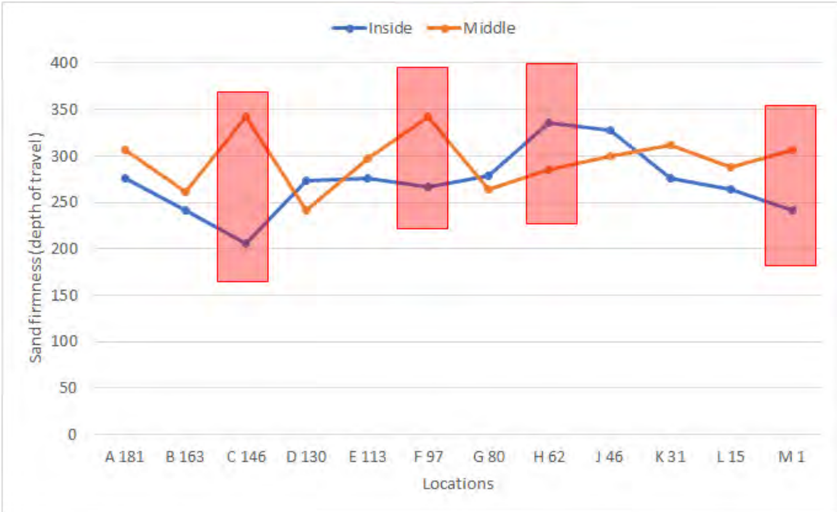


Figure 15: Sand firmness data versus different locations at the Mandurah track (11 October 2019).

The average of fluctuation between the inside and middle track moisture data is 12%. As it can be seen, the difference between the inside and middle moisture content at locations C (29%), E (18%), G (16%), K (15%), and M(27%) are higher than the average.

The average of fluctuation between the inside and middle track moisture data is 14%. As it can be seen, the difference between the inside and middle firmness data at locations C (14%) and F (22%), H (18%) and M (21%) are higher than the average.

Having multiple track regions with high fluctuation between the inside and middle track reading is concerning. The high fluctuation between the inside and the middle track surface properties, would expose trailing greyhounds to a running surface with different properties as they tend to jostle and change direction to avoid bumping and checking. Any sudden change in the surface condition may contribute to injuries.

The surface moisture content range after the fourth harrow was 16.9% to 23.8%, which does not fully fall within the recommended range. The data show that there was a slight increase in the moisture content after the harrowing[11].

The surface firmness range after the third harrow was 261 mm to 433 mm, which does not fully fall within the recommended range. The data show that there was a slight improvement in data after the harrowing.

Apart from the fact that the sand moisture content and firmness should fall within the recommended

[11]Frequent and deep harrowing coupled with appropriate irrigation program, would improve the water retention. In other words, the sand could retain more water and become damper as a result.

range, the fluctuation between the inside and middle track reading should be minimum, suggesting a homogeneous surface and therefore lower risk of injuries. Therefore, the sand moisture content and firmness after the fourth harrow are plotted against different locations at the track and given in Figures 16 and 17.

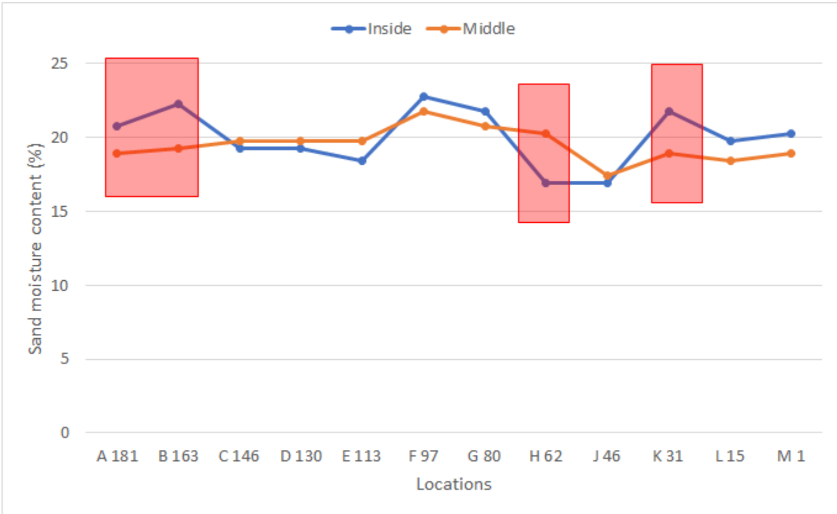


Figure 16: Sand moisture content versus different locations at the Mandurah track (17 October 2019).

Figure 17: Sand firmness data versus different locations at the Mandurah track (17 October 2019).

The average of fluctuation between the inside and middle track moisture data is 8%. As it can be seen, the difference between the inside and middle moisture content at locations A and B (10% and 16%), H (17%), and K (15%) are higher than the average.

The average of fluctuation between the inside and middle track moisture data is 16%. As it can be seen, the difference between the inside and middle firmness data at locations B (18%), D and E (21%

and 23%), J (38%), and L (33%) are higher than the average.

It seems that the harrowing was successful in terms of making the sand moisture content more homogeneous throughout the track (less fluctuation percentage between the moisture content). However, the moisture content range is still below the recommended range and can be considered 'very' dry.

It seems that the harrowing was not successful in terms of making the sand firmness value homogeneous throughout the track as the average of fluctuation between the inside and middle track has increased after the harrow (16% vs 14%).

2.5 Harrow: 11 December 2019

The surface moisture and firmness data before (6 December 2019) and after (12 December 2019) the third harrowing practice at Mandurah track are compared with each other.

The surface moisture content range before the fifth harrow was 17.9% to 26.7%, which does not fully fall within the recommended range.

The surface firmness range before the fourth harrow was 297 mm to 445 mm, which does not fully fall within the recommended range. Based on the data, the surface is softer than the recommended range.

Sand moisture content is plotted against different locations at the track and given below in Figure 18. Sand firmness data is plotted against different locations at the track and given below in Figure 19.

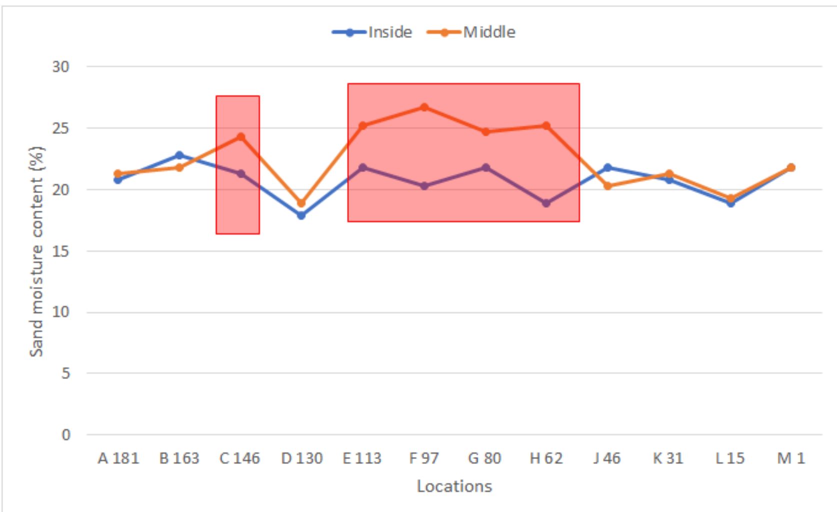


Figure 18: Sand moisture content versus different locations at the Mandurah track (6 December 2019).

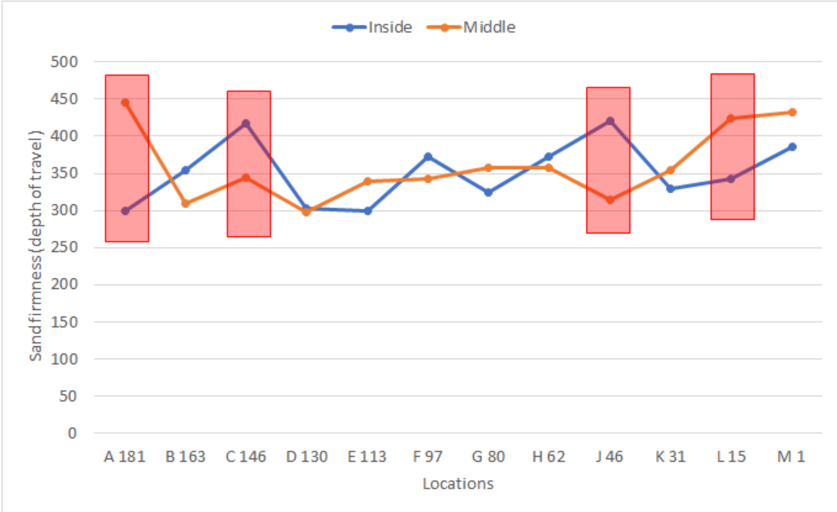


Figure 19: Sand firmness data versus different locations at the Mandurah track (6 December 2019).

The average of fluctuation between the inside and middle track moisture data is 9%. As it can be seen, the difference between the inside and middle moisture content at locations C (12%), E(13%), F (24%), G (12%), and H (25%) are higher than the average.

The average of fluctuation between the inside and middle track moisture data is 15%. As it can be seen, the difference between the inside and middle firmness data at locations A (14%), C (21%), J (34%) and L (19%) are higher than the average.

Having multiple readings with high fluctuation between the inside and middle track reading is concerning. The high fluctuation between the inside and the middle track surface properties, would expose trailing greyhounds to a running surface with different properties as they tend to jostle and change direction to avoid bumping and checking. Any sudden change in the surface condition may contribute to injuries.

The surface moisture content range after the fifth harrow was 16.9% to 28.2%, which does not fully fall within the recommended range.

The surface firmness range after the fifth harrow was 333 mm to 645 mm, which does not fully fall within the recommended range. Based on the data, the surface is softer than the recommended range.

Apart from the fact that the sand moisture content and firmness should fall within the recommended range, the fluctuation between the inside and middle track reading should be minimum, suggesting a homogeneous surface and therefore lower risk of injuries. Therefore, the sand moisture content and firmness after the fourth harrow are plotted against different locations at the track and given in Figures 20 and 21.

Figure 20: Sand moisture content versus different locations at the Mandurah track (12 December 2019).

Figure 21: Sand firmness data versus different locations at the Mandurah track (12 December 2019).

The average of fluctuation between the inside and middle track moisture data is 8%. As it can be seen, the difference between the inside and middle moisture content at locations E (16%), G and H (14% and 21%), and K and L (13% and 14%) are higher than the average.

The average of fluctuation between the inside and middle track moisture data is 16%. As it can be seen, the difference between the inside and middle firmness data at locations B (19%), E (25%), J (33%), and L and M (33% and 22%) are higher than the average.

However there was an improvement on the range of moisture content after the harrow, the fluctuation percentage between the moisture content after the harrow has not changed. However, the moisture content range is still below the recommended range and can be considered 'very' dry. This suggest that either the harrow is not deep enough or the irrigation system is inappropriate (or combination of both) that does not allow sand to absorb the water.

However there was an improvement on the range of sand firmness value after the harrow, the fluctuation percentage between the moisture content after the harrow has not changed. The surface is still firm with multiple locations with high fluctuation between the inside and middle track readings.

3 Cannington and Northam greyhound tracks

UTS was not provided with data for the Cannington and Northam greyhound tracks.

Appendix A: The moisture meter used by RWWA

TruFirm
Turf Firmness Meter

PRODUCT MANUAL

Item #6490, 6490S, 6491S

Spectrum® Technologies, Inc.

Table of Contents

This manual will familiarize you with the features and operation of your new Field Scout TruFirm Turf Firmness Meter. Please read this manual thoroughly before using your instrument. For customer support, or to place an order, call Spectrum Technologies, Inc. at 800-248-8873 or 815-436-4440 between 7:30 am and 5:30 p.m. CST,
FAX at 815-436-4460, or E-Mail at info@specmeters.com.
www.specmeters.com

Spectrum Technologies, Inc
3600 Thayer Court
Aurora, IL 60504

General Overview

Based on technology developed by the USGA, the Field Scout TruFirm Turf Firmness Meter is used to measure the firmness of sports playing surfaces, especially golf greens, fairways and bunkers. The device consists of an impact plunger and a rotary position sensor. Once motion of the plunger is detected the electronics will collect and process the signal and send a measurement to an LCD display. The measurement may also be streamed to a handheld device via a wireless communications protocol using a Bluetooth accessory (items 6490S, 6491S).

Specifications

Power: 2 AA batteries (included)

Weight: 4.3 lb. (1.95 kg)

Height: 27 in (69 cm)

Height: 46 in (117 cm), with plunger extended

Diameter of Plunger: (1.68 in, 4.27 cm)

Measurement units: Depth of travel (inches)

Range: 0.1 in - 1.5 in

Resolution: .01 in at 1.00 in - 1.50 in

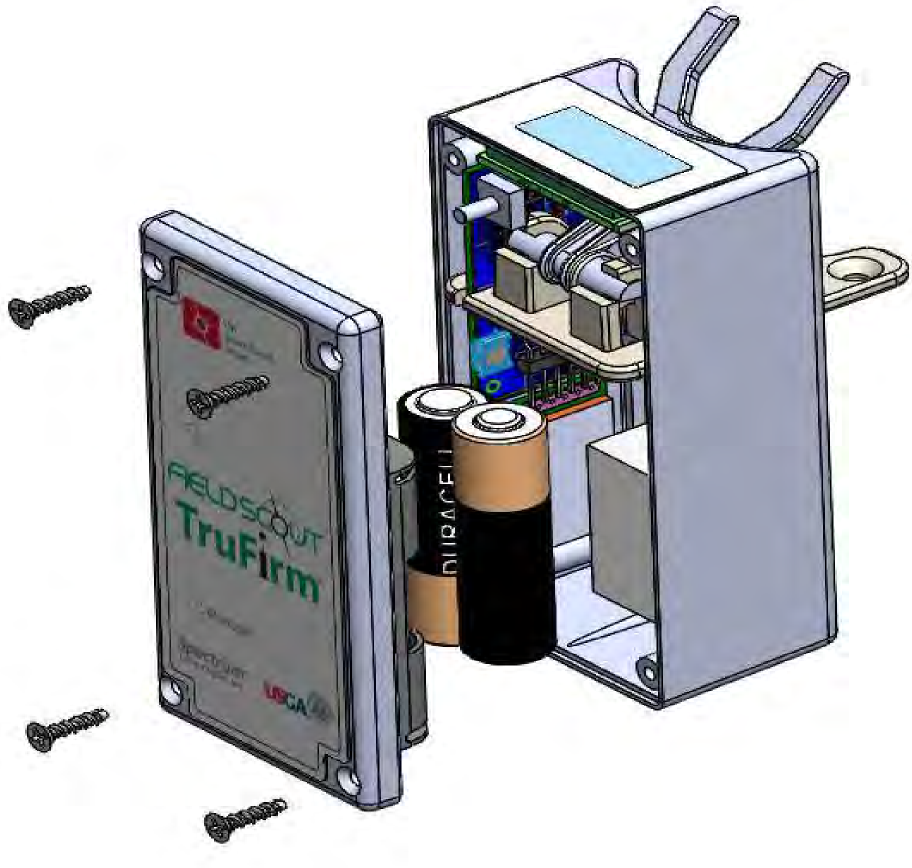
.003 in at 0.100 in - .999 in

Display: LCD with backlight

Component Part Names

SET UP

The TruFirm unit requires 2 AA Batteries (included). They are installed inside the plastic housing. Remove the four screws holding the lid in place to access the battery holder.



Note: If the TruFirm will not be used for an extended period of time (over one month), it is recommended that you remove the batteries.

Using the TruFirm

The TruFirm Model measures the depth the plunger depresses a surface when it is released from a set height. The value of this depth is displayed on an LCD readout.

The unit will also display the average of a series of measurements and the number of measurements included in the average on its LCD.

Activating/Deactivating the Display:

The unit is activated by briefly pressing the Button. The LCD will display the percent battery life for 5 seconds and then show zeros when it is ready to take a measurement.

The TruFirm will power off after 5 minutes of inactivity.

Taking a reading:

1. Place the unit on the surface being measured. If the surface is sloped, orient the Base so that it is pointing downhill.
2. Step lightly on the Foot Support. This will ensure the unit does not tip over after the reading is taken.
3. If the Display is blank, press the Button briefly and wait for the unit to turn on.
4. Lift up the Plunger all the way. The display will now show the number of measurements that have been included in the average (or zero for the first reading).
5. Release the Plunger so that it drops smoothly.
6. On the first measurement, the value of the current measurement is displayed. For subsequent measurements, the LCD will display the current reading for 2 seconds and the average after 2 seconds.

To reset the average, press the Button briefly while the average value is being displayed. If the average is not reset, the next reading will be included in the average as well. The average will also be reset if the meter is powered off.

Lift plunger straight up to top of travel. Use foot support to stabilize the unit.

Release smoothly to avoid affecting drop speed.

FIELDSCOUT MOBILE APP

Using the FieldScout Mobile app

Download the free FieldScout Mobile app in the App Store or Google Play Store.

The FieldScout Mobile app will run on iOS (Apple) and Android smart devices with Bluetooth Smart. The App receives readings directly from a TruFirm firmness meter that is equipped with Bluetooth Smart (item 6490S) or basic and legacy units that have been upgraded (see **Bluetooth Option**, p. 9). The FieldScout app for Android can also receive data from legacy TruFirm meters with Bluetooth (item 6490B).

The FieldScout Mobile app allows you to store firmness measurements on multiple courses, multiple holes, multiple surfaces (green, fairway, etc.) and at multiple times (sessions). It will also allow you to define additional surfaces from those pre-defined. The App has a reporting function that plots the measurements. See the FieldScout Mobile app manual for more information on using the app.

FieldScout Pro for SpecConnect (item 3035) users can sign in to a Pro account in FieldScout Mobile using their SpecConnect username and password. FieldScout Mobile Pro users can use Pro features in the app as well as transmit all TruFirm data to the SpecConnect Cloud. Call Spectrum Technologies or look online for more information on the SpecConnect FieldScout Pro web portal.

Bluetooth Option

FieldScout TruFirm meters can be purchased with a Bluetooth Smart module installed (item 6490S), or an optional Bluetooth Smart upgrade (Item 6491S) is available for the original TruFirm (item 6490) or original TruFirm with Bluetooth (item 6490B). The Bluetooth module transmits the TruFirm depth measurement to a connected Bluetooth device. It is designed to be used with the FieldScout Mobile app for iOS and Android. Note: Only the actual measurement, not the average, is transmitted. The FieldScout Mobile app will average readings for each measurement zone.

The Bluetooth module, when installed, will automatically send each measurement. A separate FieldScout Mobile manual is available for the app.

Pairing the TruFirm Bluetooth Smart module to a smart device:

The TruFirm meter and the smart device must be paired to share data. In the app, create a new course and data session, then tap on the desired measurement zone to access the Take Readings screen. The app will guide you through the process of connecting to a Bluetooth device.

The App will only pair with one FieldScout meter at a time. The FieldScout Mobile app is also compatible with the TDR 300.

When powered on, the TruFirm is always in pairing mode. No additional steps are required on the TruFirm to allow your Apple or Android device to search for and pair with the TruFirm. Consult the FieldScout Mobile user manual for additional information on pairing your device with the TruFirm.

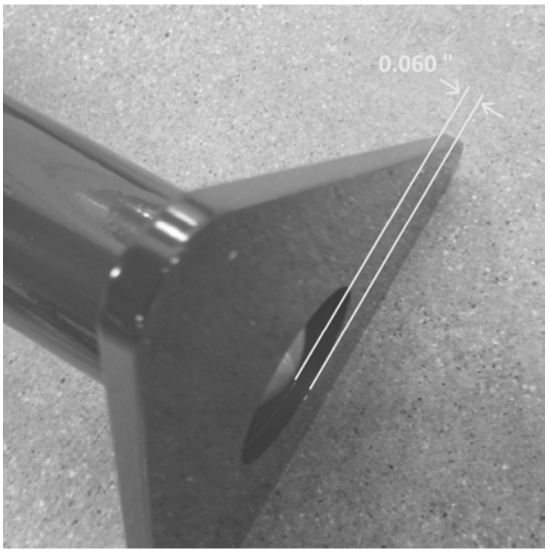
TroubleShooting

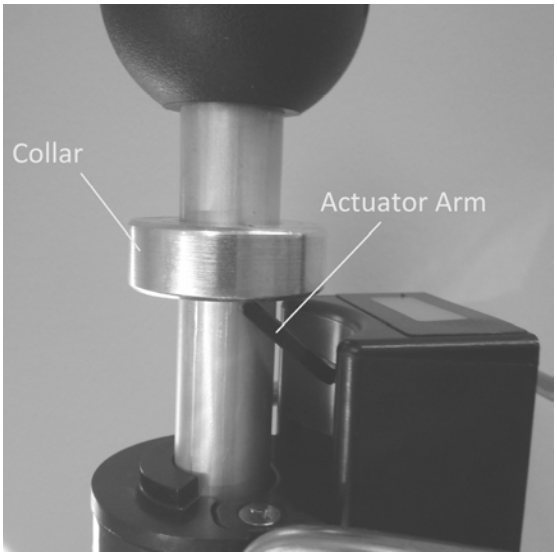
Resetting The Zero Point

The TruFirm is calibrated at the factory and should not need recalibration under normal usage. If the unit is disassembled or the collar is moved for any reason the collar point should be reset.

Start by placing the TruFirm on a hard flat surface such as a floor or table top with the plunger raised 0.06”. This can be accomplished by placing a flat object about the thickness of 15 sheets of paper under plunger. The collar should just touch the actuator arm in its up-most position as shown below when the plunger is raised 0.060” above the bottom of the base. The flat object should only raise the plunger, the base must remain on the flat surface.

To adjust the collar, loosen the bolt in the collar until it slides easily. Make sure the collar is not depressing the actuator arm and then retighten the bolt.





Warranty

This product is warranted to be free from defects in material or workmanship for one year from the date of purchase. During the warranty period Spectrum will, at its option, either repair or replace products that prove to be defective. This warranty does not cover damage due to improper installation or use, lightning, negligence, accident, or unauthorized modifications, or to incidental or consequential damages beyond the Spectrum product. Before returning a failed unit, you must obtain a Returned Materials Authorization (RMA) from Spectrum. Spectrum is not responsible for any package that is returned without a valid RMA number or for the loss of the package by any shipping company.

Spectrum® Technologies, Inc.

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www.specmeters.com

Rev 3/15

Appendix B: The penetrometer used by RWWA

FIELDSCOUT®

TDR 300
Soil Moisture Meter

PRODUCT MANUAL

Item # 6430FS

Spectrum®
Technologies, Inc.

Established 1954
VANDEN BUSSCHE
IRRIGATION
2515 Pinegrove Rd, Delhi, ON N4B 2X1
1-800-387-7246 Tel: 519-582-2380 Fax: 519-582-1514
visit us at: vandenbussche.com

CONTENTS

This manual will familiarize you with the features and operation of your new FieldScout™ TDR 300 Soil Moisture Meter. Please read this manual thoroughly before using your instrument. For customer support, or to place an order, call Spectrum Technologies, Inc. at

(800) 248-8873 or (815) 436-4440
between 7:30 am and 5:30 p.m. CST
FAX (815) 436-4460
e-mail: info@specmeters.com
www.specmeters.com

General overview

Thank you for purchasing the Field Scout™ TDR 300 Soil Moisture Meter. This manual describes the features and operation of the meter.

Soil moisture is a critical and potentially highly variable component of the soil environment. Time-domain reflectometry is a proven technology for quickly and accurately determining volumetric water content (VWC) in soil.

The Field Scout's shaft-mounted probe allows the user to easily and rapidly take many measurements. The user can quickly transition between taking VWC readings in standard and high-clay mode. The meter's built-in data logger can record data from several sites and eliminates the need to record data manually. Through the software (included) the user can download the data, change the logger settings and program the logger to record relative water content at multiple sites.

Contents

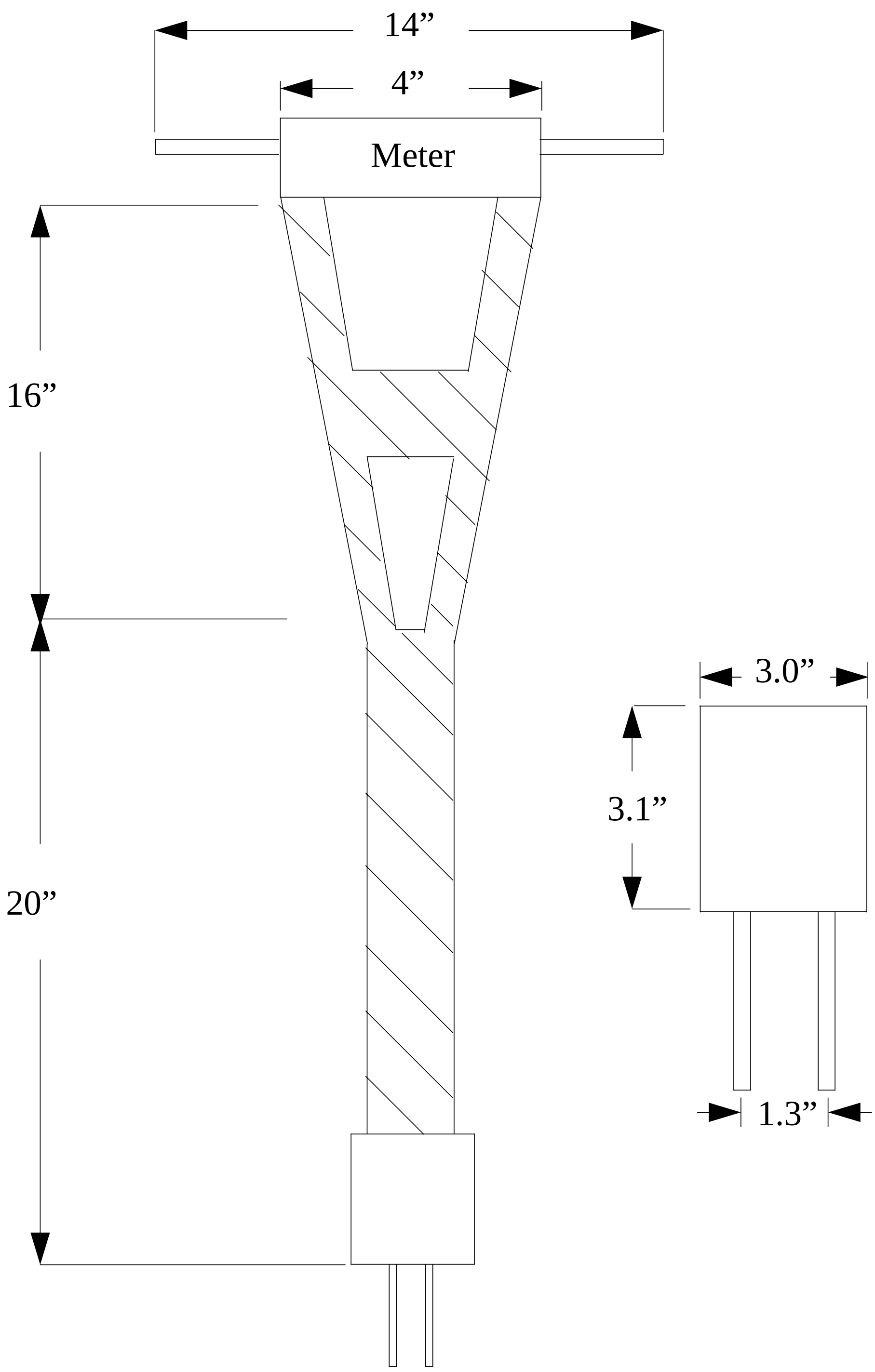
Your TDR300 shipment includes the following components:

- TDR 300 meter (in retracted position)
- Carrying case
- Wrench for tightening rods
- 4 AAA batteries
- Field Scout software installation CD
- Gray PC interface cable

Note: TDR rods are sold separately

Shaft dimensions

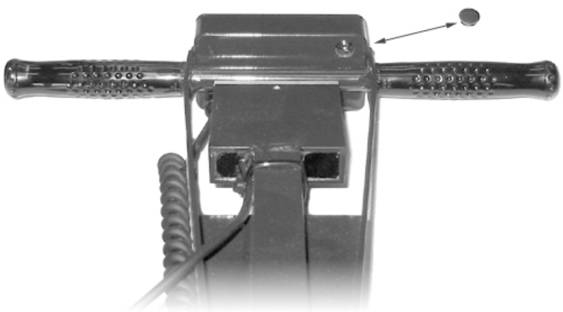
The following are the dimensions of a fully extended shaft. It is possible to reduce the length of the meter by 2" (5cm) by adjusting the lower half of the shaft.



Computer Interface/ Changing Batteries

Software Installation

Insert the CD for Field Scout software into your PC's disk drive. If auto-start is not enabled on your computer, select **Run** from the **Start** menu and type **D:\Setup.exe** (Substitute the appropriate drive letter for your CD drive). Click **OK** and follow the instructions on the screen.



TDR 300 data port

The data port on the underside of the TDR 300 meter (shown above) can be accessed by removing the plastic screw. It is through this port that the meter is connected to either a PC or to a GPS unit. The meter must be turned off before attempting communication with the software.

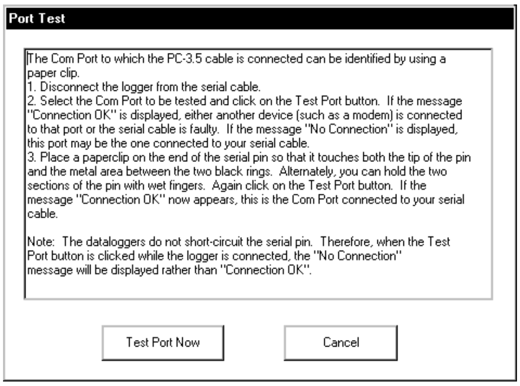
Connecting to a PC

The Field Scout software comes with a gray PC interface cable. This cable connects to the 9-pin serial port of your computer and to the meter's computer port. The meter's configuration can be modified by clicking on the **Meter Settings** button (see Meter Settings, p. 16). The **Com Port, Meter Type, Download, Clear Memory** and **Meter Settings** buttons are explained in the Field Scout Software Toolbar section (p. 14).

Changing the batteries

The battery compartment is accessed by removing the meter's face plate. The meter is powered by AAA batteries. **When installing new batteries, note whether the batteries immediately feel hot to the touch. The battery has been short-circuited and should be replaced.**

Identifying the Correct Com Port

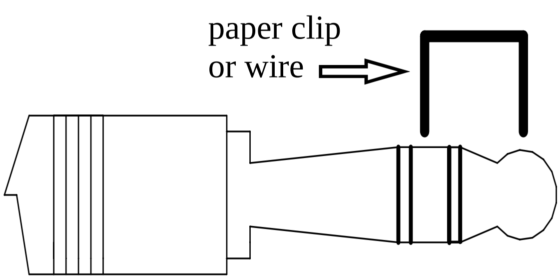


The computer **Com**munications **Port** to which the PC-3.5 serial cable is connected can be identified by using a paper clip.

1. Disconnect the serial cable from the meter.

2. To bring up the **Port Selection** screen, click on the **Com Port** Button, select the com port to be tested and click the **Port Test** button. Click the **Test Port Now** button. If the message "Connection OK" is displayed, another device (such as a modem) is probably connected to that port. If the message "No Connection" is displayed, this port may be the one connected to your serial cable and you can proceed to the next step.

3. Place a paperclip on the end of the serial pin so that it touches both the tip of the pin and the metal area between the two black rings. Again click on the **Test Port Now** button. If the message "Connection OK" now appears, this is the com port connected to your serial cable.



NOTE: The dataloggers do not short-circuit the serial pin. Therefore, when the **Test Port** button is clicked while the meter is connected, the "No Connection" message will be displayed.

METER OPERATION

ON

The ON switch turns the meter/datalogger on and off. When the meter is turned on, it will display the battery status for 3 seconds. For the next 3 seconds, it will display how much logger memory has been used and, if the logger was enabled in the software, whether the GPS signal was found. If a GPS signal is found, latitude and longitude data will be included in the data file. The screen will then display the most recently used MODE screen.

Logger 75% Full GPS=Yes DGPS=No	Logger 75% Full No GPS Found

Sample meter power-up screens with datalogger enabled: left screen indicates GPS signal was found.

If you are using GPS, but the meter doesn't find the GPS signal when powering up, the meter will **not** search for the GPS signal when taking readings. Turn the meter off and on so it can look for the GPS signal. Once the signal is found, GPS information will be included in the data file until the signal is lost or the GPS unit is disconnected from the meter.

Note: If the data logger is disabled (see Meter Settings, p. 16), the meter will not seek the GPS signal when it is powered up. It will, instead, proceed immediately to the most recently used mode (see MODE button, p. 8) screen.

MODE

Pressing the MODE button allows the user to determine the type of measurement that will be taken or select the length of rods connected to the probe.

Data Collection Modes

Available measurement options are volumetric water content (VWC) using the standard or high clay mode (see p. 22), up to two relative water content modes (see p. 24), or measurement period (in microseconds). Relative water content options will only appear if they are configured in the software (see Meter Settings, p. 16). The period measurement is available for users interested in performing soil-specific calibrations (see Appendix 2).

Note: There is not a high clay measurement calibration for the 1.5” rods. The meter will display dashes if this mode/ rod length combination is selected.

Changing Rod Length

```
ROD=MED  (4.7in)
HIT DEL To Chnge
```

Rod Length Options Screen

In order to get accurate volumetric or relative water content (VWC or RWC) readings, the rod length setting must be correct. In the VWC modes, the currently selected rod length appears in the lower left corner of the LCD screen. The options are **T**urf (1.5”), **S**hort (3.0”), **M**edium (4.7”), and **L**ong (7.9”) rods. Press the MODE button until the LCD displays the rod length options screen. Pressing the DELETE/CLR AVG button will allow you to toggle between the three choices.

Meter Calibration Mode

```
CALIBRATION MODE
HIT READ To Cal
```

Meter Calibration Screen

This mode allows you to calibrate the meter. The calibration procedure is performed in air and distilled water (see Meter Calibration, p. 10). Requires firmware v. 6.5 or greater.

Delete
Clr Avg

When the DELETE/CLR AVG button is pressed and immediately released, the last data point will be taken out of the logger file and removed from the running average. Pressing and holding this button will reset the running average but will not affect data stored on the data logger.

READ

Press the READ button to read the probe and update the screen values. Data values, along with GPS or DGPS information if applicable, are sent directly to the data logger. If the logger searches for, but doesn't find a GPS signal, an error message will briefly appear in the lower right corner. In this case, a data point will be stored without the GPS data. The data point can be cleared from memory with the DELETE/CLR AVG button (above).

When the data logger is full, the LCD will display the message "Error: Memory Full". To resume normal operation, the logger memory must be cleared using the **Clear Memory** button in Field Scout software (see p. 15)

Meter Calibration

The meter has internal calibrations for standard and high-clay soil types. These calibrations will work for a large number of soils. However, each meter will have a small difference in how it responds to identical soil conditions. This is due to sensor drift or variability in the electronic components used during manufacturing. Meters with *firmware v. 6.5 or greater* allow for adjustments to the meter calibration to account for these differences. Therefore, if two meters are giving slightly different readings in the same soil, the output of the meters can be standardized such that the meters can be used interchangeably. The calibration procedure is as follows:

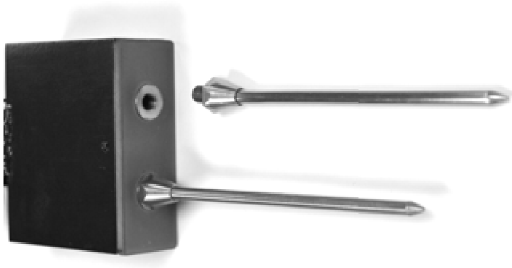
1. Use the MODE button to put meter in Calibration mode (see p. 8). Hit the READ button
2. Hold the meter so the rods are in the air. Press the READ button and wait until the meter indicates it is ready.
3. Immerse the rods completely in <u>distilled</u> or <u>de-ionized</u> water. The container should have a minimum diameter of 3 inches. Press the READ button and wait until the meter indicates it is ready.

The meter will then show that the calibration is complete for that specific rod length. <u>If more than one rod size is being used, a calibration operation must be done for each one</u>.

Note: This procedure is different than a soil-specific calibration (Appendix 2, p. 28) where a unique calibration curve is generated.

Taking Readings

- Remove one of the hand screws from the shaft. This will allow you to unfold the shaft to its full length. Return the screw to lock the shaft in the extended position.



- Screw the rods into the sockets at the bottom of the probe block.

- Turn on the meter and ensure that it is configured with the correct rod length setting (see Changing Rod Length, p. 8).

- Select the correct mode setting (see Data Collection Modes, p. 8). This will bring you to one of the data collection screens. The TDR 300 can be set to one of two VWC modes, Standard or High Clay.The Standard mode will be appropriate for most mineral soils. The High Clay mode will be more accurate for soils with higher clay contents (>27%). In VWC mode, the top line of the display shows the VWC mode and the water content. The bottom line has probe setting and data file information.

```
STNDRD VWC%=35.1
PL=S N015 A=36.3
```

Sample Data Screen

PL: Probe Length (**T**urf, **S**hort, **M**edium, or **L**ong rods)

N: Number of readings included in the Average

A: Average of all readings taken since meter was turned on or DELETE/CLR AVG button was pressed

Note, the internal calibrations are valid for a wide range of mineral soils. However, for soils that are high in clay, organic matter or salt, the meter will give values that are higher than the actual VWC. In this case, it is recommended that the meter be operated in relative water content mode (see p. 24) or that a soil-specific calibration be developed (see Appendix 2).

The meter can also be set to give the raw reading if it is set to **Period** mode. This mode is intended primarily for soil-specific calibrations.

- Push the rods into the soil. When taking a measurement, it is important that the rods be fully inserted into the soil. If not, part of the sampling volume will be composed of air and the reading will be inaccurately low. For the same reason, the probe should be inserted with a steady, downward pressure. If the rods are wiggled into the soil, air pockets can be created adjacent to the rods that will result in low readings. The probe should not be struck with a hammer or other blunt instrument as this can cause damage to the internal electronics. Also, care should be taken to ensure the rods are inserted as parallel to one another as possible. This will not have a large affect on the reading but will decrease the chances the rods will be bent or broken. Likewise, it is best to avoid areas with rocks or other material that can cause the rods to deflect or bend. If the ground is especially hard or compact, you can use a Pilot Hole maker (item 6430PH) to make 1½" holes to aid in starting the insertion of the probe rods.

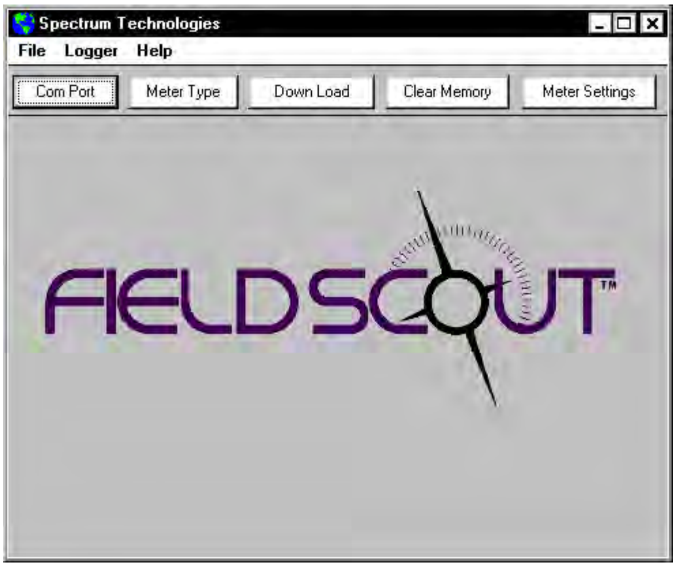
- Press the **READ** button to initiate the measurement sequence. The reading should appear almost instantaneously.

Note: The TDR rods are manufactured from type 303 stainless steel and are designed to bend if non-vertical force is applied to them. This serves to protect the TDR block electronics from potential damage that could be caused by excessive force.

Occasional rod bending is normal, and can be expected during the course of sampling. Longer rods will be more susceptible to bending than shorter rods. If bending occurs, rods should simply be bent back to parallel position, perpendicular to the TDR block. Measurements will continue to be accurate provided that rods are reasonably close to parallel.

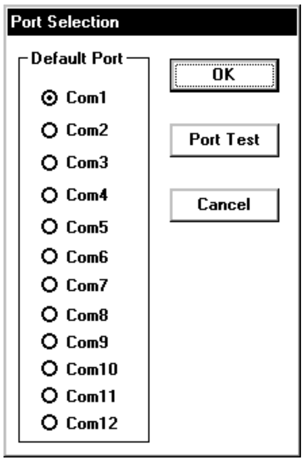
If care is not taken to reposition rods to a parallel position, subsequent pressure on the rods will accentuate the bending and may cause the rods to break. Rods should be considered maintenance items that may need to be replaced over time, depending upon the nature and frequency of sampling.

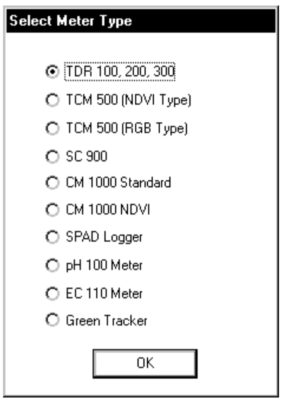
Field Scout software Toolbar



Com Port

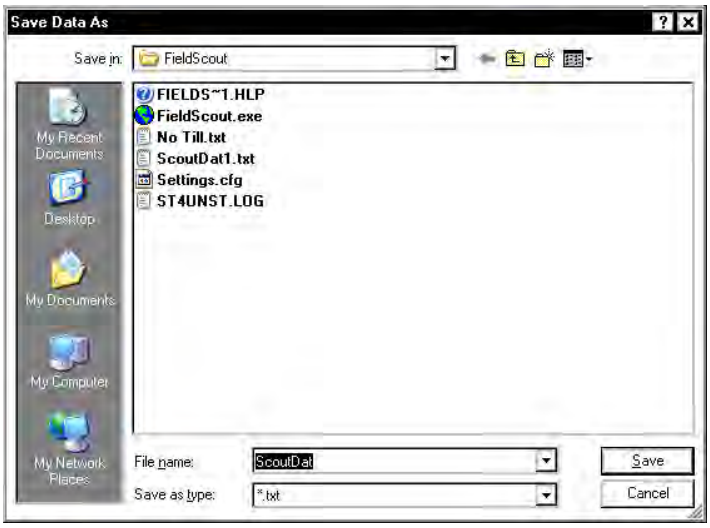
The gray software cable connects the meter to the computer data port. Select the Com Port that is assigned to the computer data port. See Identifying the Correct Com Port (p. 6) for instructions on how to determine which port to select.





Meter Type

Select the TDR option from the list of available Field Scout meters.



Download

To download data from the internal data logger, turn the meter off and connect the gray serial cable to the RS-232 port on the underside of the meter. Click the **Download** button on the main software screen. In the **Save Data As** screen, give the file a descriptive name and select the location where it will be saved.

When the file has been saved, the software will give you the option of immediately viewing the file. The data file is stored as a comma-delimited text file and may be viewed in text editor or spreadsheet software.

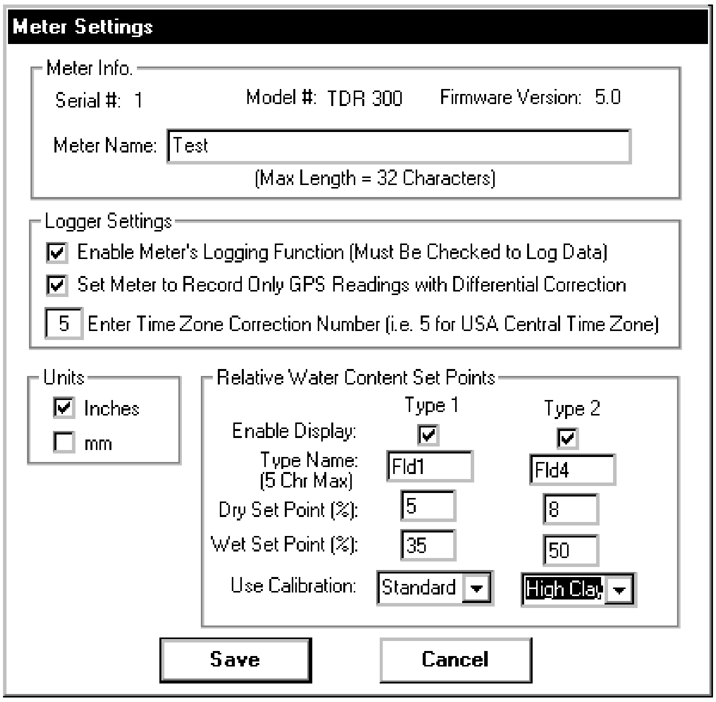
Clear Memory

Data is not automatically removed from the logger memory after a download. The **Clear Memory** button clears all data from the logger memory.

Meter Settings

Click this button to configure the meter and data logger. Refer to "Meter Settings" (p. 16) for more details.

Meter Settings



The Meter Settings screen in the Field Scout software is used to configure the meter and data logger for your specific application. The fields are described below.

Meter Name: The name given the meter will be the title on the first line of the downloaded text file.

Logger Settings: The data logger is enabled and disabled by checking the first box. If the data logger is enabled, it will search for a GPS signal when the meter is turned on. If a signal is found, position data will be stored along with the soil moisture data. If no GPS signal is available when the logger is turned on, the logger will no longer look for one when measuring and recording soil moisture data. If the second box is checked, the logger will store the GPS value **only** if it has been differentially corrected. <u>In general, this option should remain unchecked.</u> If the differential correction is not found, only the soil moisture value will be stored in the data file. A time-zone correction should be entered in the third box.

Units: When operating the meter in Relative Water Content mode, the LCD can display the rod length options in English or metric units. The meter will calculate and display the water deficit (see Relative Water Content p. 24) in the same unit system.

Relative Water Content Set Points: Up to 2 Relative Water Content (see p. 24) modes can be programmed into the meter by entering the wet and dry set points into the appropriate boxes. From the dropdown menus near the bottom of the screen, select which VWC calibration (Standard or High Clay) should be used for each RWC mode. Each of these modes can be given a descriptive name of 5 characters. These names can be used to identify a certain field or soil type.
Finally, for an RWC mode to be available, it must be enabled by checking the Enable Display box. If this box is not checked, that RWC mode will not appear on the LCD during meter operation.

Connecting to a GPS Unit

The data logger function must be enabled using the Field Scout software in order to record a GPS signal (see Meter Settings p. 16).

The GPS unit must be plugged into the TDR 300 meter and running when the meter is first turned on. If a GPS signal is found at startup, the logger will search for a GPS signal for every reading. If no GPS signal is found when the meter is first turned on, the meter will not search for one when taking readings, thereby saving time when taking readings. In this case the LCD will display the **No GPS Found** message.

If the GPS signal is found while taking geo-referenced readings, the LCD will briefly display the message, "**Reading GPS ..**" before displaying the measurement. If the GPS signal is lost during a series of readings, or if the specified differential correction is not found, the LCD will read "**Reading GPS .. ERR**" before returning to measurement mode. In this case, the data will be recorded without latitude and longitude. During subsequent readings, the meter will again search for a GPS.

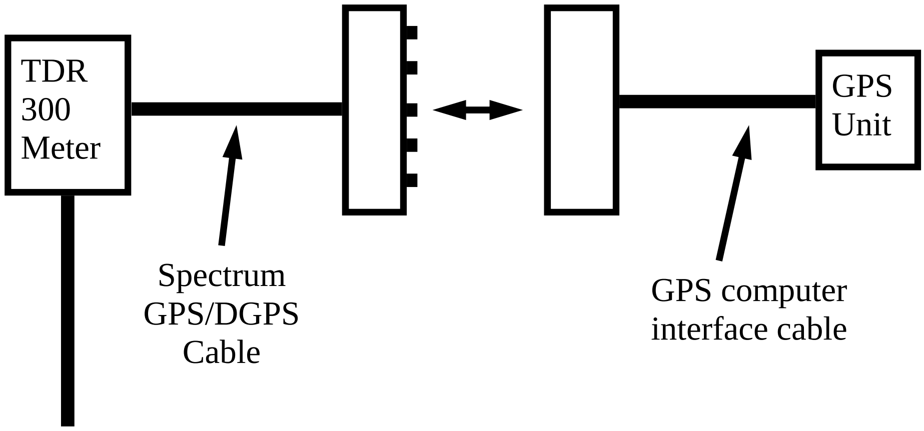
GPS Setting

Your GPS unit must be set for NMEA 0183 input/output messages. If the meter has trouble receiving the GPS signal, check that it has the following settings:

Data bits: 8	Stop bits: 1
Baud rate: 4800 bps	Parity: None
Timing: 1 second	GGA data string

Cable Connections

A GPS/DGPS cable (item # 2950CV5) is required to connect the TDR 300 meter to a GPS unit. This cable has a 9-pin male connection and a stereo pin that connects to the meter's data port. You will also need a cable that allows the GPS unit to connect to a 9-pin male serial port. If this cable doesn't come standard with your GPS unit, it should be available from the manufacturer. This cable is generally used to upload information from a computer to the GPS unit. These components should be connected as shown in the figure below.



Connecting the TDR 300 meter to a GPS unit

Data Files

No Till.xls

	A	B	C	D	E	F
1	Name: Test					
2	Serial #: 1					
3	Datum: WGS 84					
4	Longitude	Latitude	No.	% Water	Type	Rod Length
5			Logger Started: 8:01:30			
6	-88.3582	41.31085	N=1	30.7	Standard VWC	7.9in
7	-88.3582	41.31085	N=2	30.7	Standard VWC	7.9in
8	-88.3582	41.31085	N=3	30.7	Standard VWC	7.9in
9	-88.3613	41.31134	N=4	17.3	Standard VWC	7.9in
10			Logger Started 9:06:10			
11	-88.3595	41.31217	N=1	22.1	Standard VWC	4.7in
12	-88.3595	41.31217	N=2	22.5	Standard VWC	4.7in
13	-88.3595	41.31217	N=3	22.5	Standard VWC	4.7in
14	-88.3595	41.31217	N=1	14.5	Hi Clay VWC	4.7in
15	-88.3595	41.31217	N=2	14.5	Hi Clay VWC	4.7in
16	-88.3595	41.31217	N=3	14.5	Hi Clay VWC	4.7in
17			Logger Started			
18			N=1	27	Asnte	3.0in
19			N=2	31	Asnte	3.0in
20			N=3	42	Asnte	3.0in
21			N=4	78	Asnte	3.0in
22			Logger Started			
23			N=1	2750	Period uS	7.9in
24			N=2	2770	Period uS	7.9in
25			N=3	2780	Period uS	7.9in
26			N=4	2760	Period uS	7.9in
27						
28						

No Till

Sample data showing results of data collected with and without GPS activated. Note: GPS signal not found when recording data in lines 17 through 26.

The data is stored in comma-delimited text files. These files can be opened with text-editing software (e.g. Microsoft Word) or spreadsheet software (e.g. Excel).

The first two lines of the data file give the logger's name and serial number. The third line indicates that latitude and longitude are referenced to the 1984 World Geodetic Survey datum. The fourth line shows the column headings for the rest of the data file.

Logging sessions are started and completed by turning the meter on and off. The start of a logging session is indicated by the data line "Logger Started." If a GPS signal was found at the start of a logger session, a time stamp is included on the "Logger Started" line.

The data is separated into 6 fields: Latitude and Longitude (blank if a GPS unit was not connected), sample number, value, measurement type, and rod length. The "measurement type" data field indicates whether the reading is volumetric water content, relative water content or measurement period. For volumetric water content data, the calibration equation (Standard or High Clay) for that data point will also be included in measurement type.

Volumetric Water Content Measurements

Volumetric Water Content (VWC)
The soil can be thought of as being composed of soil, water and air. The volumetric water content (VWC) is the ratio of the volume of water in a given volume of soil to the total soil volume. This can be expressed as either a decimal or a percent. Three soil moisture levels of importance can be defined as follows:

Saturation: All soil pores are filled with water. The VWC will equal the percent pore space of the soil.

Field Capacity: The condition that exists after a saturated soil is allowed to drain to a point where the pull of gravity is no longer able to remove any additional water.

Permanent Wilting Point: The highest moisture content at which a plant can no longer extract water from the soil.

Additionally, we can define Plant Available Water as the amount of water between Permanent Wilting Point and Field Capacity. One rule of thumb is that irrigation should be initiated when half the Plant Available Water has been depleted.

Time Domain Reflectometry (TDR)
The underlying principal of TDR involves measuring the travel time of an electromagnetic wave along a waveguide. The speed of the wave in soil is dependent on the bulk dielectric permittivity (ε) of the soil matrix. The fact that water ($\varepsilon = 80$) has a much greater dielectric con-

stant than air (ε = 1) or soil solids (ε = 3-7) is exploited to determine the VWC of the soil. The VWC measured by TDR is an average over the length of the waveguide.

Electronics in the TDR 300 generate and sense the return of a high energy signal that travels down and back, through the soil, along the waveguide composed of the two replaceable, stainless steel rods. The sampling volume is an elliptical cylinder that extends approximately 3 cm out from the rods. The high frequency signal information is then converted to volumetric water content. High amounts of clay or high electrical conductivity (EC>2 dS/m) will attenuate the high-frequency signal and affect the reading displayed by the meter. Very high organic matter content will similarly affect the VWC reading.

Relative Water Content Mode

```
RWC=25.5 D=3.17in
A=23.4 N=06 Asnte
```

In addition to displaying volumetric water content (VWC), the meter can also display the relative water content (RWC) and Water Deficit (see MODE button, p. 8). RWC is an index value calculated with respect to upper (wet) and lower (dry) VWC set points. The set points are configured with the software (refer to Meter Settings, p. 16). An RWC of 0 indicates the soil is at the dry set point while an RWC of 100 indicates the soil has reached the wet set point. (Example: Assume the dry set point is VWC=25% and the wet set point is VWC=40%. If the meter measured a VWC of 35%, this would translate to a RWC of 67 because 35% is 2/3 between 25% and 40%.) If the soil's volumetric water content is outside the range of the set points, it is possible to get a negative RWC or an RWC greater than 100.

If the volumetric water contents for field capacity and permanent wilting point are the wet and dry set points respectively, the RWC value will be equivalent to Plant Available Water (PAW). A general rule of thumb is to recommend irrigation when the soil has reached 50% of the PAW.

Also included on the first line is the Water Deficit. The Water Deficit is the amount of rain or irrigation water necessary to raise the soil water content to the wet set point. This calculation applies to a soil depth equal to the probe rod length. The water deficit can be extrapolated further into the profile if the porosity and water-holding characteristics are similar to the volume of soil sampled by the probe.

The second line of the LCD gives the Average (A) of all readings taken, the Number (N) of readings taken and the 5-symbol name given to this soil type in the Meter Settings screen (see p. 16).

Specifications

Measurement Units	Percent volumetric water content
Resolution	0.1%
Accuracy	±3.0% volumetric water content with electrical conductivity < 2 dS m^{-1}
Range	0% to saturation (*Saturation is typically around 50% volumetric water.*)
Power	4 AAA alkaline batteries Approximately 12 month life
Logger Capacity	2700 readings without GPS, 1250 readings with GPS/DGPS
Display	16 character, 2 line LCD
Weight	3 lbs. (1.4 kg)
Probe Head Dimensions	3.1" x 3" x 1" (7.8cm x 7.5cm x 2.5cm)
Rod Dimensions	Length : 1.5" (3.8cm), 3" (7.6cm), 4.7" (12cm) or 7.9" (20cm) Diameter: 0.2" (0.5cm) Spacing: 1.3" (3.3cm)

The internal data logger and RS-232 port are compatible with GPS/DGPS. The data logger's LCD screen will display the data in one of three modes (see MODE button p. 8):

1. Volumetric water content - in Standard or High Clay mode
2. Relative water content - up to 2 RWC modes can be established
3. Measurement period - in microseconds

Appendix 1
Time zone corrections

Time Zone Correction	City
0	Dublin, Lisbon, London
3	Rio de Janeiro, Montevideo
4	Asuncion
5	Atlanta, Indianapolis, New York, Ottawa, Bogota, Montreal, Toronto
6	Guatemala City, Houston, New Orleans, Chicago, Mexico City, Winnipeg
7	Phoenix, Denver, Edmonton
8	San Francisco, Los Angeles, Vancouver
9	Anchorage
10	Honolulu
11	Wellington
13	Adelaide, Melbourne, Sydney
14	Vladivostok, Brisbane
15	Seoul, Tokyo
16	Beijing, Hong Kong, Manila, Singapore, Taipei
17	Hanoi, Jakarta, Vientiane
18	Calcutta, New Delhi
19	Kabul, Islamabad
20	Tehran, Abu Dhabi, Dubai
21	Moscow, Nairobi, Kampala, Riyadh
22	Ankara, Athens, Helsinki, Istanbul, Cairo, Johannesburg, Harare
23	Amsterdam, Barcelona, Berlin, Geneva, Paris, Prague, Rome, Brussels, Madrid, Stockholm, Warsaw, Lagos

Appendix 2
Soil-Specific Calibration

Period = 0950 uS N015

For maximum accuracy, you may choose to perform a soil-specific calibration rather than use either of the internal (Standard or High Clay) soil calibrations coded into the TDR 300's firmware. In these cases, an independent soil moisture content measurement is required. A relation can then be developed that relates the meter's period reading (see MODE button, p. 8) to actual volumetric water content (VWC). This is most easily accomplished by doing a regression of one set of data against another.

VWC data can be obtained with a device such as a neutron probe, by measuring the weight of a saturated soil column of known volume as it is gradually dried, or by gradually wetting a known volume soil with the addition of known increments of water. In most cases, however, the calibration will be done with gravimetric sampling. This procedure is briefly described below.

In the field, establish a number of sites to sample. Each site should be wetted to a different soil moisture content by adding varying amounts of water. At each site a Field Scout TDR reading is taken followed by the extraction of a known volume of soil. Ideally, this would be an undisturbed soil core. The wet weight of this soil must be determined. If the soil cannot be weighed immediately, it should be stored in a plastic bag to reduce evaporation. The soil is then oven-dried (105^{o}C for 48 hours is a common requirement) and weighed again. The volumetric water content is calculated as follows:

VWC = $100*(M_{wet} - M_{dry})/(\rho_w*V_{tot})$
Where:

M_{wet}, M_{dry} =	mass (g) of wet and dry soil respectively
V_{tot} =	total soil volume (ml)
ρ_w =	density of water (1g/ml)

An alternate, but equivalent, calculation can be obtained from the gravimetric water content and soil bulk density.

VWC = GWC $*(\rho_b/\rho_w)$
Where GWC is the gravimetric water content and ρ_b is the bulk density:

GWC =	$100*(M_{wet} - M_{dry})/M_{dry}$
ρ_b =	M_{dry}/V_{tot}

The final step is to plot the calculated the measured period values with the readings obtained from Field Scout TDR meter. Regression analysis can then be performed on this data to develop an equation to convert from period to VWC.

Appendix 3
Troubleshooting

1. **Unable to bring up the Meter Settings screen.**
Generally, this indicates that the PC is not able to communicate with the meter. Check the following:
- The interface cable is securely connected to both the PC and the meter
- The meter has fresh batteries
- The meter is off
- The correct COM port is selected (see p. 6)
- The **Meter Type** is set to the TDR family (see p. 14)

2. **I am getting the “VWC%=ERR!” message.**
This message appears for two reasons.
1. If the meter is set to read 1.5” (TURF) rods while in **HiClay** mode. There is no high clay calibration for the rod length option. Change the rod length or switch to **Standard** calibration mode.
2. The probe block is damaged. Meter must be returned for repair. Contact Spectrum Technologies or your distributor to obtain a Return Goods Authorization (RGA) number.

3. **I am getting VWC values near 0% for all measurements, even in very wet soil.**
Most likely a circuit component in the display is damaged and must be repaired. Contact Spectrum Technologies or your distributor to obtain a Return Goods Authorization (RGA) number.

4. **When turning the meter on, it indicated it had found the GPS signal. However, when taking readings I get a GPS error message.**
This can happen if the meter is set to only accept GPS readings that have been differentially corrected. In general, this is not necessary. On the **Meter Settings** screen (p. 16), uncheck the second box in the Logger Settings section.

5. **The meter is not logging any data.**
The meter is shipped with the data logger disabled. It must be enabled in the Meter Settings screen (p. 16).

6. **My Average reading suddenly went to 0%.**
The average is only calculated for a maximum of 65 readings. If additional readings are taken, the LCD will display a value of 0% for the average. Press and hold the DELETE/CLR AVG button (p. 9) to return to normal operating mode.

7. **My LCD is stuck at N = 250.**
250 is the maximum number the LCD will display. At this point, additional water content readings can be made, but the index number (N value) will stay at 250. Press and hold the DELETE/CLR AVG button (p. 9) to return to normal operating mode.

8. **I'm getting a "Memory Full" message.**
The meter must be connected to Field Scout software to clear the memory (see p. 15).

Warranty

This product is warranted to be free from defects in material or workmanship for one year from the date of purchase. During the warranty period Spectrum will, at its option, either repair or replace products that prove to be defective. This warranty does not cover damage due to improper installation or use, lightning, negligence, accident, or unauthorized modifications, or to incidental or consequential damages beyond the Spectrum product. Before returning a failed unit, you must obtain a Returned Materials Authorization (RMA) from Spectrum. Spectrum is not responsible for any package that is returned without a valid RMA number or for the loss of the package by any shipping company.

DECLARATION OF CONFORMITY

Spectrum Technologies, Inc.
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Aurora, IL 60504 USA

Model Numbers:	6430FS
Description:	Portable Soil Moisture Probe
Type:	Electrical Equipment for Measurement, Control, and Laboratory Use
Directive:	2004/108/EC
Standards:	EN 61326-1:2006
	EN 61000-4-2:1995, including A1:1998 and A2:2001
	EN 61000-4-3:2002

As a consequence of the meter's measurement principle, radio frequencies less than 950 MHz can affect the meter's readings. Operating the meter in areas where such transmissions are present should be avoided.

EN 55011:2007

Douglas L. Kieffer, Soil/Water Products Manager   March 18, 2009

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