Rehabilitation of degraded land to increase soil carbon storage in Northwest Queensland

Final project report

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Rehabilitation of degraded land to increase soil carbon storage in northwest Queensland project was initiated in July 2012 for a 3-year period to examine the management practices that may lead to increase in soil carbon and thereby increased infiltration and reduced erosion and runoff. The management and grazing practices examined were: wet season spell, shallow water pondage, spiral ploughing and shallow ripping. These were compared against the soil "D" condition and "A/B" condition, the former indicating the worst (degraded land / pasture) and the latter indicating the potential improvement expected from the management practices examined. Since soil organic carbon (SOC) increases slowly it was decided to measure the soil organic carbon levels at (or close to) the initiation of the management practices to establish a baseline for future measurements, for example after 5 years. For time-series expected changes in soil organic carbon a dynamic soil carbon model "CENTURY" was used to predict the changes after a number of years for example up to 50 years or more if these management practices are continued. However, soil infiltration measurements were made more frequently, initially and approximately every 6 months to assess the changes in infiltration rates within a short period, which will directly impact on seed germination, seed establishment and growth as well as tussock persistence. This was done for almost a 24-month period. The results of this study are reported in three sections obtained from three properties: Roselvale (near Houghendon), Granada (near Julia Creek), and Herbertvale (near Cammoweal). These are:

Section 1: Soil carbon measurement and interpretation

Andrew Jones and Ram Dalal

Soil Organic Carbon Summary:

Rosevale: Soil organic carbon stocks in the top 0.1 m depth were 5 t C/ha higher under D condition than AB land condition; similar trends were observed for total N stocks. For 0.1-0.3 m depths, the SOC stocks were similar across all treatments while N stocks were marginally higher in D and AB condition (0.1-0.5 t N/ha higher) (Fig. 2, Table 3). For the top 0.3 m depths, soil organic carbon stocks were approximately similar across all sites except D condition was 3 to 4 t C/ha and 0.1 to 0.3 t N/ha higher. This result suggests that the paddock treatment identified as D condition at Rosevale may in fact be better suited as representing the maximum SOC sequestration potential for these soils therefore, there is potential soil carbon storage of 3 -5 t C/ha at Rosevale (Fig. 2, Table 3).

Granada: Soil organic C stocks for the top 0.1 m depth varied from 11 t C/ha in soil under A/B land condition to 5 to 6 t C/ha in soil for the 1-4 treatments (Fig. 2, Table 4). Both soil organic C and total N concentrations were lower in soil under D condition than A/B condition. Essentially similar trends in SOC stocks were generally observed at 0.1-0.3 m depths except D condition was higher than AB condition. When considering the 0-0.3 m depth range, AB and D condition were higher than the other treatments with AB highest in SOC and N stocks. There is a potential for carbon storage of 5 to 6 t C/ha in soil under 1-4 treatments in the top 0.1 m. Similarly, for 0.1-0.3 m depths, from 1 to 2 t C/ha potential soil carbon storage if A/B land condition is achieved over time.

Herbertvale: At Herbertvale, soil organic C and total N concentrations in soil under A/B land condition were essentially similar to those under D condition but almost 30% higher than those in other treatments (Fig. 2, Table 5) in the 0-0.1, 0.1-0.3 and 0-0.3 m depths. If the objective of the imposed treatments is to achieve similar soil organic carbon stocks to that under A/B condition (approximately 6 t C/ha in 0-0.1 m depth, and 5 t C/ha in 0.1-0.3 m depth) then up to 1 to 2 t C/ha respectively is the potential soil carbon storage at Herbertvale (Fig. 2, Table 5).

MIR-spectra: A higher proportion of resistant C (ROC) is found at Granada relative to the paddock at Rosevale and Herbertvale (Fig. 3, 4). This is indicative of long-lasting SOC that may be the product of low fertility in these soils or build-up of resistant char-derived material over time. In contrast, Herbertvale has a high relative proportion of labile C (POC) that makes up the total SOC stocks. This may indicate higher fertility at these soils; however, this is not reflected in total SOC stocks at this site (which are low relative to Granada and Rosevale). Rosevale has an intermediate relative proportion of POC and ROC fractions.

In summary, soil organic carbon storage potentials at the three paddocks at Rosevale, Granada and Herbertvale were estimated to be 2-5, 5-6 and 1-2 t C/ha, respectively, at 0-0.1 m depth; 1, 3-4 and 1 t C/ha, respectively, at 0.1-0.3 m depth, and 3-5, 8 and 3 t C/ha, respectively, at 0-0.3 m depth. These are the potential soil organic C storage at these three properties; what can be achieved depends on soil and pasture management, stocking rate and stocking density and removing any other limitation to pasture growth. These are discussed following the outputs from the CENTURY model.

1. Introduction

This document reports on the soil carbon monitoring activities undertaken by the Queensland Government Department of Science, Information Technology and Innovation (DSITI). All activities are consistent with the Soil Carbon Research Program (2009-2012) including data management, verification and reporting.

The study aimed to assess the effectiveness of different pasture seeding and land and pasture management methods to sequester soil organic carbon (SOC). We sampled the paddocks after the establishment of the treatments.

For all soil samples taken, laboratory analyses were undertaken to;

- Analyse soil samples for total organic C and N
- Determine functional SOC fractions / pools using mid-infrared spectra (MIR)
- Analyse soil samples for silt, clay and pH

This data was collated and distributed for modelling using the ‘CENTURY’ model.

2. Materials and methods

The trial identified and implemented four different seeding and land and pasture management methods: shallow water pondage, contour ripping, crocodile seeding, wet season spelling. The treatments at each property were compared with control sites that had D condition and A/B condition coverage of perennial pastures.

2.1. Study area

This study was based on three properties in Northern Queensland; Rosevale, Granada and Herbertvale (see property map in *Appendix I*). These properties lie within areas receiving annual rainfalls of 565 mm, 479 mm and 378 mm, respectively. The study sites cover a range of soil types and pastures:

1) Rosevale: Outwash plains of brown and grey clays with a shallow loamy surface horizon which has been eroded away, exposing clay subsoil and water-worn stone (0.2-0.5% slope); a sparse cover of annual pastures.

2) Granada: Red-yellow earths and grey brown clays; annual pastures only surrounded by gidgee and buffel grass.

3) Herbertvale: Grey cracking clays with scalded surface (0.66% slope); annual pastures only such as spider couch.

Table 1: Differential GPS locations of all six treatments for properties Granada, Rosevale and Herbertvale. See *Appendix I* for property maps.

Treatment	Latitude	Longitude
Rosevale		
AB condition	-20.80945	144.25215
D condition	-20.79868	144.24670
Wet season spell	-20.79889	144.23361
Shallow pondage	-20.79708	144.23511
Spiral ploughing	-20.79714	144.23196
Shallow ripping	-20.79571	144.23261
Granada		
AB condition	-20.02944	140.40575
D condition	-20.02259	140.39637
Treatment 1	-20.03308	140.39850
Treatment 2	-20.03433	140.39805
Treatment 3	-20.03330	140.39683
Treatment 4	-20.03564	140.39724
Herbertvale		
AB condition	-18.94719	138.08890
D condition	-18.95638	138.08685
Wet season spell	-18.96461	138.08622

Shallow pondage	-18.96073	138.08483
Spiral ploughing	-18.96123	138.08667
Shallow ripping	-18.96137	138.08528

2.2. Sampling strategy

This study used a random sampling strategy within a set area (33 m x 40 m) at each of the six treatments of each property. A sampling template (Fig.1) was used by corresponding the central point with a prepared star-picket used by previous activities at each treatment. Using ArcGIS tools, 10 coring locations were randomly allocated within the area. Soil cores were taken at each sampling location to 0.3 m depth at intervals of 0-0.1 m and 0.1-0.3 m depths. The location of each core was noted with a differential GPS accurate to 0.1 m.

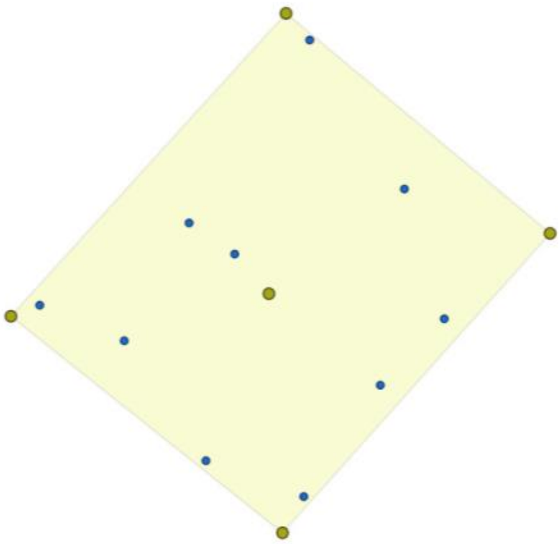

Figure 1. The random sampling template used for all treatments. The template is encompassed by four corner points and one central point (brown points). Ten coring locations (blue points) were randomly allocated within each stratum.

2.3. Analytical methods

Soil samples were dried to 40°C for 48 hours. To estimate total gravimetric moisture content, a subsample of 10 g was further dried at 105°C for an additional 48 hours. The samples were then sieved through a 2 mm mesh to collect coarse roots, charcoal and rocks. Subsamples of this soil (< 2mm) were ground to fine particles (< 100 µm) using a ring mill (SRM- 2000). All soil samples were analysed for total carbon and nitrogen (TruMac CN, LECO Corporation, USA). Calcareous soil samples were identified by a fizz test using HCl and these samples were acid treated to remove carbonates (inorganic C) before elemental carbon analysis. The calcareous soil samples were treated with sulphurous acid H_2SO_3 for 24 hours on a hotplate at 60'C. For other soil analysis, composite samples were made by bulking all 10 samples at each depth range for each treatment. Individual sample weights for a composite sample of 250 g were evenly calculated according to individual bulk density. These composite samples were analysed for EC and pH, clay, silt and sand contents (Rayment & Higginson 1992).

2.4. Soil carbon fractionation

To understand functional soil carbon properties, finely ground subsamples were analysed by diffuse reflectance infrared spectroscopy on a Spectrum One FT-IR Spectrometer (Perkin Elmer) with spectra acquired in the mid infrared (MIR) range. The MIR spectra were then used to provide predictions of SOC properties using a partial least squares regression approach detailed in Baldock *et al.* (2013a). This MIR-PLSR routine provides predictions of particulate organic carbon (POC), humus organic carbon (HOC) and resistant organic carbon (ROC) fractions (Baldock *et al.* 2013b).

2.5. Data analyses

Bulk density of each individual sample was calculated using the depth and dry weight of each sample from the intact core. Soil carbon stocks were calculated according to the method of Pringle *et al.* (2011). In summary, this method uses an equal-area spline (Bishop *et al.* 1999, Malone *et al.* 2009) to disaggregate the depth functions of bulk density and carbon concentration at 0.01 m intervals down the soil profile. Carbon stock at each interval is then calculated, and accumulated until a threshold soil mass of interest, equivalent soil mass for each treatment or paddock is reached. This study selected the soil mass references 1500 t and 3000 t to encompass first, the top 0.1 m, and second the minimum soil mass at 0.3 m at all sites.

3. Results

All analytical results derived from this study are reported in the *Appendix II* of this report.

Comparative paddock and property summaries are given in this section.

3.1. Soil properties

Table 2. Soil properties for each property.

Property	Soil analysis	Depth (m)	
		0-0.1	0.1-0.3
Rosevale	pH	7.7	8.3
	EC	0.09	0.44
	Clay content (%)	39.3	42.4
	Coarse sand (%)	14.6	12.4
	Fine sand (%)	37.8	36.0
	Silt (%)	12.2	12.9
Granada	pH	8.0	8.6
	EC	0.14	0.91
	Clay content (%)	33.1	34.3
	Coarse sand (%)	5.2	4.4
	Fine sand (%)	52.5	49.4
	Silt (%)	14.7	16.6
Herbertvale	pH	7.2	7.9
	EC	0.02	0.03
	Clay content (%)	45.6	46.1
	Coarse sand (%)	7.7	13.1
	Fine sand (%)	39.3	34.1
	Silt (%)	12.4	11.7

Soil pH at 0-0.1 m depth was mildly alkaline at all three properties (pH 7.2 – 8.0). Only at Granada, soil pH at 0-1-0.3 m depth was greater than 8.5, and high electrical conductivity (EC, a measure of salt content) indicating a saline-sodic subsoil. The soils at all three properties were clayey, with highest clay content at the Herbertvale property.

Table 3: Stocks of soil C, N and SOC fractions for Rosevale soils.

Property	Paddock	Depth (m)	Avg SOC Stock (tC/ha)	Avg N Stock (tN/ha)	POC stock (tC/ha)	HOC stock (tC/ha)	ROC stock (tC/ha)
Rosevale	Shallow water Pondage	0-0.1 m	5.29	0.80	0.3	4.0	1.0
		0.1-0.3 m	10.47	1.65	0.7	5.8	4.0
Rosevale	Contour ripping	0-0.1 m	6.52	0.84	1.1	4.2	1.3
		0.1-0.3 m	12.48	1.63	1.1	7.7	3.6
Rosevale	Crocodile seeding	0-0.1 m	5.88	0.82	0.5	4.4	0.9
		0.1-0.3 m	11.61	1.65	1.1	7.5	3.0
Rosevale	Wet Season spelling	0-0.1 m	5.77	0.79	0.6	4.2	1.0
		0.1-0.3 m	11.19	1.60	1.1	6.4	3.6
Rosevale	D condition	0-0.1 m	9.19	0.99	1.2	5.9	2.1
		0.1-0.3 m	15.53	1.78	0.7	9.8	5.0
Rosevale	AB condition	0-0.1 m	5.23	0.72	0.7	3.5	1.1
		0.1-0.3 m	10.82	1.47	1.9	5.5	3.5

Table 4: Stocks of soil C, N and SOC fractions for Granada soils.

Property	Paddock	Depth (m)	Avg SOC Stock (tC/ha)	Avg N Stock (tN/ha)	POC stock (tC/ha)	HOC stock (tC/ha)	ROC stock (tC/ha)
Granada	Treatment 2	0-0.1 m	5.55	0.55	0.32	3.73	1.50
		0.1-0.3 m	11.83	1.04	0.11	7.52	4.20
Granada	Treatment 4	0-0.1 m	4.65	0.60	0.47	2.91	1.27
		0.1-0.3 m	9.79	1.26	0.61	3.52	5.84
Granada	Treatment 3	0-0.1 m	5.90	0.59	0.20	3.81	1.89
		0.1-0.3 m	11.83	1.23	0.05	6.64	5.14
Granada	Treatment 1	0-0.1 m	5.73	0.51	0.33	3.74	1.66
		0.1-0.3 m	11.93	1.03	0.20	7.16	4.58
Granada	D condition	0-0.1 m	7.65	0.81	0.27	5.75	1.63
		0.1-0.3 m	16.89	1.57	0.45	9.75	6.69
Granada	AB condition	0-0.1 m	10.58	1.10	1.10	6.94	2.54
		0.1-0.3 m	17.77	1.92	1.25	11.08	5.45

Table 5: Stocks of soil C, N and SOC fractions for Herbertvale soils.

Property	Paddock	Depth (m)	Avg SOC Stock (tC/ha)	Avg N Stock (tN/ha)	POC stock (tC/ha)	HOC stock (tC/ha)	ROC stock (tC/ha)
Herbertvale	Shallow water Pondage	0-0.1 m	4.65	0.50	1.2	3.1	0.3
		0.1-0.3 m	8.31	0.98	1.8	5.7	0.8
Herbertvale	Contour ripping	0-0.1 m	4.49	0.48	1.0	3.0	0.5
		0.1-0.3 m	8.18	0.90	1.8	5.2	1.2
Herbertvale	Crocodile seeding	0-0.1 m	5.05	0.51	0.8	3.8	0.4
		0.1-0.3 m	8.87	0.92	3.3	5.0	0.5
Herbertvale	Wet Season spelling	0-0.1 m	4.96	0.50	0.9	3.6	0.5
		0.1-0.3 m	8.95	0.91	1.6	6.5	0.9
Herbertvale	D condition	0-0.1 m	5.97	0.55	1.6	4.0	0.4
		0.1-0.3 m	10.59	1.00	2.9	7.1	0.6
Herbertvale	AB condition	0-0.1 m	6.10	0.58	0.8	4.8	0.4
		0.1-0.3 m	10.93	1.05	1.7	8.4	0.8

3.2. Soil carbon and nitrogen stocks

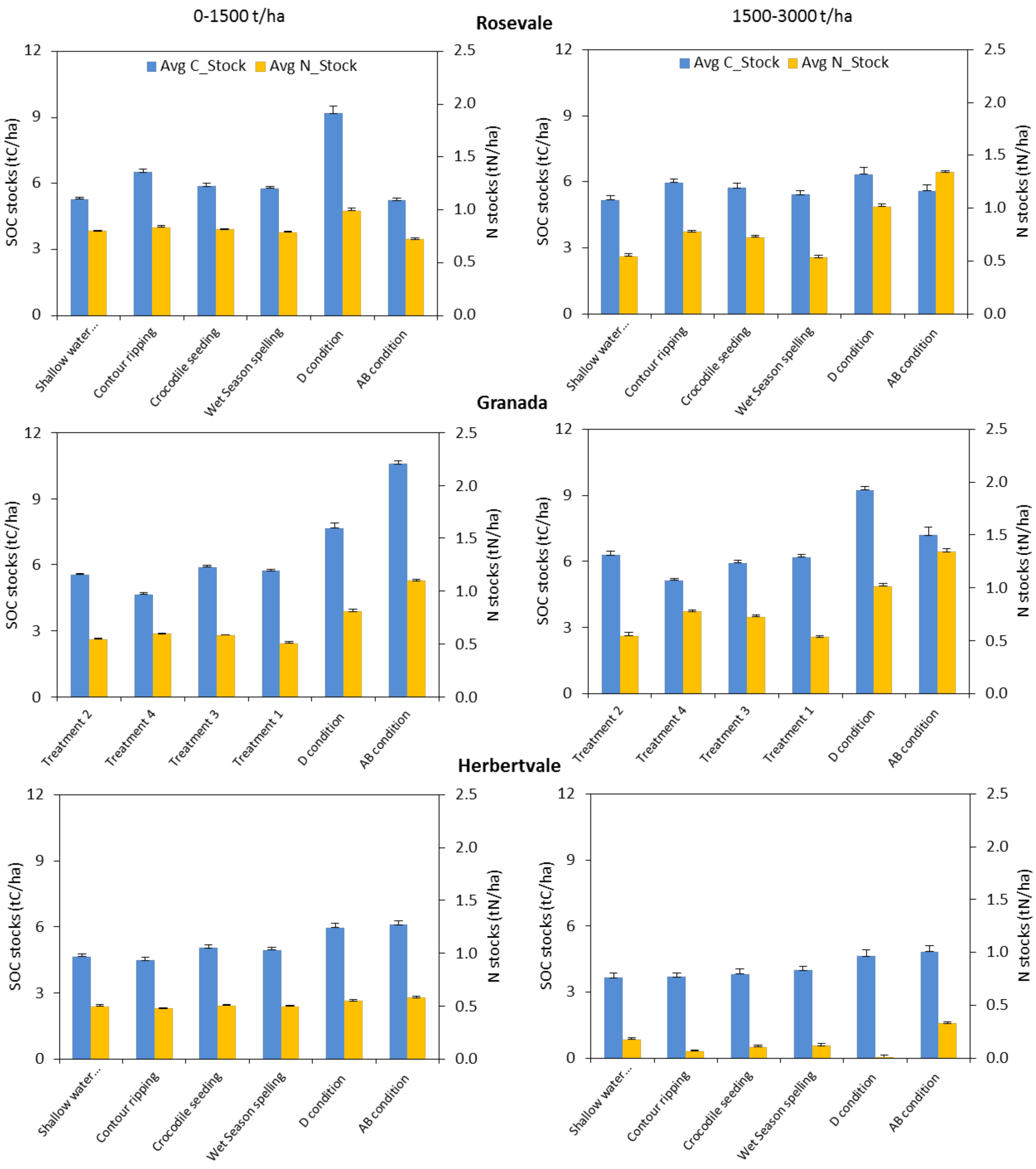

Figure 2: Stocks of total SOC (blue) and Nitrogen (yellow) at 0-1500 t (0-0.1 m) and 1500-3000 t (0.1-0.3 m) soil mass reference. All six treatments at each property are as follows: shallow water pondage, contour ripping, crocodile seeding, wet season spelling, D condition, A/B condition. Treatments had not been established on the Granada property and so paddocks have the interim labels “Treatments 1-4”.

3.3. MIR-derived fractions

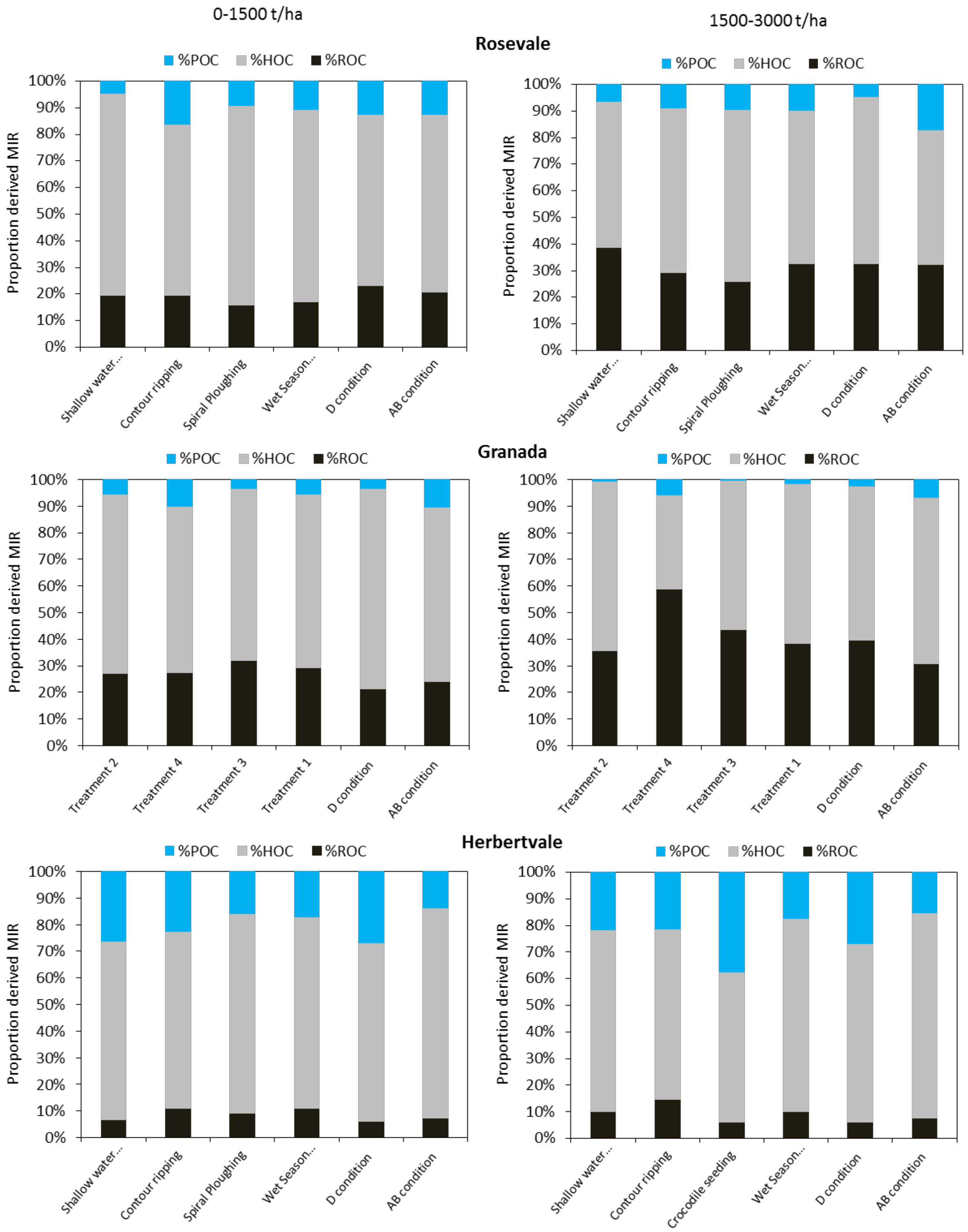

Figure 3: Proportion of MIR-derived SOC fractions at 0-1500 t (0-0.1 m) and 1500-3000 t (0.1-0.3 m) soil mass reference. Fractions are divided into the proportional contribution to total concentration of all fractions POC, ROC and HOC. All six treatments at each property are as follows: shallow water pondage, contour ripping, crocodile seeding, wet season spelling, D condition, A/B condition. Treatments had not been established on the Granada property and so paddocks have the interim labels “Treatments 1-4”.

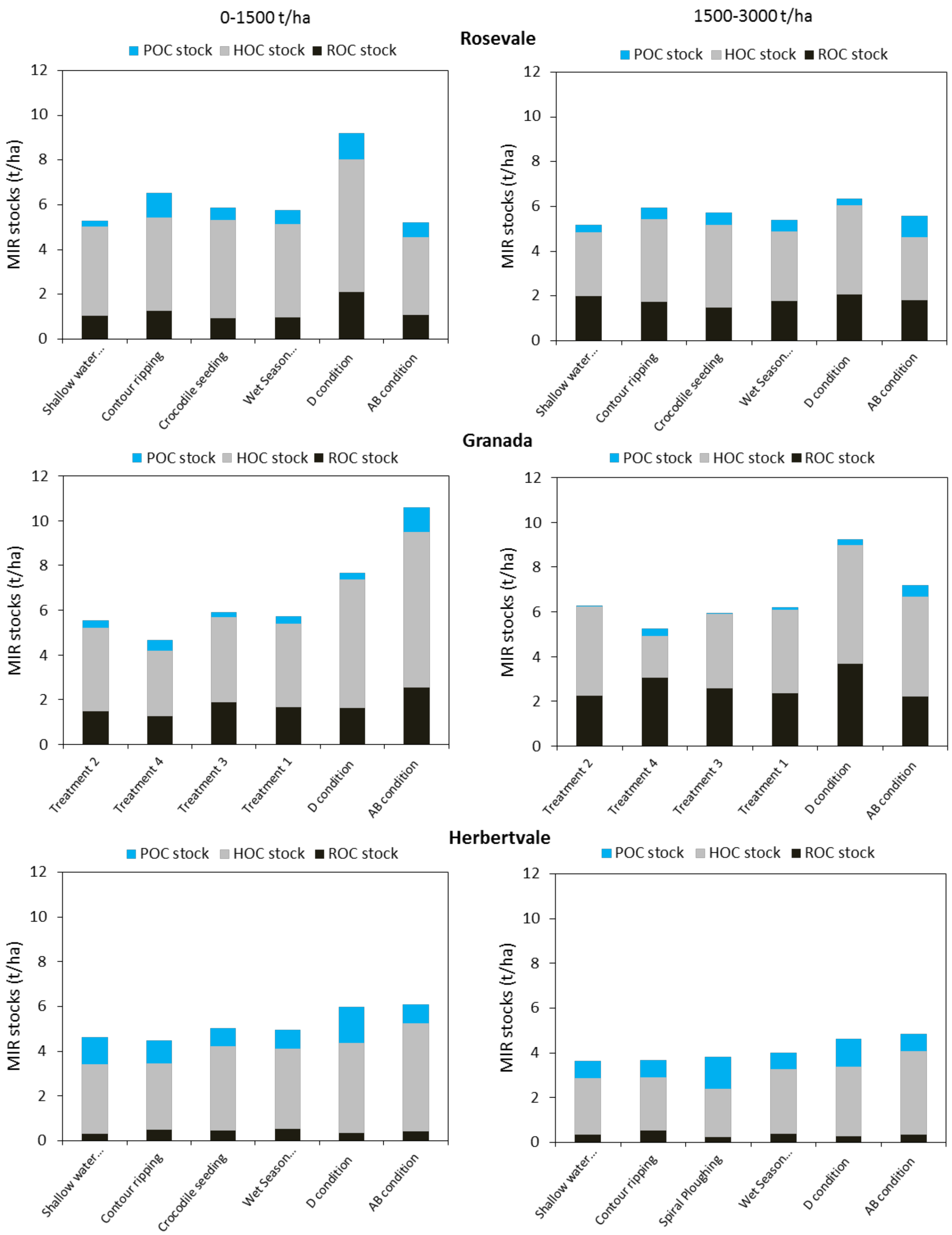

Figure 4. Soil carbon stocks on each property at 1500 t (0-0.1 m) and 1500-3000 t (0.1-0.3 m) soil mass reference. Total soil carbon stocks (as determined by LECO) are divided into the proportional contribution of MIR-derive fractions POC, ROC and HOC. All six treatments at each property are as follows: shallow water pondage, contour ripping, crocodile seeding, wet season spelling, D condition, A/B condition. Treatments had not been established on the Granada property and so paddocks have the interim labels “Treatments 1-4”.

4. Discussion: Trends in soil organic C

Rosevale: Soil organic carbon stocks in the top 0.1 m depth were 5 t C/ha higher under D condition than AB land condition; similar trends were observed for total N stocks. For 0.1-0.3 m depths, the SOC stocks were similar across all treatments while N stocks were marginally higher in D and AB condition (0.1-0.5 t N/ha higher) (Fig. 2, Table 3). For the top 0.3 m depths, soil organic carbon stocks were approximately similar across all sites except D condition was 3 to 4 t C/ha and 0.1 to 0.3 t N/ha higher. This result suggests that the paddock treatment identified as D condition at Rosevale may in fact be better suited as representing the maximum SOC sequestration potential for these soils therefore, there is potential soil carbon storage of 3 -5 t C/ha at Rosevale (Fig. 2, Table 3).

Granada: Soil organic C stocks for the top 0.1 m depth varied from 11 t C/ha in soil under A/B land condition to 5 to 6 t C/ha in soil for the 1-4 treatments (Fig. 2, Table 4). Both soil organic C and total N concentrations were lower in soil under D condition than A/B condition. Essentially similar trends in SOC stocks were generally observed at 0.1-0.3 m depths except D condition was higher than AB condition. When considering the 0-0.3 m depth range, AB and D condition were higher than the other treatments with AB highest in SOC and N stocks. There is a potential for carbon storage of 5 to 6 t C/ha in soil under 1-4 treatments in the top 0.1 m. Similarly, for 0.1-0.3 m depths, from 1 to 2 t C/ha potential soil carbon storage if A/B land condition is achieved over time.

Herbertvale: At Herbertvale, soil organic C and total N concentrations in soil under A/B land condition were essentially similar to those under D condition but almost 30% higher than those in other treatments (Fig. 2, Table 5) in the 0-0.1, 0.1-0.3 and 0-0.3 m depths. If the objective of the imposed treatments is to achieve similar soil organic carbon stocks to that under A/B condition (approximately 6 t C/ha in 0-0.1 m depth, and 5 t C/ha in 0.1-0.3 m depth) then up to 1 to 2 t C/ha respectively is the potential soil carbon storage at Herbertvale (Fig. 2, Table 5).

MIR-spectra: A higher proportion of resistant C (ROC) is found at Granada relative to the paddock at Rosevale and Herbertvale (Fig. 3, 4, Table 3, 4, 5). This is indicative of long-lasting SOC that may be the product of low fertility in these soils or build-up of resistant char-derived material over time. In contrast, Herbertvale has a high relative proportion of labile C (POC) that makes up the total SOC stocks. This may indicate higher fertility at these soils; however, this is not reflected in total SOC stocks at this site (which are low relative to Granada and Rosevale). Rosevale has an intermediate relative proportion of POC and ROC fractions.

In summary, soil organic carbon storage potentials at the three paddocks at Rosevale, Granada and Herbertvale were estimated to be 2-5, 5-6 and 1-2 t C/ha, respectively, at 0-0.1 m depth; 1, 3-4 and 1 t C/ha, respectively, at 0.1-0.3 m depth, and 3-5, 8 and 3 t C/ha, respectively, at 0-0.3 m depth.

Acknowledgements

We are grateful to the landholders, Rosevale station – David and Jan Collyer, Bruce and Jess Collyer; Granada station – Peter and Fran Hacon; and Herbertvale station – Clint and Shelly Hawkins, who allowed soil sampling on their properties and for which they provided detailed land use history. We thank Larissa Lauder and Emma Hegarty for assistance in soil sampling, and Kerrilyn Catton, Angelique Woods, Lynn Appleton, Bernadette Jones and Justin McCoombes for processing and analysis of soil samples in the laboratory.

5. References

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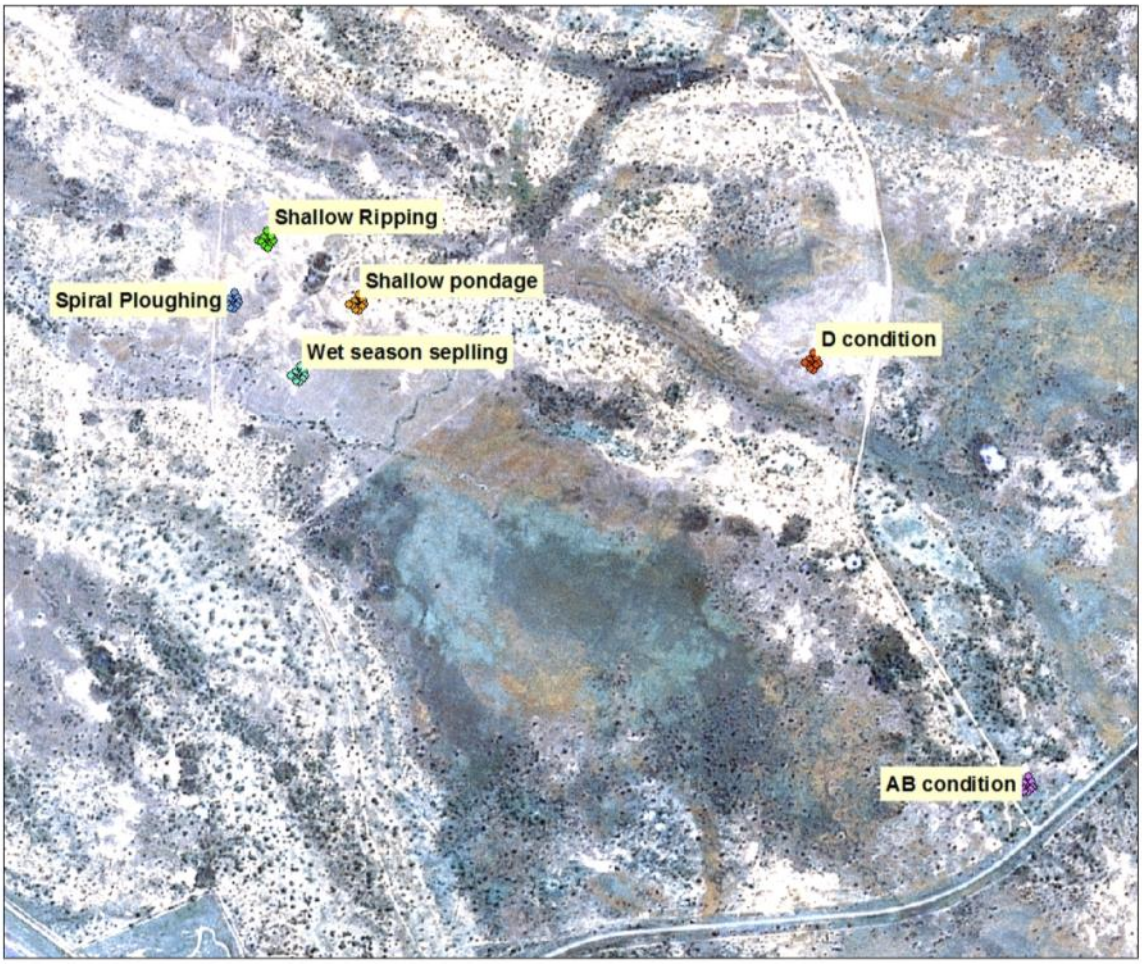
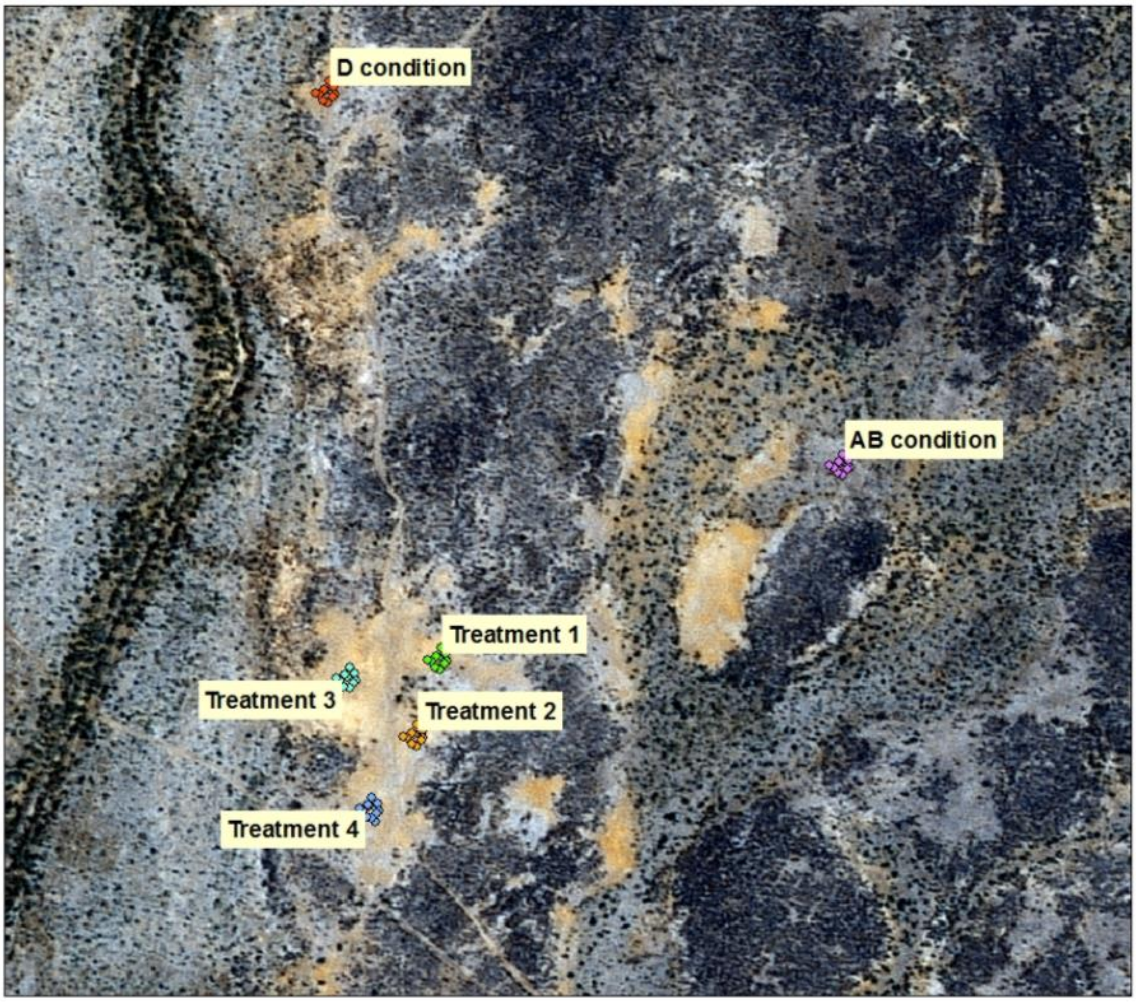
Appendix I: Property maps with sampling locations

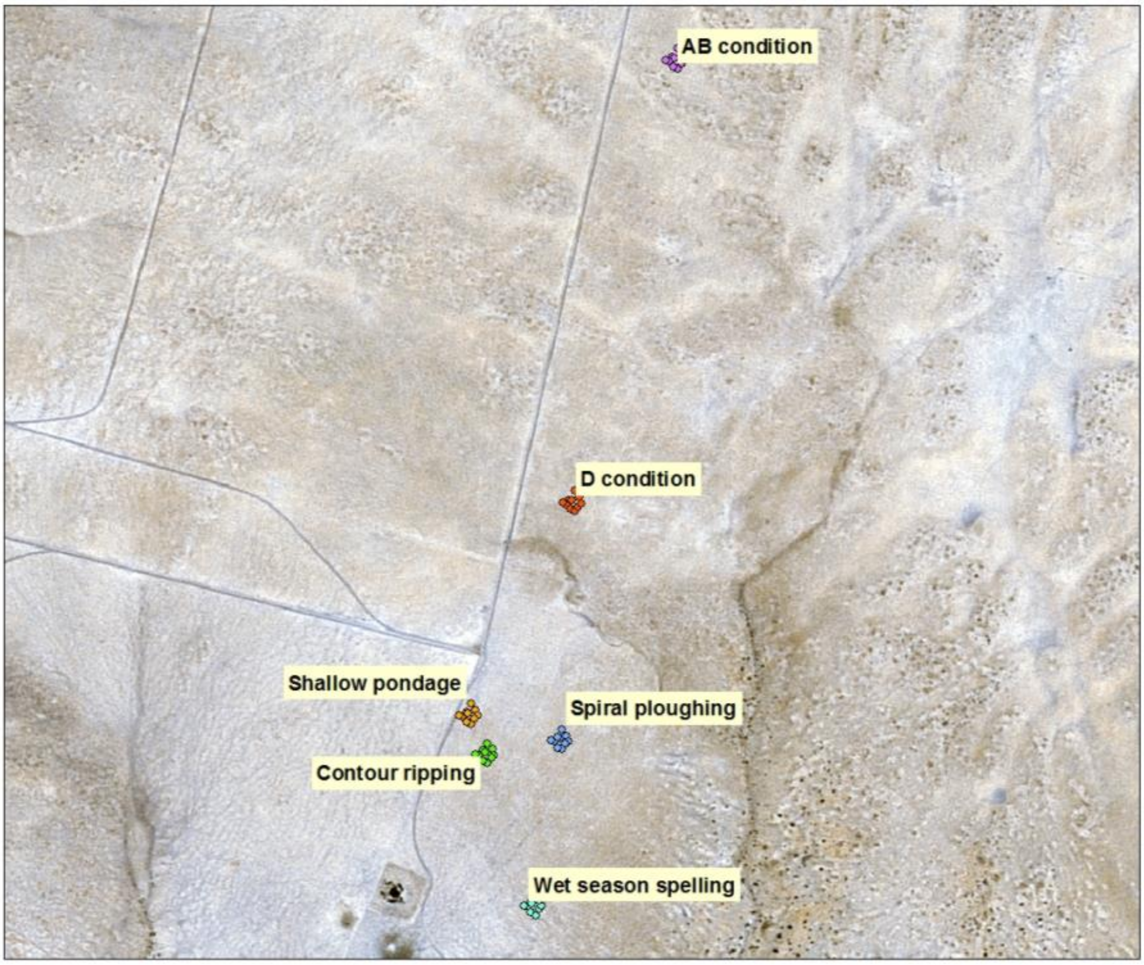
Rosevale property map with treatment sampling locations



Granada property map with treatment sampling locations



Herbertvale property map with treatment sampling locations



Appendix II

Table 6: Elemental and fractional concentrations for Rosevale soils.

Property	Paddock	Depth (m)	EC (dS/m)	pH	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)
Rosevale	Shallow water Pondage	0-0.1 m	0.08	7.9	6.1	44	13	42
		0.1-0.3 m	0.4	8.9	5.2	45	14	40
Rosevale	Contour ripping	0-0.1 m	0.04	7.6	8.4	40	14	42
		0.1-0.3 m	0.41	8.2	6.4	39	14	45
Rosevale	Crocodile seeding	0-0.1 m	0.06	7.3	6.4	41	14	44
		0.1-0.3 m	0.45	8.2	4.9	35	16	49
Rosevale	Wet Season spelling	0-0.1 m	0.08	7.9	9.9	35	11	49
		0.1-0.3 m	0.6	8.6	7.8	34	11	50
Rosevale	D condition	0-0.1 m	0.17	7.8	47.2	27	8	19
		0.1-0.3 m	0.07	7.3	44.1	26	8	24
Rosevale	AB condition	0-0.1 m	0.09	7.6	9.7	40	14	42
		0.1-0.3 m	0.71	8.4	6.2	37	15	47

Table 7: Total soil nitrogen, soil organic carbon concentration and proportion of organic c fractions for Rosevale soils.

Property	Paddock	Depth (m)	Soil N (%)	SOC (%)	POC (%)	HOC (%)	ROC (%)
Rosevale	Shallow water Pondage	0-0.1 m	0.053	0.35	5	76	19
		0.1-0.3 m	0.058	0.34	6	55	38
Rosevale	Contour ripping	0-0.1 m	0.056	0.43	16	64	19
		0.1-0.3 m	0.052	0.38	9	62	29
Rosevale	Crocodile seeding	0-0.1 m	0.054	0.39	9	75	16
		0.1-0.3 m	0.055	0.37	10	64	26
Rosevale	Wet Season spelling	0-0.1 m	0.053	0.39	11	72	17
		0.1-0.3 m	0.054	0.36	10	58	33
Rosevale	D condition	0-0.1 m	0.086	0.87	13	64	23
		0.1-0.3 m	0.049	0.37	5	63	32
Rosevale	AB condition	0-0.1 m	0.048	0.35	13	67	21
		0.1-0.3 m	0.050	0.38	17	51	32

Table 8: Soil properties for Granada soils.

Property	Paddock	Depth (m)	EC (dS/m)	pH	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)
Granada	Treatment 2	0-0.1 m	0.14	8.3	5.4	56.5	15.7	28.1
		0.1-0.3 m	1.34	8.5	5.3	49.4	17.5	31.6
Granada	Treatment 4	0-0.1 m	0.11	8	6.1	53.8	12.3	33.2
		0.1-0.3 m	0.68	8.8	4	47.9	19.5	33.2
Granada	Treatment 3	0-0.1 m	0.24	8.5	3.7	51.1	19.4	31.4
		0.1-0.3 m	1.57	8.2	3.9	51.3	14.3	34.9
Granada	Treatment 1	0-0.1 m	0.23	8.2	6	53.5	12.5	33.1
		0.1-0.3 m	0.91	9	4.8	55.6	10.9	33
Granada	D condition	0-0.1 m	0.09	7.8	2.8	57	14.2	31.2
		0.1-0.3 m	0.91	8.6	1.9	50.7	21.3	31.6
Granada	AB condition	0-0.1 m	0.05	7.4	7.2	42.8	14	41.7
		0.1-0.3 m	0.06	8.4	6.5	41.5	15.9	41.7

Table 9: Total soil nitrogen, soil organic carbon concentration and proportion of organic c fractions for Granada soils.

Property	Paddock	Depth (m)	Soil N (%)	SOC (%)	POC (%)	HOC (%)	ROC (%)
Granada	Treatment 2	0-0.1 m	0.070	0.33	6	67	27
		0.1-0.3 m	0.032	0.42	1	64	36
Granada	Treatment 4	0-0.1 m	0.040	0.31	10	63	27
		0.1-0.3 m	0.045	0.35	6	36	60
Granada	Treatment 3	0-0.1 m	0.039	0.39	3	65	32
		0.1-0.3 m	0.043	0.39	0	56	43
Granada	Treatment 1	0-0.1 m	0.034	0.38	6	65	29
		0.1-0.3 m	0.035	0.42	2	60	38
Granada	D condition	0-0.1 m	0.054	0.51	4	75	21
		0.1-0.3 m	0.049	0.65	3	58	40
Granada	AB condition	0-0.1 m	0.074	0.71	10	66	24
		0.1-0.3 m	0.050	0.42	7	62	31

Table 10: Soil properties for Herbertvale soils.

Property	Paddock	Depth (m)	EC (dS/m)	pH	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)
Herbertvale	Shallow water Pondage	0-0.1 m	0.02	7.3	7.2	40	16	42
		0.1-0.3 m	0.03	8.3	6.9	41	12	45
Herbertvale	Contour ripping	0-0.1 m	0.02	7.2	8.3	43	9	45
		0.1-0.3 m	0.03	7.8	7.6	43	10	43
Herbertvale	Crocodile seeding	0-0.1 m	0.03	7.1	7.6	41	10	45
		0.1-0.3 m	0.03	7.8	41.7	7	10	45
Herbertvale	Wet Season spelling	0-0.1 m	0.03	7.1	8.8	40	12	46
		0.1-0.3 m	0.03	7.8	8.2	39	12	47
Herbertvale	D condition	0-0.1 m	0.02	7.1	5.9	39	13	48
		0.1-0.3 m	0.03	7.9	6.1	39	12	47
Herbertvale	AB condition	0-0.1 m	0.02	7.1	8.1	33	15	49
		0.1-0.3 m	0.03	7.7	8	35	14	49

Table 11: Total soil nitrogen, soil organic carbon concentration and proportion of organic c fractions for Herbertvale soils.

Property	Paddock	Depth (m)	Soil N (%)	SOC (%)	POC (%)	HOC (%)	ROC (%)
Herbertvale	Shallow water Pondage	0-0.1 m	0.033	0.31	26	67	7
		0.1-0.3 m	0.032	0.22	22	68	10
Herbertvale	Contour ripping	0-0.1 m	0.032	0.30	23	66	11
		0.1-0.3 m	0.027	0.22	21	64	15
Herbertvale	Crocodile seeding	0-0.1 m	0.034	0.34	16	75	9
		0.1-0.3 m	0.025	0.22	38	56	6
Herbertvale	Wet Season spelling	0-0.1 m	0.033	0.33	17	72	11
		0.1-0.3 m	0.025	0.24	18	73	10
Herbertvale	D condition	0-0.1 m	0.036	0.39	27	67	6
		0.1-0.3 m	0.027	0.25	27	67	6
Herbertvale	AB condition	0-0.1 m	0.038	0.40	14	79	7
		0.1-0.3 m	0.027	0.28	15	77	8

Appendix IIV: Photos during sampling field trips

Photo 1: Granada – 'Treatment 3'

Photo 2: Granada – 'A/B condition'

Photo 3: Herbertvale – Gate sign entry

Photo 4: Herbertvale – ‘Wet Season Spelling’

Photo 5: Herbertvale – Ram Dalal and Andrew Jones at ‘Crocodile seeding’

Section 2: Infiltration and land condition analysis

Grant Fraser, Emma Hegarty and Rebecca Gunther

Contents

1.0 Study methods of quantifying land condition and infiltration rates

The method used to quantify infiltration rates in this study was based on the technique developed by Fraser and Stone (2014) for an investigation of land condition impacts on infiltration rates for 18 paired land condition plots. The following paragraphs in this section are from Fraser and Stone (2014) (with some modification) which provides an overview of this sampling technique.

"Grazing land may consist of individual patches of bare ground, grass litter cover, tree litter cover and standing grass biomass (e.g. Fig 1.). Each of these components may affect infiltration rates differently and as the tussock to tussock spatial scale is typically less than 1 m we chose a comparable scale of measurement by using a 40.5 cm diameter stainless steel single ring falling head infiltration measurement (e.g. Talsma 1969). Due to the differences in scale between the selected plot being 75 m × 75 m and the scale of the infiltration measurement (i.e. being 40.5 cm), each plot was stratified based on a 4 quadrat scale classification system of 'A', 'B', 'C,' and 'D'. The quadrat scale 'A', 'B', 'C', 'D' classification system developed in this study to rank quadrat condition is not related to the qualitative 'A', 'B', 'C', 'D' land condition classification system used in other rangeland land condition studies. In addition, land condition assessment includes differences in pasture species which may not be related to differences in infiltration. A description of the quadrat scale 'A', 'B', 'C', 'D' classification system used in this study follows. Along each of the 75 m transects for a plot, a 0.5 m × 0.5 m quadrat was placed at each 1 m interval along the tape and both visual estimates of total projected cover and an 'A', 'B', 'C' or 'D' classification was assigned (Fig. 2). 'A' and 'B' classifications were allocated based primarily on the presence of a perennial pasture tussock base. An 'A' classification was recorded when the perennial grass tussock crown(s) were a prominent feature of the quadrat. 'B' classification was allocated if the perennial grass tussock crown(s) were less dominant. Importantly, the amount of above-ground biomass was not a determining feature. In the absence of any perennial pasture tussock a 'C' or 'D' classification was allocated based on the amount of surface cover, with 'C' condition class having on average 37% cover compared to 'D' condition class having 10% cover (Table 1). The 'C' and 'D' classification occasionally had some standing biomass in the form of annual grass or forbs (Table 1).

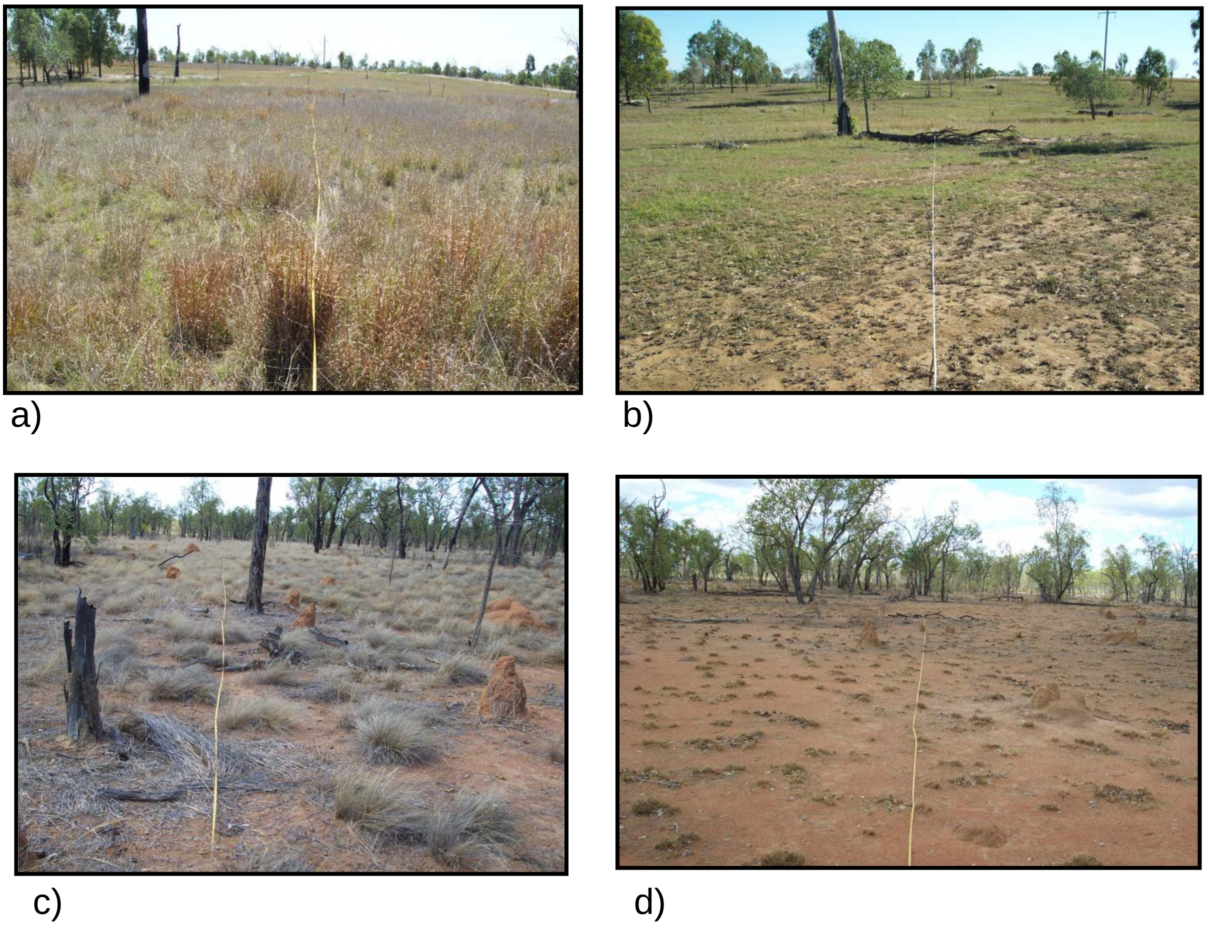


Fig. 1. Examples of the plot-scale land condition on pasture attributes at two sites, Site 1 in a) and b) and Site 2 in c) and d)

Table 1. The mean crown basal area and mean surface cover for each of the classification categories A, B, C and D for all 18 sites.

Quadrat Pasture Attribute	A	B	C	D
Grass Crown Area (%)	7.9	2.8	1.1	0.1
Surface Cover (%)	78	55	37	10

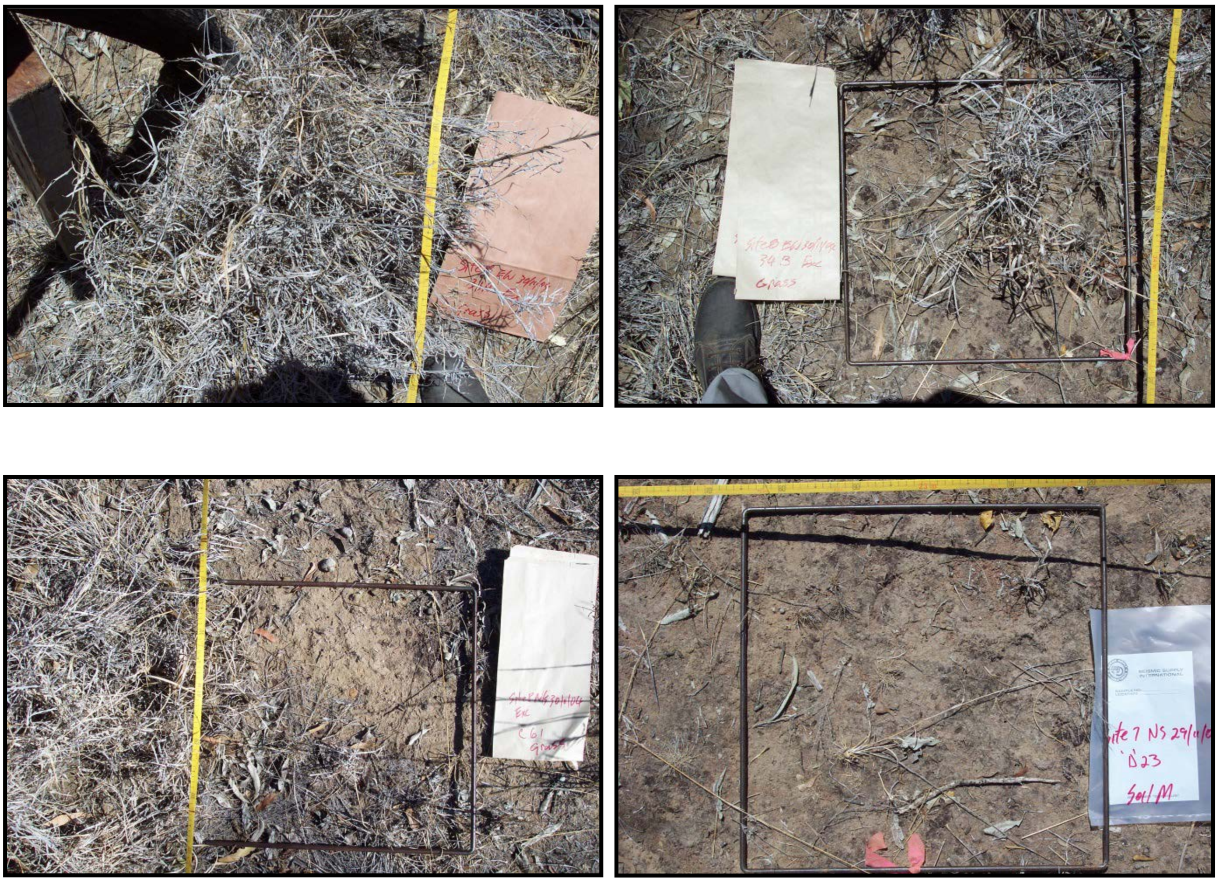


Fig. 2. The classification of the 0.5 m × 0.5 m quadrat into four possible condition class classifications ‘A’, ‘B’, ‘C’ or ‘D’.

Once the quadrats had been classified for the two 75 m transects (within a plot), a representative quadrat was selected for each of the A, B, C and D classifications along each transect. At each plot, eight infiltration measurements were taken. The infiltration measurements within a plot provided the base information for sampling a plot in terms of the infiltration capacity, pasture and soil attributes. The 150 quadrat classification observations (proportion of plot in ‘A’, ‘B’, ‘C’ or ‘D’ category) were also used to scale individual quadrat infiltration measurements up to a weighted average plot infiltration capacity.

1.3.

2.3. 1.1 Measurement of infiltration capacity

Measurements of surface runoff in rangeland studies (e.g. O’Reagain *et al.* 2005) are expensive, labour intensive and are often conducted on a very limited range of sites for a number of years. In this study, we have instead chosen to measure infiltration capacity using a single ring falling head infiltrometer across 18 sites with paired plots varying in land condition for a given point in time.

Single ring falling head infiltration measurements have been used previously in a number of Australian rangelands studies (e.g. Bonnell and Williams 1986 and Witt *et al*. 2011).

For each of the 0.5 m × 0.5 m quadrat-scale infiltration measurements, the following procedure was undertaken.

1) The standing pasture and litter were collected separately for later drying and calculation of dry biomass components (kg DM/ha).

2) A photograph was taken of the quadrat after harvesting to use to calculate the grass tussock crown area. This calculation was made by projecting a grid of 100 one percent categories on top of the photographed quadrat area and summing the areas covered by the tussock crowns.

3) The stainless steel ring (40.5 cm diameter, wall thickness 2.5 mm) with a sharpened leading edge was 'driven' by hand ~3 cm into the surface soil.

4) The disturbed surface soil on the inside edge of the ring was sealed by smearing moulded bentonite clay between the inside ring edge and the undisturbed soil surface. A folded piece of canvas was laid inside the ring to pour the water onto and thus minimise the soil surface disturbance. Water (7.5 l) was carefully poured into the ring and the rate of fall in the surface head was recorded in the centre using a mounted ruler on a 1 minute time basis for 10 minutes and a final measurement was recorded at 15 minutes.

Runoff events can often occur in Queensland's semi-arid rangelands from early season storms occurring on soils with low antecedent soil moisture content (Fraser and Waters 2004). In this study the average soil water gravimetric water content was 3.9 g water / 100 g of dried soil which indicates that the soils were in a dry state when sampled.

We found that infiltration rates closely matched the Philip (1957) equation for estimating sorptivity in the first 5 minutes. After this initial period of rapid infiltration, rates would quickly reduce to an almost constant rate by 10 to 15 minutes. Therefore, in this study we defined the infiltration capacity of a quadrat as the quantity of water that infiltrated in the 15 minute time period (expressed in terms of mm/hr)."

2.0 Rosevale

Land condition and infiltration measurements were taken at five separate sampling times at Rosevale station. The first infiltration measurements were undertaken between the 12th and 14th of November 2012. At this time no remedial treatments had been undertaken at the site and hence infiltration rates taken at this time represent the sites inherent infiltration rates given the current land condition. Soon after these measurements were taken three remedial treatments were imposed – spiral ploughing, contour ripping and shallow water pondage. Subsequently, follow up land condition and infiltration measurements were taken at approximately 6 months (13/5/13 – 15/5/13), 12 months (28/10/13), 18 months (31/3/2014) and 24 months (3/11/2014) after the treatments were imposed. In addition to these mechanical treatments aimed at improving water infiltration rates, there were three additional treatments – control treatment (which was exclosed from grazing) and also two nearby adjoining grazed plots in 'A/B' and 'D' land condition.

2.1 Land condition measurements

For each treatment, 150 quadrat scale land condition measurements were assessed using 0.5m × 0.5m quadrats. This involved quadrat scale land condition assessment as being in one of the following four classes - 'A' or 'B' or 'C' or 'D' and also a visual estimate of total ground cover. A summary of the treatment results for quadrat scale land condition (Table 2a-f) and for surface cover (Fig. 3) follow.

Table 2. Percentage of treatment area in quadrat scale land condition categories ‘A’, ‘B’, ‘C’ and ‘D’ for: a) control treatment; b) ‘A/B’ grazed; c) shallow water pondage; d) spiral plough; e) contour rip and f) ‘D’ grazed.

a) Rosevale control

Sampling Stage	Date	A	B	C	D
0 months	12/11/2012	0	0	0	100
6 months	15/05/2013	0	0	0	100
12 months	28/10/2013	0	0	5	95
18 months	31/03/2014	0	0	40	60
24 months	3/11/2014	0	0	1	99

b) Rosevale ‘A/B’ grazed

Sampling Stage	Date	A	B	C	D
0 months	13/11/2012	5	77	0	18
6 months	15/05/2013	8	75	1	16
12 months	28/10/2013	49	29	5	17
18 months	1/04/2014	19	51	22	8
24 months	4/11/2014	37	48	2	13

c) Rosevale shallow water pondage

Sampling Stage	Date	A	B	C	D
0 months	13/11/2012	0	3	9	88
6 months	13/05/2013	0	5	8	87
12 months	28/10/2013	0	0	0	100
18 months	31/03/2014	2	19	37	42
24 months	28/10/2013	1	19	23	57

d) Rosevale spiral plough

Sampling Stage	Date	A	B	C	D
0 months	13/11/2012	0	3	0	97
6 months	13/05/2013	0	6	5	89
12 months	28/10/2013	0	1	0	99
18 months	31/03/2014	1	19	45	35
24 months	3/11/2014	0	2	14	84

e) Rosevale contour rip

Sampling Stage	Date	A	B	C	D
0 months	12/11/2012	0	7	8	85
6 months	13/05/2013	0	3	3	94
12 months	28/10/2013	0	0	0	100
18 months	1/04/2014	1	4	52	43
24 months	3/11/2014	0	6	7	87

f) Rosevale 'D' grazed

Sampling Stage	Date	A	B	C	D
0 months	13/11/2012	-	-	-	-
6 months	13/06/2013	0	0	1	99
12 months	28/10/2013	0	0	1	99
18 months	31/03/2014	0	0	40	60
24 months	4/11/2014	0	0	8	92

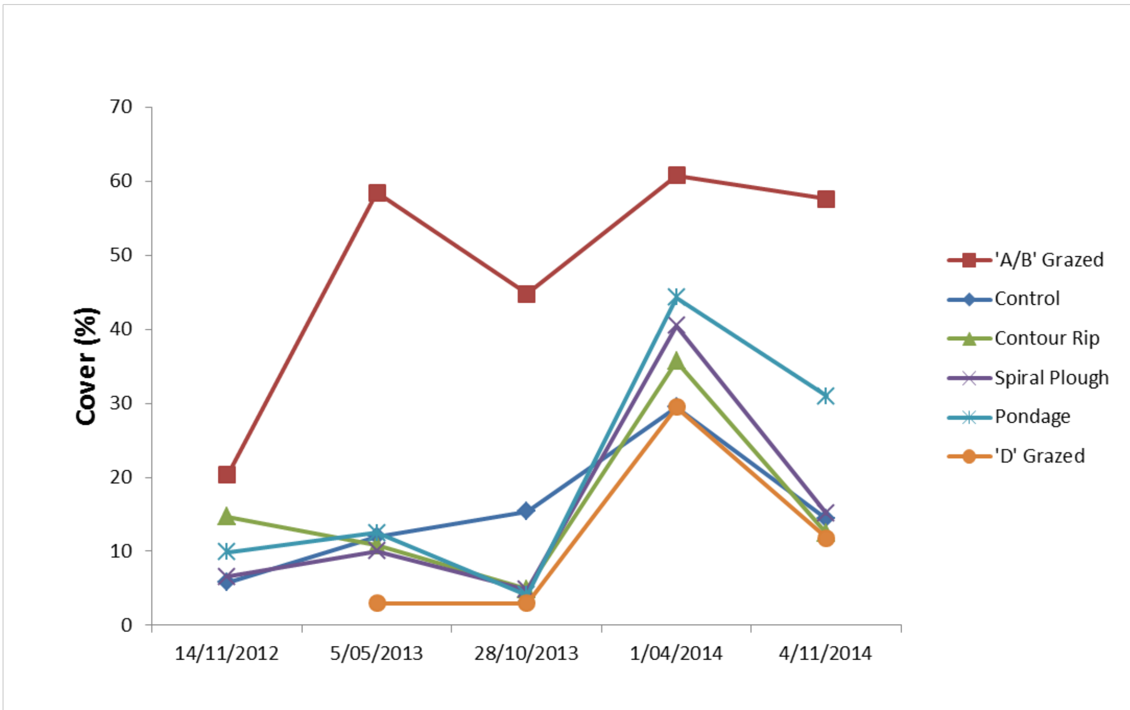


Fig. 3. Average cover for the six treatments at Rosevale for the full experimental time period.

The ‘A/B’ grazed plot had 80% of the area in either ‘A’ or ‘B’ quadrat scale classification which is a large contrast to the degraded plots which had less than 10% of quadrats in ‘A’ or ‘B’ classification (Table 2). Table 2, also shows that there was no discernable change in land condition over the 12 months following the imposed treatments of spiral ploughing, contour ripping and shallow water pondage. This was due to only 149mm of rainfall being received, close to the lowest over the last 40 years (Fig. 4) which prevented applied seed from growing.

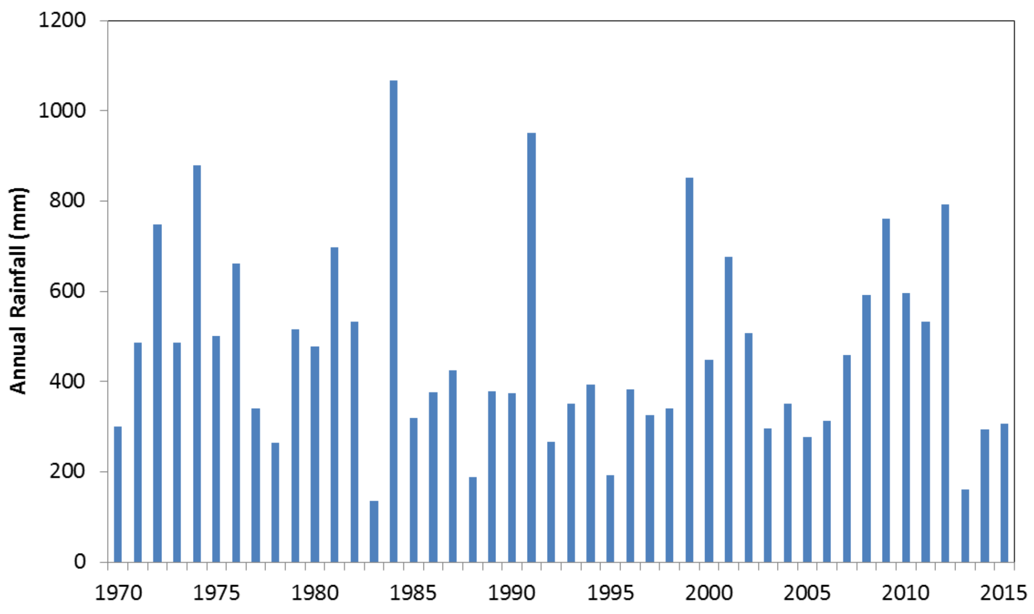


Fig. 4. Rosevale annual average growing season rainfall (1st April – 31st March). Note- years 1970 – 2008, 2015 based on Hughenden Post Office rainfall observations and for 2008 - 2014 based on rainfall observations taken at Rosevale station.

2.2 Infiltration measurements

Some 131 individual 'ponded ring' infiltration measurements were taken during the five sampling times. These individual infiltration measurements were combined with the quadrat scale land condition measurements to estimate an overall plot scale infiltration rate. The technique used to combine these two measurements involved making a weighted average infiltration rate. This technique is briefly described below.

'The land condition and infiltration measurements were combined by weighting the quadrat scale infiltration measurements by the proportion of the plot with that classification. For example if the plot was 10% - 'A', 20% - 'B', 30% - 'C' and 40% 'D' then the plot weighted average infiltration rate = 0.1 × 'A' Infiltration Rate + 0.2 × 'B' Infiltration Rate + 0.3 × 'C' Infiltration Rate + 0.4 × 'D' Infiltration Rate. This calculation allows for the weighted average plot infiltration rates to be compared between treatments.'

The weighted average plot scale infiltration measurements and the individual quadrat scale measurements have been used to report on three aspects of infiltration for the Rosevale experiment

a) The pre-treatment infiltration rates at the quadrat and plot scale
b) The impact of the treatments on plot scale infiltration capacity.
c) Runoff rates for 'A' and 'D' land conditions based on the infiltration measurement results

a) Pre- treatment infiltration rates

Infiltration measurements taken at the quadrat scale (i.e. 0.5m × 0.5m scale) were averaged based on the quadrat scale condition classification as shown in Table 2 (shown in Fig. 5 below). The results indicate that the classification method used to stratify the plots was appropriate with 'A' quadrats (which have a perennial grass tussock base present) having infiltration rates on average nine times faster than 'D' quadrats (predominantly bare surface). Interestingly the 'D' quadrat scale infiltration rates in the good land condition plot ('A/B' Grazed) were more than twice as fast as the 'D' quadrat scale infiltration rates measured in the degraded land condition plots. This indicates that the 'D' class infiltration rate at the quadrat level is not only influenced by the vegetation characteristics in the actual quadrat area but is also influenced by the land condition in the nearby vicinity. This finding is similar to the findings of Fraser and Stone (2014) where 'D' class infiltration rates in long term exclosures was close to two times the infiltration rate from areas that had been grazed under a high utilisation rate.

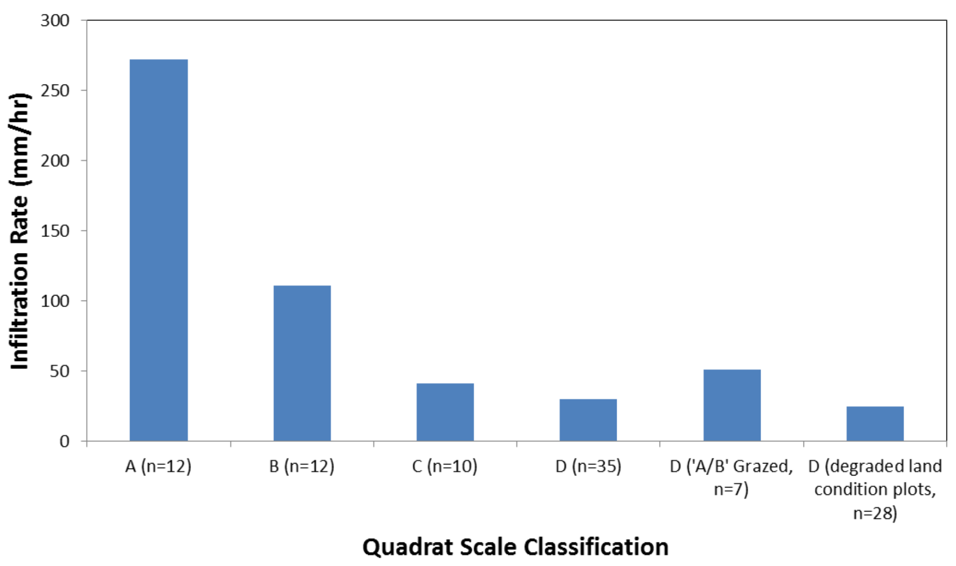


Fig. 5. Quadrat scale classification effect on quadrat infiltration rate. Note these measurements have been taken across the range of treatments except for 'D' quadrat measurements which have been split into 'D' in the 'A/B' grazed treatment and 'D' in the degraded plots (i.e. the ones where treatments were imposed + the control). Note: the number of measurements taken for each classification level is also shown on the x axis.

The infiltration rates measured in this study were compared to measurements of surface soil bulk density (0-5cm) which were taken upon completion of the ponded ring infiltration measurement. Figure 6 shows that the infiltration rate can be related to the surface soil bulk density with a coefficient of determination of 0.94. This result was to be expected as when the bulk density of the soil increases there is a reduction in volume of soil pores which act as flow pathways for infiltrating soil water. Importantly, by establishing a relationship between bulk density and infiltration, this can allow bulk density measurements to be used as an estimate of surface soil infiltration capacity.

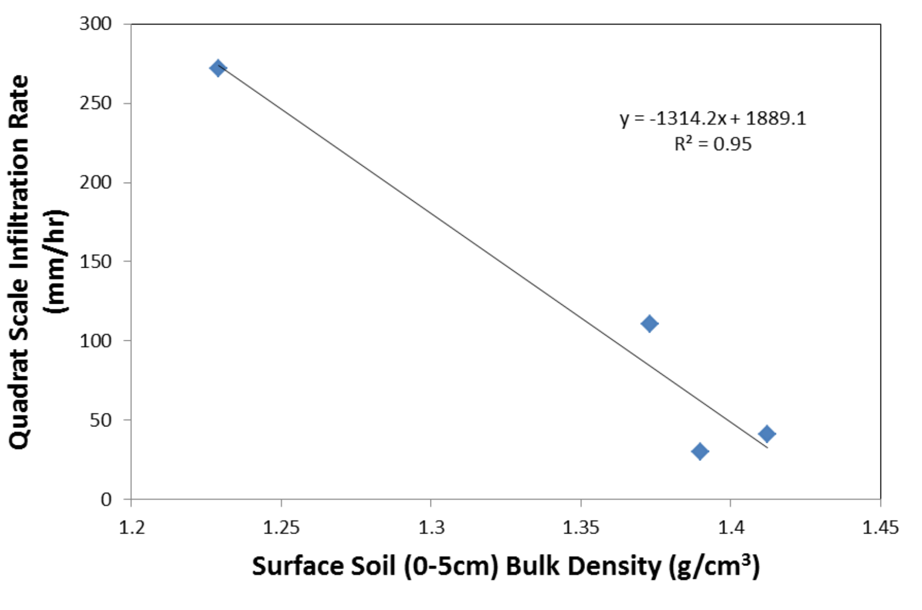


Fig. 6. The relationship between surface soil bulk density and infiltration rate for the four quadrat classes ('A', 'B', 'C' and 'D') measured across all treatments at Rosevale station.

When the infiltration rates for the different quadrat classifications are combined with each of the plots quadrat scale land condition measurements (i.e. to determine the weighted average plot infiltration), the results show that plot scale infiltration rates for the degraded areas are about one fifth of the grazed land in 'A/B' land condition (Fig. 7).

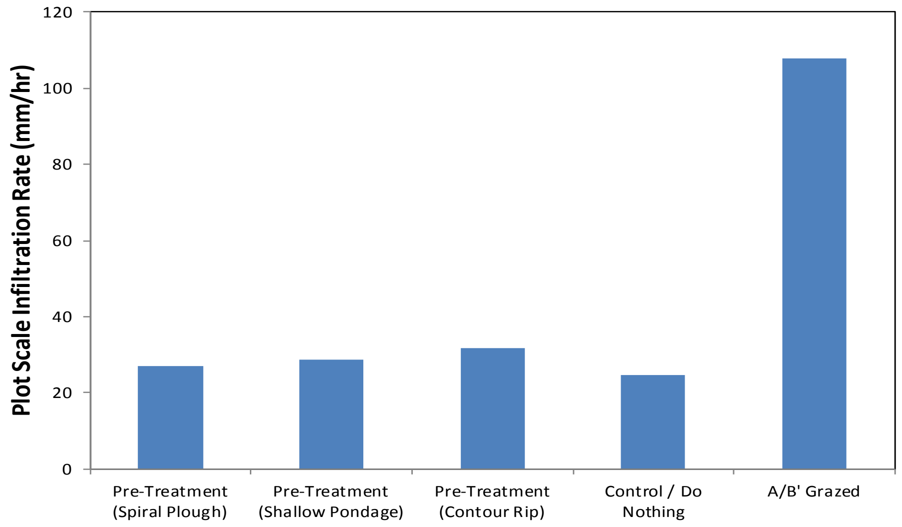


Fig. 7. Plot scale infiltration for the first sampling period prior to implementation of mechanical intervention treatments.

b) The impact of the mechanical treatments on plot infiltration capacity

Sampling Time: 6 months after imposing treatments (14/5/13)

A major sampling was undertaken 6 months after treatments were imposed. For Spiral Plough and Contour Rip treatments that mechanically disturbed the soil, there was a large increase in the infiltration rate. Figure 8 shows the plot scale infiltration rates for the degraded pre-treatment plots, ‘A/B’ grazed plot and the post treatment plot for the spiral plough treatment. From this figure it can be clearly seen that the mechanical intervention led to a large increase in infiltration rate. For the Shallow Water Pondage treatment, there was a mix of disturbed soil patches with high infiltration rates and soil patches where infiltration remained low similar to the pre-treatment plot conditions.

However, the aim of this treatment was to dam shallow areas of water which would allow infiltration to take place over a longer period of time.

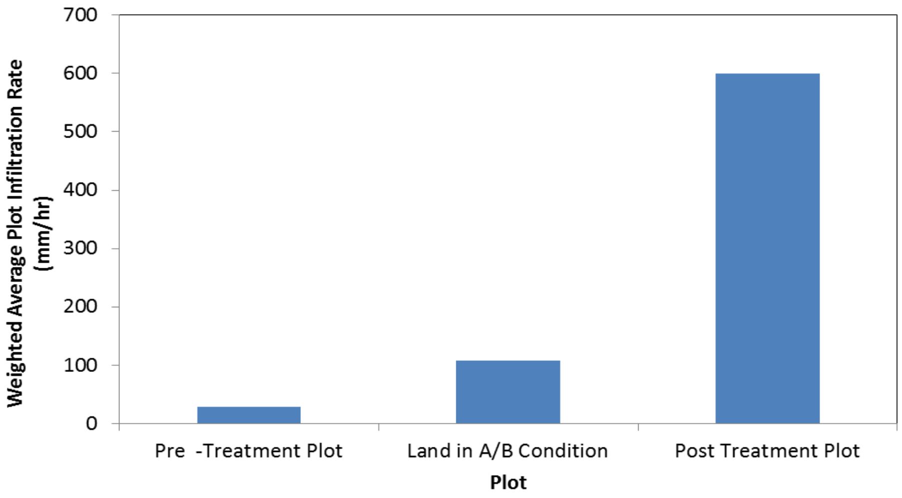


Fig. 8. Weighted average plot scale infiltration rates for the pre-treatment plots, A/B condition plot and the spiral plough post treatment.

Sampling Time: 12 months after imposing treatments (28/10/13)

A minor sampling was undertaken at 12 months after imposing the treatments. This sampling was minimal as there had been minimal pasture growth since the treatments had been imposed due to the low rainfall (Fig. 4). Three infiltration measurements were taken on the mechanical treatment plots and confirmed that the infiltration rates were still very rapid, (i.e. same as just after the treatments had been imposed).

Sampling Time: 18 months after imposing treatments (1/4/14)

Between the 12 and 18 month sampling time there had been some vegetation growth in the treated plots with cover levels reaching between 28 - 45 % cover though these levels were almost half of the ‘A/B’ grazed plot which was 60% cover (Fig. 3). Approximately seven infiltration measurements were taken in each plot. Average infiltration rates for Spiral Plough, Shallow Water Ponding and Contour Ripping were 32, 36 and 30 mm/hr respectively. This was less than half the infiltration rates measured in the ‘A/B’ grazed plot at 78 mm/hr for this sampling time. Interestingly, the treated plots (Spiral Plough, Contour Rip and Shallow Water Pondage) had volumetric soil moisture contents ranging from 15 – 25%. In comparison the ‘A/B’ Grazed treatment only had an average volumetric soil moisture content of 3.7%. These results suggest that the treated plots which are some distance from the ‘A/B’ grazed plot have received extra water, possibly from surface runoff from the surrounding area, and or plant root density was inadequate to remove soil water. It is believed that the low infiltration rates in the treated plots for this sampling time were due to the high soil moisture content. For this sampling period the average surface soil bulk density in the Spiral Plough, Shallow Water Ponding and Contour Ripping was 1.20, 1.16, and 1.22 respectively indicating that under drier conditions infiltration rates in the treatments would likely be much higher (Fig. 6).

Sampling Time: 24 months after imposing treatments (Nov 2014)

This sampling was conducted after a long period of dry conditions and volumetric soil moisture in the 0-10cm layer was only 3.4%. Nineteen infiltration measurements were taken in the mechanically treated plots. Of these, 14 had very rapid infiltration rates of greater than 3000 mm/hr. Upon closer inspection, after these rapid infiltration measurements had been taken it was found that there was sub-surface soil cracking. Due to the extremely dry conditions (24mm over the last 6 months) the soil at this site appears to have cracked which had allowed for these rapid infiltration rates.

c) Runoff rates for ‘A’ and ‘D’ land conditions based on the infiltration measurement results.

The rate of infiltration measured under ‘D’ class land condition quadrats (i.e. 26 mm/hr or 6.5 mm in 15 minutes) at Rosevale was similar to the lowest ‘D’ class infiltration measurements taken at another 18 rangeland experimental sites Fraser and Stone 2014 (Fig. 9). This indicates that this site is particularly susceptible to generating large amounts of surface runoff.

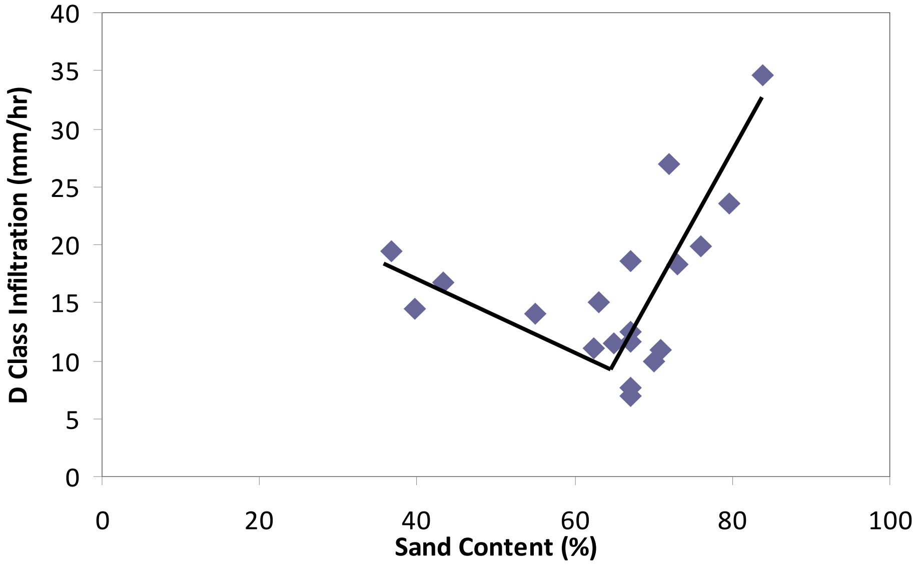


Fig. 9. Figure from Fraser and Stone (2014): ‘D’ class infiltration measurements (i.e. 15 minute infiltration) taken on 18 rangeland soils in Qld. Note Rosevale ‘D’ class infiltration rate was 6.5 mm.

The 15 minute sub-daily rainfall intensity for Hughenden was derived using an equation developed in Fraser *et al.* 2011. These estimates of rainfall intensity distribution are based on the Hughenden Post Office rainfall and temperature records collected from 1965 – 2014 for days when the daily rainfall quantity exceeded 15mm (Fig. 10). Methods of calculating sub-daily rainfall intensity are described in Appendix 1.

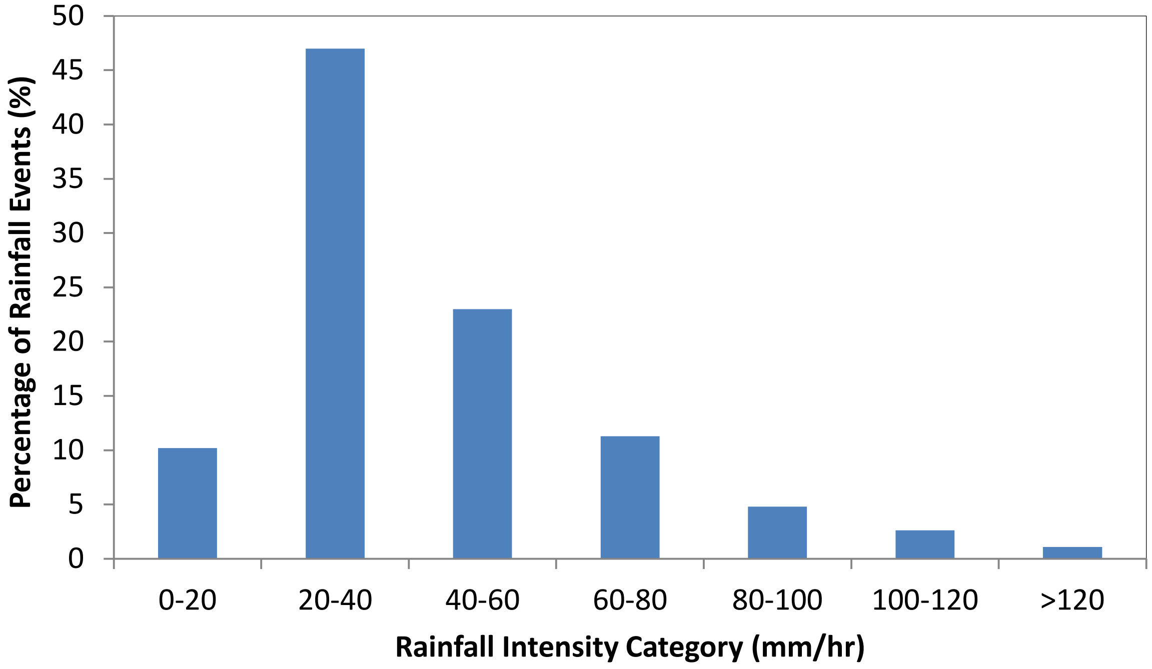


Fig. 10. 15 minute rainfall intensity rainfall intensity distribution for Hughenden, for some 522 rainfall events (>15mm) that fell between 1965 – 2014.

Figure 10 shows that for days with daily rainfall greater than 15mm, sub-daily rainfall intensity regularly exceeds the infiltration capacity for 'D' class land condition on Rosevale (i.e. 26 mm/hr). By combining the field measurements of infiltration capacity with the rainfall intensity it is possible to estimate the long term runoff rates for varying levels of land condition using runoff model equations described in Appendix 2. Annual average rainfall for Hughenden for 1965 – 2014 was 512mm. For 'D' class land condition supporting a standing grass biomass of 200 kg dry matter per ha (i.e. pre-treatment conditions) the annual average runoff rate is estimated to be 196 mm or 38% of rainfall. In comparison for a site that had 2000 kg dry matter per ha (i.e. less than the A/B land condition site) the average annual runoff is estimated to be 23mm or 4.5% of rainfall.

2.3 Summary of Rosevale infiltration and land condition measurements

The land in a degraded state at Rosevale had very low infiltration rates which indicated that up to 38% of rainfall could be lost to runoff compared to only 4.5% of rainfall for land in good condition. Using mechanical intervention to enhance infiltration rates was successful in that infiltration rates were far greater than land in good condition. Land condition improvement was impeded by the poor seasonal climate conditions which prevented the successful establishment of sown seed. However, it appears that the mechanical intervention treatments allowed for higher infiltration rates up until at least 18 months when it was noted that these treatments had much higher soil water contents than the 'A/B' grazed site, which suggested that run-on may have occurred. Soil cracking occurred on this site after an extended dry period, which made it difficult to assess the impact of the treatments at the 2 year sampling time.

3.0 Granada

Land condition and infiltration measurements were taken at three separate sampling times at Granada station. The first sampling occurred in February and March 2013. The plot selected for the A/B land condition at this time was deemed to be too different to the degraded land sites and hence a new site was chosen and subsequently sampled for infiltration on the 20/11/2013. The remediation treatments were to be undertaken in November 2013, however due to the dry conditions it was decided to leave the works until at least some storm rainfall had fallen. This did not occur until 12th February 2014 when the treatments were subsequently applied. The second sampling (land condition and infiltration measurements) occurred four months later in June 2014 and a final sampling was undertaken eight months after treatments were imposed at the end of October 2014.

3.1 Land condition measurements

The same land condition sampling methods as outlined in the Rosevale results were used for sampling at the Granada site. A summary of these results for quadrat scale land condition (Table 3a – e) and for surface cover (Fig. 10) follow.

Table 3. Percentage of treatment area in quadrat scale land condition categories ‘A’, ‘B’, ‘C’ and ‘D’ for: a) Control treatment; b) ‘A’ Grazed; c) Shallow Water Pondage; d) Contour Rip and e) Crocodile Seeding. All treatments except the ‘A’ Grazed were exclosed during the experiment.

a) Granada control

Sampling Stage	Date	A	B	C	D
Pre-Treatment	22/02/2013	0	0	0	100
4 months	3/06/2014	0	1	3	96
8 months	29/10/2014	0	1	2	97

b) Granada ‘A’ grazed

Sampling Stage	Date	A	B	C	D
Pre-treatment	20/11/2013	5	46	15	34
8 months	28/10/2014	29	26	27	18

c) Granada shallow water pondage

Sampling Stage	Date	A	B	C	D
Pre-Treatment	21/02/2013	0	3	2	95
4 months	3/06/2014	0	1	29	70
8 months	28/10/2014	0	1	26	73

d) Granada contour rip

Sampling Stage	Date	A	B	C	D
Pre-Treatment	24/03/2013	0	0	0	100
4 months	2/06/2014	0	1	1	98
8 months	29/10/2014	0	1	1	98

e) Granada crocodile seeding

Sampling Stage	Date	A	B	C	D
Pre-Treatment	21/02/2013	0	1	5	94
4 months	2/06/2014	0	1	0	99
8 months	28/10/2014	0	1	0	99

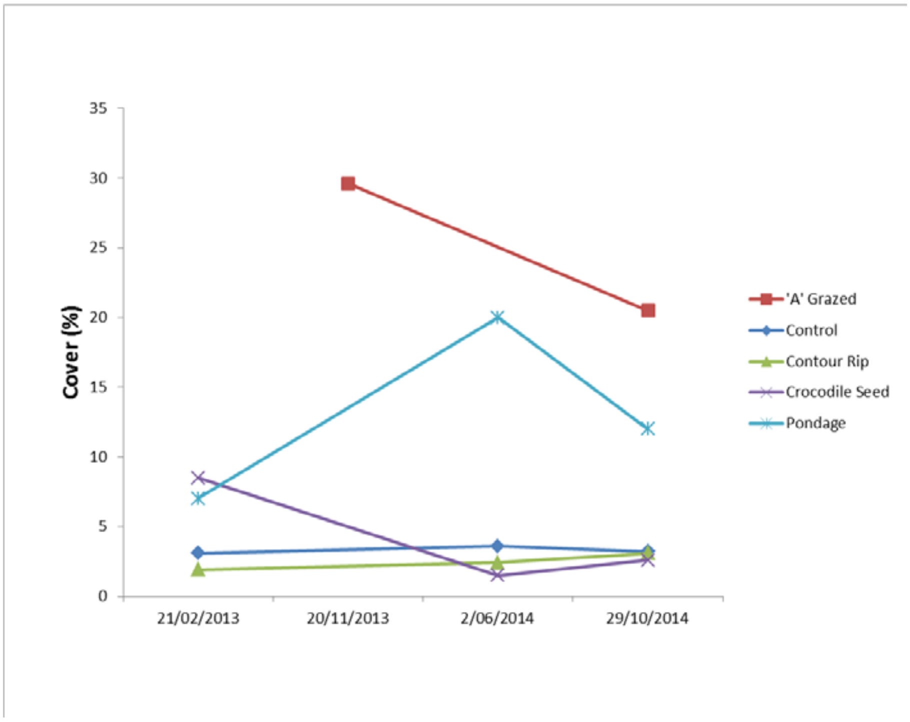


Fig. 11. Average cover for the five treatments at Granada for the full experimental time period.

The land condition results show that the degraded sites were in very poor condition with virtually no grass tussock bases present and very little surface cover (i.e. below 10%). In comparison the 'A' land condition site still had relatively low cover of ~ 30% but still had 50% of the area with quadrats containing perennial grass tussock bases. Rainfall leading up to the first sampling had been lower than the long term average (501mm for 1909 – 2015) with spring and summer rainfall totalling only 184mm *Note rainfall results presented here are based on the Silo Data Drill https://www.longpaddock.qld.gov.au/silo/ . A long term analysis of historical rainfall for this site indicates both lower than average rainfall leading up to the start of the project and as well throughout the project (Fig. 12). The mechanical treatments were implemented in February 2014. There was 182mm of rainfall between the February 2014 and June 2014 when the second sampling was undertaken. There was no improvement in land condition for all treatments except the Shallow Water Pondage which responded with some vegetation growth providing cover levels similar to the 'A' condition site. From the second sampling till the third sampling there was no further rainfall and hence no response from the implemented treatments.

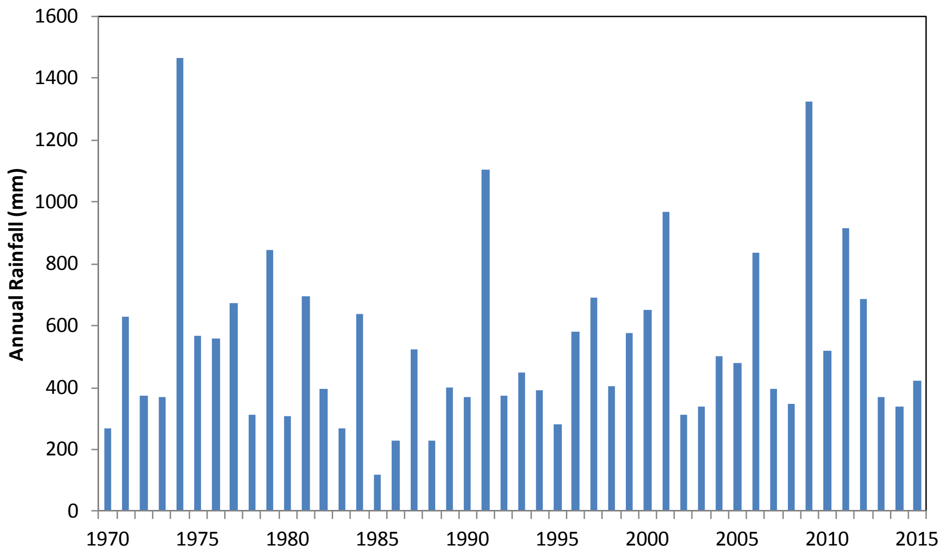


Fig. 12. Granada annual average growing season rainfall (1st April – 31st March). Note: data is from Silo Data Drill.

3.2 Infiltration measurements

Some 57 individual infiltration measurements were taken during three sampling times at Granada station. The individual infiltration measurements can be combined with the quadrat scale land condition measurements to estimate a plot scale infiltration rate (this was described in more detail in the Rosevale section).

The infiltration results at Granada will be reported based on-

d) The field infiltration measurements
e) Runoff rates for ‘A’ and ‘D’ land conditions based on the infiltration measurement results.

a) The field infiltration measurements

The infiltration results at Granada can be categorised into three groups – pre-treatment degraded land infiltration, ‘A’ land infiltration and post-treatment infiltration for each of the treatment types (Fig. 13). The average infiltration rate in the degraded plots prior to treatment was only ~ 1/7th the infiltration rate for the land in ‘A’ condition. After the treatments were imposed there were very large increases in infiltration rate for the Contour Rip treatment and the Pondage treatments. However, there was only a minor increase in infiltration rate for the Crocodile Seeding treatment which may reflect the lower disturbance of soil associated with this treatment. It must be noted that the infiltration rates in the Contour Rip and Pondage treatment were often a mix of both very rapid infiltration and infiltration rates similar to ‘D’ land condition. This reflects the patchiness of these treatments on infiltration rates. Both of the post treatment samplings were conducted within eight months after they were imposed, therefore it is difficult to assess for how long the treatment effects on infiltration rates would continue into the future. The vegetation response in the pondage treatment (Fig. 11) suggests that this treatment is likely to have provided the best option for remediating degraded land during dry times.

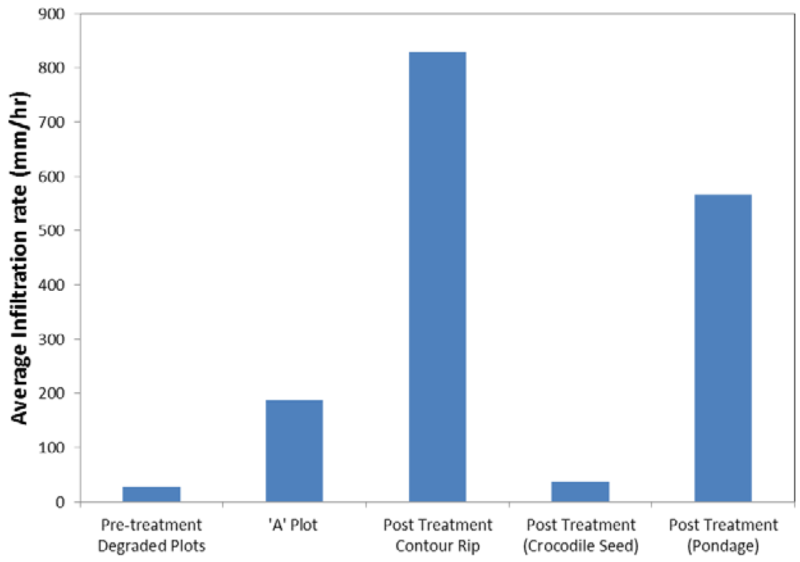


Fig. 13. Weighted average plot infiltration rate for the plots prior to treatment, post treatment and for the 'A' condition plot

b) Runoff rates for 'A' and 'D' land conditions based on the infiltration measurement results.

The method used to estimate runoff rates for land in 'A' and 'D' condition at Granada was the same as described for Rosevale station in section 2.2c. The infiltration rate measured under 'D' class land condition was only 28.5 mm/hr which is a relatively slow infiltration rate compared to measurements taken on other degraded rangeland sites (Fraser and Stone 2014).

The low infiltration rate (28.5 mm/hr) for the degraded plots at Granada is frequently exceeded by the 15 minute peak rainfall intensity rates at this site (Fig. 14). Annual average rainfall for Granada for 1965 – 2014 was 516mm. For the scenario of a plot with 'D' class land condition supporting a standing grass biomass of 200 kg dry matter per ha (i.e. similar to pre-treatment conditions) the annual average runoff rate is estimated to be 242mm or 47% of rainfall. In comparison for a site that has 2000 kg dry matter per ha the average annual runoff is estimated to be 26mm or 5% of rainfall.

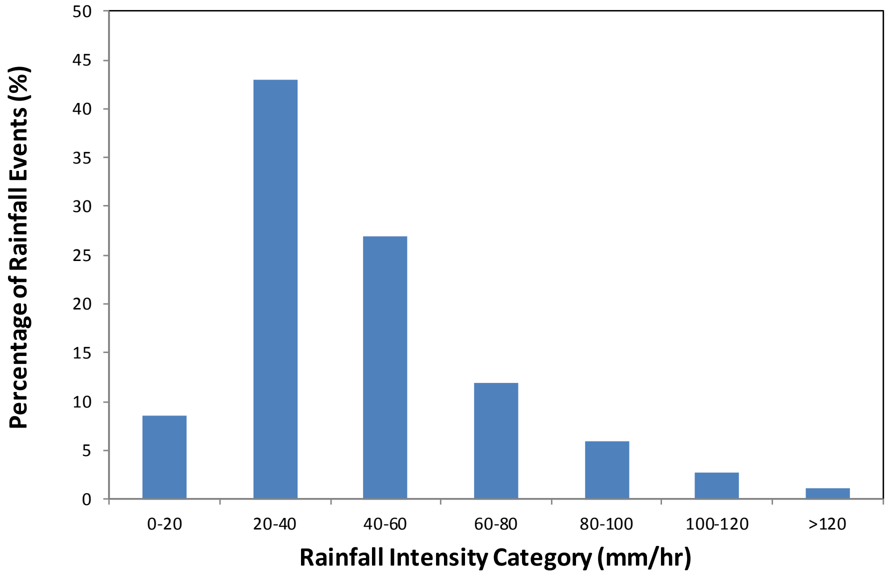


Fig. 14. 15 minute rainfall intensity rainfall intensity distribution for Granada, for some 522 rainfall events (>15mm) that fell between 1965 – 2014.

3.3 Summary of Granada infiltration and land condition measurements

The land condition of the degraded plots at the Granada sites was severe, with there being no perennial grass tussock bases present. Runoff under these conditions was estimated to be 47% of the rainfall. These results indicate that there is minimal likelihood that the plots could recover without using mechanical intervention to enhance infiltration and provide an environment for seedling establishment. The Contour Rip and the Pondage treatment gave the greatest increase in average infiltration rates although rates were still patchy within these treatments. The crocodile seeded treatment provided minimal improvements in infiltration rates and ultimately the success of this treatment would depend greatly on whether grass could be quickly re-established and thereby further enhance infiltration rates.

The dry season conditions led to no improvement in land condition for all treatments except the shallow water pondage. Interestingly the shallow water pondage treatment also led to the greatest improvement in land condition at the Rosevale site. It is difficult to ascertain how the treatments will progress from when this relatively short-term project ends, although there is some evidence (from the Rosevale station site) that the mechanical treatment effects will last for a number of years and that if viable seed were present and with better rainfall conditions, then land recovery might begin to occur.

4.0 Herbertvale

Land condition and infiltration measurements were taken at five separate sampling times at Herbertvale station. The first infiltration measurements were undertaken on the 19/11/12 to the 21/11/12. At this time no remedial treatments had been undertaken at the site and hence the infiltration rates represent the sites inherent infiltration rates given the current land condition. Soon after these measurements were taken three remedial treatments were imposed – crocodile seeding, contour ripping and shallow water pondage. Subsequently, follow up land condition and infiltration measurements were taken at approximately 6 months (4/6/13 – 6/6/13), 12 months (4/11/13 – 6/11/13), 17 months (9/4/14 – 10/4/14) and 24 months (10/11/2014 – 12/11/2014) after the treatments were imposed. In addition to these mechanical treatments aimed at improving water infiltration rates, there were three additional treatments –control treatment (which was exclosed) and also two nearby adjoining grazed plots in ‘A/B’ and ‘D’ land condition.

4.1 Land condition measurements

For each treatment, 150 quadrat scale land condition measurements were assessed using 0.5m x 0.5m quadrats. Table 4 and Fig. 15 show that there was an improvement in land condition for all the treatments over the five sampling periods. The climatic conditions during the experiment were much more favourable at the Herbertvale site (Fig. 16) compared to the other two sites in this project.

Over the length of the project it is difficult to ascertain whether the treatments made much difference at this site as there was little difference between the control treatment and the ‘treated’ plots both in terms of quadrat condition score and cover amount. Despite this all the treated plots were in better condition than when the experiment started and this is most likely due to the removal of grazing pressure. It may take a number of more years of measurement to discern clear benefits from the mechanical treatments imposed.

Table 4. Percentage of treatment area in quadrat scale land condition categories ‘A’, ‘B’, ‘C’ and ‘D’ for a) Control / ‘Do Nothing’ treatment; b) ‘B’ Grazed; c) Shallow Water Pondage; d) Contour Rip; e) Crocodile Seeding and f) ‘D’ Grazed

a) Herbertvale Control

Sampling Stage	Date	A	B	C	D
0 months	21/11/2012	0	3	10	87
6 months	4/06/2013	0	7	73	20
12 months	4/11/2013	1	8	57	34
17 months	9/04/2014	0	29	70	1
24 months	11/11/2014	0	16	47	37

b) Herbertvale ‘B’ Grazed

Sampling Stage	Date	A	B	C	D
0 months	21/11/2012	7	62	27	4
6 months	5/06/2013	1	73	20	6
12 months	6/11/2013	14	59	21	6
17 months	10/04/2014	11	81	8	0
24 months	12/11/2014	9	49	21	21

c) Herbertvale Shallow Water Pondage

Sampling Stage	Date	A	B	C	D
0 months	19/11/2012	0	1	2	97
6 months	6/06/2013	0	26	21	53
12 months	5/11/2013	0	12	19	69
17 months	10/04/2014	0	30	54	16
24 months	11/11/2014	0	12	41	47

d) Herbertvale Contour Rip

Sampling Stage	Date	A	B	C	D
0 months	19/11/2012	0	1	4	95
6 months	5/06/2013	0	16	48	36
12 months	5/11/2013	0	18	62	20
17 months	10/04/2014	0	27	63	10
24 months	11/11/2014	0	23	51	26

e) Herbertvale Crocodile Seeding

Sampling Stage	Date	A	B	C	D
0 months	20/11/2012	0	2	5	93
6 months	5/06/2013	0	34	37	29
12 months	4/11/2013	0	13	25	62
17 months	9/04/2013	0	45	45	10
24 months	10/11/2014	0	14	19	67

f) Herbertvale ‘D’ Grazed

Sampling Stage	Date	A	B	C	D
0 months	N/A	-	-	-	-
6 months	6/06/2013	0	12	0	88
12 months	N/A	-	-	-	-
17 months	10/04/2014	0	32	44	24
24 months	11/11/2014	0	1	6	93

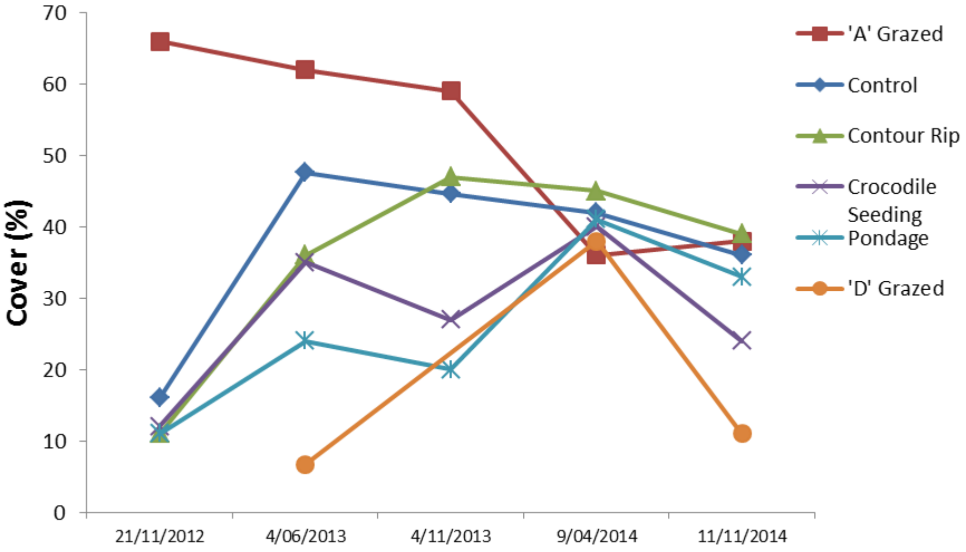


Fig. 15. Average cover for the six treatments at Herbertvale for the full experimental time period.

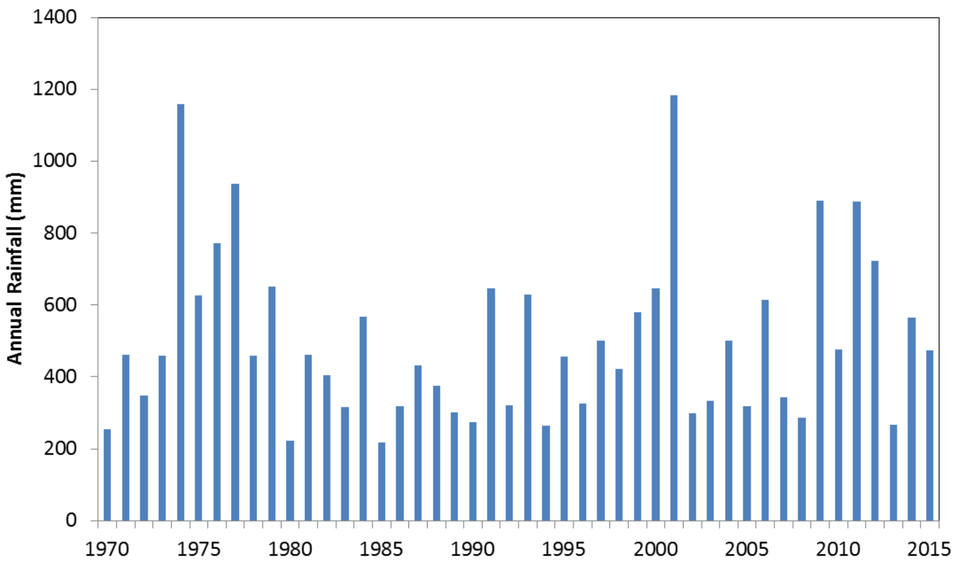


Fig. 16. Herbertvale annual average growing season rainfall (1st April – 31st March). Note: data is from Silo Data Drill with some rainfall records from Herbertvale station used for the 2012 – 2015 years.

4.2 Infiltration measurements

Some 137 individual infiltration measurements were taken over five sampling periods. Of these 137 measurements of infiltration, 63 had very rapid infiltration rates (i.e. > 300 mm/hr) due to the presence of large cracks in the soil surface. These rapid infiltration rates occurred in both treated and non-treated plots indicating that at Herbertvale, the soil has a high resilience to not losing infiltration capacity (even in a poor land condition state). In fact, patches that were classified as 'D' patches had a higher likelihood of having very rapid infiltration rates Table 5. It was very dry at each of the sampling times with volumetric soil moisture content ranging between 3- 7% across the sampling times. If infiltration measurements were taken under conditions where there was more soil moisture, and hence minimal surface soil cracking, the effects of the mechanical treatments may have been more apparent. The cracking soil at this site provides an inherent resilience for degraded land condition to recover if perennial pastures tussock bases can be re-established.

Table 5. Quadrat scale infiltration rates measured at Herbertvale for non-cracked soil and number of measurements for cracked and non-cracked surface soils.

Quadrat condition class	A	B	C	D
Infiltration rate for non-cracked soil (mm/hr)	286	132	147	125
Number of Infiltration samples where cracking **was** present	3	23	31	17
Number of Infiltration measurements where cracking **was not** present	5	14	16	28

5.0 Acknowledgements

We are grateful to the landholders: Rosevale station – David and Jan Collyer, Bruce and Jess Collyer; Granada station – Peter and Fran Hacon; and Herbertvale station – Clint and Shelly Hawkins who allowed the experimental treatments to be implemented on their properties and for their ongoing support throughout the trial.

We thank Bob Shepherd for his support in designing the land rehabilitation treatments and providing oversight for their implementation. We thank Larissa Lauder, Joe Rolfe, Bernie English, Mark Keating, Steven Dayes, Kiri Broad, Craig Lemin, Kendrick Cox, Kate Brown, Nicole Spiegal and Megan Munchenburg for undertaking the arduous tasks of infiltration measurement and land condition sampling on these three properties.

6.0 Appendix

Appendix 1

Sub-daily rainfall intensity model used to derive sub-daily rainfall intensity estimates for Hughenden (from Fraser *et al*. 2011)

I15 *(a)* = Minimum Temperature × minimum (100, Daily Rainfall) × Diurnal Temperature Range/*k*

I15 *(b)* = minimum (4 × Daily Rainfall, I15 *(a)*)

I15 = maximum (0.25 × Daily Rainfall, I15 *(b)*)

Where:

I15 is the daily 15 minute peak rainfall intensity in mm/hr

I15 *(a)* and I15 *(b)* are estimates of daily 15 minute peak rainfall intensity in mm/hr prior to applying all the model constraints

Minimum Temperature is the daily minimum temperature in ^{o}C

Diurnal Temperature Range is the daily temperature range in ^{o}C

Daily Rainfall is the daily rainfall total in mm

k is a coefficient which was found to be 150 when optimising to minimise the root mean square error between measured and estimated I15

Appendix 2

Runoff model used to estimate long term runoff rates for Rosevale site under two contrasting land condition states (from Fraser 2014)

Daily Runoff $_{(C\text{-}S)}$ = (Runoff $_{Percentage}$ / 100) × (Rain – 10)

Runoff $_{Percentage}$ = Soil Cover Response × (1 – Surface Cover $_{effective}$) × exp (I15$_{new}$ × 0.013)

Where:

Daily Runoff – Daily runoff depth (mm)

Rain – Daily rainfall (mm)

Surface Cover $_{effective}$ – Proportion groundcover that impacts on infiltration in a functional way (0-1)

$I15_{new}$ - The daily maximum 15 minute rainfall intensity (mm/hr)

Soil Cover Response – A variable derived from surface soil texture (note-this was identified as Runoff Potential in Chapter 4)

The components: *Surface Cover* $_{effective}$, $I15_{new}$ and *Soil Cover Response* are calculated as follows.

Surface Cover $_{effective}$

The derivation of this model has been given previously in Chapter 4

Surface Cover $_{effective}$ = Total Standing Dry Matter $^{k\ cover}$ / (Total Standing Dry Matter $^{k\ cover}$ + Standing Dry Matter Yield to achieve 1550 kg/ha above-ground biomass $^{k\ cover}$) / 100

Where:

Surface Cover $_{effective}$ – Proportion groundcover that impacts on infiltration in a functional way (0-1)

Total Standing Dry Matter – standing pasture dry matter (kg/ha)

Standing Dry Matter Yield to achieve an above-ground biomass of 1550 kg/ha – A parameter that is set at 1150 (kg/ha) for grazed pasture, 650 (kg/ha) for long term exclosed pasture with low tree density, 100 (kg/ha) for exclosed treed plots with tree basal area > $5m^2$/ha

K cover – is 0.95

$I15_{new}$ – 15 minute Rainfall Intensity

The derivation of this model was explained in Chapter 2

$I15_{new}$ = Minimum Temperature × minimum (100, Rain) ×Diurnal Temperature / *k*

Range Limits: $I15_{new}$ cannot be below 0.25 × Rain. $I15_{new}$ cannot be greater than 4 × Rain

Where:

$I15_{new}$ – The daily maximum 15 minute rainfall intensity (mm/hr)

Rain – The daily rainfall total (mm)

Minimum Temperature – Minimum daily temperature on the rainfall day (°C)

Diurnal Temperature – Daily diurnal temperature range (°C)

k - is a constant which was found to be 150.

Soil Cover Response

SCR = 43.63 – 0.76 × 'D' class infiltration

Where:

SCR – Soil Cover Response

'D' class infiltration – measured ponded ring infiltration rate (mm/hr)

7.0 References

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Section 3: Simulation of carbon stocks and dynamics using the CENTURY model

John Carter

Introduction

The purpose of this study was to simulate carbon stocks and dynamics in scald reclamation areas in north western Queensland using the CENTURY model (Parton et al. 1988) to provide indicative estimates of carbon pools in the future. Modelling to simulate the processes of degradation and rehabilitation is difficult as models have incomplete dynamical linkages between grazing, plant growth, and soil processes. In addition, there are few if any detailed long term data sets available for building and parameterising robust functions for such situations. In the CENTURY model, soil carbon and pasture growth do not directly feedback on soil bulk density or infiltration /runoff and this process has to be manually specified in parameter sets. The detailed processes of germination and plant establishment are also not simulated and in this simulation study it is assumed that plant establishment on scalded areas is possible.

Feedbacks through the soil water, carbon and nitrogen cycles are reasonably well described in the model enabling an assessment of future stocks. The model outputs (in the absence of measured experimental data from the region) can provide some indicative assessments as to the rate of carbon storage into the future, the amount of carbon likely to be stored at equilibrium for the given treatments, and provide some insight as to which sites and treatments are likely to give the largest carbon responses. Removal of carbon by grazing appears to be the main driver of carbon losses and reduction in local grazing pressure by wet season spelling and lower utilisation rates seem to offer prospects for soil carbon storage.

Methods

The CENTURY model was initially parameterised to simulate “AB” and “D” condition lands. This involved setting high utilisation rates to drive degradation and adjustment of soil pool C:N ratio to roughly reproduce the observed measurements. In degraded areas, erosion was parameterised to reflect measurements of soil carbon and nitrogen. Runoff was calibrated to give estimates similar to initial studies with the GRASP model. The CENTURY model has been demonstrated to work under Australian conditions in natural systems and cropping (Carter et al. 2004, Chilcott et al. 2007).

It should be noted that there are no measurements for above ground pasture growth, no real quantification of pasture utilisation by animals, and no estimates of prior erosion. The fact that scalds exist at these sites suggest that they have been very heavily grazed over time. High utilization results from animals preferentially grazing the bulk of the small amount of grass and forbs that grow on or at the edge of scalds each season as these plants generally have high nitrogen contents. The soil carbon data collected and used for model calibration has been influenced by: (a) pre European fire, (b) more than 100 years of variable grazing pressure, (c) erosion and, (d) evaporative concentration of nitrogen within low lying parts of the scald.

Lack of data collected over time makes it impossible to quantify model parameters with any degree of certainty, especially as carbon and nitrogen masses are a balance between parameters controlling plant inputs and those controlling decomposition and removal processes. Climate data and other modelling information are provided in the “notes” section below with some of the key model driving variables are set out in Table 1.

The “treatments” simulated were:

- Shallow water ponding – Runoff made negligible – grazing pressure high but reduced to generate about 50% utilization (a value between that likely for “AB” and “D” condition sites). Runoff was reduced to about half that for “AB” condition land.

- Contour ripping – Runoff reduced to “AB” levels and a small reduction in grazing pressure to generate about 50% utilization.

- Wet season spelling (no grazing Nov, Dec, Jan, Feb, Mar, Apr) – reasonably high dry season grazing pressure, annual utilization was set to 31%

- Crocodile seeding was not simulated as it was not reasonable to differentiate this disturbance from ripping in the modelling methodology.

- AB and D condition plots (similar grazing pressure into the future).

Results

There was a reasonable match between the simulated and measured soil carbon (Figure 1), however nitrogen estimates were less well simulated (Figure 2). Simulations were poorest at the Rosevale site which also had the greatest variability in measurements.

Despite caveats about functionality and parameterisation, modelling provides a basis for systems analysis and an estimate of the likely rates of change in carbon stocks (Figures 3-18). Estimates of the rate carbon stock increase are useful as a starting point for assessing the economics of carbon trading over 25-100 year time frames

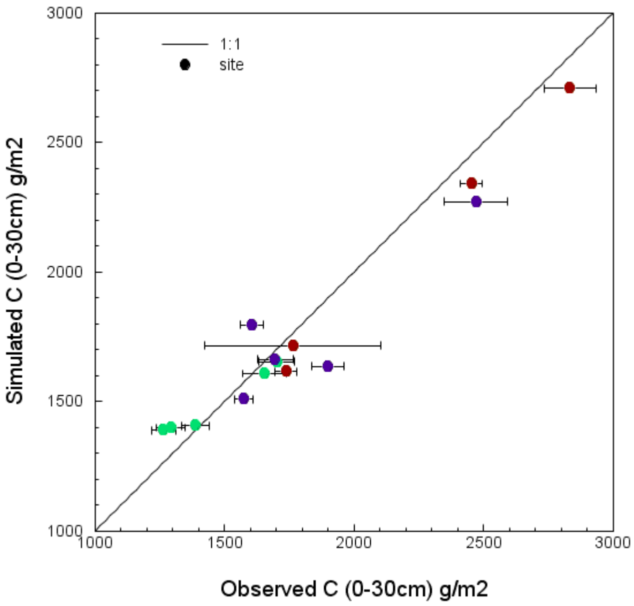


Figure 1. Measured and simulated soil carbon after calibration for 5 “treatments” at 3 locations. Error bars are one standard deviation for measured data. (Brown=Grenada, Green=Herbertvale, Purple = Rosevale)

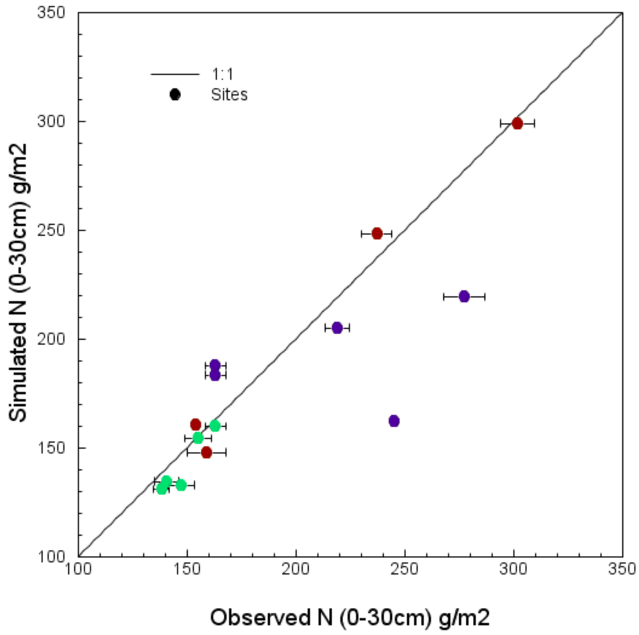


Figure 2. Measured and simulated soil nitrogen after calibration for 5 “treatments” at 3 locations. Error bars are one standard deviation for measured data. (Brown=Grenada, Green=Herbertvale, Purple = Rosevale)

Analysis of the time series plots indicate (shown in the appendix):

(1) Carbon stocks and nitrogen at the locations modelled using assumptions about grazing pressure are all currently lower than pre-European grazing, assuming about one fire per decade prior to 1890, This is consistent with findings from “Toorak”, Julia Creek (Pringle et al. 2014)

(2) Under current grazing pressure in all but “AB” condition locations there appears to be small ongoing losses of soil carbon (loss of 0.5 t/ha to 2 t/ha by 2100)

(3) The wet season spelling treatment appears to be the most successful strategy for building soil carbon, provided perennial plants can actually be established. (Though the model does not test this). It would appear that further control of grazing to limit annual offtake to less than 20% of growth is desirable. Averaged across the three locations about 4.8 tonnes / hectare of carbon were stored within 25 years and about 8.4 tonnes / hectare stored by 2100 for rehabilitation treatments.

(4) Physical treatments that reduce runoff to “AB” condition type levels seem to improve soil carbon, but as cover and carbon continue to be removed by uncontrolled grazing, total carbon storage is limited and generally do not return to “AB” levels. On average about 3 tonnes / hectare of carbon are stored after 25 years and about 5 tonnes / hectare by 2100, provided plants can actually be established.

(5) The model suggests that it would require 5-10 years of successful treatment before changes in soil carbon exceed measurement error.

(6) Equilibrium soil carbon under proposed management is usually achieved by 2080 or earlier.

(7) The Herbertvale site shows the lowest response storing only about 1 t/ha soil carbon , (average of spelling, ponding and ripping) with Granada 5.5 t/ha and Rosevale about 4.5 t/ha within 25 years.

(8) Simulated pasture utilization rates are high, but not unreasonable when compared to impacts observed in the 80% utilization paddock at Toorak Research Station utilization trial, (Julia Creek). The treatment was stocked to eat 80% of end of summer growth season pasture biomass and achieved less that 80% utilization on an annual basis. The utilization rates at the patch scale are likely to be considerably higher than the paddock average.

(9) All carbon stock change estimates have high uncertainty.

Table (1) Key CENTURY model parameters describing fire, grazing, erosion and runoff for each site and treatment.

Site/treatment *	**Pre 1890 fire interval (years), Post 1890**	**Utilization % ** 1960-2013, 2014-2100**	**Soil Erosion kg/m^2/y *** 1890-1960, 1960-2013, 2014-2100**	**Runoff %**** 1960-2013, 2014-2100**
Granada(AB)	8, 0	73, 73	0.2, 0.2, 0.2	4.3, 4.6
Granada(D)	8, 0	78, 81	0.2, 0.2, 0.2	37.8, 38.0
Granada(summer spell)	8, 0	78, 31	0.6, 0.6, 0.0	37.8, 6.4
Granada(ponding)	8, 0	78, 57	0.6, 0.6, 0.0	37.8, 1.6
Granada(ripping)	8, 0	78, 57	0.6, 0.6, 0.0	37.8, 4.7
Herbertvale (AB)	12, 0	43, 42	0.0, 0.0, 0.0	4.8, 3.4
Herbertvale (D)	12, 0	46, 49	0.0, 0.0. 0.0	37.7, 35.5
Herbertvale (summer spell)	12, 0	62, 31	0.1, 0.1, 0.0	37.7, 4.02
Herbertvale (ponding)	12, 0	62, 50	0.1, 0.1, 0.0	37.7, 1.4
Herbertvale (ripping)	12, 0	62, 50	0.1, 0.1, 0.0	37.7, 4.46
Rosevale (AB)	10, 0	38, 38	0.0, 0.0, 0.0	3.1, 4.1
Rosevale (D)	10, 0	75, 78	0.3, 0.3, 0.3	35.0, 36.7
Rosevale (summer spell)	10, 0	74, 31	0.7, 0.7, 0.0	35.0, 4.95
Rosevale (ponding)	10, 0	75, 52	0.6, 0.6, 0.0	35.0, 2.0
Rosevale (ripping)	10, 0	74, 52	0.6, 0.6, 0.0	36.2, 4.3

*All treatments include some gain from CO_2 fertilization

** Ponding and Ripping treatments include a reduction in utilization to amount 50% as it is assumed that some reduction in stocking would occur to preserve plant cover on scalded areas (In mechanically treatments, utilization is set to between that for AB and D condition)

*** Erosion rates were set to best calibrate treatment site carbon and nitrogen after setting fire, and utilization.

**** Set to estimates from earlier GRASP modelling, may be small differences due to different climate sequences 1960-2013 vs 2014-2011

Notes

Modelling was run forward to 2100 with a range of the applied treatments with plausible changes in parameters with the speed and extent of recovery of carbon stocks noted.

Treatments producing the best outcomes were: (1) wet season spelling (grazing between May and October at about 35% annual utilization for six months compared to constant grazing at about 70% annual utilization); (2) ponding where runoff would only occur on rare occasions where rainfall was in excess of 100mm/month. (3) Once off mechanical treatment.

In addition to actual experiments a reduced grazing scenario (15% - 20%) was modelled for on the “AB” and “D” condition plots from 2014 – 2100.

- Climate data files for each location were obtained from SILO.
- Model spin up was from 500 BC to 1890 using rolling instances of 1890-2014 climate data.
- Climate for the period 2015 to 2100 was taken from the existing 1890-2014 data set.
- The impacts of climate change were beyond the scope of this project and not simulated. It is likely that these locations will be impacted by rising temperature, increased rainfall intensity.
- CO_2 fertilization was used throughout the model runs and CO_2 was changed in a linear fashion from 280 ppm in 1890 to 703 ppm in 2100, following the A1FI, SRES scenario.
- Sand, Silt, Clay, pH and bulk density were set to the values measured at each treatment site.
- Grazing was assumed to have started in 1890.
- Fire frequency post grazing was set to none as almost no fire was detected by satellite for the three locations (1996-2014). Pre grazing (1890) was set to 1 fire every eight to ten years.
- Sites were set to heavily grazed, as animals patch graze and select the low biomass but high nutritional value species on and around the scalded areas.
- CENTURY does not directly link cover and runoff, so in a rehabilitation phase cover does not automatically decrease runoff. Runoff has been parameterised to generate either “A” condition or “D” condition percentage runoff (based on estimates in phase 1 report)
- Herbertvale was set to have faster soil decomposition parameters which give a higher decomposition rate (commonly required for self-mulching soils).
- It was assumed that extra pasture biomass does not increase fire frequency.
- Pasture utilization was calculated by dividing annual average eaten by annual average pasture growth.

References

Carter, J., Wynn, J. and Bird, M. (2004). Estimating NPP and impacts of climate change on sandy soils in Australia using a soil carbon model calibrated to measurements of soil carbon, nitrogen and carbon isotopes. In Proceedings: Supersoil 2004 3rd Australian New Zealand Soil Conference, University of Sydney, Australia 5-9 December 2004. www.regional.org.au/au/asssi/

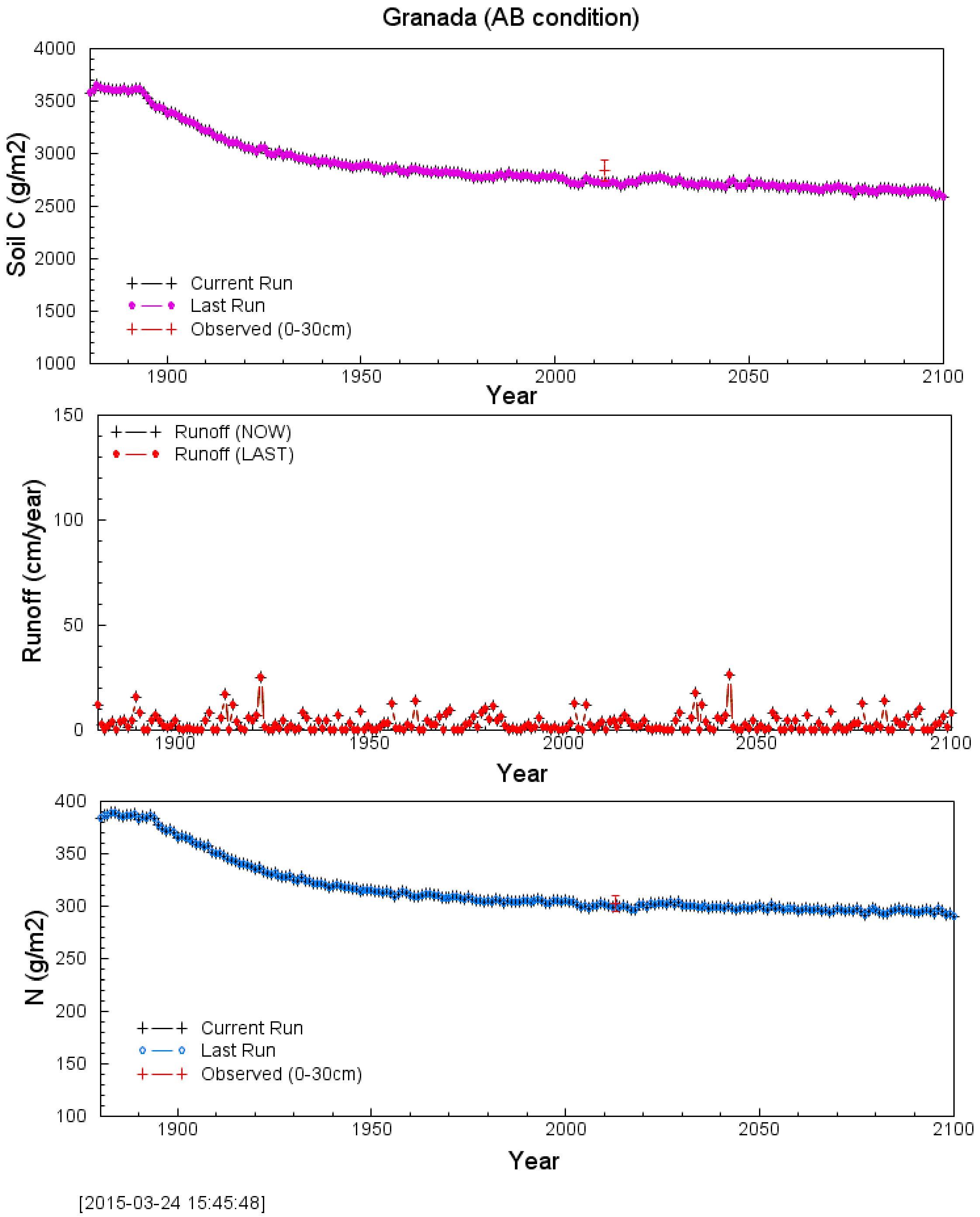
Chilcott CR, Dalal RC, Parton WJ, Carter JO, King AJ (2007) Long-term trends in fertility of soils under continuous cultivation and cereal cropping in southern Queensland. IX*. Simulation of soil carbon and nitrogen pools using CENTURY model. Australian Journal of Soil Research 45, 206–217.

Parton, W.J., J.W.B. Stewart, and C.V. Cole. (1988) Dynamics of C, N, P and S in grassland soils: a model. Biogeochemistry 5:109-131.

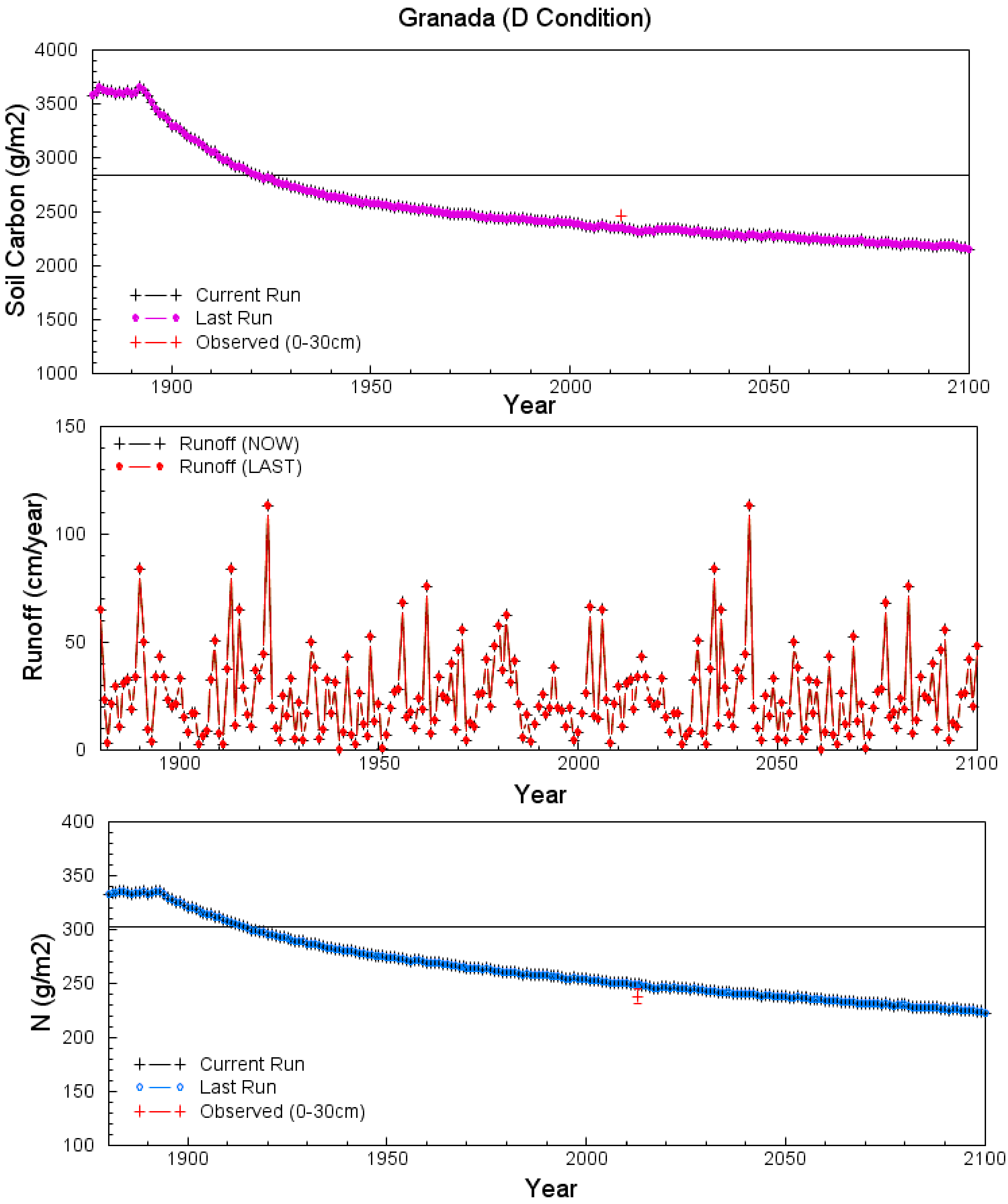
Pringle, M. J., Allen, D. E., Phelps, D. G., Bray, S. G., Orton, T. G. and Dalal, R. C. (2014) The effect of pasture utilization rate on stocks of soil organic carbon and total nitrogen in a semi-arid tropical grassland. Agriculture, Ecosystems and Environment, 195 83-90. doi:10.1016/j.agee.2014.05.013

Appendix

Figures (3-15 following) show simulated trends in carbon, nitrogen for 0-30cm and runoff for Granada, Herbertvale and Rosevale. Observed values and uncertainty estimated for 0-30cm for C and N are displayed (in some cases errors are too small to be visible). The horizontal lines on the plots are the measured ‘A/B’ condition values for that location and suggest reasonable target outcomes for well managed grazing pressure.



Granada (AB condition)
4000
3500
3000
2500
2000
1500
1000
Soil C (g/m2)
Current Run
Last Run
Observed (0-30cm)
1900
1950
2000
2050
2100
Year
150
100
50
0
Runoff (cm/year)
Runoff (NOW)
Runoff (LAST)
1900
1950
2000
2050
2100
Year
400
350
300
250
200
150
100
N (g/m2)
Current Run
Last Run
Observed (0-30cm)
1900
1950
2000
2050
2100
Year
[2015-03-24 15:45:48]



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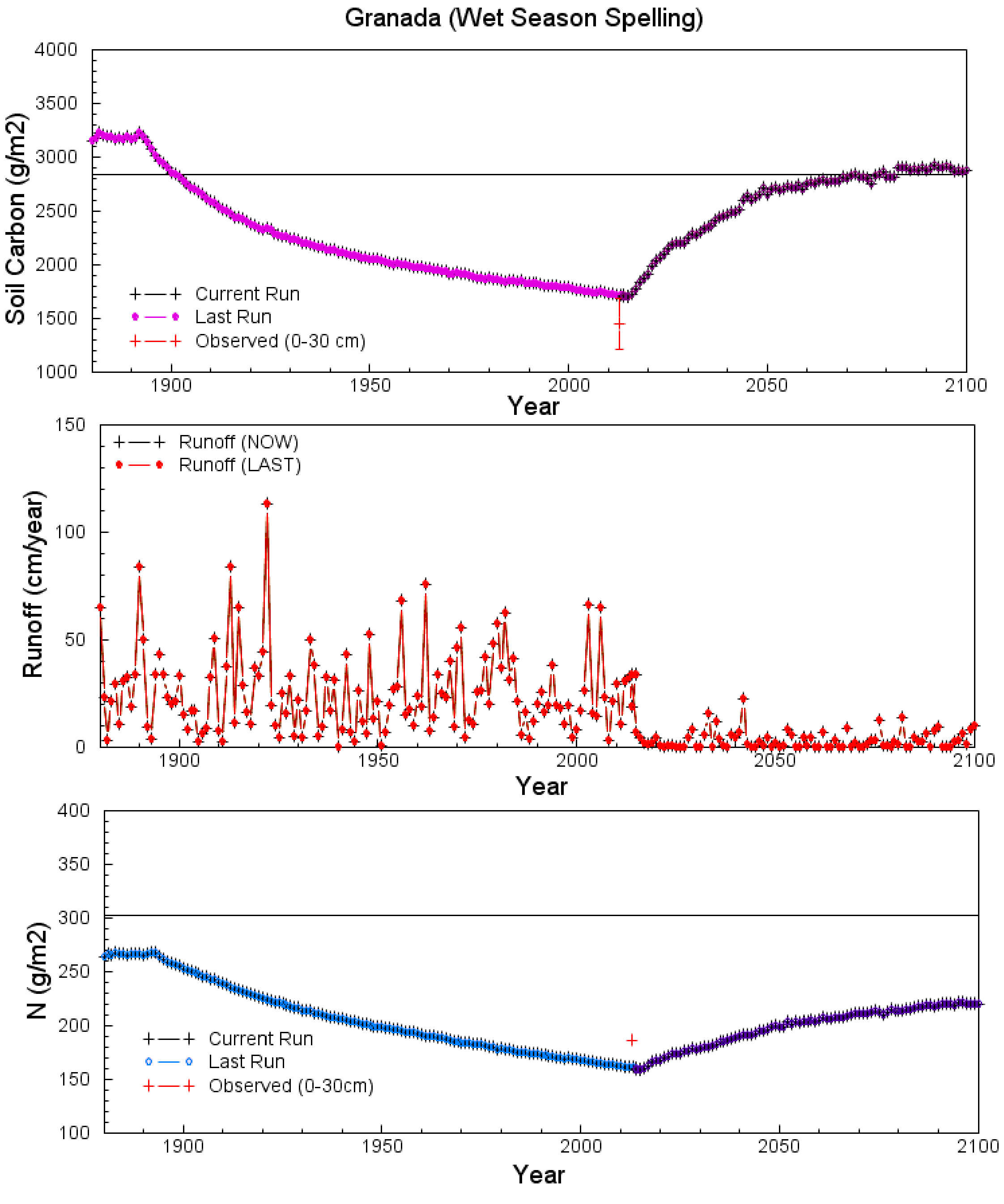

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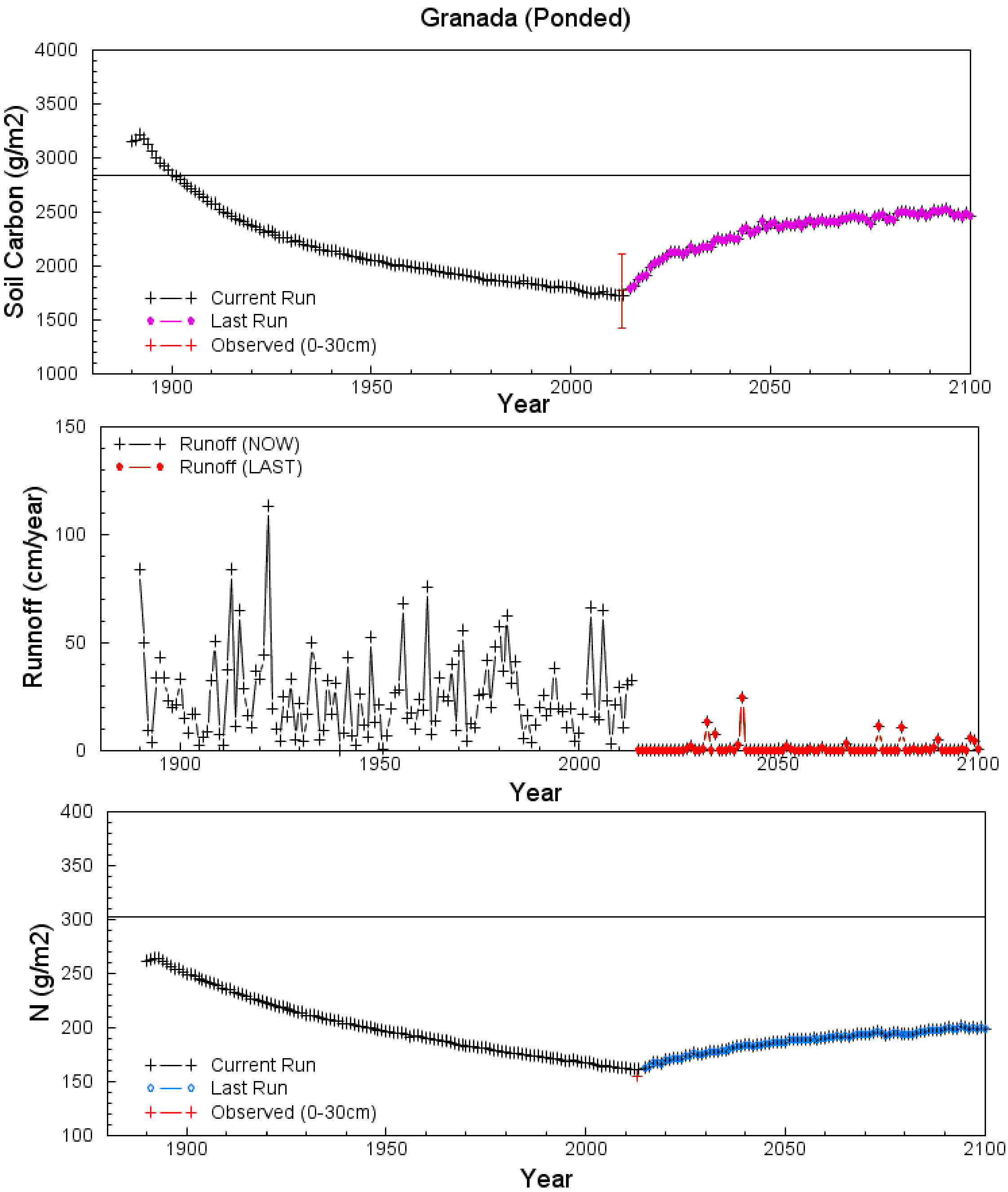

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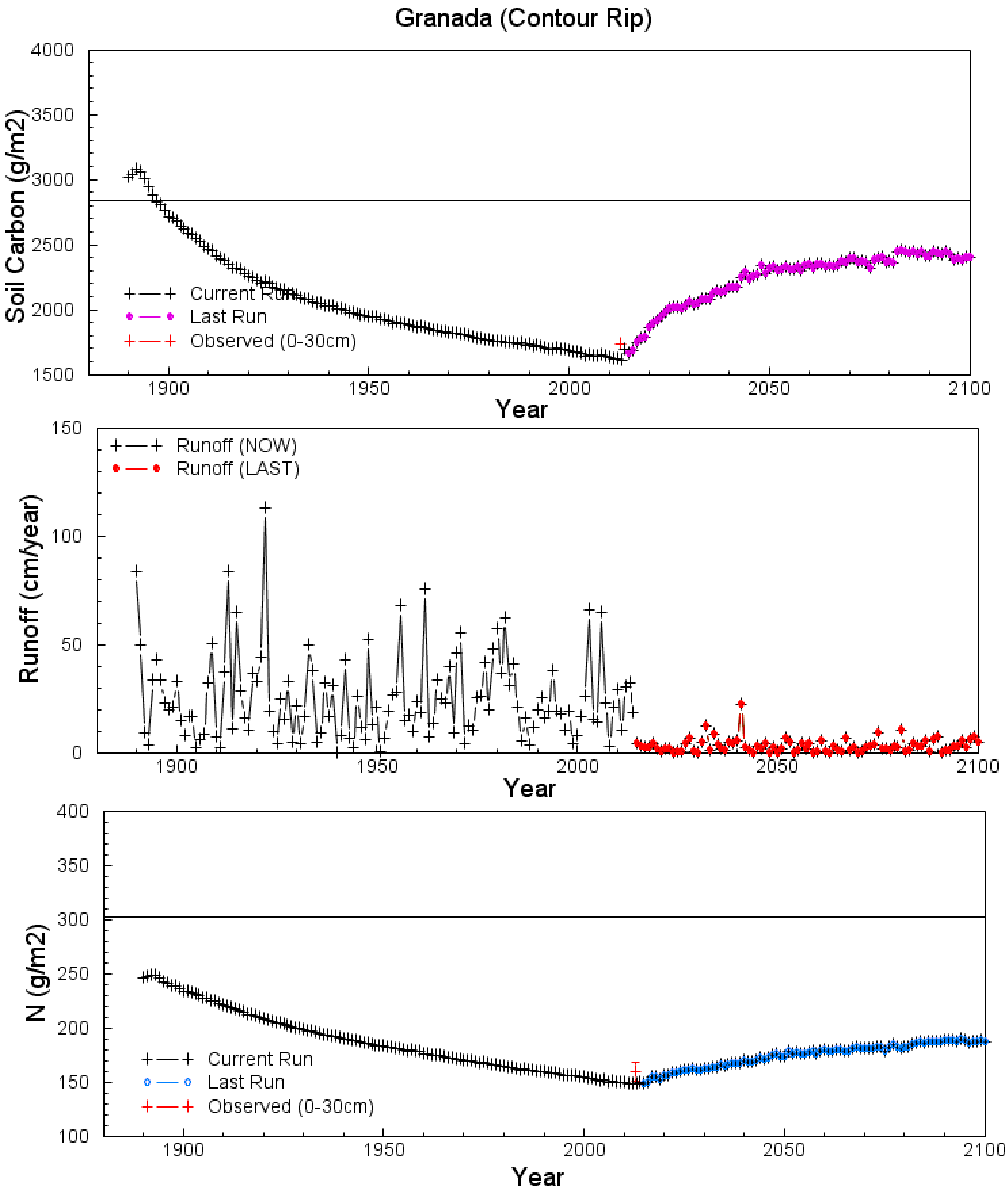

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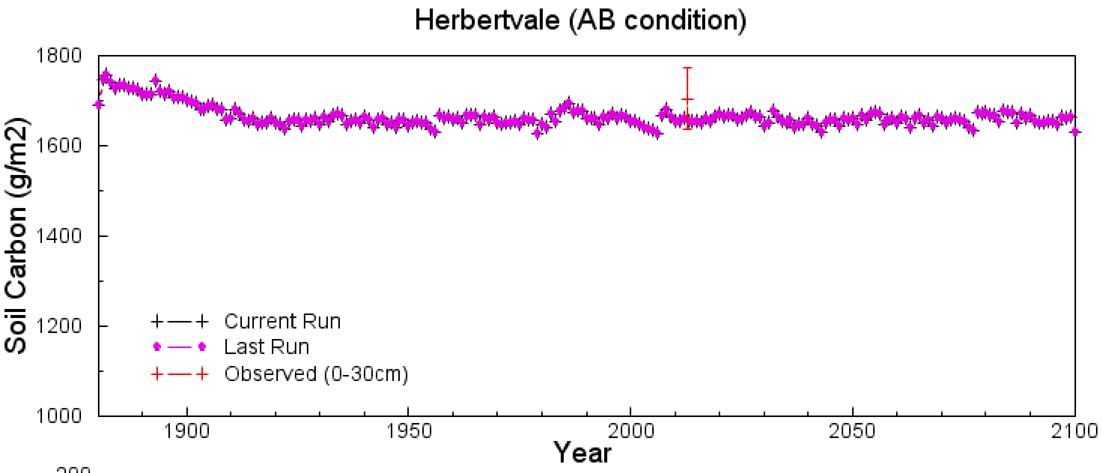

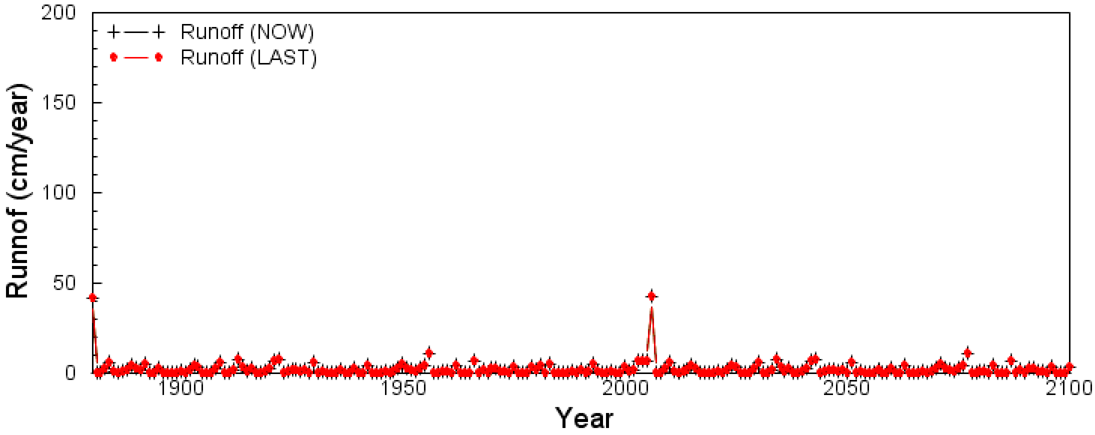

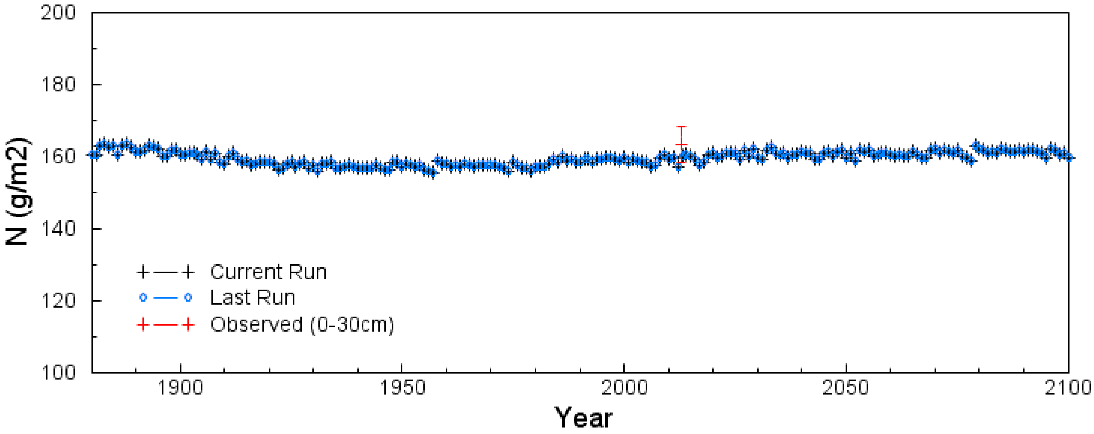

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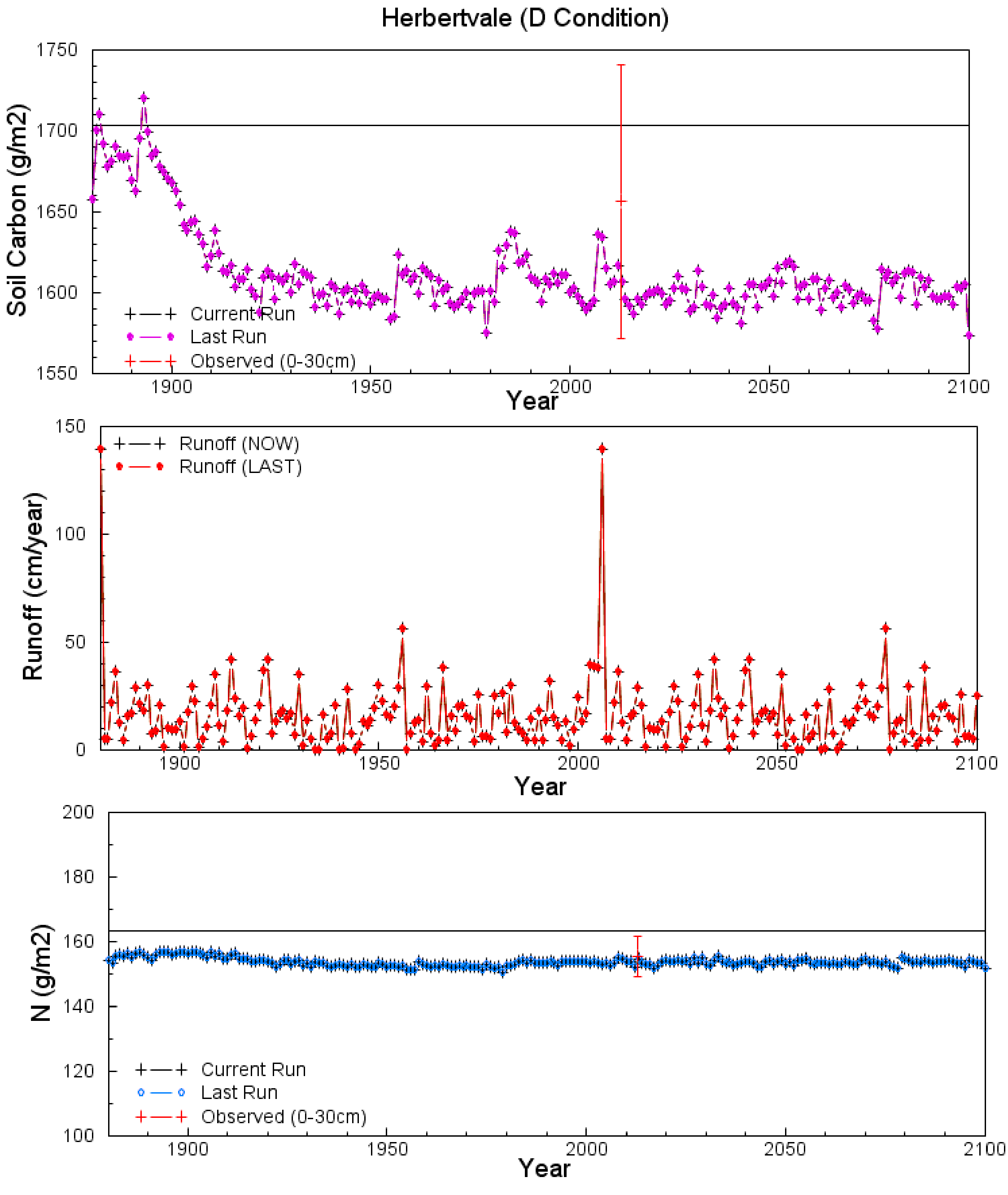

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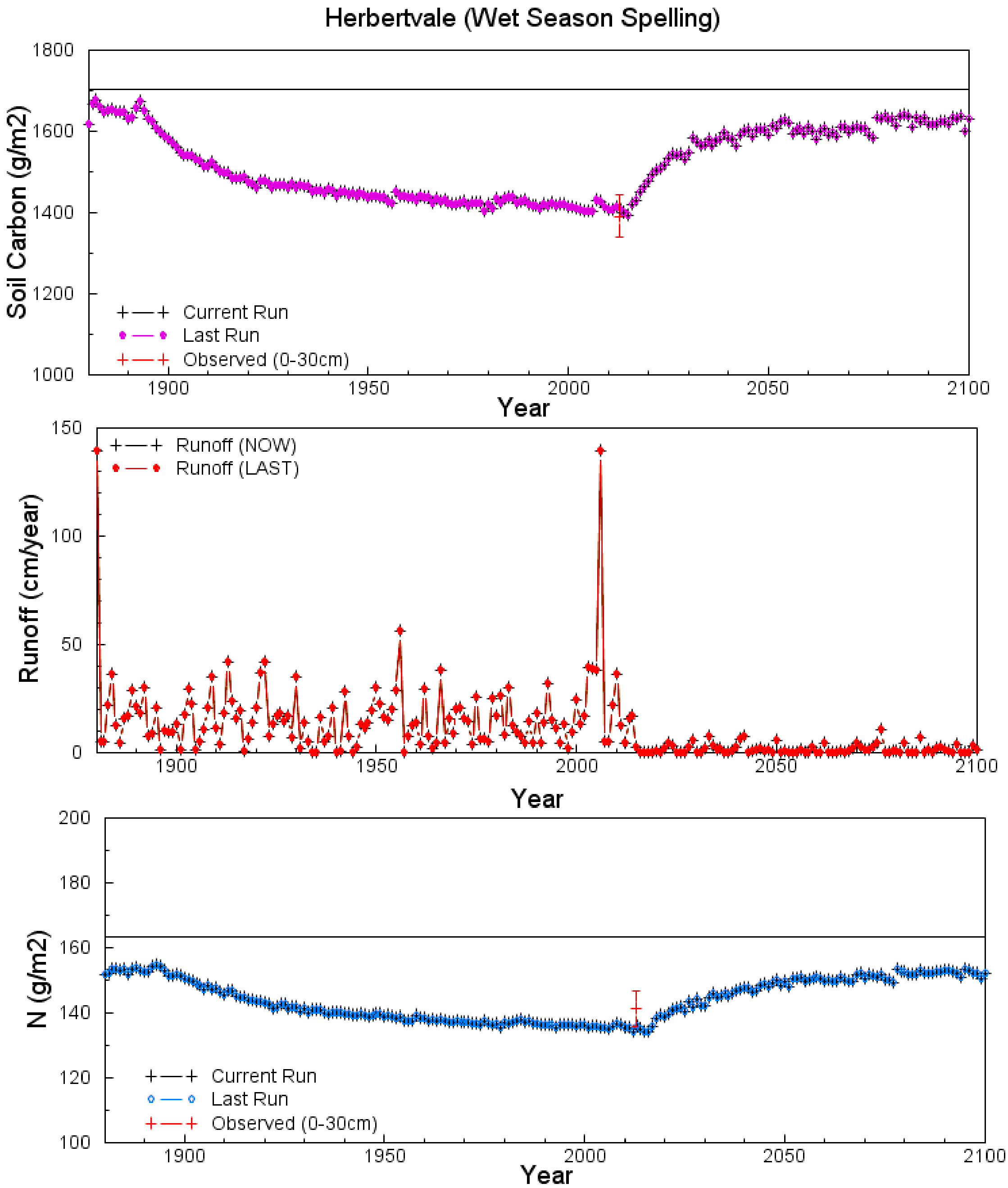

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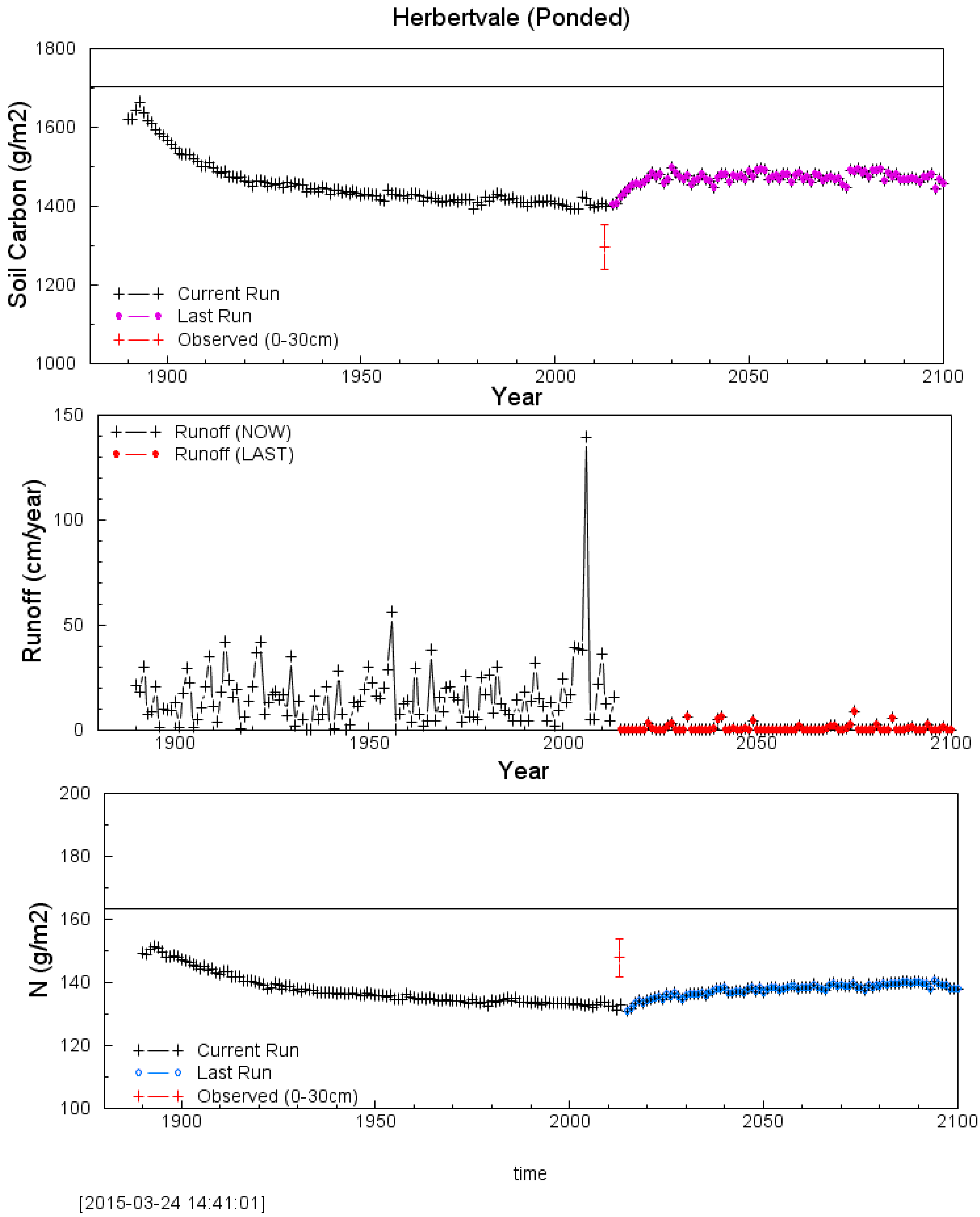
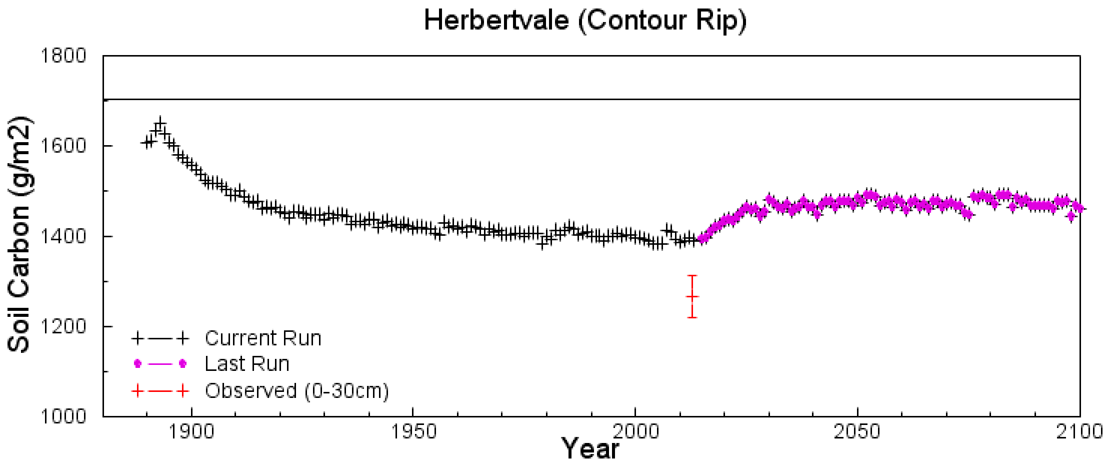
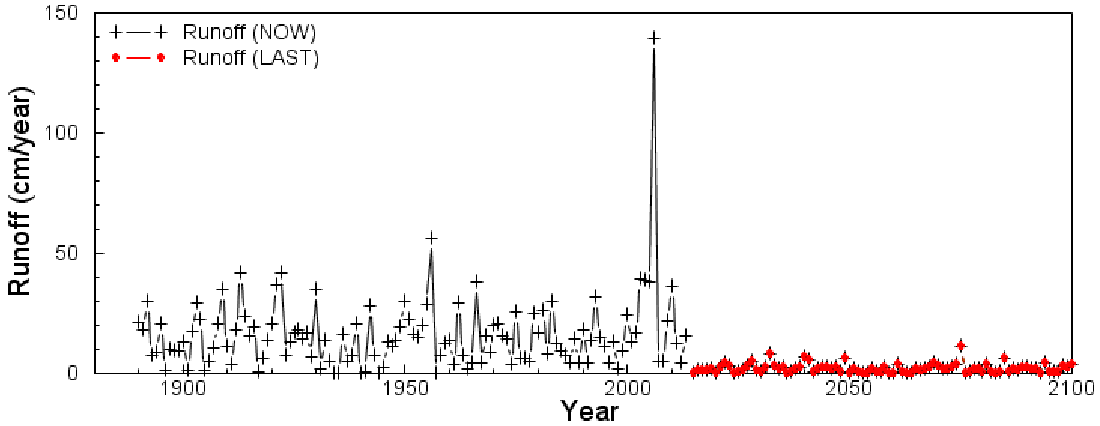
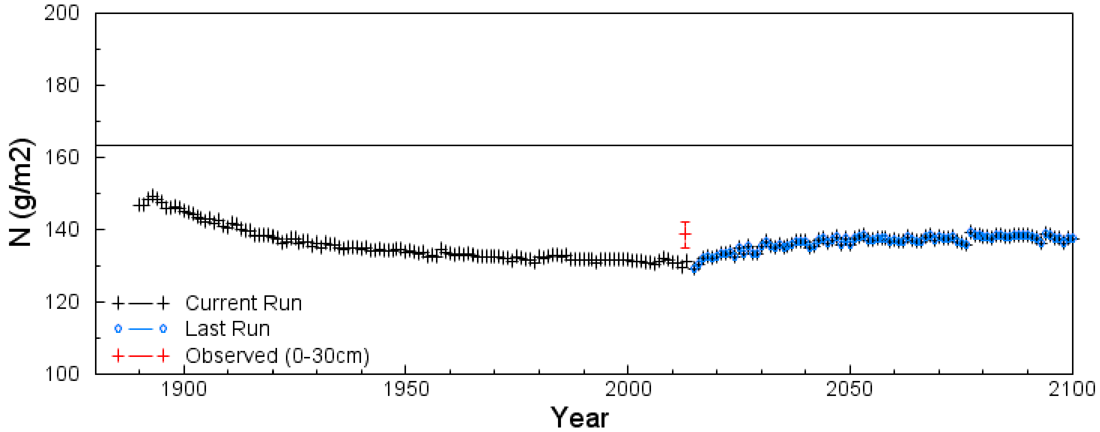


Herbertvale (Ponded)
Soil Carbon (g/m2)
1800
1600
1400
1200
1000
Current Run
Last Run
Observed (0-30cm)
1900
1950
2000
2050
2100
Year
Runoff (cm/year)
150
100
50
0
Runoff (NOW)
Runoff (LAST)
1900
1950
2000
2050
2100
Year
N (g/m2)
200
180
160
140
120
100
Current Run
Last Run
Observed (0-30cm)
1900
1950
2000
2050
2100
time
[2015-03-24 14:41:01]







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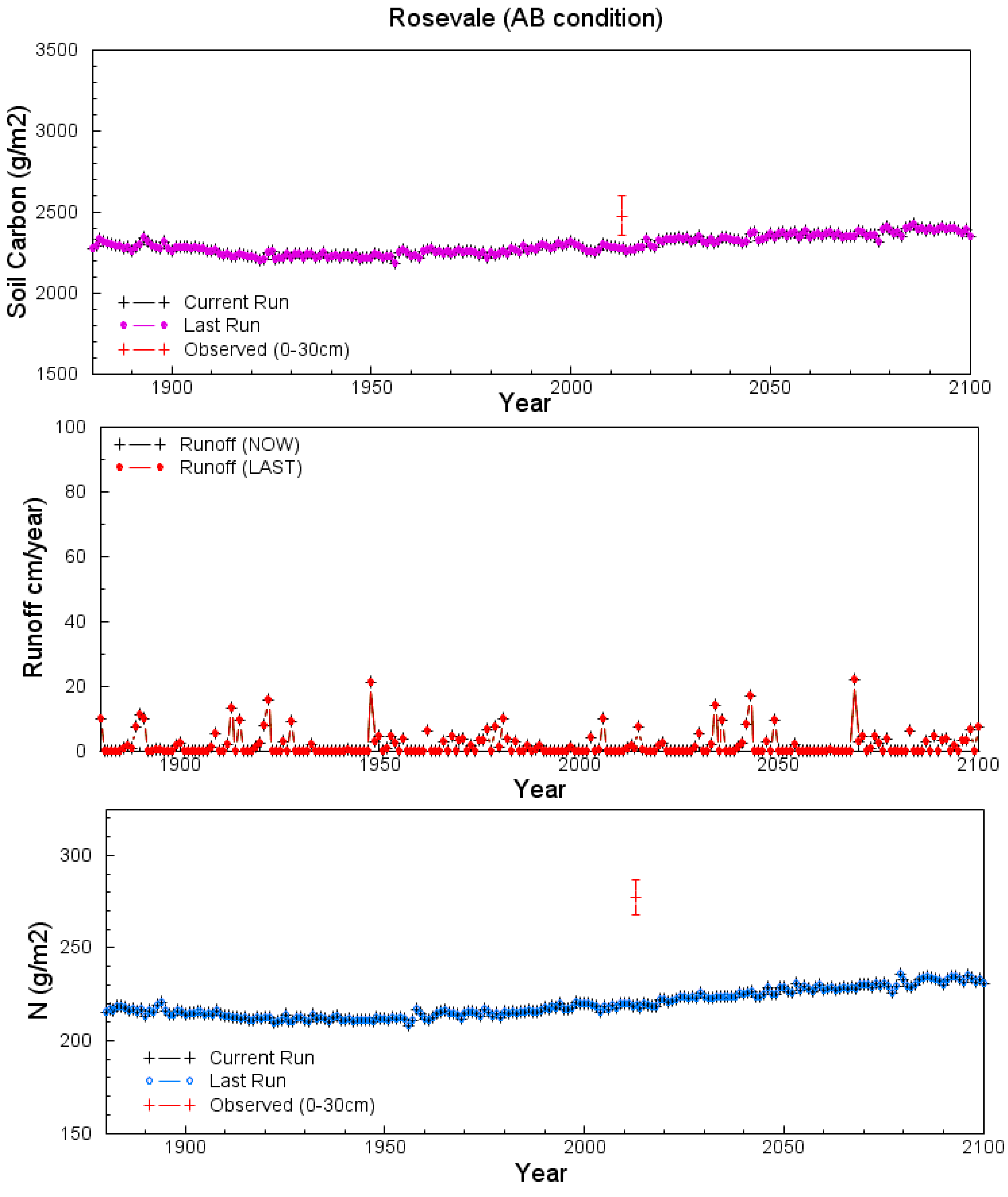

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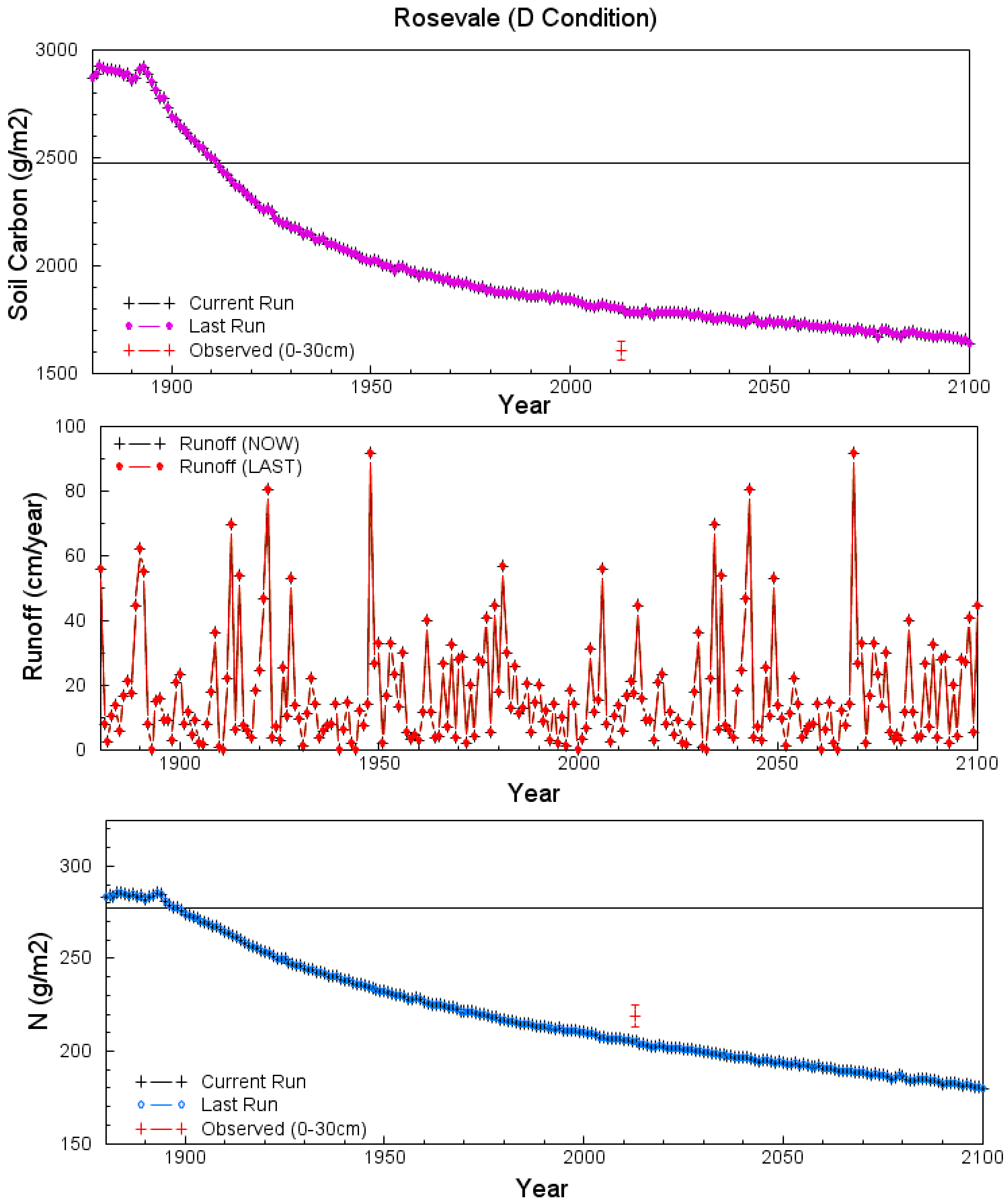

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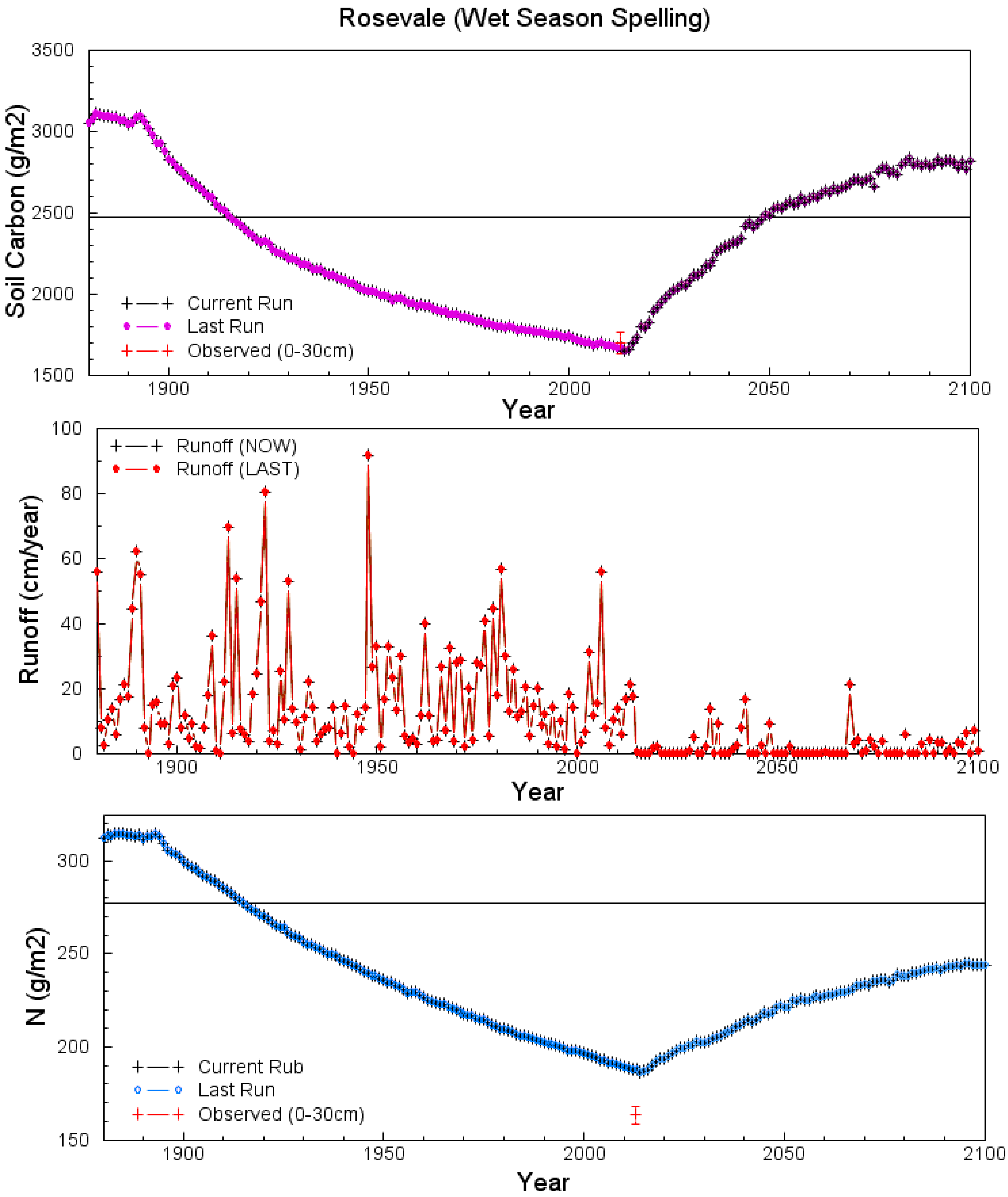

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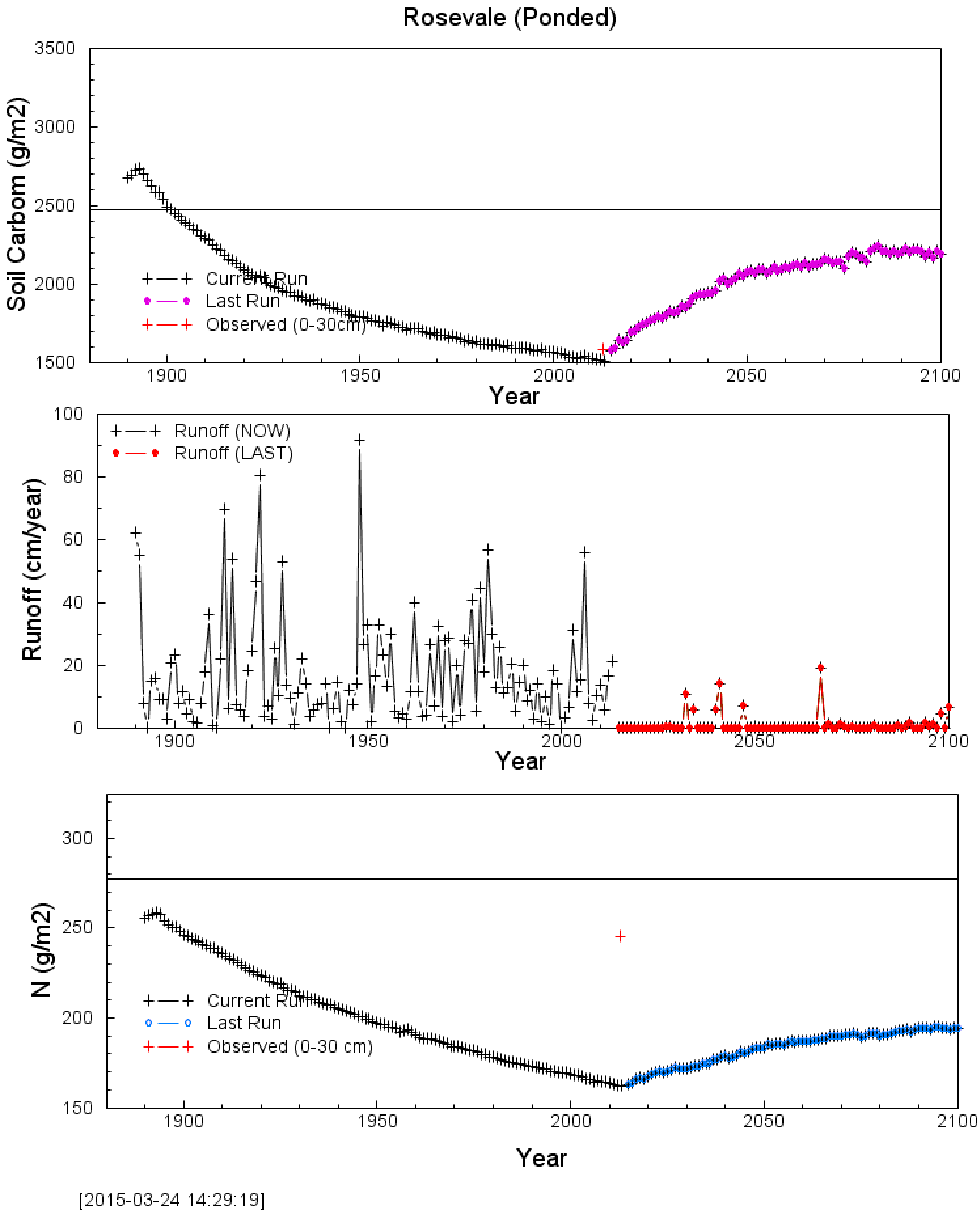
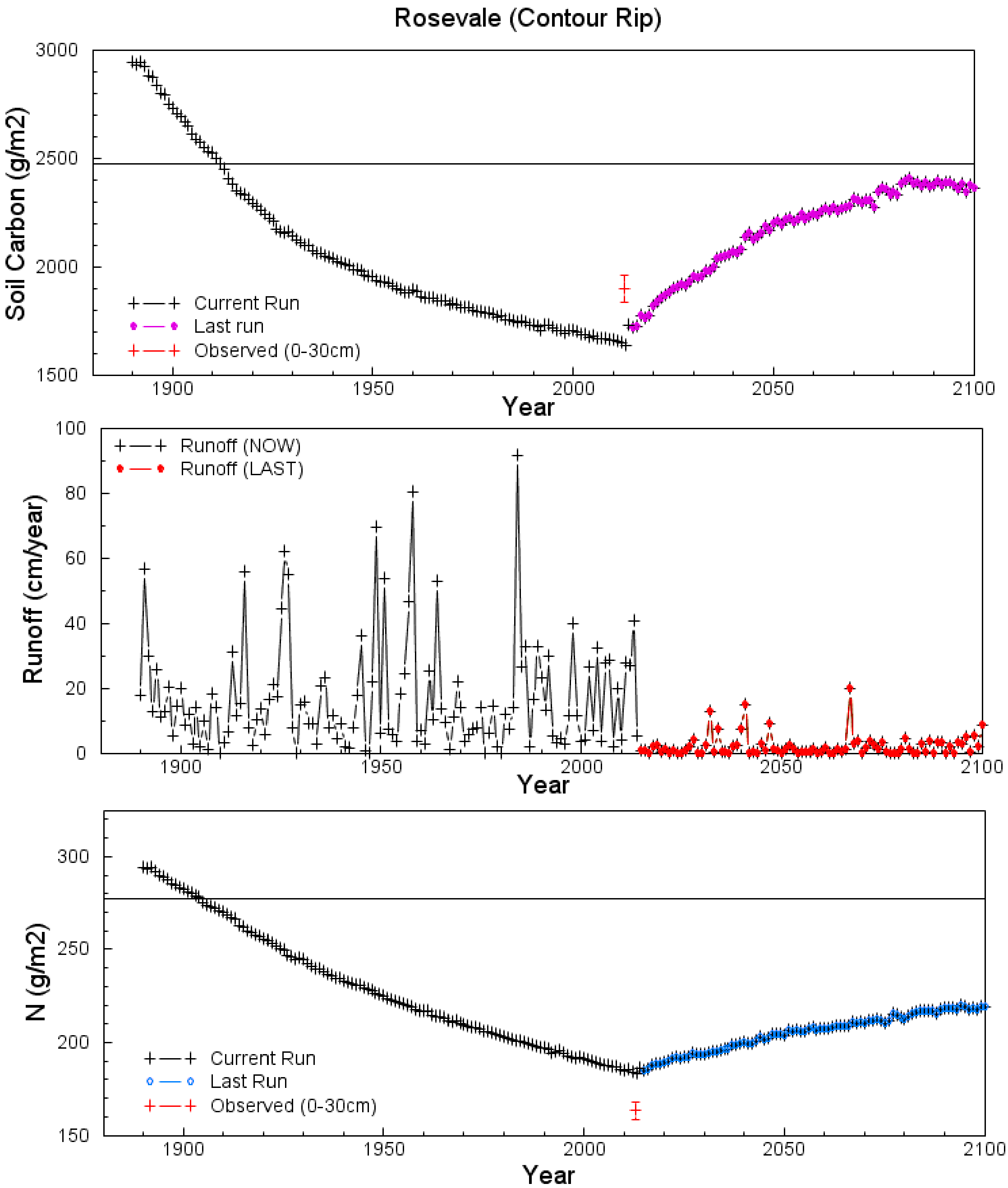

Rosevale (Ponded)
Soil Carbom (g/m2)
3500
3000
2500
2000
1500
Current Run
Last Run
Observed (0-30cm)
1900
1950
2000
2050
2100
Year
Runoff (cm/year)
100
80
60
40
20
0
Runoff (NOW)
Runoff (LAST)
Year
N (g/m2)
300
250
200
150
Current Run
Last Run
Observed (0-30 cm)
Year
[2015-03-24 14:29:19]



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