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The Nerrigundah data set: Soil moisture patterns, soil characteristics, and hydrological flux measurements

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Abstract. This paper presents a data set that describes the spatial and temporal variability of soil moisture within the 6 ha Nerrigundah catchment, located in a temperate region of eastern Australia. The data set includes high-resolution elevation data; high-resolution (20 m) near-surface soil moisture maps; soil moisture profile measurements at 13 locations, with one being applicable for one-dimensional modeling; soil moisture measurements from four different measurement devices at a single location; soil temperature profile measurements; soil heat flux and supporting meteorological measurements, including data obtained with two pluviometers and four collecting rain gauges; surface roughness measurements; soil information for 19 locations, including field measurements of saturated hydraulic conductivity; and catchment runoff measurements. These data are available on the World Wide Web at http://www.civag.unimelb.edu.au/~jwalker/data/nerrigundah.

1. Introduction

Soil moisture in the top 1–2 m of the Earth's surface is widely recognized as a key parameter in numerous environmental studies, including meteorology, hydrology, agronomy, and climate change studies. Although this thin layer of soil water may seem insignificant when compared to the total amount of water on the global scale, it is this soil water that controls the success of agriculture and regulates partitioning of precipitation into runoff, evapotranspiration, and ground water storage. Furthermore, soil moisture content is one of the few directly observable hydrological variables that play an important part in the water and energy budgets required in climate studies [*Jackson*, 1993]. However, as a result of the heterogeneity of soil properties, topography, land cover, evapotranspiration, and precipitation, soil moisture is highly variable both spatially and temporally [*Engman*, 1991; *Wood et al.*, 1993; *Western et al.*, 1999].

This paper describes data from a field experiment investigating the spatial and temporal variability of soil moisture in the Nerrigundah catchment, New South Wales, Australia. The data set has been collected as a twin experiment to the series of field experiments investigating the spatial variability of soil moisture in the Tarrawarra catchment, Victoria, Australia [*Western and Grayson*, 1998]. This data set also complements European and North American field efforts, such as the Weiherbach project [*Bronstert and Plate*, 1997] and the Southern Great Plains experiments [*Famiglietti et al.*, 1999; *Mohanty et al.*, 2000], and extends the Global Soil Moisture Data Bank [*Robock et al.*, 2000].

The aim of experiments in the Nerrigundah catchment was to collect data applicable to soil moisture modeling in both a one-dimensional soil column and at the small catchment scale. The resulting data set includes high spatial and temporal resolution maps of near-surface soil moisture and a range of supporting information, including soil moisture profile and meteorological, runoff, and soil data. While we will continue to conduct our own analyses of this data set, we are making it available to the general research community so that it may be used to its fullest potential and may provide unrestricted access to the much needed field data that land surface modelers require for evaluation studies.

These data sets have a variety of potential uses. Specific analyses we have conducted include evaluation of data assimilation schemes in both one-dimensional [*Walker et al.*, 2001] and three-dimensional (J. P. Walker et al., Three-dimensional soil moisture profile retrieval by assimilation of near-surface measurements: Simplified Kalman filter covariance forecasting and field application, manuscript in preparation, 2001) settings; evaluation of synthetic aperture radar (SAR) data from the second European Remote Sensing (ERS-2) satellite for soil moisture estimation (J. P. Walker et al., Active microwave remote sensing for soil moisture measurement: A field evaluation using ERS-2, manuscript in preparation, 2001); comparison of soil moisture point measurement techniques (J. P. Walker et al., In situ measurement of soil moisture: A field comparison of techniques, manuscript in preparation, 2001) (hereinafter referred to as Walker et al., manuscript in preparation, 2001); and calibration of hydrological model parameters with soil moisture, evapotranspiration, and runoff data (S. A. Wooldridge et al., The importance of soil moisture measurements for conceptual model parameter inference in low-yielding ephemeral catchments, submitted to *Environmental Modelling and Software*, 2001).

2. Catchment Description

The Nerrigundah experimental catchment is located in the Williams River catchment on a property called Nerrigundah, approximately 11 km northwest of Dungog, New South Wales, Australia (32°19′ south, 151°43′ east). The catchment runs east

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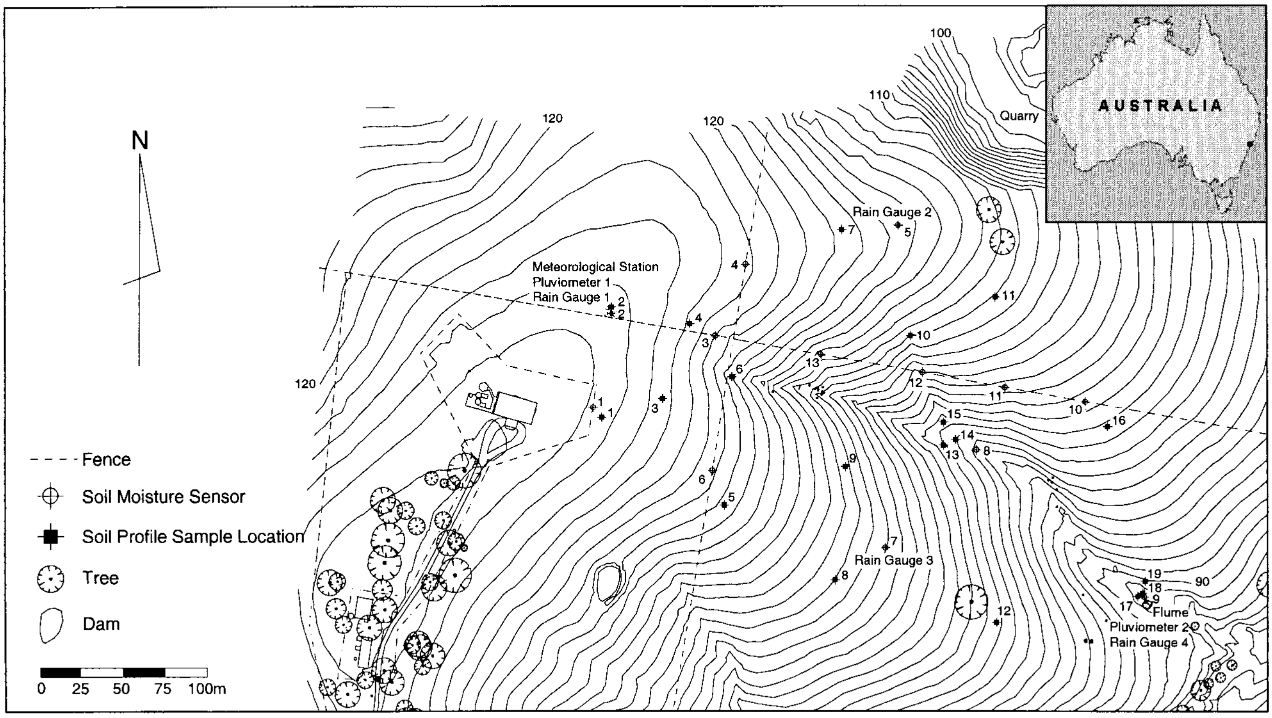

Figure 1. Topography, location of monitoring equipment, and location of soil sampling sites in the Nerrigundah catchment. The approximate geographic location of the Nerrigundah catchment is indicated on the inset.

to west with a relief of 27 m and a catchment area of 6 ha. Hillslopes are typically 11% with a range from 3% to 22%, and the main drainage line has an average slope of 9% with a range from 1% to 17% (Figure 1). The catchment has an elevation of ~110 m Australian Height Datum (AHD) and is used for grazing of beef cattle. The catchment is vegetated mostly with natural grasses and has been cleared of timber for ~50 years. There were no external or man-made influences on the soil moisture or runoff in the catchment during the period of data collection.

Nerrigundah has a temperate climate with a mean annual summer-dominant rainfall of 1000 mm and a class A pan evaporation of 1600 mm. The maximum mean monthly rainfall occurs in January (147 mm), and the minimum occurs in July (37 mm), while the maximum mean monthly pan evaporation occurs in December (225 mm) and the minimum occurs in June (60 mm). Mean summer maximum and minimum temperatures are 30°C and 16°C, respectively, and mean winter maximum and minimum temperatures are 15°C and 6°C, respectively [*Australian Bureau of Meteorology*, 1988].

The catchment is situated on a variant of the Tillegra Erosional Landscape, which is located on the Wooton Beds. The Wooton Beds consist of sandstone, siltstone, claystone, shale, limestone, and lavas, dating from the Carboniferous period [*New South Wales Department of Mines*, 1966]. In this soil landscape the soils are usually shallow (30–90 cm) consisting of well-drained to moderately well drained bleached loams, structured loams, and lithosols on a siltstone parent material, with the occasional moderately deep to deep (55–290 cm) patch consisting of well-drained to imperfectly drained Soloths and Solodic soils, and yellow Podzolic soils on sandstone [*Henderson*, 2000].

3. Data Summary

The Nerrigundah experimental catchment was instrumented from October 12, 1996, through October 20, 1998, for soil moisture content, soil temperature, runoff, rainfall, and meteorological data. The continuously monitored soil moisture instrumentation (Figure 2) was located such that lateral redistribution of soil moisture would be negligible, and measurements for estimating the surface fluxes (precipitation/evapotranspiration) would be representative of the entire catchment. Therefore the continuous instrumentation was located in a level location in the upper reaches of the catchment (Figure 1, soil profile sample/soil moisture sensor 2). Monitoring of the spatial variation in soil moisture data could not be performed economically using continuous instrumentation. Hence the spatial and temporal variation of both near-surface soil moisture and soil moisture over the soil profile was extensively monitored during an intensive field campaign from August 27, 1997, to September 22, 1997. Monitoring of soil moisture profiles was continued from September 22, 1997, through October 20, 1998, on a less frequent basis. Soil moisture profiles were also measured on August 22, 1997, to provide background soil moisture values for the intensive field campaign.

3.1. Terrain Data

An accurate digital elevation model of the Nerrigundah catchment was generated from a total station field survey, with horizontal coordinates on the Australian Map Grid (AMG) and elevations on AHD. Approximately 4600 elevation data points were observed with an average spacing of 7.5 m. In addition to elevation data for the experimental catchment and its surrounds the survey located fences, buildings, dams, trees/shrubs, monitoring equipment, and soil sample locations (Figure 1). Elevation data are available as both the original x, y, z data and as interpolated onto a 20 m × 20 m grid on both the AMG and local coordinate system. The gridded elevation data correspond with the near-surface soil moisture sampling grid, which is aligned with the natural axis of the catchment given by

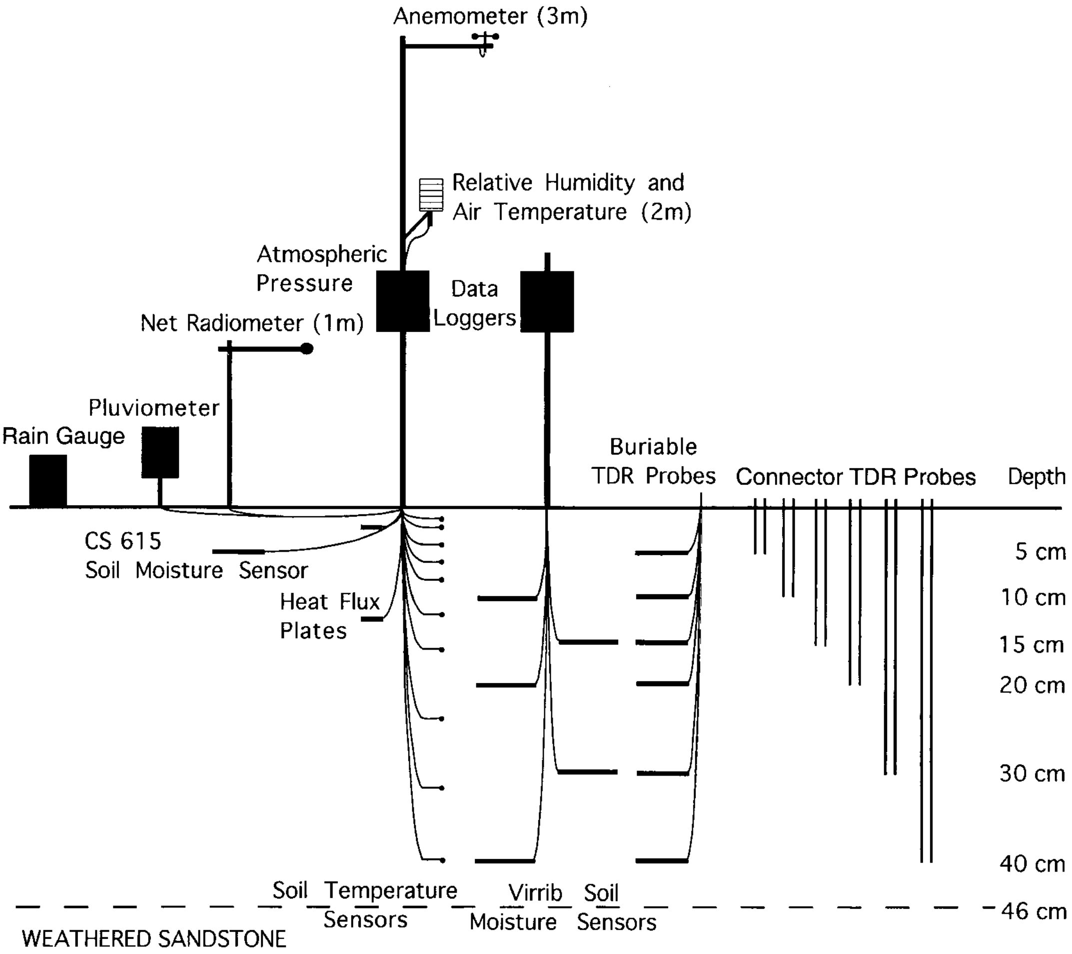

Figure 2. Diagrammatic illustration of the continuously monitored instrumentation setup in the Nerrigundah catchment.

the orientation of the fence lines dissecting the catchment (Figure 1).

3.2. Near-Surface Soil Moisture Maps

Twelve near-surface soil moisture maps were collected on a 20 m × 20 m grid (238 measurement sites per coverage) over the catchment during the 1 month intensive field campaign in August–September 1997. These data were collected using the University of Melbourne's Terrain Data Acquisition System (TDAS): an all-terrain vehicle with a differential Global Positioning System and hydraulic ram for insertion of the two-wire connector-type time domain reflectometry (TDR) probes used for measuring the near-surface soil moisture [*Tyndale-Biscoe et al.*, 1998]. The TDR system used was the Soil Moisture Equipment Corporation TRASE® TDR, using the standard TRASE calibration to determine the volumetric soil moisture content from the measured dielectric constant over a probe length of 15 cm. (The mention of trade and company names is for the benefit of the reader and does not imply an endorsement of the product.) Calibration of the TDR against gravimetric measurement of soil moisture indicated that data should be accurate to within ±2.5% vol/vol. The ERS-2 SAR data were collected coincidently with two of the measurement dates, but these data are not available as part of the public data set. An example of the near-surface soil moisture map data is given in Figure 3.

3.3. Soil Moisture Profile Measurements

The soil moisture profile was monitored at 13 locations in the catchment using two-wire connector-type TDR probes to the lesser of depth to bedrock or 100 cm. Probes were inserted vertically for nominal lengths of 5, 10, 15, 20, 30, 40, 50, 60, 70, 80 and 100 cm, yielding an average soil moisture measurement for the length of the probe. The TDR probes were permanently installed, and the measurements were made by attaching the balun and TRASE signal unit. These measurements were made coincident with the near-surface soil moisture mapping measurements during the intensive field campaign. The locations of soil moisture profile measurement sites are shown in Figure 1.

In addition to the connector-type TDR data the one-dimensional soil moisture profile monitoring site located near the weather station (Figure 1, soil moisture sensor 2) was monitored using three-wire buriable-type TDR probes, Virrib® soil moisture sensors, and a Campbell Scientific CS615 water content reflectometer. Both the Virrib and CS615 soil moisture sensors provided a continuous monitoring of the soil moisture, while both the connector- and buriable-type TDR measurements were made periodically. The horizontal layout of instrumentation at this site is given in Figure 4.

Virrib soil moisture measurements were made with five sen-

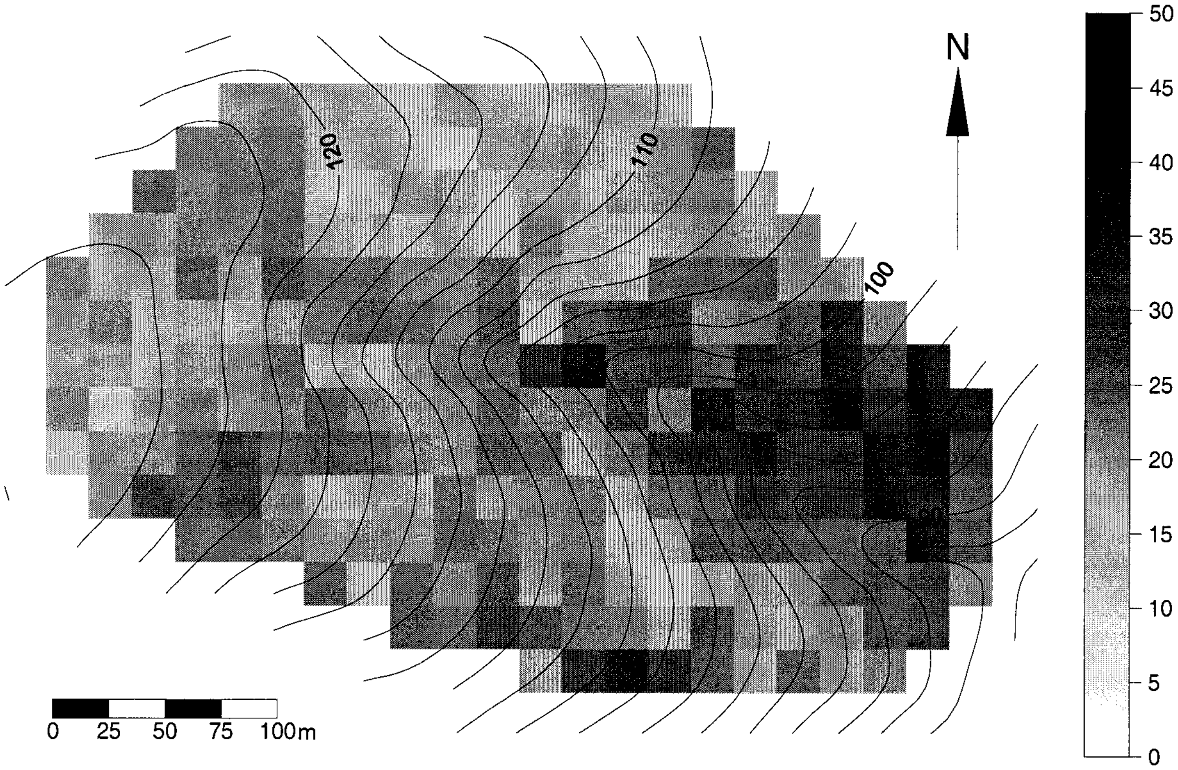

Figure 3. Near-surface soil moisture map of Nerrigundah catchment on September 15, 1997. The contours are for elevation in meters.

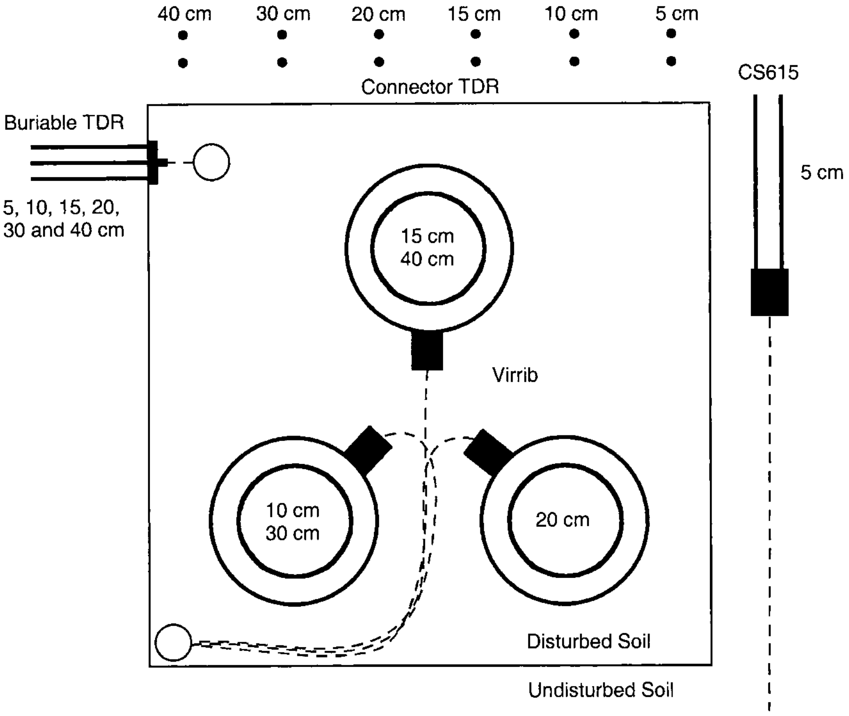

Figure 4. Diagrammatic illustration of the horizontal layout of soil moisture sensors for monitoring soil moisture at the weather station. Cables are indicated by a dashed line, and measurement depths/probe lengths are indicated on the diagram.

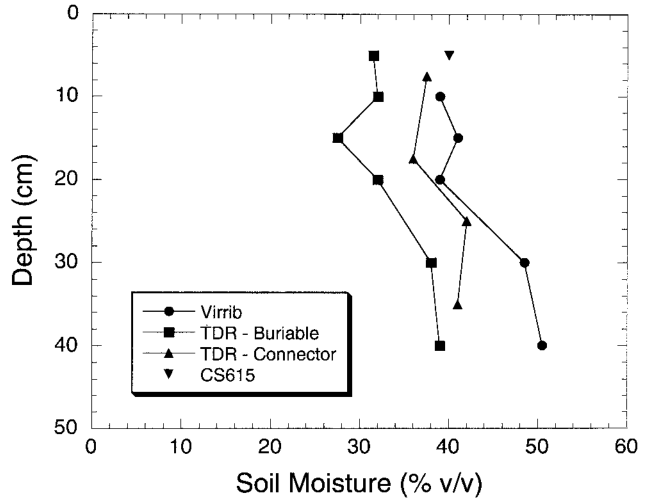

Figure 5. Comparison of Virrib, connector-type time domain reflectometry (TDR), buriable-type TDR, and CS615 reflectometer soil moisture measurements at soil moisture monitoring site 2.

sors installed horizontally at depths of 10, 15, 20, 30, and 40 cm, providing soil moisture measurements over a layer thickness of 12 cm (Komin, technical data). These measurements were logged every 15 min. A single CS615 sensor was installed horizontally at a depth of 5 cm, providing a soil moisture measurement over a layer thickness of ~4 cm [*Campbell Scientific Inc.*, 1995]. These measurements were logged every 10 min. Buriable-type TDR probes were installed horizontally at depths of 5, 10, 15, 20, 30, and 40 cm, providing an average soil moisture measurement over a layer thickness of ~4 cm [*Soil Moisture Equipment Corp.*, 1989]. The connector-type TDR probes gave an average soil moisture measurement over nominal probe lengths of 5, 10, 15, 20, 30, and 40 cm. The minimum depths at which the Virrib and buriable-type TDR probes could be installed without causing a loss of accuracy were 10 cm (Komin, technical data) and 5 cm [*Soil Moisture Equipment Corp.*, 1989], respectively. The vertically inserted connector-type TDR probes were installed on April 24, 1997, and the Campbell Scientific CS615 sensor was installed on May 8, 1997. All other measurements commenced on October 12, 1996, and continued until October 20, 1998. An example of the soil moisture profile data is given in Figure 5, and a time series of the depth-averaged soil moisture data is shown in Figure 6. The differences between these various soil moisture measurements are discussed by Walker et al. (manuscript in preparation, 2001).

3.4. Meteorological and Flux Measurements

Meteorological measurements were made with an automatic weather station which monitored relative humidity and air temperature; soil temperature at 0.5, 1, 2, 4, 6, 8, 12, 16, 24, 32, and 40 cm depths using thermocouples; soil heat flux at 2 and 12 cm depths using soil heat flux plates; atmospheric pressure; rainfall; net all-wave radiation; and wind speed. Apart from rainfall, all measurements were made at 1 min intervals, and the average was logged every 10 min. Rainfall was recorded for each tip of the 0.2 mm tipping bucket. Eddy correlation measurements of evapotranspiration were made on 6 days during the intensive field campaign.

A 1 foot 6 inch (45 cm) Parshall flume [*Working Group on Small Hydraulic Structures*, 1976] was installed at the catchment outlet to monitor surface runoff. Runoff was monitored by measuring the water level in a stilling well to the side of the flume with a water level pressure sensor. Water levels were scanned every minute and recorded if they varied by more than 2 mm from the previous measurement.

A second pluviometer was located at the flume, and four collecting rain gauges were distributed throughout the catchment to check the spatial variability of rainfall. These data indicated that there was minimal spatial variability during the time period monitored. Collecting rain gauges were located at the weather station, flume, and one either side of the catchment at approximately halfway between the flume and weather station. Collecting rain gauges were recorded approximately fortnightly from December 31, 1996. During the intensive field campaign in August–September 1997, collecting rain gauges were recorded every 2–3 days.

3.5. Other Data

Surface roughness measurements were made at five locations for each of 2 days (coincident with the ERS-2 overpasses) during the intensive field campaign in August–September 1997, using a 1 m long drop pin profiler with a pin separation

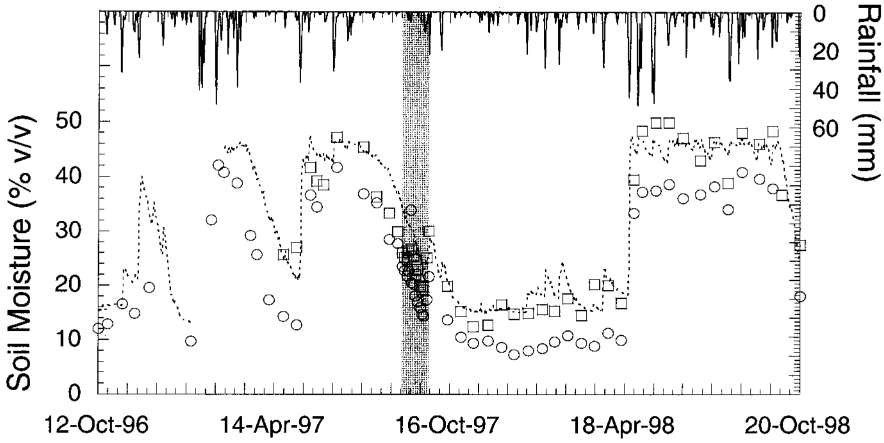

Figure 6. Time series of daily rainfall totals (solid line) and average soil moisture to a depth of 46 cm at soil moisture monitoring site 2 from Virrib (dashed line), connector-type TDR (squares), and buriable-type TDR (circles). The shaded region indicates the period of intensive soil moisture monitoring.

of 25 mm. Two sets of 1 m measurements were made in north-south, east-west, and northeast-southwest directions at each of the five locations. The roughness measurements were made near soil moisture profiles 2, 5, 7, 8, and 9 (Figure 1). Surface roughness measurements provide a measure of the depression storage in the catchment when modeling soil moisture and runoff. A visual inspection of the Nerrigundah catchment indicated that the spatial distribution of surface roughness was relatively uniform, apart from the main drainage line and steeper portions of the site. These portions were slightly rougher as a result of cattle hoofprints being more pronounced in areas subject to wetting.

Soil characterization of the Nerrigundah catchment was undertaken from 19 minimally disturbed soil cores retrieved from throughout the catchment (Figure 1) using the soil-coring capabilities of the TDAS [*Tyndale-Biscoe et al*., 1998]. Core holes were refilled with a mixture of sand and bentonite so that no high-conductivity flow paths were created. As the majority of soil within the Nerrigundah catchment has a depth of less than 60 cm, these soil cores gave a view of the entire soil profile at their individual locations.

The soil profile was described according to its horizons by the Northcote Factual Key Soil Classification System [*Northcote*, 1979]. The thickness of soil horizons was noted where identifiable, and each soil core was dissected into its horizons for laboratory assessment. Where the A1 horizon was too shallow to give a sufficient soil sample for laboratory testing by itself, the A1 and A2 horizons were combined. The laboratory testing for all 19 cores included bulk density, porosity, organic matter content (by the method of ignition), and particle size analysis (by dry sieving and laser diffraction). In addition, the quartz content was determined (by X-ray diffraction) for the core taken near the weather station. Saturated hydraulic conductivity was estimated in the field using a Guelph permeameter and a double ring infiltrometer near the soil sample locations.

In addition to soil depth measurements at soil sample and soil moisture profile monitoring sites, soil depth was determined by probing with a 6 mm steel rod on a 40 m × 40 m grid during a period when the soil was moist. The bottom of the B horizon could be detected by a sudden, large change in force needed to insert the probe. The grid was coincident with that used for near-surface soil moisture measurements during the intensive field campaign. Additional measurements were made on a 20 m × 20 m grid for the area in the vicinity of the main drainage line.

4. Data Availability

Apart from the SAR data all of the data described above are available via the World Wide Web at http://www.civag.unimelb.edu.au/~jwalker/data/nerrigundah. The web site provides all the information needed for interpretation of these data, along with general information on the Nerrigundah catchment, photographs of the landscape and sampling methods, and links to a detailed description and analyses of the data. Due acknowledgement in any publication or presentation arising from the use of these data is required.

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