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Developing a WaterCAST model for Western Queensland to support investment in NRM planning

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ABSTRACT

The community has taken on greater responsibility for the delivery of natural resource management (NRM) across Australia through community-based regional NRM bodies. State and Commonwealth Governments require the NRM bodies to establish targets for natural resource management including water quality. Targets setting is based on the assumption that investment in on ground works activities such as riparian fencing, off stream watering and fencing by land type will result in an improvement in water quality. Identifying where the priority areas are to invest in and measuring a change in water quality resulting from that investment is extremely challenging given climatic influences, lag time in water quality response and uncertainty associated with measurement. The complexity has necessitated a whole-of-catchment modeling approach to assist NRM bodies identify where to invest and the effectiveness of their investment.

A collaborative project between The Department of Environment and Resource Management (DERM) and the regional NRM group, South West NRM, was undertaken in 2008 to develop a catchment scale water quantity and quality model using the eWater CRC WaterCAST model. The aim was to build a model for the region to be used in the future to assist in the prioritisation process and to assess the effectiveness of on ground works investment.

A WaterCAST model was developed for the Warrego, Paroo and Bulloo catchments of South Western Queensland covering approximately 180,000 km^2. Runoff, total suspended sediment (TSS), total phosphorus (TP) and total nitrogen (TN) were modeled. Land use classification was based on landscape type given grazing is the dominant land use (>96% by area). Average long term modeled runoff was within 10% of measured data. The majority of modeled event (7-30 days) sediment and nutrient loads were within 50% of loads estimated from measured event samples. Spatial data on the location of previous on ground works investment was not available at the time of writing. One scenario was run to assess the changes in water quality resulting from increasing ground cover/reduction in pasture utilisation as an example.

The development of the WaterCAST model for the South West NRM region has provided an insight into the relative contribution of sediment and nutrients for each of the major catchments and the annual and inter annual contribution to long term loads. The modeling results in conjunction with previous catchment and tracer studies provided a better understanding of the sediment and nutrient generation processes across the region. Average annual runoff for the Warrego catchment was 2% of annual rainfall in contrast to 10% for both the Paroo and Bulloo catchments. Runoff was proportional to the area of weathered sediments (mulga) in each catchment.

The development of the WaterCAST model for the region will enable staff to independently assess a range of current and future land management changes and their associated impacts on water quality pre and post investment. An additional benefit resulting from the work has been the acquisition of Bureau of Meteorology (BOM) funding to purchase and install mobile water quality sampling trailers across the catchment in remote areas identified from the work requiring sediment and nutrient data to validate model results.

Keywords: *WaterCAST, water quality modeling, South West NRM*

1. INTRODUCTION

The community has taken on greater responsibility for the delivery of natural resource management (NRM) across Australia over the past decade, through regional NRM bodies. State and Commonwealth Governments require regional bodies to establish aspirational and resource condition targets for natural resources. Specific performance and implementation monitoring and reporting information is needed to meet management and accountability needs. One such organisation is South West NRM (SWNRM) in Charleville, western Queensland.

A common aspirational target for NRM bodies is to 'maintain or improve water quality'. The assumption is that on ground works activities such as riparian fencing, off stream watering and fencing by land type will result in an improvement in water quality. Quantifying an improvement in water quality resulting from on-ground works investment as opposed to environmental influences such as natural variability is complex. The complexity has necessitated the need for additional tools such as whole-of-catchment modeling approaches to assist NRM bodies identify where to invest, and to assess the relative change in water quality resulting from the investment.

The use of predictive tools by NRM groups to demonstrate the effects of land use and land management change has increased over recent years (Waters and Webb 2007, Argent et al., 2007). Catchment modeling tools developed through the eWater CRC (www.ewatercrc.com.au) were designed to assess the impacts of land use and management change, adoption of best management practices, climate variability and climate change on catchment response in terms of contaminant loads and runoff. The WaterCAST modeling environment (Cook et al. 2009) was used by SWNRM as it had the capacity to represent typical catchment-scale activities and processes at a level of complexity appropriate to current knowledge and data for the region. A collaborative project between (DERM) and South West NRM, was undertaken in 2008 to develop a catchment scale water quantity and quality model for the south West NRM region (Figure 1). The aim of the project was to develop a base model to quantify the relative contribution of sediment and nutrient loads for the major subcatchments of the region, use the model to assess the effectiveness of on ground works investment into the future.

1.1. Catchment description

The Warrego, Paroo, Bulloo and Mungallala-Nebine-Wallam catchments make up the South West NRM reporting region draining some 187,000 km^2 (Figure 1) . The catchment has highly variable summer dominated annual rainfall ranging from 200 - 900mm from west to east, with annual evaporation exceeding 2000mm. Stream flow is ephemeral with the Warrego River at Augathella exhibiting mean annual flow of 34,793 ML (± 50,287 ML). In contrast the Bulloo River at Quilpie has a mean annual flow of 494,525 ML (± 477,952 ML). Vertosols are predominant along the mid to lower reaches of the main drainage network. Particualry the Warrego and Bulloo rivers, making up approximately 40% of the total catchment area.

Weathered sediments (yellow areas fig 1) (Kandosols and Tenosols) are associated with extensive areas of hard and soft mulga and make up approximately 50% of the region. Due to their hard setting nature, Kandosols are known to generate significant runoff in comparison to the other major soil types under low cover. Landforms are predominantly flat to undulating plains (<1% slope) over much of the region (Power et al. 2007). Land use is predominantly sheep and cattle (>96% by area) with small areas of forestry and national parks. Small areas of irrigation are found along the Warrego River with dryland cropping on the Vertosols in the north of the catchment .

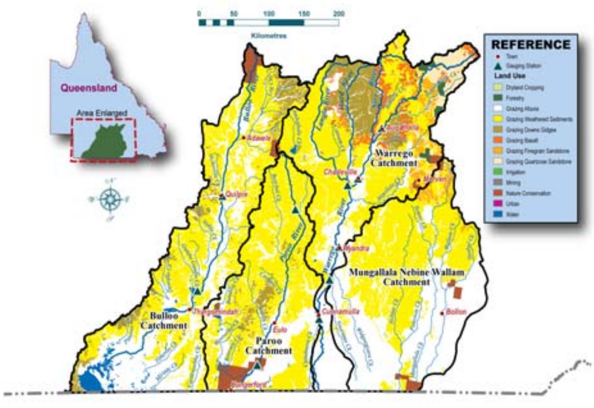

Figure 1: South West NRM catchment boundaries and land use

1.2. Previous studies on erosion processes

There have been a small number of studies undertaken in the region which provide an insight into the erosion processes occurring in the region. The Western Arid Land Use Survey (DPI 1978), found from a survey of western Queensland that degradation was evident with the area most severely affected being the mulga lands associated with the Kandosol soils. Erosion is a natural process in the region particularly on the uplands areas, however land management practices such as clearing sloping country and overgrazing have accelerated it. The main zones affected by erosion include the weathered sediments which are inherently unstable. Sheet erosion although not as obvious as gully erosion is the most common form of erosion in these areas (DPI 1978).

Miles (1990) found erosion rates from 1987 – 1990 were in the range 0.6 – 6.6 t/ha/yr on hard mulga and 1.0 – 4.0 t/ha/yr on soft mulga for cover levels ranging from 20 – 40%. Additional work by Miles and Campbell (1991) examined erosion rates from hillslopes using Caesium tracers and concluded that the mulga lands of Western Queensland have lost approximately 20-30 mm of soil on average over 40 years from both wind and water erosion. Miles also noted that deposition in the valley floors was negligible with erosion products generally removed from the catchment. Titmarsh et al., (2002) estimated erosion rates from 1995-1997 ranging from 0.1 – 0.7 t/ha/yr. Wind erosion can also be significant in the area with Miles and McTanish (1991) reporting that ‘at cover levels of 10% …annual losses due to wind erosion exceeded 0.4mm depth of soil’. It was also estimated that wind erosion represents about 80% of the sediment lost in comparison to water erosion. Stream bank erosion is evident in isolated reaches of the main stream and tributaries of the Warrego, Paroo and Bulloo catchments (DPI 1978). The findings from these studies were used to validate model outputs.

2. METHODOLOGY

2.1. WaterCAST model build

The WaterCAST model consists of a node link network for transport of water and constituents within the channels in a catchment. The catchment is broken into sub-catchments which have a node as the outflow point. The sub-catchments are made up of functional units (FUs) which are considered to have homogeneous hydrologic properties within the model. (Cook et al. 2009).

The WaterCAST model was built with 70 subcatchments with runoff and pollutant generation modeled on a daily time step. There were eight major functional unit/land use categories with grazing then broken up into a further 6 land system categories given grazing occupied over 95% of the catchment area. Total Suspended Sediment (TSS), Total Nitrogen (TN) and Total Phosphorus (TP) were modeled via the EMC/DWC approach .

The following outlines the input data sets used to build the model:

- Modeling period (1967-2007) to cover wet and dry periods and to reflect current conditions.
- Daily rainfall & potential evapotranspiration files were generated from Silo Data Drill (Silo, 2004).
- Given the dominance of grazing in the catchment (96% of area) grazing areas were further broken into landscape types which are a function of soil and vegetation, geology and landform (Power et al. 2007).
- Event mean concentration (EMC) and dry weather concentration (DWC) parameter values were obtained from a collation of local data collected over the previous 30 years (Waters 2008)
- The universal soil loss equation (USLE) (Wischmeier & Smith 1978) was used to derive an average annual hillslope soil loss layer, incorporating the Bare Ground Index/Ground Cover satellite imagery for C factor generation. The USLE layer was then used in WaterCAST to spatially scale EMC/DWC values across the catchment
- The SACRAMENTO rainfall runoff model (Burnash 1995) was chosen to maintain consistency with NRW’s Surface Water Assessment groups IQQM modeling for water planning purposes across Queensland.

2.2. Hydrology and water quality parameterisation and validation

There were 10 gauging stations in the catchment. Stream flow data from eight gauges were of a sufficient duration to be deemed suitable for calibrating the hydrologic model. The two gauges omitted were used in the validation. The Rainfall Runoff Library (RRL) software (Podger 2004) was used to optimise parameter values for the Sacramento model. A set of Sacramento hydrologic parameters were derived upstream of each gauging station. For ungauged catchments, one of the eight parameter sets were assigned to each sub-catchment based on comparisons of annual rainfall, soil type and elevation.

Modeled sediment and nutrient loads were validated against both long term estimates (average annual) and short term (event based) observed data sets.

2.2.1. Average annual load estimation methods

Average annual loads used to compare to modeled output were derived by three methods:

1) *Median concentration method* – The median TSS, TP and TN concentration derived from all historic water quality data collected at gauging stations was multiplied by the daily discharge at the gauge to determine a daily load. Daily loads were then summed to determine average annual loads over the modeled period.

2) *Equation from small catchment study method* - Miles (1990) derived a relationship between daily soil loss, cover and daily rainfall for a 1 ha catchment in the mulga lands. The equation was of the form:

Total soil loss (bed load + suspended load) (kg/ha/day) = $8.098\ R - 0.228\ C^2$

Where R = Event Rainfall totals greater than 10mm , C = grass canopy cover (%)

The daily soil loss calculated from this equation was summed to estimate average annual soil loss at the paddock scale. To approximate sediment loads at the gauge for WaterCAST comparison purposes, it was assumed that only the suspended sediment (44% of total soil loss, Miles, (1990)) is delivered to the main channel and in addition a commonly used hillslope delivery ratio (HSDR) of 10% was applied to account for in stream deposition processes.

3) *Comparison to catchment study estimates*

Miles (1990) estimated average annual erosion rates (suspended plus bedload) at the catchment scale (1-2 ha) for hard and soft mulga from 1987-1990 ranged between 0.6 – 6.0 t/ha/yr. Whilst Titmarsh et al. (2002) estimated suspended sediment export rates from 1995-1998 of 0.1 – 0.7 t/ha/yr . Whilst these studies were of a short duration they were a useful guide to determine if the modeled loads were of the same order of magnitude to measured data. As per method (2) small catchment loads were then scaled to approximate gauge loads.

2.2.2. Event based load estimation methods

The storm runoff event data used in the comparison against modeled loads were data collected by the (DERM). A review of the NRW Hydstra water quality data base indicated that for the 203 TSS samples collected over the previous 30 years, there were no more than a single sample collected per event. Hence event loads could not be calculated on a single sample per event. The data was then correlated against discharge to infill sediment and nutrient concentrations over each event. A QA/QC trained community event monitoring team collected samples for a further six intensively sampled events which provided data more appropriate for load comparison. All event data were collected at gauging stations so that discharge data was available and samples were laboratory analysed. Event duration ranged from 9 – 30 days.

2.3. Model application to assess the impacts of on-ground works on water quality

One objective of developing the model was to provide South West NRM with a tool to assist them in assessing the relative changes to sediment and nutrient loads that may occur as a result of the improved land management practices funded by South West NRM. The spatial location and extent of previously funded on ground works was not available at the time the model was developed. To demonstrate how the model could be applied to assess relative changes in water quality resulting from funding for fencing by land type to reduce grazing pressure, we will assume a reduction in pasture utilisation on the weathered sediment areas with ground cover increasing by 5% (thus affecting 46% of the catchment). Miles (1990) found a linear relationship between increased cover and soil loss. Increasing cover from 25% to 30% resulted in a reduction in suspended sediment concentration of 20%. Therefore this relationship was used to adjust the TSS EMC values for the weathered sediment grazing lands to reflect the increased cover. The model was then re run and average annual loads compared. Load comparison before and after changed land management scenarios was confined to the sub-catchment scale, because the model does not currently account for sediment routing in the channel network.

3. RESULTS AND DISCUSSION

3.1. Hydrology Calibration and validation

Total predicted streamflow volumes were all within 10% of observed flow volumes. Coefficient of efficiency values (E), which are a measure of the correlation between measured and modeled data, ranged from 0.51 – 0.77 when comparing daily predicted and observed values and were greater than 0.8 for monthly data at seven of the eight gauges. Figure 2 provides an example of the monthly predicted and observed runoff comparison for contrasting catchment areas.

Comparing runoff volumes for the 16 events (refer 2.2.2) where a load was calculated from measured water quality data, the ratio of observed and predicted runoff volumes was highly variable in comparison to monthly. The average predicted to observed volume ratio being 0.84 for the 16 events which is a reasonable result given the Sacramento model calibration was based on monthly volumes.

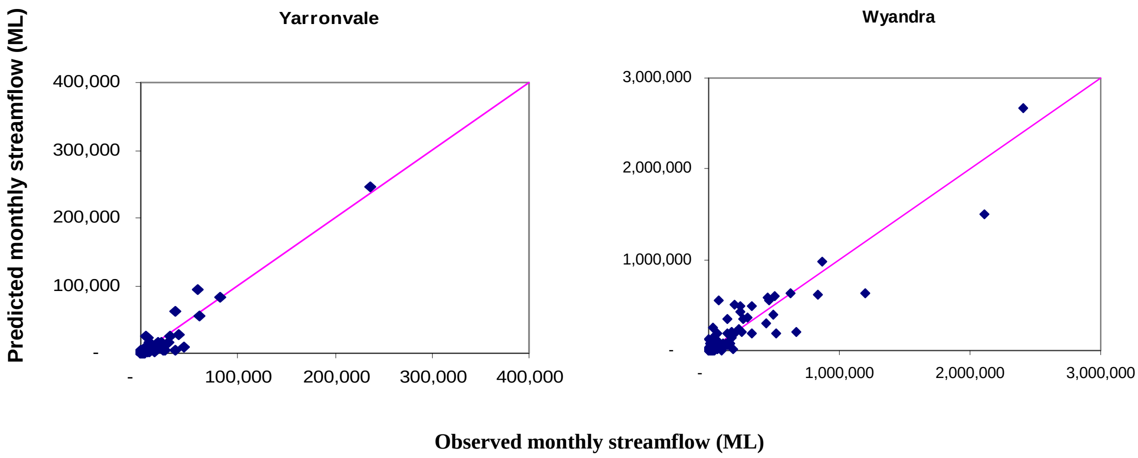

Figure 2: Scatter plots of predicted and observed monthly streamflow for Yarronvale (1,890 km^2) and Wyandra (42,865 km^2).

3.2. Water Quality Validation

3.2.1. Average annual pollutant load comparison

The results of comparing WaterCAST annual average load estimates with estimates abtained from the three methods described in section 3.3 are summarized in Figure 3. Average annual modeled soil loss at the eight gauges ranged from 40,000 - 480,000 t/yr or 0.04 – 0.26 t/ha/yr.

1) Median concentration method- loads were half to two thirds of the WaterCAST load estimates. This technique applies the median concentration across all eight gauges to the daily discharge. The majority of the water quality data was collected in the Warrego Catchment suggesting that the median concentration calculated from Warrego catchment data are not representative of the adjacent Paroo and Bulloo catchments. In addition, the majority of samples were collected in low flow conditions which would result in a median concentration skewed towards lower flows. Further community event sampling is being undertaken to improve estimates for these two catchments. The result indicate that WaterCAST long term load estimates are of the correct order of magnitude. TP and TN comparisons showed similar trends in average annual loads.

2) Equation from small catchment study method - The equation of Miles (1990) (refer section 3.3.1), for estimating soil loss showed similar long term TSS loads. All Miles equation estimates of erosion were slightly below WaterCAST estimates. This could be attributed to the fact that a single average cover value was applied across all catchments. The method could be further improved applying a variable cover estimate for each catchment.

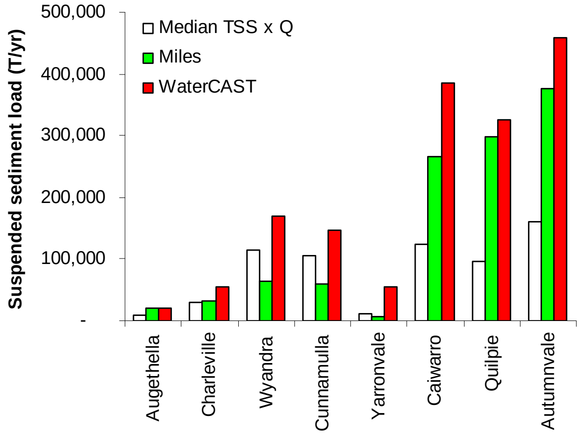

Figure 2: Comparison of Average Annual Total Suspended sediment loads for WaterCAST and two methods derived from measured data.

3) Comparison to catchment study estimates- An additional way of confirming that the modeled estimates are of the correct order is to compare modeled average annual loads to those reported from measured data by Miles (1990) and Titmarsh et al. (2002). Using the method outlined in section 2.2.1 to relate mini catchment data to gauge data, modeled loads ranged from 0.04 – 0.26 t/ha/yr in comparison to 0.01 – 0.29 t/ha/yr estimated from measured data.

3.2.2. Event pollutant load comparison

Event loads were estimated from the 16 runoff events. The ratio of predicted to observed flow volumes averaged across all events was 0.84. Hence runoff volumes were under predicted in WaterCAST. The average modeled TSS, TP and TN loads for the 16 events were 40%, 25% and 60% higher than observed loads. The addition of further event data may improve event load estimates. Figure 4 depicts a sub-sample of observed and WaterCAST load estimates for three Cunnamulla events. The February 1997 event was significant being the second largest event on record and accounted for 6% of the total flow over the 41 years of record. WaterCAST predicted flow for this event was 30% higher than observed and sediment and nutrient loads were within 50% of observed. This example is encouraging and suggests that WaterCAST is adequately representing event runoff and loads.

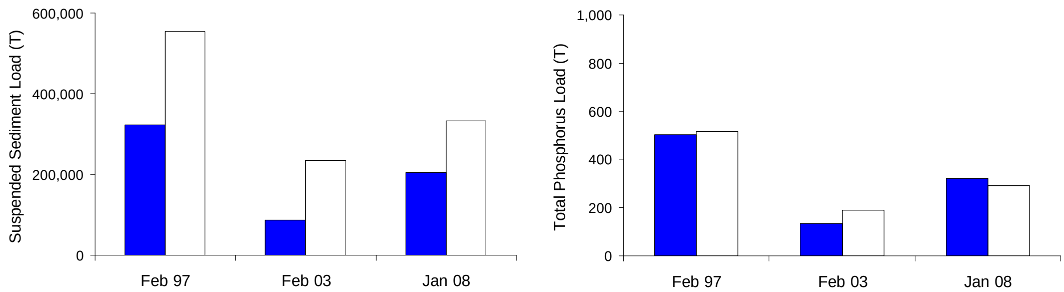

Figure 4: Example of TSS and TP modelled load(shaded) and calculated for three runoff events at Cunnamulla gauging station.

3.3. Changed land management application

The example scenario used to assess relative changes in water quality resulting from funding for fencing by land type to reduce grazing pressure applied an increase in ground cover from 25-30% on the weathered sediment grazing systems. This resulted in an estimated long term average annual reduction in sediment load of 5%. The results demonstrate the relative magnitude of water quality improvement that could be expected at a sub-catchment scale.

4. CONCLUSIONS

A WaterCAST model was developed for the South West Region. Modeled hydrology and water quality output could be regarded as acceptable. Predicted runoff and pollutant loads for events ranging from three to thirty days were on average within 50% of measured loads. Model results suggest that for the Warrego Catchment, 85% of the total runoff appears to be generated from half the catchment to the north west.
The Warrego catchment had a long term annual runoff of approximately 2% of the annual rainfall in contrast to 10% for both the Paroo and Bulloo catchments. This suggests that there is significantly more runoff and sediment generation per mm of rainfall in the Paroo and Bullo catchments. Both these observations will be important when considering where future monitoring and on grounds works activities may be focused to minimise sediment and nutrient exports. Additional flow and water quality monitoring data currently being collected will improve the calibration of the model particularly in the Paroo and Bulloo catchments. It is also recommended that an assessment of the extent of stream bank and gully erosion is required across the catchment to determine the relative contribution of stream/gully erosion to hillslope erosion to assist in further targeting investment The development of the WaterCAST model for the South West NRM Catchments will provide South West NRM with a tool for assessing current and future land management changes and their associated impacts on water quality.

5. ACKNOWLEDGMENTS

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6. REFERENCES

Argent R.M., (2007), E2 – Past, present and future. In Oxley, L. and Kulasiri, D. (eds) *MODSIM 2007 International Congress on Modelling and Simulation*. Modeling and Simulation Society of Australia and New Zealand, December 2007, pp. 860-866.

Burnash, R.J.C. (1995). The NWS river forecast system — catchment modelling. In: Singh, V.P., Editor, 1995. *Computer Models of Watershed Hydrology,* Water Resources Publications, Colorado, pp. 311–366.

Cook, F. Jordon P., Waters D., and Rahman J. (2009) WaterCAST – Whole of Catchment Hydrology Model An Overview *MODSIM 2009 International Congress on Modeling and Simulation*. Modeling and Simulation Society of Australia and New Zealand, Cairns, July 2009, (in press).

DPI (1978). Western Arid Region Land Use Study – Part IV. Queensland DPI Technical Bulletin No. 23

Miles, R.L. (1990) Soil Degradation Processes in a semi-arid woodland. Ph D thesis, Griffith University. Queensland.

Miles, R.L., and Campbell B.L. (1991) the application of Cs-137 to measure soil erosion in a semi arid woodland of south western Queensland. DPI internal publication.

Podger, G. (2004) RRL Rainfall Runoff Library users guide. Cooperative Research Centre for Catchment Hydrology. Available from http://www.toolkit.net.au

Power, R.E., Biggs, A.J.W and Burton, D.W.G. (2007). Salinity Audit – Warrego and Paroo Catchments, Queensland Murray-Darling Basin. Department of Natural Resources and Water, Queensland.

SILO - Queensland Department of Natural Resources. (2004). The SILO Data Drill. Department of NRM. Available from http://www.nrm.qld.gov.au/silo/datadrill/datadrill_frameset.html

Titmarsh, G., Lochhead, G., Bradley, L., Thorburn, P., Burrage, K., Rudder, A. Cameron, A., and Gramshaw, D. (2002), Land management to reduce nutrient movement from catchments. Final Report Project D5028, Murray-Darling Basin Commission.

Waters, D.K. and P. Webb, (2007) The application of the E2 water quality model for regional NRM planning. In Oxley, L. and Kulasiri, D. (eds) *MODSIM 2007 International Congress on Modelling and Simulation*. Modelling and Simulation Society of Australia and New Zealand, December 2007, pp. 888-894.

Waters, D. (2008). Water quality monitoring and E2 modeling in the South West NRM Region, Queensland - Technical Report for South West NRM.

Wischmeier, W. H., and Smith, D. D. (1978). Predicting Rainfall Erosion Losses – A Guide to Conservation Planning. U.S. Department of Agriculture, Agriculture Handbook No. 537.