Modelling Surface Runoff, Evapo-transpiration and Soil Profile Moisture with USDA-SWAT in the Oolloo-Dolostone Region of the Daly River Catchment

M. Dilshad
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Executive summary
The United States Department of Agriculture developed Soil and Water Assessment Tool (SWAT) was used for modelling surface runoff, soil profile water redistribution and evapo-transpiration (ET) in the Ooloo-Dolostone Region of the Daly River Catchment. It was parameterised using hydrological data and knowledge gained in the early to mid 1990’s from the Land Management Strategies for the Semi Arid Tropics (LAMSAT) project and other historic research studies and monitoring programs within and outside the region, operational over this period.

Results show that SWAT is a very capable modelling system for modelling surface runoff, soil profile water redistribution and ET in the study area. Analysis of SWAT outputs, in terms of range and distribution, show good fits against observed data from disparate periods divorced from the period of model parameterisation. Observed data was obtained from the Croplands Erosion Research Project (CERP, 1986/87) and from a Charles Darwin University project measuring ET and soil profile water (2008 to present).

The evaluation of model results provide a reasonable degree of confidence in the use of the model, as parameterised, over the entire region. A temporal and spatial sequence of surface runoff, ET and soil profile water at a monthly time-step and sub-catchment scale, is presented in this publication.

This work can be further enhanced as better data, including climate, soils, and plant rooting depth and distribution become available.
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Project Background

The Northern Territory Department of Natural Resources, Environment, Arts and Sport (NRETAS) has been funded by the National Water Commission (NWC) to enhance current knowledge of the Ooloo-Dolostone groundwater system, its connectivity and interaction with stream flow processes, identify risks to groundwater and river water quality due primarily to the application of agrochemicals and to facilitate capacity building for effective management of the water resource for setting allocations within sustainable limits. Figure 1 shows the location of the region.

The purpose of this component of the project was to:

- Parameterise the USDA-Soil and Water Assessment Tool (Neitsch et al. 2005 and Winchell et al. 2007), to model surface runoff for the Ooloo-Dolostone Region using the USDA Curve Number Method (CNM; Dilshad and Peel, 1994); and
- Evaluate, where possible, model outputs against observed data and outputs of other physically sound models of collaborators (e.g. Charles Darwin University, and CSIRO) and other projects in the area.

The CNM is described in detail by Dilshad and Peel (1994) and Neitsch et al. (2005). A simple overview is provided later in this publication. Research conducted in the 1990’s in the Daly River Catchment (refer: Dilshad and Peel 1994; Dilshad et al. 1995 and1996b; Motha et al. 1994, 1995a; and Motha and Dilshad 1997b), has shown that the CNM is highly useful in determining runoff from croplands, pastures and native vegetation. This research was conducted on experimental catchments on Red Earths (Lucas 1984, Lucas et al. 1987), in the Douglas River district of the Daly R. Catchment (Dilshad and Jonauskas 1992; and Dilshad et al. 1996a; refer Fig. 12).

A catchment/regional scale understanding of rainfall-runoff partitioning and water balance, in general, requires a spatial and temporal extrapolation of work such as those, above. The USDA SWAT model provides the modelling framework to undertake such a regional/catchment scale extrapolation.
Background to the SWAT Model

The USDA-SWAT model is described in great detail in the approximately 1500 pages of end-user documentation on the structure of the model, data input requirements, description of processes modelled, and operational manuals. Only a brief description is, therefore, provided in this publication.

Model Genesis

The SWAT model was developed at the Soil and Water Research Laboratory of U.S. Department of Agriculture (USDA, Arnold et al. 1998; Neitsch et al., 2004). The genesis of SWAT lies mainly in the SWRRB (Simulator for Water Resources in Rural Basins; Arnold et al., 1990) model and contains features from ROTO (a continuous water and sediment routing model; Arnold et al., 1995), GLEAMS (Groundwater Loading Effects of Agricultural Management System; Leonard et al., 1987), QUAL2E (Enhanced Stream Water Quality Model; Brown et al. 1987), CREAMS (Chemicals, Runoff and Erosion from Agricultural Management Systems; Knisel, 1980), and EPIC (Erosion-Productivity Impact Calculator; Williams et al., 1984).

Model Framework and Capabilities

SWAT is a physically based model and can assist natural resources managers in assessing and predicting the impact of urban and rural land uses and management on the water balance and stream flow, sediment loads and nutrient and pesticide yields in large ungauged catchments with varying soils and physiography (Winchell et al. 2007). It allows for a number of physical processes to be simulated (see Figs. 3, 4 and 5).

The first task SWAT requires, before any modelling is undertaken, is the division of the studied catchment into sub-catchments. Each sub-catchment is then further divided into Hydrological Response Units (HRUs; Figure 2), based on sub-catchment slopes, soils, and land cover/management. In other words, HRUs identify areas within the sub-catchment which are similar or dissimilar in their hydrological response. It is at this HRU level that SWAT computes the daily water balance and integrates for the whole catchment (Figure 3). A sub-catchment is commonly divided into 5 to 12 HRUs.

The major components within SWAT are: climate, hydrology, land cover/plant growth, erosion and sedimentation, nutrients and pesticides, and management (Winchell et al. 2007). It uses physically-based inputs (e.g. soil characteristics for up to 10 layers, topography, landuse, management, precipitation, air temperature, solar radiation, wind speed, and relative humidity) and is intended for continuous long-term simulation usually on a daily time step. (SWAT includes options for the Green and Ampt infiltration equation using rainfall input at any time increment and channel routing at an hourly time step; Winchell et al. 2007).

Figure 2. The makeup of Hydrological Response Units (HRUs).
Water Balance

Water balance is the driving force in SWAT model simulation, no matter what is being modelled. To accurately predict any process (e.g. movement of sediment), the hydrological cycle is modelled and must conform with what is happening in the catchment (Neitsch et al. 2004 and 2005; Winchell et al. 2007).

SWAT defines, on a daily basis, the hydrology by a specific list of processes and parameters, including: interception, evapo-transpiration, surface runoff, lateral flow, soil moisture redistribution, return flow, percolation to shallow aquifer, and ground water flow as well as river routing processes. SWAT hydrology is split into a land phase (see Fig. 3) and a routing phase (see Fig. 4). Figure 5 illustrates the schematics of pathways available for water movement in SWAT.

The land phase modelling simulates and models the process identified in Figure 3 and defines (controls) the amount of water, sediment, nutrient and pesticide loading to the main reaches (channel) in each sub catchment (Neitsch et al. 2004 and 2005).

The routing phase defines the movement of water, sediments, nutrient and pesticide in through the channel network of the catchment (and impoundments), to the outlet. Routing phase simulation is beyond the scope of this project and the rest of the report will be restricted to the land phase modelling, particularly surface runoff, evapo-transpiration and soil profile moisture.

Land Phase of the Hydrological Cycle

The various inputs and processes involved in the land phase of the hydrological cycle includes: climate (e.g. precipitation, air temperature, solar radiation, wind speed, and relative humidity); hydrology (e.g. canopy storage, infiltration, redistribution, evapo-transpiration, lateral subsurface flow, surface runoff, ponds and lakes, tributary channels, return flow); land cover/plant growth (e.g. potential growth, potential and actual transpiration, nutrient uptake, growth constraints); erosion; nutrients; pesticides; and land use/management.

The user documentation for SWAT describes all processes and inputs in detail. In this report, a brief summary of runoff, evapo-transpiration and soil profile moisture inputs and processes is provided.

Surface Runoff

SWAT provides two methods for estimating surface runoff, at the HRU level, namely:

- the USDA Curve Number Method (CNM, Dilshad and Peel 1994); and
- the Green and Ampt Infiltration Equations (Green and Ampt 1911).

The CNM, described in detail by Dilshad and Peel (1994) and Neitsch et al., (2005), has been extensively studied and used for modelling purposes in the Douglas River sub-catchment of the Daly River (refer: Dilshad and Peel 1994; Dilshad et al. 1995 and 1996; Motha et al. 1994, 1995a; and Motha and Dilshad 1997b). These studies have been undertaken by the author for cropland, pastures and native woodland, conditions. The version of CNM studied in this region include the original which utilises 5 day antecedent rainfall as an index of antecedent soil moisture and improved versions which allow for daily soil profile...
moisture with varying daily vegetation cover (refer: Motha et al. 1995a and Motha and Dilshad 1997b). The latter improved version of CNM is used for SWAT modelling in this study.

The CNM operates on a daily time step and utilises non linear curves dependent on antecedent soil moisture, retention parameter (based on changes in soils, land use, management, slope), daily rainfall, and initial abstraction (storage interception, and infiltration prior to runoff) and are used to determine surface runoff from ungauged catchments. Essentially as soil moisture drops and approaches wilting point, the Curve Number (CN) approaches 0. The CN approaches 100 as moisture approaches saturation. (Winchell et al. 2007).

The Green and Ampt Infiltration Equations can operate at very short time step (e.g. sub-hourly) and requires rainfall input at that relevant time-step. It calculates infiltration as function of a wetting front matric potential and hydraulic conductivity. Water that does not infiltrate becomes runoff (Neitsch et al. 2005).

Peak runoff rate is computed using a modified Rational Formula or using the TR-55 method (refer: Neitsch et al. 2005).

Figure 3. Terrestrial processes that can be modelled with SWAT. Adapted from the USDA-SWAT user manual.
Evapo-transpiration

Evapo-transpiration is a collective term which includes evaporation (from soils, water bodies, vegetation surfaces) and transpiration (evaporation from within the leaves of plants (Neitsch et al. 2005).

SWAT calculates potential evapo-transpiration (PET) using one of three methods, namely: Hargreaves (Hargreaves and Samani. 1982), Priestley-Taylor (Priestley and Taylor 1972), and Penman-Monteith (Monteith 1965). Actual evapo-transpiration is determined from PET, as reviewed by Neitsch et al. 2004 and 2005 and Winchell et al. 2007. The Penman-Monteith method was used for this study.

SWAT first evaporates any canopy storage and then determines maximum transpiration and maximum evaporation. The maximum ET is determined using functions related to the leaf area index (Neitsch et al. 2005). Actual ET is determined using adjusted maximum transpiration (for water and plant growth constraints) and adjusted maximum evaporation (for shading effect, plant water use etc, Neitsch et al. 2004).

Soil Water

Water that infiltrates soil may redistribute by several pathways, including plant uptake and evaporation (i.e. the ET component), percolation past the root zone and ultimately becoming
aquifer recharge, or moving laterally and becoming stream flow. Generally, the ET accounts for the bulk of the soil water redistribution.

The SWAT theoretical documentation (Neithsch et al. 2005) provides the detailed mathematics describing the above processes. In essence, SWAT uses routing techniques to predict percolation through each soil layer. Water is allowed to percolate if water content of the layer exceeds field capacity and the layer below is not saturated. SWAT also uses a “cracked flow” (“bypass”) model which allows percolation of infiltrated rainfall through cracks and macro pores, even in situations where soil water content is less than field capacity. Research has shown bypass flow to be an important percolation and recharge process in the Daly River catchment (Wilson et al. 2006). The bypass model option was utilised for this study.

The portion of soil water that does not percolate out of the layer becomes part of layer stored water and cannot percolate until storage exceeds field capacity (Neithsch et al. 2005).

Lateral subsurface flow in SWAT is computed using the kinematic storage model (Sloan et al. 1983). The model accounts for variation in conductivity, slope, soil water content, and allows flow upward to surface.
Figure 5. Schematics of pathways available for water movement in SWAT. Source: USDA_SWAT user manual.
Methodology
The broad methodology for this project is identified below:

- A “hydrologically conditioned” 3 second Shuttle Radar Topographic Mission (SRTM) DEM (Dilshad 2007), was processed for the Ooloo-Dolostone Region in order to define the stream networks and delineate sub-catchments;
- Existing physiographic and landuse/cover data was collated into a form appropriate for defining the Hydrological Response Units (HRUs; landscape classification at a level lower than sub-catchments) of the Ooloo-Dolostone Region;
- Curve Numbers, based on previous work and new or external data, were determined for the HRUs;
- The USDA-SWAT was parameterised using available data and knowledge gained from past work (refer: Dilshad and Peel 1994; Dilshad et al. 1994, 1995 and 1996; Motha et al. 1994, 1995a; Motha and Dilshad 1997a and b; and Peel et al. 1994 and 1996);
- The parameterised model was run to determine surface runoff, ET and soil profile moisture at the HRU level; and
- Model outputs were evaluated against observed data and model outputs of collaborating researcher (Charles Darwin University and CSIRO) and others projects in the region.

Model Data Preparation and Input
SWAT documentation on model input identifies detailed input data requirements for the model (refer: Neitsch et al. 2004). The MS/SWAT version (Leon 2009) was used for this project.

Figure 6. Data anomalies (red and blue dots) within the 3 second SRTM DEM. These anomalies were rectified for use of DEM for hydrological purposes by Dilshad (2007).
Digital Elevation Model (DEM)

Central to the operation of the SWAT model is a stream network defined from a DEM. A subset of the “hydrologically conditioned” 3 second (90m pixels) SRTM DEM (Figs. 6 and 7; refer: Dilshad 2007) was used for this project. The GeoScience Australia delineated river network at 1:250000 scale was used for “stream burning” and subsequent river network generation and sub-catchment delineation for the Oolloo-Dolostone Region (Fig. 8).

Based on previous work and literature (Refer Dilshad 2007) and the DEM resolution, a drainage area threshold of $35km^2$ was used for beginning the river network. D8 flow accumulation algorithms were used for catchment delineation and river network generation. The intent was to create a sufficiently detailed river network, representing all larger streams, whilst limiting the number of links across the area of interest. First order link length less than 2km have not been included in the catchment delineation and river network generation. This resulted in 101 sub-catchments (Fig. 8). Frequency distribution for sub-catchment area groups is displayed in Figure 9.

Land Use

The latest available landuse data for the Oolloo-Dolostone was used for this project. It was clipped from the larger Daly River Catchment dataset (Figure 10). The clipped data was then coded into a form appropriate for SWAT.
Figure 8. The Oolloo-Dolostone Region was “discretised” (divided) into 101 sub-catchments.

Figure 9. Frequency distribution of the discretised catchment area (km$^2$). Frequency numbers also approximate percentage of total number of catchments as total number of sub-catchments equals 101.
Soils

Soils input requirements for SWAT can include up to 10 layers of profile description for the physical and chemical characteristics of a soil (Neitsch 2005). For this study, the relevant soils data was obtained from published surveys and reports, NT and Commonwealth Government databases, and from expert knowledge. This data was collated, analysed and compiled into a form suitable for SWAT.

Figure 11, for example, shows the median soils depth for the region, which was determined from the above disparate sources. Soil depth forms an important input to hydrological modelling. Detailed description of the processes in developing such spatial inputs is beyond the scope of this paper and will be reported in subsequent publications.

Climate Data

SWAT utilises climate data (rainfall, maximum/minimum air temperature, solar radiation, wind speed, and relative humidity) for its simulation. SWAT contains a powerful climate data generator for simulating climate data at sub-catchment\HRU level and generating missing data.

Techniques developed by Motha and Dilshad (1996) were used to infill missing climate data for Douglas River and Katherine weather stations before modelling commenced. Observed
climate and rainfall data was obtained from various stations in the region (Fig. 12). Bureau of Meteorology (BOM) generated daily climate data (“drill” data, Fig. 13) was also available for the study area. However, preference was given to observed and infilled missing data where available, with BOM drill data being used as a last resort.

The way MS-SWAT operates is that for each of the 5 categories (precipitation, temperature, solar radiation, relative humidity, and wind speed), if there are no data tables (relational database) in that category, the category is simulated using a weather generator. Otherwise each sub-catchment will use observed data from the table where the weather station is the closest amongst those stations having tables in that category (Leon 2009).

For example, if there are weather stations with identifiers A, B and C, and tables Apcp, Bpcp, Atmp, Btmp, and Cslr, then the result will be:

- For precipitation: sub-catchments will use observed data from Apcp or Bpcp, according to whether station A or B is closer.
- For temperature: sub-catchments will use observed data from Atmp or Btmp, according to whether station A or B is closer.
- For solar radiation: all sub-catchments will use observed data from Cslr.
- For relative humidity: all sub-catchments will use simulated data.
- For wind speed: all sub-catchments will use simulated data (Leon 2009).

This makes it possible to combine observed data from a number of sources. It is also possible to combine simulated and observed data for different sub-catchments. For example, if all the values in Apcp are -99 (unknown, missing data), while Bpcp is observed data, then sub-
catchments closer to station A will use simulated precipitation data and those nearer to B will use observed data (Leon 2009).

Figure 12. Location of observed climate stations (blue pins) and observed rain gauges (yellow pins) in and around the Oolloo-Dolostone Region. Location of Bureau of Meteorology generated daily climate data sites are represented by red pins. LAMSTA/CERP and CDU ET instrumentation sites are also highlighted. Satellite image sourced from Google Earth.

Hydrological Response Units (HRUs)
The Hydrological Response Units (HRU’s) of the Oolloo region were identified. This is essentially a process of landscape classification at a level lower than sub-catchments.

Input Thresholds
An input threshold, defined as percentage of sub-catchment area (e.g. 10%), was set for the variables used (soil type, slope bands and landuse/vegetation) for delineating the HRUs. This weighting allowed for any potential HRU to be ignored for which the landuse, soil or slope was less than the selected threshold. The areas of HRUs that were ignored were redistributed proportionately amongst those that were retained. This is a good way of handling poor quality data at the project scale of operation.

HRU Delineation and Distribution.
The 101 sub-catchments of the Oolloo-Dolostone Region (Fig. 8) were subdivided further into just under 600 HRU’s.
HRU classification provides a very useful way of classifying the landscape. Figure 13 shows an example of the spatial distribution of an HRU within sub-catchment 8, which is located near Stray Creek. Sub-catchment 8 has an area of 4260ha and occupies 0.8% of the Oolloo-Dolostone Region (study area = 530,438ha).

This HRU identified in Fig 13, occupies 323ha (7.6% of sub-catchment and 0.06% of the region). The identifier box in the map shows the unique landuse, slope band and soil combinations of the HRU. This HRU has an agricultural landuse (data can be drilled down to the cropping activity), is on a 0-2% slope and has soils which are predominantly sandy red earths (Lucas et al. 1987). In simplistic terms, the hydrological response should be identical for all the bits within this HRU but different from other HRUs of this sub-catchment.

SWAT produces very useful statistics for describing the catchment, sub-catchments and HRUs characteristics. Appendix 1, for example, contains an extract from a SWAT generated report on HRU/catchment statistics.

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**Figure 13. Layout of HRU AGRL/4b2/0-2 on sub-catchment 8 (Stray Creek area) and basic statistics.**
**SWAT Model Run for this Study**

The model was parameterised and run over the period 1991/92 to 1994/95 to “link” with hydrological studies conducted just outside the Oolloo-Dolostone Region, namely the Land Management Strategies for the Semi Arid Topics (LAMSAT) project (Dilshad et al. 1996a, refer Figure 12).

SWAT was parameterized using data and knowledge gained from LAMSAT and other studies within and outside the region. Once parameterized, it was intended to validate the SWAT model outputs against 1986/87 measured runoff data from CERP (Dilshad and Jonauskas 1992; refer Figure 12) and against ET and soil profile data observed by Charles Darwin University (CDU) and CSIRO researchers over the last 3 years (Anon. 2010). This CDU/CSIRO work was part of the Charles Darwin University led Tropical Rivers and Coastal Knowledge (TRACK) program.

Figure 14 shows aggregated annual northern wet season rainfall for Northern Australia sourced from the Australian Bureau of Meteorology (BOM).

The SWAT model was parameterised over a relatively dry period for Northern Australia, with the 3 year annual running averages below the long term mean annual rainfall for the region. Two years individually, however, were above the long term mean. The period over which CDU collected ET and soil moisture data (2008 to present) is from well above mean annual rainfall. The 1986/87 season, the period for observed runoff, was well below average season.

![Aggregated northern wet season rainfall for Northern Australia](image)

*Figure 14. Aggregated northern wet season rainfall for Northern Australia. Source: BOM. Black and red lines represents 3 year running averages and annual average over the period 1900-2010, respectively.*
Results and Discussion

Whole of Catchment Results

Table 1 shows total monthly outputs for surface runoff and evapo-transpiration (mm/month) and for water content of soil profile (mm/day/month), lumped for the whole of the Oolloo-Dolostone Region for the period December 1992 to December 1994 (see Fig. 16). Table 1 also shows percent rainfall converted to runoff.

SWAT modelling outputs show a monthly conversion rate of rainfall to runoff, on a lumped catchment basis, of between 0 to 25.8% for the period December 1992 to December 1994 (Table 1). The figures were 0 to 19.6% when averaged over the entire duration of modelling run (Figure 15).

Table 1. Lumped observed rainfall and modelled output (monthly time-step) of key variables for the whole of the Oolloo-Dolostone Region over the period: December 1992 to December 1994. Table also shows conversion of total monthly rainfall to total monthly runoff (%).

<table>
<thead>
<tr>
<th>Month/Yr</th>
<th>Rain (mm/month)</th>
<th>Runoff (mm/month)</th>
<th>Runoff (% of Rain)</th>
<th>Soil Profile Water (mm/day/month)</th>
<th>ET (mm/month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec-92</td>
<td>190</td>
<td>19.8</td>
<td>10.4</td>
<td>160</td>
<td>130</td>
</tr>
<tr>
<td>Jan-93</td>
<td>460</td>
<td>118.5</td>
<td>25.8</td>
<td>225</td>
<td>118</td>
</tr>
<tr>
<td>Feb-93</td>
<td>356</td>
<td>59.1</td>
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The runoff values are similar in range to field observations reported by Dilshad and Jonauskas (1992), whose results showed a conversion rate of 0.03% to 24.9% of...
Figure 15. Mean daily per month observed rainfall and SWAT model outputs for evapo-transpiration (ET) and surface runoff for the whole of the Oolloo-Dolostone Region, over the period December 1992 to December 1994.
rainfall to runoff over a three year period, reflecting various management practices. Review of data for the broader Timor Sea drainage division by Eamus et al. (2006) shows similar conversion rates (upper limit = 21.5%). Hence the SWAT results provide a reasonable degree of confidence in the spatial extrapolation of runoff over the entire Ooloo-Dolostone Region, discussed later in this publication.

![Figure 16. Rainfall converted to runoff, averaged over the entire Ooloo-Dolostone Region for the total duration of model run (1991/92 to 1994/95).](image)

Point based studies in Stray Creek region by CDU, located within current study area, (Figure 12, Anon. 2010) has shown a wet season ET range (within 1 standard deviation) of approximately 1 to 7mm/day for uncleared and regrowth native vegetation and pastures and a dry season range of approximately 0.01 to 2 mm/day. SWAT model outputs for ET, averaged over the entire Ooloo-Dolostone Region, shows a very similar range and trend to that of the observed point data (Figure 16).

There is a dearth of observed soil profile data to test SWAT model outputs against at the broad catchment level. Soil profile model outputs will be examined at a finer resolution, below, against recently collected CDU data.

### Sub-Catchment and HRU Results

#### Evapo-transpiration (ET).

Figures 17 and 19, shows the uncleared native vegetation ET observed by CDU researchers in the Stray Creek region (Lat: 14.1592 S Long: 131.3881 E; Figure 12, Anon. 2010), located within the current study area. This observation period, early 2008 to mid 2010, was a period of above average wet seasons (Fig. 14).

Figure 18 shows SWAT output for the period December 1992 to December 1994, a period of below average wet seasons. Data describing the distribution of soil types used for SWAT modelling was based on soil surveys conducted at a 1:50000 scale (Lynch pers. com., 2011). Figure 18 provides SWAT modelled ET response on dominant soils upon which the CDU ET instrumentations are located and near vicinity (HRU 46 and HRU 44; sub-catchment 8), and
their mean. The LAMSAT site used for SWAT parameterisation is located approximately 40km away from the CDU site.

![Graph showing evapo-transpiration observations from Stray Creek region](image)

*Figure 17. CDU/TRACK evapo-transpiration observations from Stray Creek region of the study area over a two year period starting 1 January 2008. Date is in ordinal format e.g. 2008365 = 31 December 2008. Note Day 33 = 2 February, Day 65 = 6 March, day 97 = 7 April, Day 193 = 12 July, Day 241 = 29 August, Day 289 = 16 October, Day 337 = 3 December.*

![Graph showing SWAT ET predictions](image)

*Figure 18. SWAT ET predictions (mean daily per month, mm/day) for uncleared vegetation on the HRU upon which CDU instruments are located and for near vicinity (sub-catchment 8, HRU 44 and 46), and their mean.*

Whilst there is a temporal difference of nearly 15 years between the two periods, the SWAT modelled ET outputs have “almost identical” range and distribution to those observed in the field by CDU. This is the case when modelled output is expressed at a daily time step (Fig. 20) as well as when summarised as mean daily per month (mm/day, Fig. 18). Whilst the SWAT modelling and CDU field work periods represent below and above average rainfall periods, respectively, it would seem that for both periods soil profile moisture was sufficiently available to allow for similar evapo-transpiration (see Figures 21 and 22).

Rigorous statistical analysis between SWAT modelling and CDU observed data cannot be undertaken at present. SWAT modelling needs to be expanded to include a modelled output for the same period as the CDU research. This entails the incorporation of soil characterisation based on detailed point data descriptions of soil profiles obtained by CDU.
There is also, at present, no observed climate data available in the SWAT required format for the CDU research period.

The “drilled” BOM climate data that is available for this validation period, whilst, statistically correct over long term, does not lend itself for model testing and evaluation against observed field data over one or two seasons. This is primarily due to misalignment of generated climate data with real climate characteristics of the day and the resultant hydrological response. Observed data needs to be utilised for this validation work, with missing climate data “infilled” using various techniques such as those described by Motha and Dilshad (1996).

![Figure 19. CDU/TRACK observed and modelled daily total ET for uncleared native vegetation. Solid light blue line represents modelled output.](image)

![Figure 20. SWAT modelled daily ET, presented as a 3 day running average, for uncleared native vegetation on HRU 46. CDU ET instruments for uncleared native vegetation are situated on HRU 46.](image)

### Soil Water

Figure 21 shows observed and modelling results from CDU project over the period September 2008 to June 2010. SWAT model outputs for the period December 1992 to December 1994 are presented in Figure 22. The wet season soil profile values and range are nearly identical (0.1m to 0.35m) between the observed and SWAT modelled outputs.

For the bulk of the dry season, CDU observations suggest a stabilisation at near 0.12m. SWAT model outputs range between 0.1 and 0.2m, with soil profile water dipping below 0.1m for a few weeks at the very end of the dry season. CDU modelling shows a sharp drop in soil profile moisture in the transition from wet to dry season. The SWAT modelling output indicates a more gradual drop.
The differences in the dry season soil profile moisture could be due to the fact the SWAT modelling period was for below average wet seasons and CDU observations were made in above average wet season. Modelled and observed ET range and distribution for both SWAT and CDU periods were, however, very similar. In other words profile soil moisture did not seem to be a limiting factor for the ET response for both the above and below average wet seasons. The differences in dry season soil profile water could simply be a reflection of these factors.

These differences could also be due to SWAT model parameterisation of key factors such as soil characteristics and rooting depth and density. The CDU report describes the soils at their ET instrumentation site, located on HRU46, as a deep red sandy loam. This description is based upon results of point based surveys. Land unit survey, undertaken at 1:50000 scale and used for SWAT modelling, identifies the dominant soils at the ET instrumentation site as comprising of sands in the top layer (500mm) and changing into a loam down the profile.

![Figure 21. CDU/TRACK observed and modelled soil profile water (m)](image1)

![Figure 22. SWAT modelled soil profile water for the top 1.5m, at start of each day, over the period 1 December 1992 to 31 December 1994.](image2)

Rigorous statistical analysis between SWAT and CDU outputs can only be undertaken following the collation of infilled observed SWAT suitable climate data over the CDU observation period and minor re-parameterisation of SWAT to reflect CDU point based soils descriptions and a reassessment of rooting depth and density. The SWAT model, if so required, can be further calibrated following this work.
Runoff

Figure 23 shows the total seasonal rainfall input and runoff responses from the CERP project (Dilshad and Jonauskas 1992), for the 1986/87 wet season for conventionally tilled maize crop (Motha et al. 1995b and 1995c). Figure 23 also shows SWAT model output for the 1992/93 wet season (about 6 years later) for sub-catchment 2, HRU6. The LAMSAT site used for SWAT parameterisation is located approximately 16km away from HRU6.

![Figure 23. Total observed rainfall and runoff for 1986/87 and modelled SWAT modelled runoff for 1992/93. Rainfall for 1992/93 was observed.](image)

HRU6 was identical to the CERP site in terms of slope range and management. The CERP soils (see Lucas 1984 and Lucas et al. 1987), whilst not identical, were similar to those on HRU6. The total observed rainfall for both seasons are similar (see Figure 24), with only a 3% difference between seasons. Total difference between the observed (1986/87) and modelled runoff season (1992/93) was 27mm; under 10% (8.8%).

![Figure 24. Cumulative daily rainfall (mm) for the 1992/93 and 1986/87 wet seasons. Data source: Douglas Daly Research Farm. Day 100 = 8 October, Day 150, Day= 27 November, Day 200=16 January, Day 250= 7 March, Day 300=26 April.](image)
Rainfall for the two seasons, whilst very similar, was not identical. Figure 24 highlights the obvious differences in the daily rainfall patterns between the two seasons. For example, 1986/87 had an earlier wet season than 1992/93. 1986/87 had received nearly 100mm of rain before first rainfalls were received for the same period for the 1992/93 season.

Figure 25 shows the cumulative runoff for the two periods. The requirement for the work being reported was to compare the relative response of two seasons, 6 years apart. Therefore, for the purposes of this exercise, the time lines differences for the start of runoff for the two seasons has been removed and set to be the same (i.e. set to $t=0$) to allow for easier comparison. (For the 1996/97 wet season, surface runoff began about 3 weeks before the first runoff for the 1992/93 season).

It should be noted that for this modelling work, growth parameters for a generic tall row crop were used for SWAT modelling. Cultivar specific parameters for maize for the region (identified by Motha et al. 1995a and 1995b) are expected to provide a better modelled runoff output. However, despite these handicaps of using simplified crop growth parameters, and those due to climatic variability between the two seasons at daily time-steps, the modelling outputs are reasonably close to observed values and provide a good gauge as to how well the SWAT model may be predicting runoff for the entire Oolloo-Dolostone Region. These outputs provide reasonable confidence in the goodness of model prediction for the rest of the study area.

A generic relationship between monthly rainfall and runoff for the Ooloo, for operational purposes at a coarse planning scale only, is provided in Figure 26.
It should be noted, however, that as with modelling outputs for soil profile moisture and ET, rigorous statistical analysis to explain the variability between the two seasons, above, is only possible when differences in climatic conditions (e.g. rainfall, humidity, radiation, wind speed), soils, and plant growth parameters have been taken into account. This requires observed climate data for 1986/87, infilled for missing data, being available in SWAT required format and the model better parameterised for crop growth.

**Time Series-based Spatial Model Outputs**

SWAT was parameterized using hydrological data and knowledge gained in the early 1990’s from LAMSAT and other studies within and outside the region. Above analysis of SWAT outputs, indicates favourable comparisons against observed data from discrete periods outside the early 1990’s, within a two decade span. Getting reasonable fits in terms of range and distribution for ET, surface runoff and soil moisture gives a reasonable degree of confidence in the use of the model, as parameterised, over the entire region.

A temporal sequence of surface runoff, ET and soil profile water at a sub-catchment scale for selected months, as examples, is presented below (Figures 27 to 29).
Modelling Surface Runoff, Evapo-transpiration and Soil Profile Moisture with USDA-SWAT in the Oolloo-Dolostone Region of the Daly River Catchment

Soil Profile Moisture - Spatial and Temporal Distribution

Figure 27a. SWAT modelled soil profile moisture (mm/day) in the Oolloo-Dolostone Region - January 1993

Figure 27b. SWAT modelled soil profile moisture (mm/day) - April 1993
Figure 27c. SWAT modelled soil profile moisture (mm/day) - October 1993

Figure 27d. SWAT modelled soil profile moisture (mm/day) - December 1993
ET - Spatial and Temporal Distribution

Figure 28a. SWAT modelled ET for the Oolloo-Dolostone Region - January 1993 (mm/month)

Figure 28b. SWAT modelled ET – April (mm/month)
Figure 28c. SWAT modelled ET - October 1993 (mm/month)

Figure 28d. SWAT modelled ET – January 1994 (mm/month)
Runoff - Spatial and Temporal Distribution

Figure 29a. SWAT modelled runoff (mm/month) - December 1992

Figure 29b. SWAT modelled runoff (mm/month) - January 1993:
Figure 29c. SWAT modelled runoff (mm/month) - February 1993

Figure 29d. SWAT modelled runoff (mm/month) - March 1993
Conclusion and Recommendations

SWAT appears to be a very capable modelling system for simulating surface runoff, soil profile water redistribution and evapo-transpiration in the Daly River Catchment of the Northern Territory. Model outputs are similar in terms of range and distribution against the limited observed data available. This work can be further enhanced by:

- Collating, in a form suitable for SWAT, observed and infilled missing climate data for further model testing, particularly for periods covering CERP runoff and CDU evapo-transpiration studies (Generated climate data by BOM, whilst statistically correct over the long term, does not lend itself to rigorous short term model validation work because of misalignment of observed and generated climate events); and

- Improving the parameterisation of the SWAT as better soils, climate, plant growth, and root depth and distribution data become available.

Undertaking the above tasks will allow for more rigorous statistical testing of SWAT outputs against observed data.
References


Appendix 1: An Extract from a SWAT Generated HRU
Catchment Statistic Report (Parameterisation Date: 13 Jan 2010)

Detailed Landuse/Soil/Slope Distribution
Thursday, 13 January 2010  6:33:21 PM

Multiple HRUs Landuse/Soil/Slope option  Thresholds: 10.00 / 10.00 / 10.00 [%]
Number of HRUs: 1258
Number of sub-catchments: 101

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