

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

Modelling a small-scale rainwater harvesting system for irrigation using SWAT

A thesis presented in partial fulfilment of the requirement for the degree of Masters of
AgriScience

Masters
in
Agricultural Science

at Massey University, Manawatu,
New Zealand

Jiajia Liu
2018

Abstract

In many regions, the water available for allocation to irrigation has reached its limit and that there is a need to identify alternative sources. Large scale irrigation schemes are available for farmers to buy in in certain part of the country. However, not all farmers will have access to water from large scale irrigation schemes and this has led some hill country farmers to consider the potential to construct their own, relatively small, dams on their properties to capture and store water for irrigation. The major challenge to estimating the potential benefits of water storage for irrigation is reliably simulating the likely volume of water that can be captured.

This thesis models the rainwater harvesting potential of a hill country farm in the Wairarapa region (Riverside Farm). Soil Water Assessment Tool (SWAT) has been selected to model the water harvesting potential due its ability to separate runoff, lateral flow, and the ground water contribution to the harvestable water according to the local topographic, soil and land use properties. This allows the modeller to consider a wide range of scenarios.

A SWAT model was set up for the water harvesting catchment (WHC) on the case study farm. The WHC is ungauged, however it is nested within a larger catchment called the Calibration and Validation Catchment (CVC). CVC is gauged and therefore flow data can be obtained. Improved parameters obtained through CVC calibration is transferred to the WHC, this process of donating calibrated parameters to a hydrologically similar ungauged catchment is called parameter regionalization.

The model suggests that the storage scheme can meet the average irrigation demand of 43 ha of land 90% of the time. The predicted water harvesting potential decreases with regionalized parameters when compared to the default settings which suggests that there is a risk that some modelling may overestimate the volume of water that can be captured.

The economic impact of irrigation was also assessed in this study. The cost of one extra kilogram of pasture dry matter production is estimated to be between 39-44 cents/kg. Nitrogen fertilizer application can increase pasture yield but it is not a perfect substitution to irrigation because nitrogen fertilizer is not to be applied during drought. However, purchasing supplement feed from outside the farm might be a cheaper alternative to building a small-scale dam.

Acknowledgment

I'd like to acknowledge my supervisor Dave Horne. Me Wang for providing help with SWAT model calibration and validation. Ahmed Elwan for help with R.

Table of Contents

Abstract	1
Acknowledgment	2
<i>Table of Contents</i>	3
Table of Figures.....	6
Chapter 1 Introduction	8
1.1 Water Supply.....	12
Rain Water Harvesting Potential	12
1.2 Water Demand:.....	13
Command Area irrigation demand	13
1.3 Site Description	14
Riverside farm	14
Calibration, Validation Catchment.....	16
Command Area	16
1.4 Research Objective	18
Chapter 2 Literature Review	19
2.1 Hill Country Farming	19
Water requirement of pasture	21
2.2 Overview of SWAT	23
History and Development of SWAT	23
SWAT is a physically based model	24
SWAT model hydrologic cycles	25
Land phase hydrologic cycle	25
Routing Phase of the Hydrologic Cycle	28
2.3 Application of SWAT	29
Application of SWAT in New Zealand	29
Advantages and Disadvantages of SWAT	32
2.4 SWAT model Calibration	33
Calibrating for ungauged catchments:	33
Comparing parameter regionalization methods	34
Efficiency Criteria	35
Review of SWAT-CUP.....	37
2.5 Estimation of Irrigation system reliability.....	38
Chapter 3 Methods Development	41
3.1 How much water can be harvested and stored?.....	41

Volume and Area of the water storage	42
Maximum Dam height and Earthwork estimation	42
3.2 What is the pasture's response to irrigated water?	48
Data input	48
Pond Water balance	48
Command Area Water balance.....	50
Pasture biomass response to irrigation	51
System Reliability:	53
Suitable command area:	53
3.3 What's the cost to apply irrigation water and the cost of pasture	54
The cost of the embankment structure.....	54
Economic analysis of the WHC:	54
Chapter 4 SWAT Application.....	57
4.1 Application of SWAT	57
Data Collection.....	57
Data Processing.....	66
SWAT model Set Up	75
4.2 SWAT Calibration, Validation, and Sensitivity Analysis	78
Parameter Selected for Calibration	78
SWAT-CUP set up for Calibration Validation and sensitivity analysis	79
4.3 Parameter regionalization	81
4.4 Sensitivity of water harvesting potential to water partitioning	81
Chapter 5 Results of SWAT Analysis	84
5.1 Results.....	84
Calibration and validation of CVC	84
Parameter Sensitivity analysis for the CVC calibration.....	86
Parameter regionalization	90
5.2 Discussion:	92
CVC Calibration and Validation	92
Parameter Regionalization.....	97
Chapter 6 Results and Discussion on Water Balance	98
6.1 Results	98
Preliminary results, study of the water storage characteristics	98
WHC and command area water balance	99
Economic Analysis.....	112

6.2 Discussion.....	116
Scenario 2	120
Scenario 3	121
Economic Analysis.....	121
Chapter 7 Conclusion	123
Reference	125
Appendixes.....	131
Appendix I – Excel spreadsheet for calculating command area and pond water balance	131
Appendix II- Validating WGEN weather generator	137

Table of Figures

Figure 1-1 Cross-Sectional View of a typical embankment.	11
Figure 1-2 Location of the 'Main block' and 'Mikimiki block' on Riverside farm	15
Figure 1-3 Thirty-year (1984-2014) Average Monthly Rainfall (mm) at the riverside farm	15
Figure 1-4 Aerial Photos of the Calibration and Validation Catchment. The water harvesting catchment is nested within the Validation catchment.....	16
Figure 1-5 Aerial photo of the Water Harvesting Catchment	17
Figure 2-1 Average Daily pasture growth rate in Kg DM/ha in three Wairarapa site (DairyNZ, 2010)	20
Figure 2-2 SWAT hydrologic modeling processes flow chart (Neitsch et al., 2011).....	26
Figure 3-1 The cross section of the topography at the basin outlet of the water harvesting catchment (WHC).....	44
Figure 3-2 A cross-sectional view of the embankment	47
Figure 4-1 Map of soil types within the calibration/validation catchment (CVC)	58
Figure 4-2 Soil map of the water harvesting catchment	59
Figure 4-3 Landuse map of the CVC.....	60
Figure 4-4 Landuse Map of the WHC.....	61
Figure 4-5 Six years average Monthly precipitation from each climate station between 2008 and 2014	63
Figure 4-6 Frequency distribution of monthly rainfall from VCD (Site 001, Site 002, Site 004, Site 005) between year 1985-2014 over the CVC.....	65
Figure 4-7 Reach within the CVC basin and Greater Wellington Regional Council Flow Rate Monitoring points	66
Figure 5-1 Simulated and observed flow events plotted against one another in log scale for Mikimiki and Te Mara site	86
Figure 5-2 The relationship between parameters and the corresponding Nash-Sutcliffe efficiency in the full parameter space using Latin Hypercube sampling technique.....	90
Figure 5-3 The ratio between water yield and rainfall under both the default parameter sets and the regionalized parameter sets.....	91
Figure 5-4 The frequency of the top three water yield to rainfall ratio under both parameter sets	92
Figure 5-5 Simulated and observed flow rate during calibration period and the daily rainfall data for the period from the nearest climate record point at Mikimiki bridge.	94
Figure 5-6 Simulated and observed flow rate during calibration period and the daily rainfall for the period from the nearest climate record point at Te Mara site.	94
Figure 6-1 Cumulative frequency of annual per hectare pasture yield (kg/ha) under irrigated and unirrigated systems.....	101
Figure 6-2 Volume of the pond during a typical simulation under the assumption made in table 6-4.	102
Figure 6-3 Total dry matter production in case study 1 under two circumstances. The first scenario irrigates 40 ha of land while leaving 45 unirrigated. The second one accepts risks and irrigates 85 ha of land.	105
Figure 6-4 Screenshot of the calculation for annual cost. Opportunity cost for capital is assumed to be 8%, embankment height is set to be 9 meters with a command area of 45 ha.	113
Figure 6-5 Yearly rainfall in the command area between 1992-2015.....	117

Figure 6-6 Plotted the difference in average total biomass production between the 85 ha irrigated and 40 ha irrigated plus 45 ha dryland system. On a whole farm basis, irrigating 85 ha of land resulted in higher production in January, February, September, October, November, and December, while the 40 ha irrigated + 45 ha dryland system produce more biomass in March and April.	119
Figure 6-7 The difference between additional pasture growth per irrigated hectare under the high reliability scenario (40 ha irrigated) and additional pasture growth per irrigated hectare under the low reliability scenario (85 ha irrigated).....	120
Figure Appendix 1-1	133
Figure Appendix 1-2 Part 1	133
Figure Appendix 1-3 Part 2	133
Figure Appendix 1-4 Part 3	134
Figure Appendix 1-5 Part 4	134
Figure Appendix 1-6 Part 5	135
Figure Appendix 1-7 Part 6	135
Figure Appendix 1-8 Part 7	136