Calibration of the Enviroscan Soil Moisture Probe for the
LAMSAT Sites at Douglas Daly, N.T.

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SUMMARY:

An Enviroscan system (ES2) was used to collect soil moisture data on Red Earths of Douglas Daly, N.T. during the 94/95 season. The ES2 however, tended to underestimate real soil moisture levels when compared with, gravimetric and Neutron Probe methods. The system was calibrated against these other methods to correct for this problem, and to make the ES2 data more useful.

INTRODUCTION:

The Australian Semi Arid Tropics (SAT) experiences distinct and highly variable wet and dry seasons annually, and thus, knowledge of soil moisture levels, along with other hydrological inputs, is required to better understand the water balance of a catchment.

The Enviroscan unit developed by Sentek Pty. Ltd., is purported to reliably measures continuous volumetric moisture content (VMC) at user-defined depths. The information is stored in digital format on a logger, and is easily accessed by a laptop computer. To test the reliability of the ES2, a number of measurements of soil moisture were performed using a mixture of gravimetric and Neutron Probe readings. The Neutron Probe had already been calibrated to the soils in the experimental catchment, and was an easier way of obtaining VMC at depths greater than 30cm, compared to the gravimetric method.

DESCRIPTION OF EXPERIMENT:

Location:

The study area was situated at the Douglas Daly Research Farm (DDRF) 250 km south of Darwin at a latitude of 13°51' S and longitude 131°12' E. Measurements were taken from five (20m x 5m) sub-catchments within four catchments (Fig. 1). Each sub-catchment consisted of a trough downslope, which collected and measured runoff from the sub-catchment. To measure the soil water status within each sub-catchment, four neutron probe access tubes, and an ES2 probe surrounded by four tensiometers at different depths were installed (Fig. 2). A digital raingauge measured rainfall in each sub-catchment.

Rainfall, Evaporation and Runoff:

The historic mean annual rainfall for the research farm is 1200mm (Lucas, 1984). More than 90% of the annual rainfall is recorded over the five month period from November to March (Williams et al., 1985). These are the only months where mean monthly rainfall exceeds mean monthly evaporation (Lucas, 1984).
On average, more than 90% of the surface runoff events in agricultural catchments at Douglas Daly occur during the months of December to February (Dilshad and Jonauskas, 1990). For most of the wet season the intertropical convergence zone lies across the area and high rainfall intensity is common (Williams et al. 1985). For example, a storm with an intensity of 100mm/h over a duration of 20 minutes has an average recurrence interval of less than a year (Dilshad et al., 1994).

Fig. 1. The location and layout of the catchments and sub-catchments, not to scale.

Soils and Infiltration:

The catchments were located on the Red Earths Great Soils Group as defined by Stace et al. (1968) and grouped into the Tippera family (Lucas et al., 1987). These soils are classified as Kandosols under the new Australian Soil Classification system, by Isbell (1996).
Soils within the five sub-catchments, were relatively uniform showing minor variation in the top 40cm. The textures ranged from sandy clay loam at the top 10cm to light medium clay at 40cm. Between 40 and 150cm the soil texture ranged from light medium clay to heavy clay. Below this, bands of weathering sandstones were found throughout some of the profiles.

These soils experience infiltration rates of around $1.8 \times 10^2$ mm/h on initial dry soils. After 20 minutes flooding, infiltration rates stabilise with final infiltration rates ranging between 9 and 18mm/h (Dilshad et al., 1995).

**Preparation of Site:**

Four of the sub-catchments were sown with the improved pasture (IP) *Urochloa mosambicensis* (Sabi-grass), while the fifth was left as native bushland of *Eucalyptus foelscheana* with an understorey of *Heteropogon contortus* (black speargrass) (Fig. 1.). Other less common grass species occurring within the native pasture (NP) sub-catchment were *Themeda triandra* (kangaroo grass), *Sehima nervosum*, *Chrysopogon fallax*, and *Mnesithia rotboellioides*.

![Legend:](image)

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**Legend:**

E  Envirosan  
N  Neutron Probe  
T  Tensiometer  
O  Logged Raingauge  
□  Trough Logger  

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Fig. 2. Layout of instrumentation in a sub-catchment

Initially (93/94 season), the Envirosan Mk.I system was trialed whilst on loan from the Dept. of Primary Industries and Fisheries (D.P.I.F.), with a site established in each sub-catchment. Each site used a standard 50mm PVC tubing, installed within two metres of the leading edge of the Gerlach trough, downslope of each sub-catchment (Fig. 1.).
In August 1994, tensiometers were installed surrounding the Enviroscan probes (Fig. 2) at about a 30cm distance from the probe. At each probe site there were four tensiometers to measure soil tension at depths of 15, 30, 60 and 90cm. Readings from the tensiometers combined with the Enviroscan are to be used for further research.

In October 1994, the Enviroscan Mk.II system was set up at the same sites used for the Mk.I version. However, the new version required custom-made PVC tubing which was slightly wider (diameter) than the standard 50mm, and access tubes of 2.5m length were required instead of the 2.0m length used with Mk.I. It was decided to remove the original Enviroscan access tubes and replace them with the new tubes, as it was necessary to have the tensiometers equidistant from the ES2, and also to minimise the number of access tubes in the sub-catchments. The old sites were widened and lengthened using the auger and other equipment provided, and the new tubes installed.

The configuration of the layout and distribution of probes and sensors (Fig. 3. and Table 1.) was entered into the Enviroscan software. Sensors were then allocated to the pre-arranged positions (according to depth) on their respective probes, as described in Table 1. Normalisation was carried out on each sensor to produce a wet and dry count. Once normalisation was complete, full installation of the Enviroscan unit in the field was accomplished (Fig. 3.), and a test run was performed.

Before the Enviroscan probes were stationed in the sub-catchments (Oct. 1994), each area was subjected to different grazing pressures. Sub-catchment 1 was kept artificially bare with the use of a herbicide. Sub-catchments 2, 3 and 4 (improved pasture), were grazed at 3, 2 and 1 beasts per hectare respectively, whilst sub-catchment 5 (native woodland) was grazed at 1 beast per 10 hectares.

Table 1. Distribution of sensors for each probe site.

<table>
<thead>
<tr>
<th>Sub-catchment</th>
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<th>4</th>
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<tr>
<td>Sensor depths (cm)</td>
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After installation of the Enviroscan probes the sub-catchments were fenced to protect the instruments from cattle. Sub-catchment (S/c) 1 continued to be kept bare using herbicides. Sub-catchments 2 and 3 were mowed at approximately fortnightly intervals, so as to keep the cover level about 40% to 60%. Sub-catchments 4 and 5 were not grazed, but both were intentionally burnt in September 1994 and January 1994 respectively, which reduced the amount of cover dramatically below that usually expected in these areas. A 1 to 2 metre strip outside the S/c boundary, was managed in a similar fashion to the S/c, to allow gravimetric soil moisture samples down to 30cm to be collected outside of the sub-catchment, and to eliminate localised effects within the S/c close to the boundary.

Fig. 3. Layout of the Enviroscan system, not drawn to scale.
**METHODOLOGIES:**

Enviroscan soil moisture readings were compared against Gravimetric and Neutron probe data, for each of the sub-catchments at various times of the 1994/95 season.

**Enviroscan:**

It was originally believed that no calibration was necessary for the ES2 system to obtain the correct soil moisture. If so, once set up the only requirement in obtaining the data was to download the logger with the use of a laptop computer. After downloading, data for each sensor through time could be viewed in graphical format using the software provided. The VMC was calculated using the following equation from the ES2 manual (Anonymous, 1994):

\[ Y = A \times (X^B) + C \quad \text{eq. 1} \]

where

- \( Y \) = Universal Frequency
- \( X \) = Volumetric soil water content in mm
- \( A, B, C \) = Calibration Coefficients

The default coefficients are

\( A = 0.1957, \quad B = 0.404, \quad C = 0.02852 \)

The Universal Frequency is defined as

\[ Y = \frac{\text{Air Count} - \text{Field Count}}{\text{Air Count} - \text{Water Count}} \]

A comparison was made between the Enviroscan VMC for each sensor at the equivalent depth, date, and time, during collection of gravimetric and Neutron Probe sampling. At first linear regressions were fitted to the data from each of the individual sensors. However, due to a lack of data points and range of values, the linear regression method was unsuccessful in calibrating the system with a reasonable degree of accuracy. Thus, it was required to alter the calibration coefficients used by the Enviroscan unit to develop a more accurate function.

Solving for \( X \) using eq. 1 above:

\[ X = \left( \frac{\text{Air Count} - \text{Field Count}}{\text{Air Count} - \text{Water Count}} - C \right) / A \quad \left( \text{eq. 2} \right) \]

The Enviroscan calculated VMC using equation 2, by manipulating the default coefficients \((A, B, C)\), an improved value for VMC could be obtained. A default coefficient was changed while the remaining two coefficients remained constant, for the data points from February to April, for each sensor. A default coefficient was changed until the new moisture readings compared favourably with the manually measured values. This was repeated for each of the default coefficients, giving new coefficients \((A,B,C)\). The best new coefficient was chosen for each sensor using least
squares analysis. The soil moisture readings collected in September 1995 were used to determine how well the new coefficient for each sensor was performing.

**Gravimetric:**

These samples were collected from an area outside the boundary of the sub-catchment which closely resembled the Enviroscan probe site. All sub-catchments had a 1.5m strip immediately outside the boundary which had the same vegetation management regime as inside the boundary.

At each random sampling period, soil moisture samples were collected for 0-10cm, 10-20cm, and 20-30cm depths. A 50mm diameter auger was used to collect soil at these depths and the sample placed in a sealable tin container. Samples were collected from a 10cm deep section equivalent to that of the corresponding sensor on the Enviroscan probe. The samples were oven dried at 104°C for 24 hrs to obtain the gravimetric moisture content.

The same sampling method was used to sample selective depths to 150cm (on one occasion) instead of using the Neutron Probe, which measures VMC from a larger volume of surrounding soil, compared with the ES2 and Gravimetric methods.

**Neutron probe:**

The first reading was taken at a 40cm depth, and every 20cm interval thereafter down to 1.8m. For this experiment the access tube closest to the ES2 probe was used for measuring soil moisture, the distance being no more than five metres (Fig. 2.).

This method measures soil moisture through the use of fast moving neutrons from a radioactive source (Am241). The probe emits fast moving neutrons which travel up to 3 metres into the surrounding soil. Fast moving neutrons lose energy and are converted to slow neutrons through collisions with atoms of low atomic weight (Linsley et al., 1982). The hydrogen in water is normally the major atom of low atomic weight in the soil. When the neutron returns to the probe, it may have hit many water molecules and slowed down considerably. The speed with which the neutron returns to the probe is proportional to the moisture content in the surrounding soil (Goodspeed, 1981).

At each depth, three 16 second counts were taken and an average of the three was used. Calibration equations developed internally for the soils studied, were used to convert neutron probe counts for all depths and sites into VMC (%).

**Tensiometers:**

Tensiometers were installed around the Enviroscan probe (Fig. 2.), at a distance of 30cm from the probe. Each site had four tensiometers, with depths of 15cm, 30cm,
60cm, and 90cm. A protective PVC capping covered the tops of the tensiometers from external elements. The pressure in the tube was measured daily at 0900 hrs.

Tensiometer readings were not used for comparison with the Enviroscan, but may be used at a later date for comparison or in conjunction with the readings collected from other soil moisture measuring devices.

RESULTS AND DISCUSSION:

Levels of VMC for each Enviroscan probe at every sensor location (Table 1), were graphed through time against corresponding values obtained from conventional methods (Fig.4). These graphs display the Enviroscan and measured values, along with the calibrated Enviroscan values, and the coefficient which was changed to obtain this improved value.

The manually measured values displayed for sensors at the 5, 15, and 25cm depths were measured using the gravimetric method. For all other depths the neutron probe method was used. The gravimetric method was used for all depths of probe 1, 4, and 5 on the 13th September 1995. The soil moisture at this time is generally uniform throughout the profile thus, a greater accuracy of readings was possible using the gravimetric method. Probe 2 and 3 were inoperable at this time.

Probe 1:

Sensors for probe 1 (except the 5cm sensor) generally underestimated soil moisture content by 5 to 17% VMC (Fig. 4a-g.). The 5cm sensor, although subjected to a large range of soil moisture fluctuations, was the most reliable when compared to the manually measured values. The 5cm sensor was further improved by adjusting the coefficient C to -0.052 (Fig. 4a.). By utilising their respective improved coefficients, the remaining sensors had their values improved in comparison with originally measured values.

The altered coefficient for each of the sensors continued to improve the Enviroscan value for the September 1995 reading in all cases except the 15cm sensor. This could be due to either the sensor taking more reliable readings or an error with the manually measured value. A more reliable reading by the sensor may be due to the soil drying out or from the filling in of any air gaps which may have been present. An error in the measured value, could simply be due to the site variations of each of the small volumes of soil (gravimetric and Enviroscan) which are sampled to give a reading of soil moisture. There was a gravel layer present at 160cm which did not allow for a gravimetric reading at 195cm for September 1995.
Fig. 4. Calibration and Comparisons of Moisture Content for Probe 1 sensors

a. 5cm sensor, improved coefficient $C = -0.052$

b. 15cm sensor, improved coefficient $B = 0.365$

c. 25cm sensor, improved coefficient $A = 0.159$

d. 45cm sensor, improved coefficient $C = +0.095$
Fig. 4. contd.

c. 65cm sensor, improved coefficient $B = 0.315$

![Diagram showing % VMC over dates for 65cm sensor with measured, ES2, and improved data points.]

f. 145cm sensor, improved coefficient $C = +0.1204$

![Diagram showing % VMC over dates for 145cm sensor with measured, ES2, and improved data points.]

g. 195cm sensor, improved coefficient $C = +0.13$

![Diagram showing % VMC over dates for 195cm sensor with measured, ES2, and improved data points.]

**Probe 2:**

Sensors for probe 2 (except the 5cm sensor) generally underestimated soil moisture by 5 to 10% VMC (Fig. 5b-d). The 5cm sensor (Fig. 5a) measured soil moisture reasonably well for all dates except for the April reading. The larger variation for April could possibly be due to the slight differences between sites (gravimetric and Enviroscan), or operator error.

All VMC values were improved by utilising the respective improved coefficients of each sensor (Fig. 5a-d). It is not possible to state whether these improved coefficients continue to be effective for probe 2, as it was not functioning at the time of the September 1995 sample.
Fig. 5. Calibration and Comparisons of Moisture Content for Probe 2 sensors

a. 5cm sensor, improved coefficient $B = 0.3802$

b. 25cm sensor, improved coefficient $C = +0.04$

c. 45cm sensor, improved coefficient $C = +0.092$

d. 105cm sensor, improved coefficient $C = +0.044$
Fig. 6. Calibration and Comparison of Moisture Contents for Probe 3 sensors

a. 5cm sensor, improved coefficient $B = 0.3578$

b. 15cm sensor, improved coefficient $B = 0.2439$

c. 25cm sensor, improved coefficient $B = 0.2639$

d. 45cm sensor, improved coefficient $C = +0.365$
Probe 3:

All sensors on probe 3 underestimated soil moisture (Fig. 6a-e); the 5cm sensor by 6% VMC on average, while the rest of the sensors by 15 to 25% VMC.

The Enviroscan values in almost all cases were improved significantly through the use of the altered coefficients. Some measured values for the April sample (5, 15, and 25cm sensors) were possibly high due to site variations.

Probe 4:

The 5, 15, and 25cm sensors (Fig. 7a-c) underestimated by up to 10%. By utilising the altered coefficients for each of the sensors the Enviroscan values were improved. This decreased the difference between measured and the improved Enviroscan values to less than 3% VMC. The measured values for the April sample could be slightly higher due to site variations, or operator error. If this set of readings was overlooked, the improved values were highly correlated to the measured values. The September 1995 reading experienced a reduction in the difference between the Enviroscan and the measured values, but the altered coefficient generally continued to improve the Enviroscan values, even if only marginally.

Sensors at 45, 65, 105, and 145cm were underestimating by approximately 15% VMC for most of the season (Fig. 7d-g). The altered coefficients for these sensors greatly improved the Enviroscan values for the calibration period (February to April).

The difference between Enviroscan and manually measured values had greatly decreased at the September sample, for all but the 65cm sensor (Fig 7e). The decrease in the difference could be due to the filling of air gaps during the dry season, or possibly operator error.

When compared with the measured values, the 195cm sensor produced values which were very nearly equal (Fig. 7h). Thus, only an insignificant improvement was required and was possible. A gravimetric sample was not possible in September due to difficulties in reaching this depth.
Fig. 7. Calibration and Comparisons of Moisture Contents for Probe 4 sensors

a. 5cm sensor, improved coefficient $B = 0.3774$

![Graph a. 5cm sensor, improved coefficient $B = 0.3774$](image)

b. 15cm sensor, improved coefficient $C = +0.024$

![Graph b. 15cm sensor, improved coefficient $C = +0.024$](image)

c. 25cm sensor, improved coefficient $C = +0.024$

![Graph c. 25cm sensor, improved coefficient $C = +0.024$](image)

d. 45cm sensor, improved coefficient $C = +0.185$

![Graph d. 45cm sensor, improved coefficient $C = +0.185$](image)
e. 65cm sensor, improved coefficient $C = +0.184$

f. 105cm sensor, improved coefficient $C = +0.169$

g. 145cm sensor, improved coefficient $C = +0.164$

h. 195cm sensor, improved coefficient $C = -0.005$
**Probe 5:**

The 5cm sensor values for the Enviroscan were under and overestimating real values (Fig. 8a), thus any changes in the coefficients were not going to produce any improvement in values. The manually measured value for April could be higher than the Enviroscan value due to site variations. The April value is the only time when Enviroscan underestimates moisture, the remainder of the values were equal or overestimated within 5% of the measured values.

The remainder of the sensors (Fig. 8b-h) were underestimating by 10 to 15% VMC (15, 25, 45, 65, and 105cm sensors), or by 25 to 30% VMC (145 and 195cm sensors). A number of tree roots were encountered whilst augering the hole for this probe site. This may have caused air gaps or, localised drier conditions due to tree root uptake of moisture. Most of these sensors improved their values with the use of the altered coefficients for the calibration period. The measured values for the 15 and 25cm sensors (April) could be higher than the improved Enviroscan value due to site variations, as similarly found with the 5cm sensor (Fig 8a-c).

Differing results were experienced for each of the sensors (Fig. 8a-h) when the altered coefficients were applied to the Enviroscan values in September 1995.

The Enviroscan and gravimetric VMC values for the 15 and 25cm sensors were nearly equal, thus the altered coefficient caused the improved value to overestimate VMC. This could be due to the generally drier conditions at the time, or the filling of any air gaps in these sensors’ range. The 45 and 145cm sensors in September 1995 continued to underestimate VMC by a similar amount as was calibrated for, thus the improved coefficient continued to yield VMC’s which compared well against the measured VMC’s.

The 65 and 105cm sensors improved values for September 1995, and continued to underestimate VMC by 7 and 6% respectively. This could be due to the presence of tree roots, the generally drier conditions, further increases in the amount of air gaps in the vicinity of these sensors, or the unsuitability of the improved coefficient under drier conditions.

The 195cm sensor experienced good results for the improved values for the calibration period. It was not possible to test this improved coefficient for September as a gravimetric sample at this depth was not obtained then.
Fig. 8. Calibration and Comparisons of Moisture Content for Probe 5 sensors

a. 5cm sensor, No Improved coefficient possible

b. 15cm sensor, improved coefficient $B = 0.3226$

c. 25cm sensor, improved coefficient $C = +0.05$

d. 45cm sensor, improved coefficient $C = +0.04$
Fig. 8. contd.

e. 65cm sensor, improved coefficient $C = 0.1$

![Graph showing data points for 65cm sensor over time]

f. 105cm sensor, improved coefficient $C = 0.141$

![Graph showing data points for 105cm sensor over time]

g. 145cm sensor, improved coefficient $C = 0.337$

![Graph showing data points for 145cm sensor over time]

h. 195cm sensor, improved coefficient $C = 0.39$

![Graph showing data points for 195cm sensor over time]
CONCLUSION:

The level of reliability of the Enviroscan system in terms of accurately determining soil moisture in the profile is poor. The ES2 generally tended to underestimate VMC, the amount by which it underestimated varied between probes, and between sensors. The data available was insufficient to completely assess and rectify the reliability of the system in measuring soil moisture.

The Enviroscan values for VMC have been rectified by the use of the improved coefficients to make its data for this period more useful. A more accurate calibration could possibly be achieved by altering all three coefficients simultaneously to produce the best combination which would improve the VMC values. This was not feasible due to constraints of time and labour, as this would had to be conducted on each of the 32 sensors.

The accuracy of the calibration could have been increased if there were a greater number of readings, and a greater range of soil moisture values measured. This was not possible as the calibration period coincided with the monsoonal period, when the workload is heavy. When manual measurements were collected at other times, unfortunatley the Enviroscan system malfunctioned.

The data which fell within the calibrated period (Feb. to April) can be rectified to produce a more accurate VMC for all sensors with reasonable certainty. Data outside this period (April to Sept. 95) can also be rectified with less reliability due to a lack of data for calibration over this period.

ACKNOWLEDGMENTS:

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