LOWER MANUHERIKIA VALLEY WATER RESOURCES STUDY

HYDROLOGY STUDY

(SUPPLEMENTING DETAILED CONCEPT STUDY)

MANUHERIKIA IRRIGATION CO-OPERATIVE SOCIETY LTD

Lower Manuherikia Valley Water Resources Study

Hydrology Study

(Supplements Detailed Concept Study)

Manuherikia Irrigation Co-operative Society Ltd

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Contents

1 Introduction

This Hydrology Study supplements our Detailed Concept Study which forms part of a feasibility study of extending the Dairy Creek Irrigation Scheme to incorporate a wider area of the Lower Manuherikia Valley. The report discusses the feasibility of combining the various water and irrigation schemes in the command area into a single entity, with possibly a single water source. Estimates are presented of the likely water demand, and the supply capability with the existing consent to abstract water from Lake Dunstan. A detailed study report will then be based on the conclusions and recommendations. Specifically, this report presents an analysis of the natural moisture availability and variability as a result of climate, and a soil classification and characterisation based on their hydraulic properties.

2 Study Area

This project considers the Manuherikia region to be that area bounded by Lake Dunstan to the south west and Tiger Hill in the east, stretching the entire lower Manuherikia Valley. Within this area the steep slopes of the Dunstan Mountain Range drop down to the banks of the Manuherikia River and Lake Dunstan. The Manuherikia area is used for agriculture and horticulture and is part of the Otago Region.

Surrounded by mountains, the Central Otago area where the Manuherikia Valley is located is generally cut off from rain-bearing winds. The Southern Alps create a general rain-shadow effect over the area and as a consequence, Central Otago has one of the driest climates in New Zealand. As is usual in dry climates, the rainfall regime is highly variable from year to year. Extremes of temperature, especially the diurnal temperature range, are associated katabatic winds followed by clear, sunny days.

3 Soils

While the climate of a region controls the effective precipitation, soil plays a critical role in determining the nature and amount of water available to plants. Soil moisture provides a buffer against short term climatic variability, while the size of the buffer is determined by the volume and distribution of the pores within the soil (Hawke *et al.* 2000).

Once the natural annual and seasonal availability of water has been assessed, the hydraulic characteristics of the soil must be quantified. Soil is the product resulting from the interaction, through time, between environmental factors such as: the parent material from which it is derived; the position in the landscape where it is situated; the climate under which it developed; and the biological influences, particularly vegetation, which have modified it. At any one place the soil represents the effect of all these factors in combination. Therefore, the soil pattern of a region is a reflection of variation in one or more of these soil-forming factors (Hawke *et al.* 2000).

All of these environmental factors require time to operate and affect soil development, in particular the weathering of parent rock to soil parent material. The soil profile reflects the length of time weathering processes have been operating, along with any modification by biological activity. Physical weathering processes cause the rock to disintegrate without any change in chemical or mineralogical composition. These include mechanical abrasion, wetting and drying, and frost shattering. Chemical weathering processes, however, change the chemical and/or mineralogical composition of the original rock. These include oxidation and reduction, hydrolysis, solution, and hydration. The temperature regime and moisture availability influence the nature and rate of the chemical and physical weathering processes.

Soils can be classified by either their attributes, or their environmental characteristics. Classification enables differences and similarities to be accentuated. The New Zealand Soil Classification (Hewitt, 1998) groups soils on the basis of properties that can be precisely measured and observed. This allows, either directly or by tested inferences, the field assignment of soils to particular classes. These soil classes are analysed to quantify the hydraulic properties and moisture capacity of the soils within the study area. This will allow irrigation needs to be "tailored" to specific zones, situations, and anticipated results. Understanding the irrigation requirements of the area is of critical importance to the long term management of the Dairy Creek irrigation scheme within the lower Manuherikia Valley.

3.1 Data

Soil type and depth data were extracted from the Grow Otago Climate and Soils Maps (2004) GIS layers. It should be noted that the soil maps provide only an indication of soil properties in certain areas. The spatial distribution of data is derived from the Grow Otago soil map G42 (compiled from Beecroft 1985 1:15 000; Orbell 1974 1:31 680; McCraw 1964 1:15 840; McCraw 1966a 1:31 680; Leamy & Wilde 1971a 1: 63 360; and NZ Soil Bureau 1968 1:253 440). These data were clipped to the study area, and then to specific zones for interpretation (Figure 3.1).

Soil characteristic data were also obtained from the New Zealand Fundamental Soil Layer (NZFSL). These are reproduced with the permission of Landcare Research NZ Ltd. These data were compiled for use at scales up to 1:50,000. Caution is therefore advised when used at scales more detailed than 1:50,000. Note: the maps produced in this report are at a scale of approximately 1:90,000.

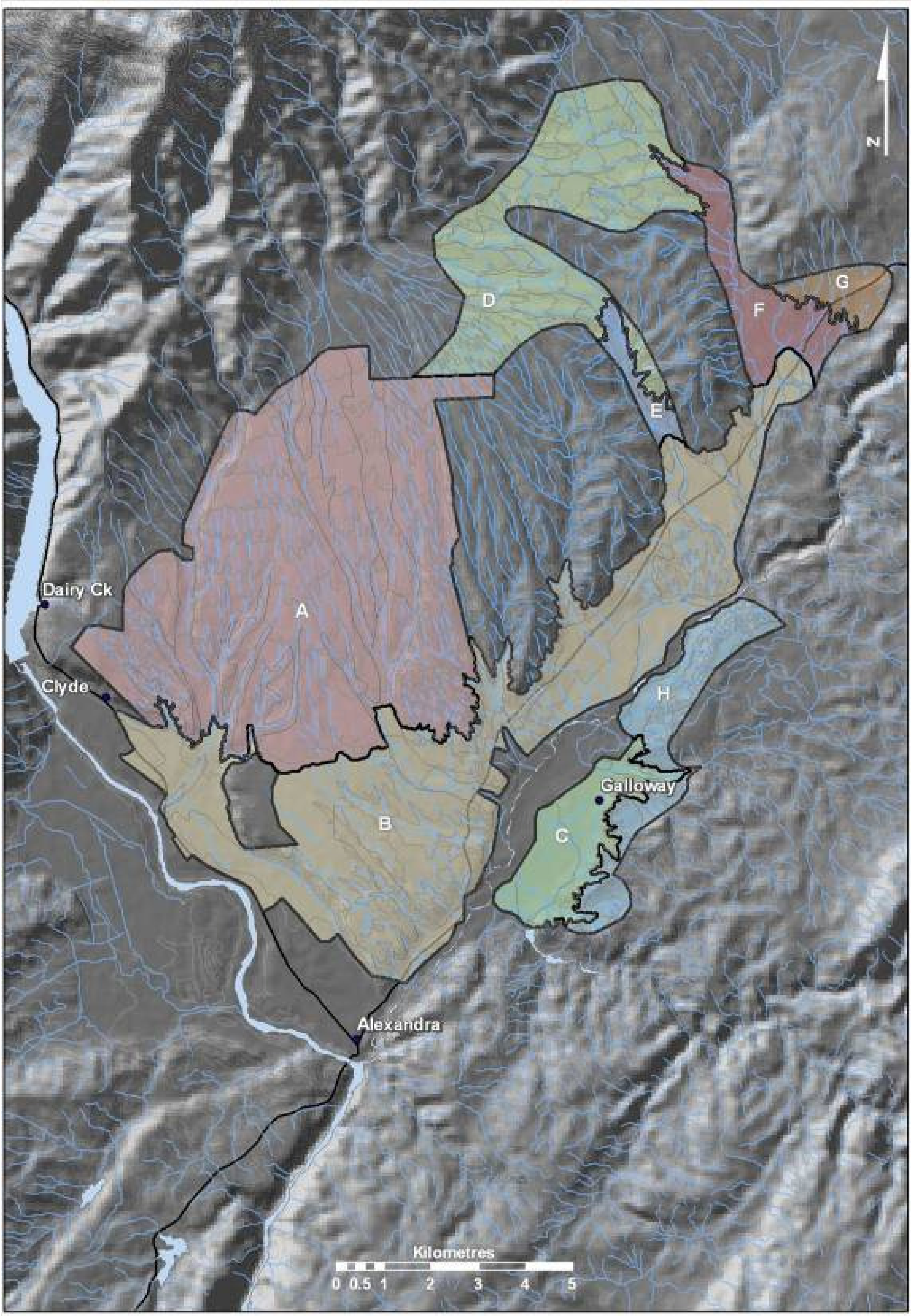

Figure 3.1 Location of specific zones of the study area.

3.2 Soil type

Nine soil types are found in the study area (Figure 3.2), as determined by the Grow Otago soil layers. Definitions of the six major groups are presented in Table 3.1. The majority of the soil types w ere found to be semiarid; and of these most w ere anthropic (Table 3.2).

Table 3.1 Definition of soil types (Grow Otago, 2004).

Soil Type	Description
Anthropic	Soils drastically disturbed/created by human activity, e.g as a result of mining activity.
Argillic	Have an accumulation of silicate clays.
Gley	Saturated by water for prolonged periods, originally wetlands.
Pallic	Have pale coloured high bulk density subsoils, weak structure, are slowly permeable, and have limited rooting depth. They are dry in summer and wet in winter.
Recent	Formed in young sediments. Have a distinct topsoil, but weakly developed subsoils, with moderate to high fertility, and well to imperfect drainage. These have widely variable rooting depths and water storage capacity.
Semiarid	These are dry for most of the growing season, with moderate to high natural fertility, and well to imperfect drainage. They are fragile with weak soil structure, and have very low organic matter.

Table 3.2 Soil types of the specific zones.

Soil Type (area in hectares)											
Zone	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total**
A	0.00	323.15	0.00	727.31	11.34	0.00	164.64	2863.23	509.60	328.46	4927.74
B	6.24	0.00	16.11	0.00	0.00	0.00	341.37	1365.54	793.38	1639.94	4162.59
C	6.31	0.00	31.33	0.00	0.00	0.00	46.48	0.00	494.86	2.69	581.67
D	0.00	165.44	0.00	674.56	78.21	0.00	0.00	350.26	479.09	21.62	1769.16
E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	34.34	26.20	85.90	146.44
F	0.00	119.07	0.00	0.00	0.62	0.00	112.61	16.71	118.60	159.95	527.56
G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.74	42.63	150.79	203.16
H	5.76	0.00	0.00	0.00	0.00	25.54	96.04	121.64	413.46	0.00	662.44
Total	18.31	607.65	47.43	1401.87	90.17	25.54	761.14	4761.46	2877.83	2389.36	12980.76
% Total	0.14	4.68	0.37	10.80	0.69	0.20	5.86	36.68	22.17	18.41	100

Where the soil types are as follows:

1) Anthropic - Firm, Fibric, Fill, Fluv
2) Gley - Organic
3) Gley - Recent
4) Pallic - Argillic
5) Pallic - Firm, Fibric, Fill, Fluv
6) River
7) Recent - Firm, Fibric, Fill. Fluv
8) Semiarid - Anthropic
9) Semiarid - Argillic
10) Semiarid - Immature, Impeded

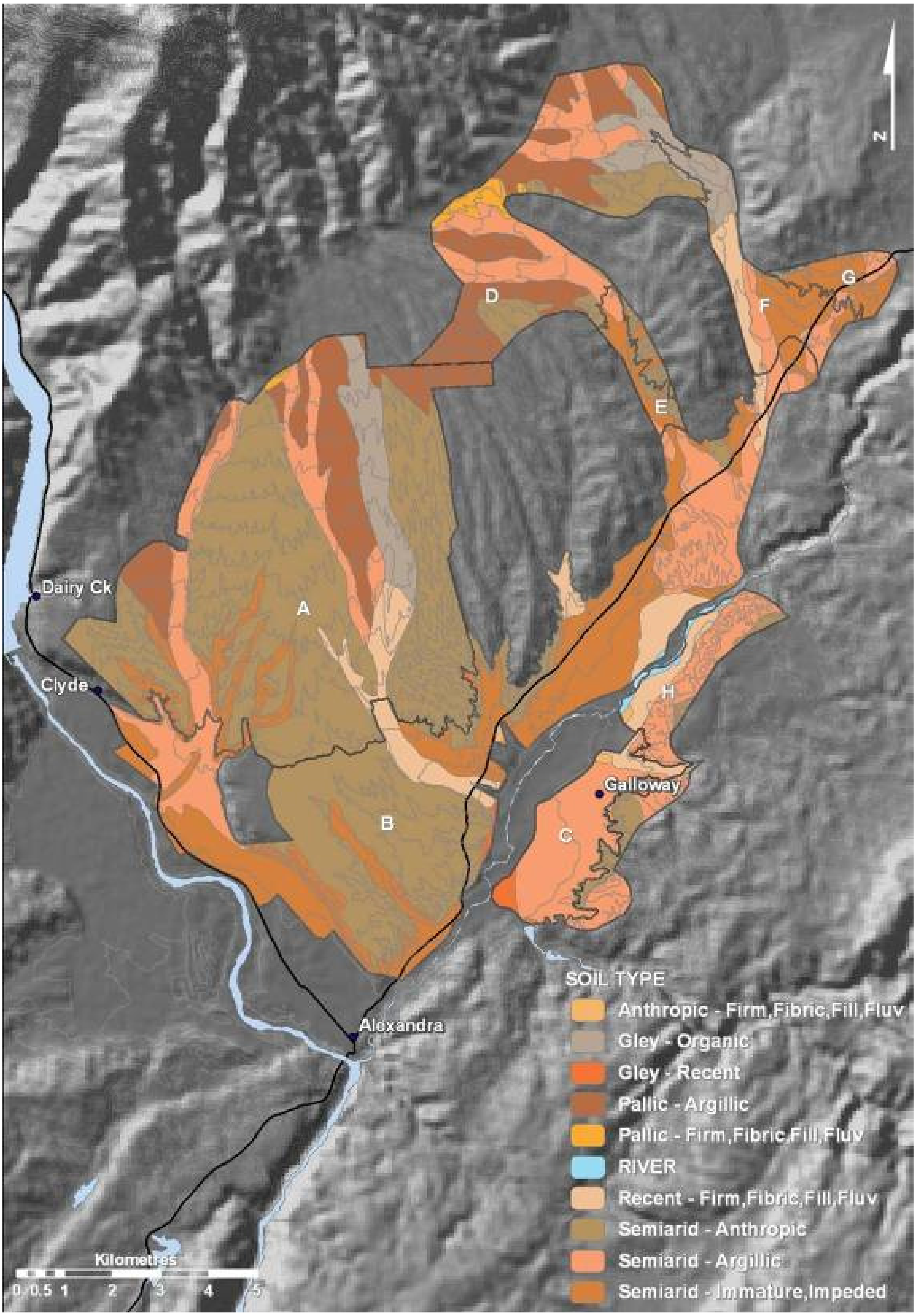

Figure 3.2 Soil name classification in the study area.

3.3 Soil depth

The soil maps provided depth parameters for the lowland soils only. Upland (hill) soils found mainly in Zones H, C, and a fraction of Zone A have unspecified depths. Dominant and some sub-dominant soil depths were, however, classified across the study area (Appendix A: Figures A1 & A2). The total combined soil depths (Figure 3.3) were reclassified using the weighted average of the dominant soil depths (60%) and sub-dominant soil depths (40%). Where no sub-soil type was identified, 100% of the dominant soil type depth was used. The total combined soil depths of the study area are listed in Table 3.3. The total combined soil depth is mainly stony (100–200mm), with relatively isolated pockets of shallow to moderately deep soil (200-450mm to 450-900mm) throughout the study area.

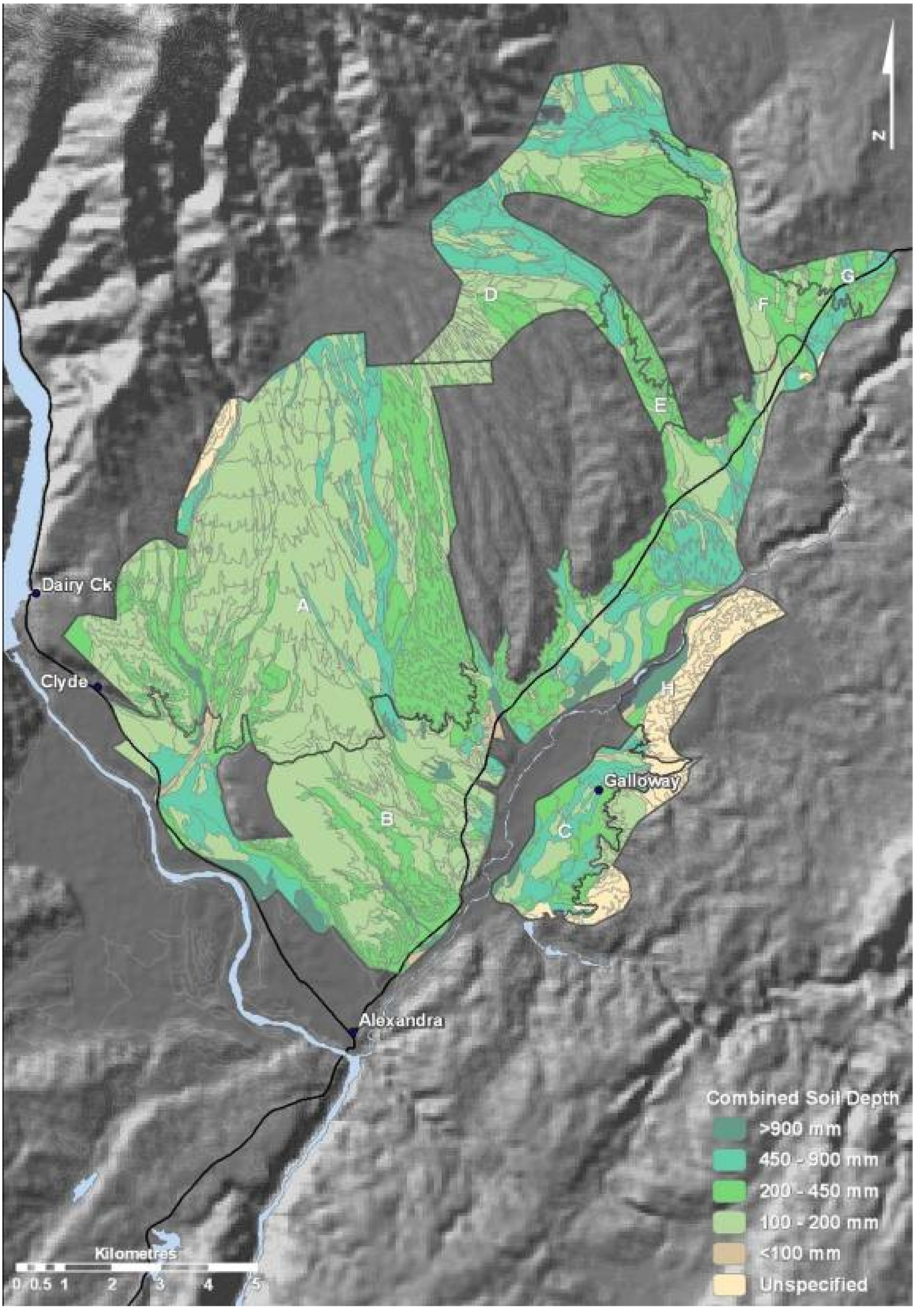

Figure 3.3 Combined soil depth of study area.

Table 3.3 Combined soil depths of the specific zones.

Soil Depth (area in hectares)							
ZONE	**>900mm (deep)**	**450 - 900mm (mod. deep)**	**200 - 450mm (shallow)**	**100 - 200mm (stony)**	**<100mm (v. stony)**	**Unspecifie d**	**TOTAL**
A	21.47	450.34	1399.24	2984.83	2.88	68.98	4927.74
B	180.64	829.54	1346.93	1734.56	70.30	4.64	4166.61
C	15.79	244.11	143.49	134.85	2.88	48.62	589.74
D	0.00	632.44	454.28	661.82	0.00	0.00	1748.54
E	0.00	38.32	98.44	9.68	0.00	0.00	146.44
F	0.00	108.89	202.03	212.71	1.08	3.15	527.86
G	0.00	51.66	122.43	29.07	0.00	0.00	203.16
H	44.19	8.21	27.47	95.47	5.06	456.18	636.58
TOTAL	262.09	2363.51	3794.32	5862.99	82.20	581.58	12946.6 8
% TOTAL	2.02	18.26	29.31	45.29	0.63	4.49	100.00

3.4 Soil characteristics

The hydraulic characteristics of a soil are critical in determining its capacity to hold water and to make this available for crops or pasture. As with soil type and depth, the characteristics of soils, and therefore their response to efficient irrigation, differ within each zone and across the study area.

Estimation of the field values for each soil property in the NZFSL is based on the analysis or measurements of the soil under the best case scenario. These are the most reliable data. Estimates extrapolated from relationships with other soils are also considered reliable. However, some data within the NZFSL are estimated from relationships with other soils. These data have an unknown level of accuracy. The least reliable data have been estimated from the general soil survey. The reliability of the following data will be described in each section, and in the figures in Appendix A.

3.4.1 Potential rooting depth

Potential rooting depth refers to the depth of a layer within the soil profile which may impede root extension. This could be associated with soil depth to bedrock, poor aeration or very low available water (Newsome *et al.,* 2008). The most reliable potential rooting depth data available from the NZFSL is found in a small strip of land along the eastern border of Zone C. The remainder of the command area is, however, of unknown data quality. These data were derived from relationships with other soils in the area (Figure A.3).

The potential rooting depth of the command area is generally shallow (250–440mm) (Figure 3.4); with almost half of the soils falling into this category (Table 3.4). This is slightly deeper than the combined soil depth data (Table 3.3). Pockets of soils with deeper potential rooting depths occur in all other zones apart from Zone A.

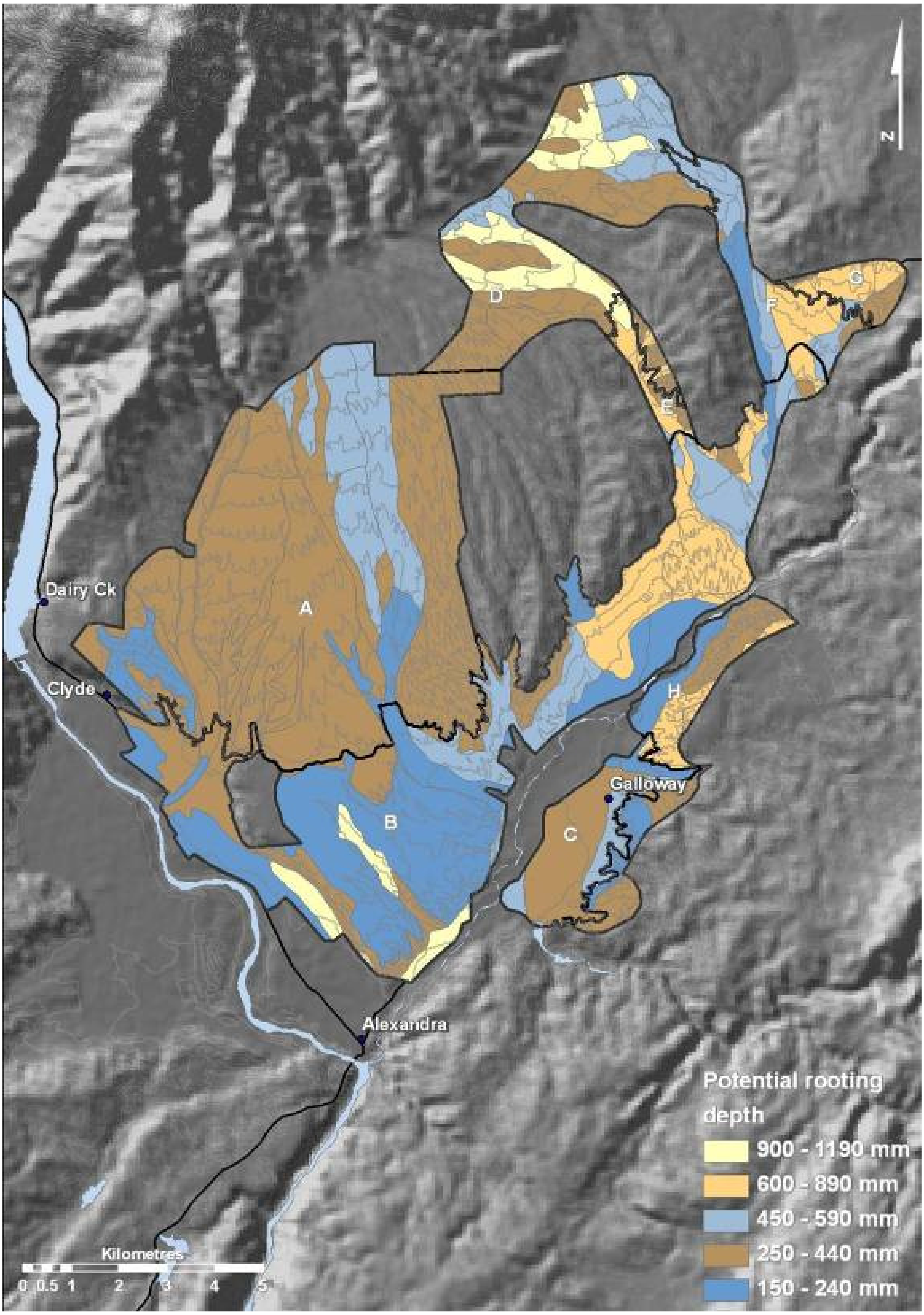

Figure 3.4 Potential rooting depth of study area.

Table 3.4 Potential rooting depths of specific zones.

Potential Rooting Depth (area in hectares)						
ZONE	**900 - 1190mm (deep)**	**600 - 890mm (mod. deep)**	**450 - 590mm (slightly deep)**	**250 - 440mm (shallow)**	**150 - 240mm (v. shallow)**	**TOTAL**
A			782.28	3784.47	361.16	4927.92
B	200.26	685.76	661.35	766.18	1849.05	4162.59
C		11.26	127.95	389.67	60.86	589.74
D	479.09	21.62	355.53	913.01		1769.25
E	21.79	85.90	4.41	34.34		146.44
F		141.12	237.57	37.71	112.61	529.01
G		129.30	10.90	67.92		208.12
H		138.02	10.10	298.07	190.72	636.90
TOTAL	701.14	1212.98	2190.08	6291.38	2574.39	12969.97
% TOTAL	5.41	9.35	16.89	48.51	19.85	100

3.4.2 Drainage

Drainage assesses the soil's ability to allow the downward flow of excess water through the profile. The NZFSL classifies drainage using criteria such as soil depth and water table duration, and is often inferred from soil colours and mottles (Hewitt, 1993) (Table 3.5).

Table 3.5 Drainage classes.

Key to drainage classes using the diagnostic horizons and features of the New Zealand Soil Classification (Hewitt, 1993)	
Drainage Class 1	Soils have an O horizon in place of the A horizon, and a distinct lack of topsoil.
Drainage Class 2	Soils that have a gley profile form.
Drainage Class 3	Soils that have a mottled profile form.
Drainage Class 4	Soils that have either a reductimorphic horizon between 60 and 90cm, or a redox-mottled horizon between 30 and 90cm.
Drainage Class 5	Soils that do not have a redox mottled horizon at less than 90cm.

The drainage data are the most reliable of all the soil characteristics data. There are only a few pockets of unknown quality data derived from relationships with other soils scattered throughout the study area. Zone C has the highest ratio of unknown quality data of all the zones (Figure A.4).

The soils within the study area are mainly moderately-well to well drained; covering 93% of the area. Only small pockets of imperfect or poorly drained soils occur in Zones A, C, D and F (Figure 3.5 & Table 3.6).

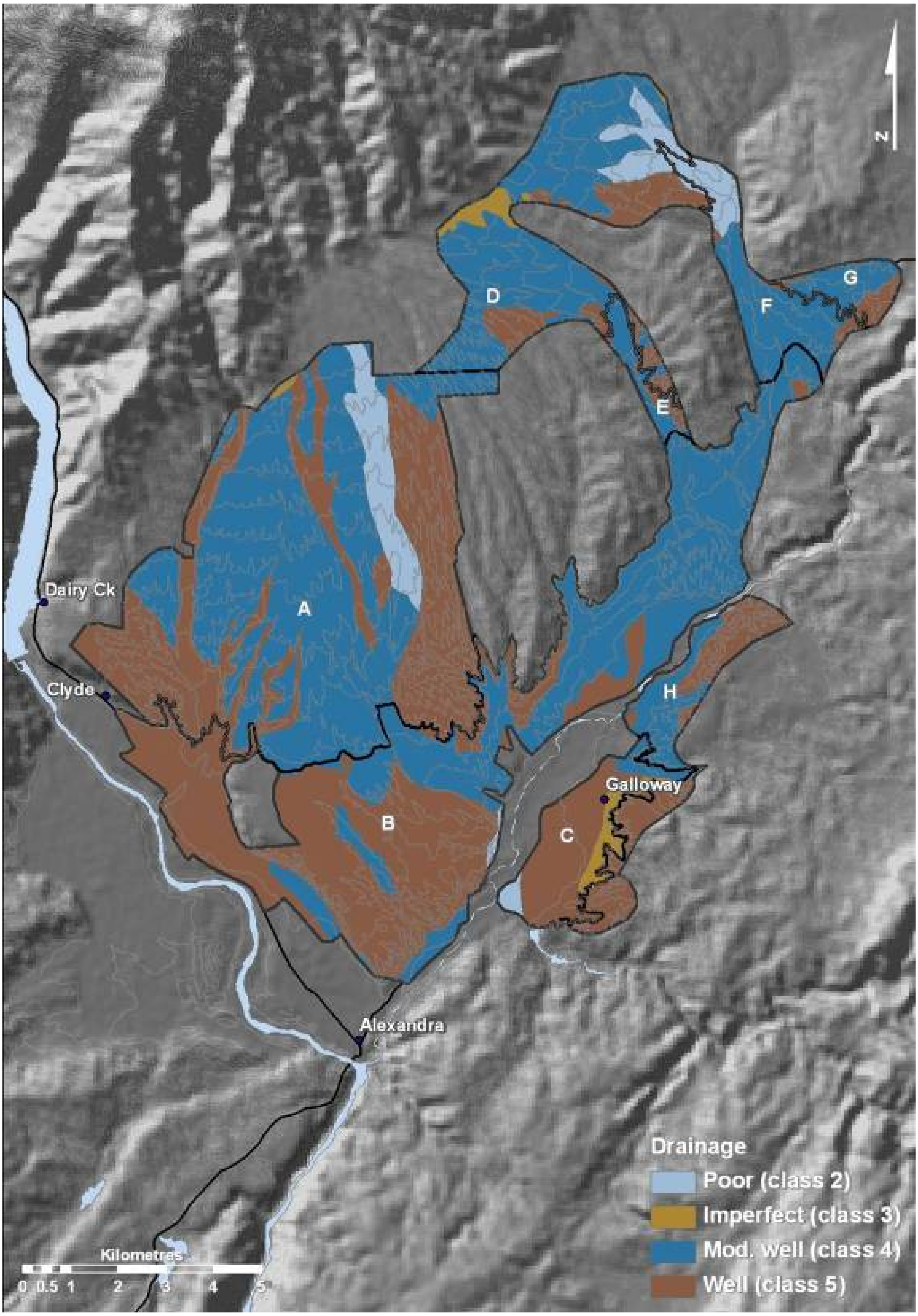

Figure 3.5 Soil drainage of study area.

Table 3.6 Soil drainage of specific zones.

Drainage (area in hectares)					
ZONE	**(Poor)**	**(Imperfect)**	**(Mod. well)**	**(Well)**	**TOTAL**
A	323.15	11.34	2613.74	1979.69	4927.92
B	16.12		1994.43	2152.05	4162.59
C	31.33	93.93	57.74	406.74	589.74
D	165.53	78.21	1175.27	350.26	1769.25
E			112.10	34.34	146.44
F	119.90	0.62	370.78	37.71	529.01
G			140.20	67.92	208.12
H		10.096	201.35	425.46	636.90
TOTAL	656.01	194.19	6665.59	5454.17	12969.97
% TOTAL	5.06	1.50	51.39	42.05	100

3.4.3 Permeability

Permeability measures the rate at which water moves through a saturated soil profile. This is affected by factors such as drainage, potential rooting depth and depth to a lower permeability horizon. Some more layered soils may have different permeability at different depths. For example, a moderately permeable soil over a slow permeability soil (or rapid over slow), will alter the rate at which water can move through the profile. Much of the permeability data for the study area is of unknown quality. The data are derived from relationships with other soils in the area. Some pockets of reliable data are found around the outer edges of Zones B, F, G and H (Figure A.5).

The majority of the soils in the study area have moderate over low permeability soils. These mainly occur in all zones except Zones C and H which have only either moderate or slowly permeable soils (Figure 3.6). Zone A has a large sector of rapid over slowly permeable soils covering 1718.3ha (Table 3.7). This configuration could slow the permeability of the soil at field capacity as the rapidly permeable soil saturates as the water encounters the slowly permeable layer which acts as a barrier to the downward movement of water.

Permeability is also a factor in the drainage of a soil. A high water table can effectively create poor drainage in both highly permeable sandy soils, and slowly permeable clay soils. However, the lowering of the water table would improve the drainage of the sandy soil far greater than that of the clay (Ministry of Works, 1974).

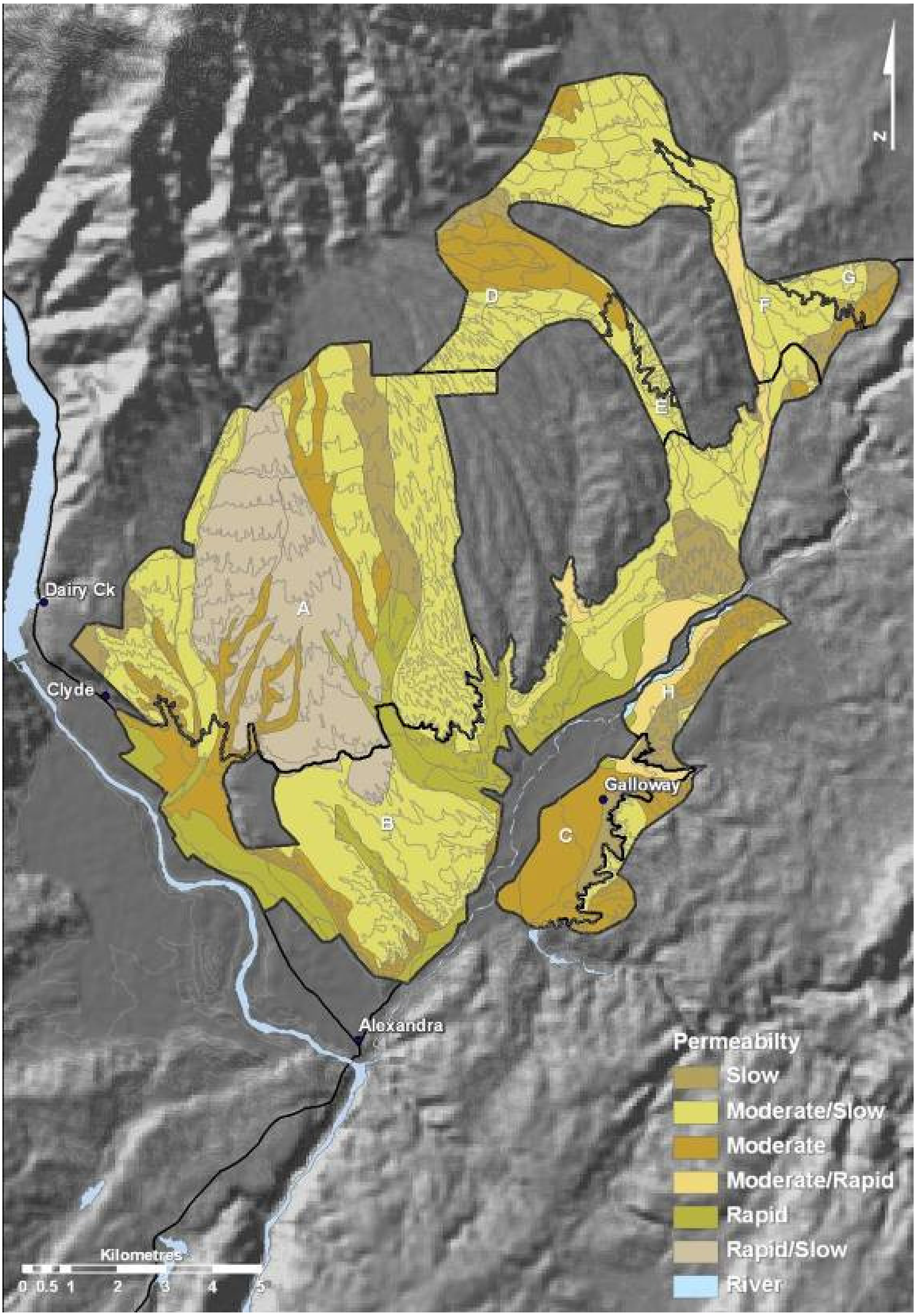

Figure 3.6 Soil permeability of study area.

Table 3.7 Soil permeability of specific zones.

Permeability (area in hectares)							
ZONE	Slow	Mod./Slow	Moderate	Mod./Rapid	Rapid	Rapid/Slow	TOTAL
A	424.77	2044.85	571.87		168.17	1718.26	4927.92
B	265.84	1989.63	478.00	196.91	1131.22	100.98	4162.59
C	105.19	54.55	423.69		6.31		589.74
D	78.21	1250.40	440.65				1769.25
E		124.65	21.79				146.44
F	46.56	348.57	20.96	112.61			528.69
G	42.63	165.49					208.12
H	115.40	121.64	298.07	96.05	5.76		636.90
TOTAL	1078.59	6099.77	2255.03	405.56	1311.46	1819.24	12969.66
% TOTAL	8.32	47.03	17.39	3.13	10.11	14.03	100

3.4.4 Porosity

Porosity is a measure of the space within the soil (e.g. pores or cavities) through which water or air can move. Macroporosity in the NZFSL refers to the air-filled porosity of the soil at field capacity and is expressed as percentage of soil volume (Newsome *et al.* 2008). Macropores can assist water to flow through the soil, quickly bypassing the root zone, and simply recharge the ground water (Hawke *et al.* 2000). Thus, a high percentage of macropores in the soil may impede the effectiveness of irrigation, or at least reduce the rate at which water should be applied.

The quality of the macroporosity data has been derived from relationships with other soils and is of unknown reliability for the entire study area. Moderate macroporosity (7.5 – 9.9%) covers 40% of the study area; with very few areas being either very high or very low (Figure 3.7 & Table 3.8).

Table 3.8 Soil macroporosity of specific zones.

Macroporosity (area in hectares)						
ZONE	**15 - 25% (v. high)**	**10 - 14.9% (high)**	**7.5 - 9.9% (moderate)**	**5 - 7.4% (low)**	**0 - 4.9% (v. low)**	**TOTAL**
A		933.83	1939.25	2043.49	11.34	4927.92
B	424.62	755.93	1656.73	1059.47	265.84	4162.59
C	6.31	49.17	51.11	471.89	11.26	589.74
D		552.45	951.45	187.14	78.21	1769.25
E		21.79	34.34	90.30		146.44
F		112.92	37.71	331.82	46.56	529.01
G			67.92	97.57	42.63	208.12
H	5.76	96.05	418.78	11.02	105.30	636.90
TOTAL	436.69	2522.14	5157.30	4292.70	561.14	12969.97
% TOTAL	3.37	19.45	39.76	33.10	4.33	100

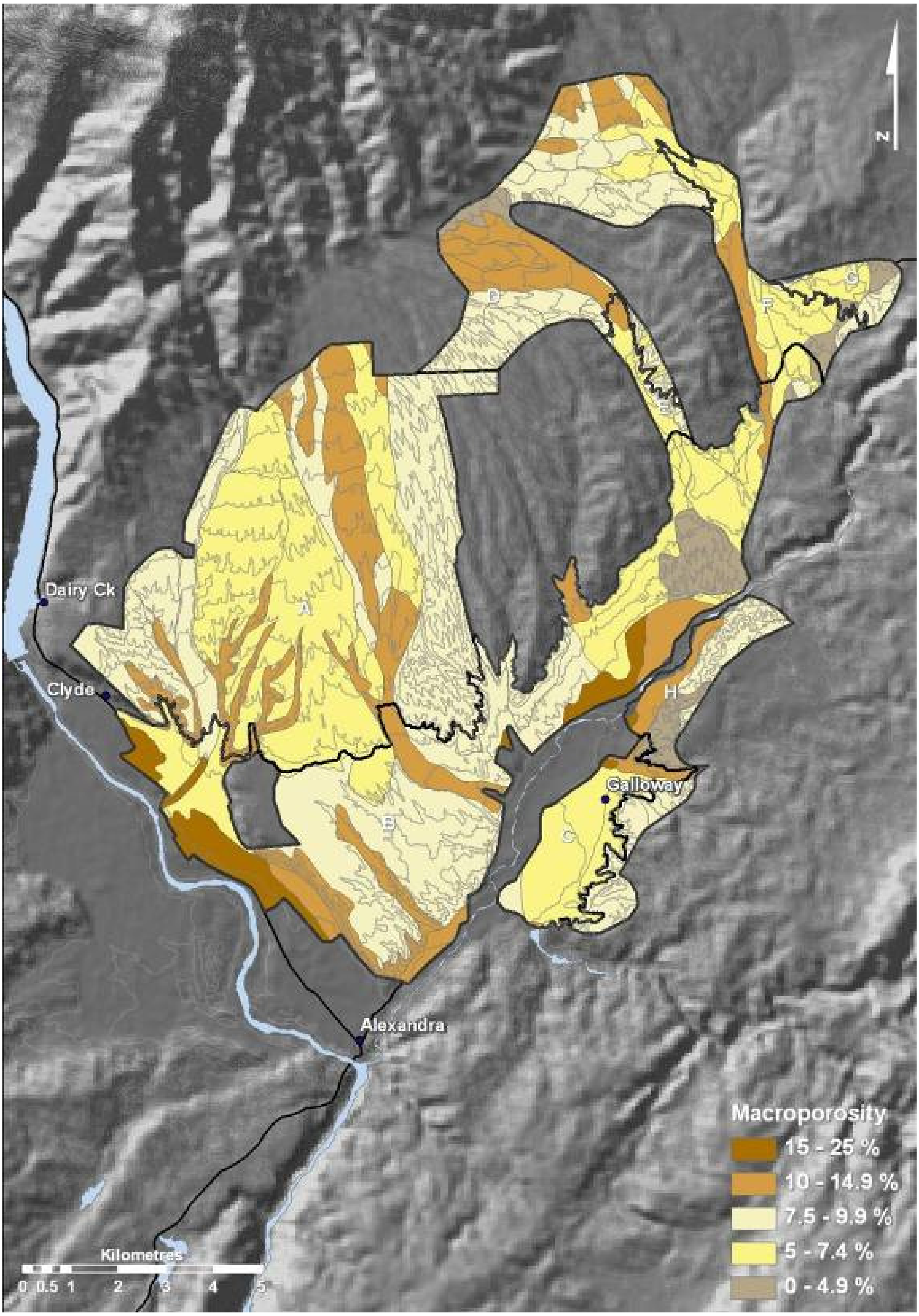

Figure 3.7 Soil macroporosity of study area.

3.4.5 Salinity

Salts are common in semiarid to arid and coastal regions, with sulphates, chlorides and carbonates of calcium, magnesium, and sodium commonly occurring within these soils. Plants vary considerably in their tolerance to salts but it is generally considered that toxic effects of total soluble salts become evident within the range of 0.1–0.2% (Ministry of Works, 1974).

Much of the salinity data for the study area is of unknown quality as it has been derived from relationships with other soils in the area. Some pockets of reliable data are found in portions of all zones except Zone E (Figure A-6); Zones D and H have the highest proportion of reliable data.

The majority of the study area is of very low to low salinity (0–0.14%) (Figure 3.8 & Table 3.9). Although the upper limits of this range may still affect some less salt-tolerant vegetation.

Table 3.9 Salinity of specific zones.

Salinity (area in hectares)					
ZONE	**0 - 0.04% (v. low)**	**0.05 - 0.14% (low)**	**0.15 - 0.29% (medium)**	**0.3 - 0.69% (high)**	**TOTAL**
A	1675.94	3246.37		5.61	4927.92
B	585.31	2253.93	823.11	500.24	4162.59
C	9.00	160.19	31.33	389.22	589.74
D	1503.90	243.73	21.62		1769.25
E	56.14	4.41	85.90		146.44
F	35.57	306.37	141.12	45.94	529.01
G	67.92		97.57	42.63	208.12
H	5.76	524.92		106.22	636.90
TOTAL	3939.54	6739.93	1200.65	1089.86	12969.97
% TOTAL	30.37	51.97	9.26	8.40	100.00

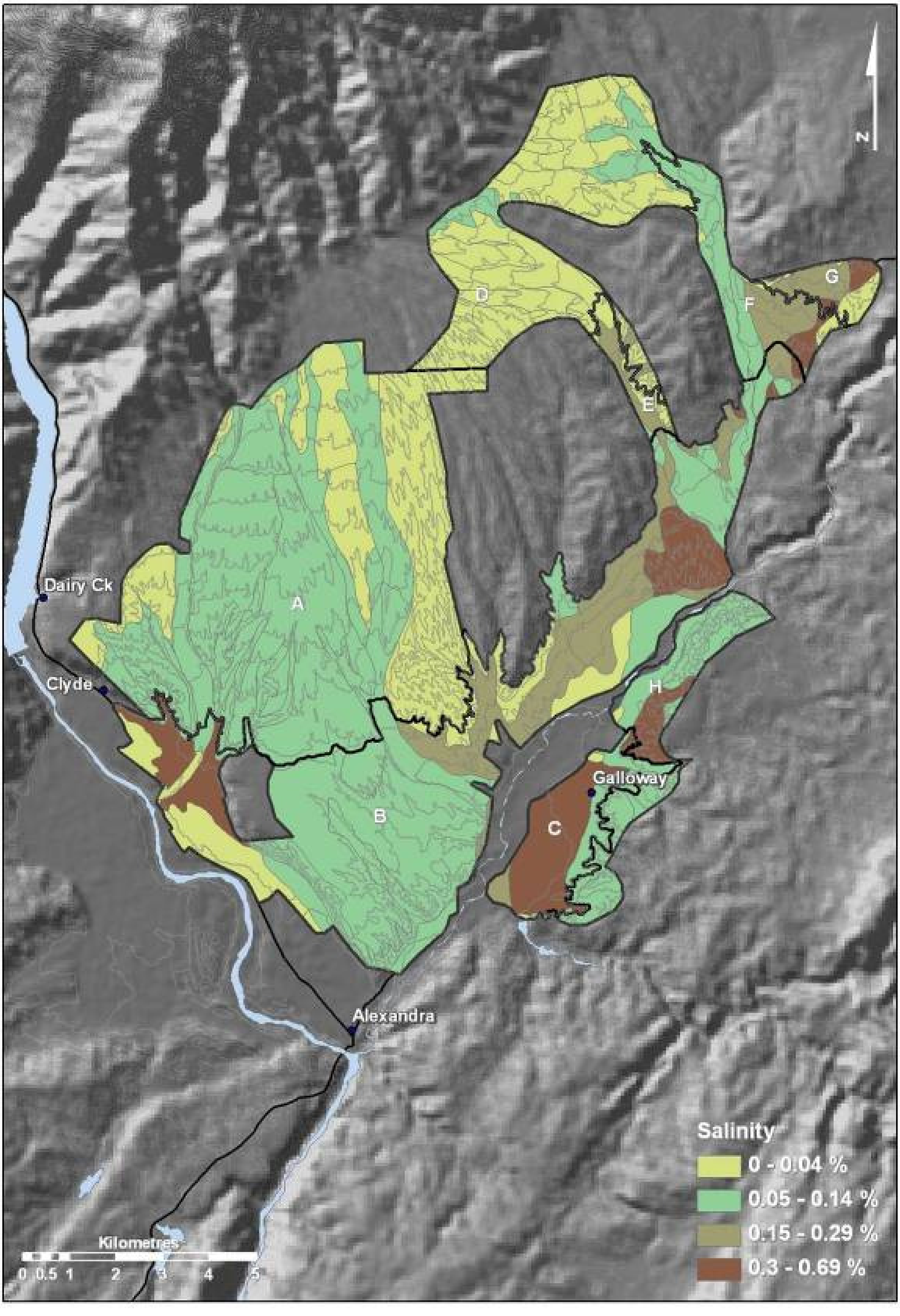

Figure 3.8 Salinity of study area.

3.4.6 Profile readily available water content

The soil's Profile Readily Available Water content (PRAW) also known as Available Moisture Content (AMC) describes the water that can be readily absorbed by plant roots without resulting in water deficit stress. This is generally assumed to be the water content difference between field capacity and permanent wilting point. Field capacity describes the maximum amount of water a soil can hold against gravitational force. Permanent wilting point is the moisture content below which plants can no longer extract water against capillary tension. At this point plants will suffer extreme water stress and die.

The quality of the profile readily available water content data has been derived from relationships with other soils. It is therefore of unknown reliability for the majority of the study area. There is however, a small pocket of reliable data on the eastern boundary of Zone C (Figure A7).

Over 70% of the study area is considered to have very low PRAW (Figure 3.9 & Table 3.10). This is largely a reflection of this classification being a function of the soil profile to 0.9m, or the potential rooting depth (which ever is the lesser) (Newson *et al.*2006).

Table 3.10 Profile readily available water content of specific zones.

Profile readily available water (area in hectares)					
ZONE	**75 – 99mm (mod. high)**	**50 - 74mm (moderate)**	**25 - 49mm (low)**	**0 - 24mm (v. low)**	**TOTAL**
A		11.34	858.16	4058.41	4927.92
B		200.26	710.97	3251.36	4162.59
C			105.19	484.55	589.74
D	202.47	354.82	298.95	913.01	1769.25
E		21.79	85.90	38.75	146.44
F		0.62	307.27	221.11	529.01
G			140.20	67.92	208.12
H			148.12	488.78	636.90
TOTAL	202.47	588.83	2654.75	9523.91	12969.97
% TOTAL	1.56	4.54	20.47	73.43	100.00

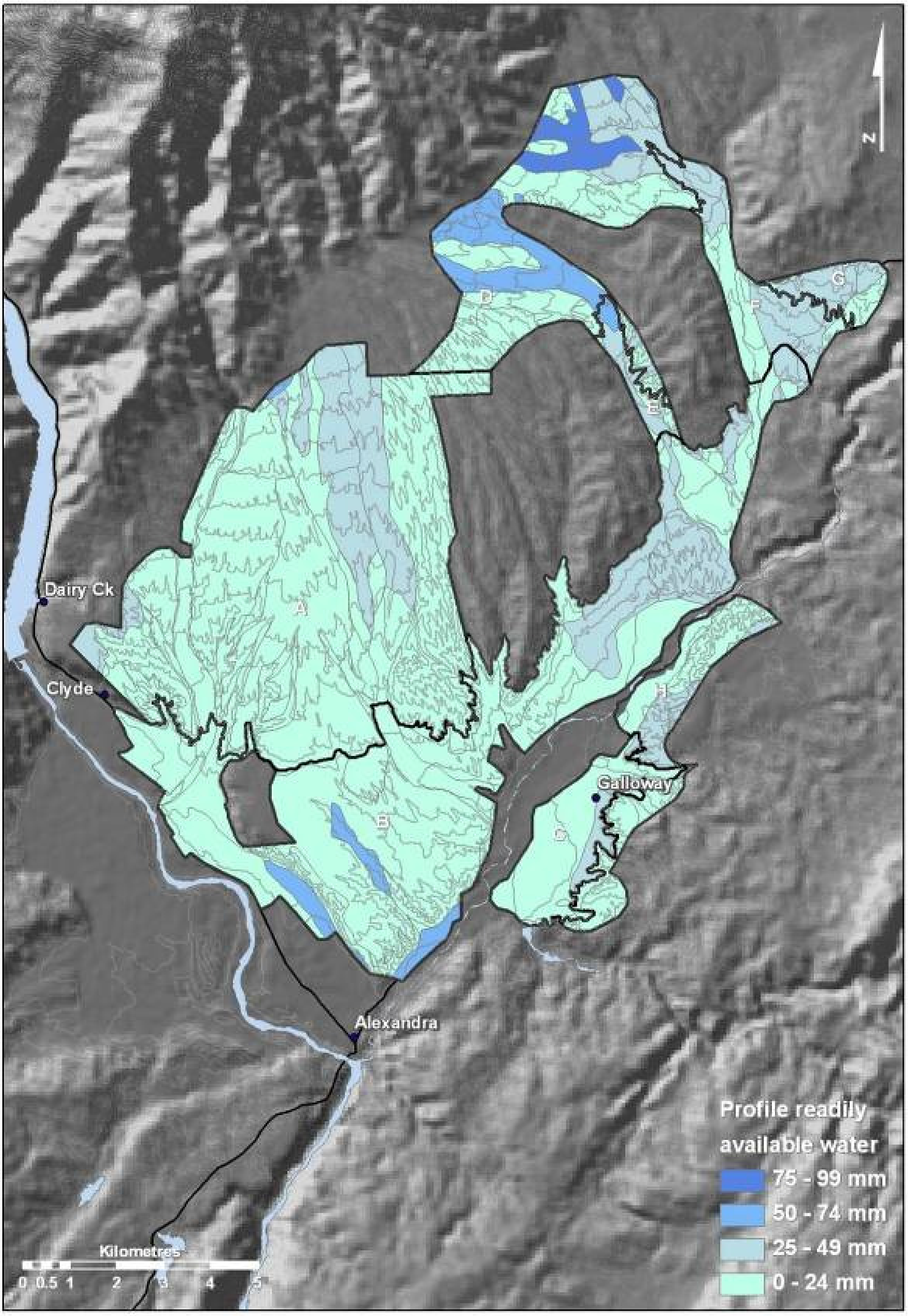

Figure 3.9 Soil profile readily available water of the study area.

3.5 Soils by zones

The above discussion shows that each specific zone within the study area has distinctive soil properties. These properties are likely to affect the hydraulic behaviour of the soils, their capacity to store water, and their response to irrigation. These properties will also affect how any irrigation should be applied so that the water is used effectively and efficiently.

Zone A

Zone A is the largest of the areas in the study (approx. 4930ha). A small portion of this zone is currently being irrigated. Three quarters of the soils in Zone A are semiarid, mostly anthropic, with 60% of these being between 100–200mm deep (Table 3.2 & 3.3). Along the eastern boundary of this zone a band of slightly deeper (200-450mm) semiarid soil occurs. A thin finger of 450-900mm deep soils are found to the west of this; mainly associated with gley organic soils.

The majority of the soils in Zone A are moderately well drained with a rooting depth of 450–590mm (Tables 3.5 & 3.6). There appears to be a slowly permeable horizon underlying some of these soils; with 41% of the area being moderate/slow, while 35% has rapid/slow permeability (Table 3.7). Moderate to low macroporosity (between 5–9.9%) covers 80% of this zone with a sector of high macroporosity (10-14.9%) found in a similar area to the deepest soils (Figures 3.3 & 3.7, Table 3.8).

Very low salinity (0–0.04%) covers 65% of Zone A. The remainder of the area has low salinity (0.05–0.14%) (Figure 3.8, Table 3.9). Similarly, the profile readily available water content (PRAW) for this zone is very low < 24mm for 82% of the area, and low (25 – 49mm) for the remainder (Figure 3.9, Table 3.10).

Zone B

Zone B also covers a large area (approx. 4163ha) and is currently being irrigated. Semiarid soils cover 90% of this zone; where 40% of these soils are immature with impeded drainage. The majority of these soils are stoney, although deeper soils up to 900mm are found in the northern areas. A few small pockets of deep soil are scattered across the zone. The potential rooting depths also largely follow this pattern (Figures 3.3 & 3.4). These soils are mainly moderately-well drained in the north–eastern sector and well-drained to the south (Figure 3.5). Moderate/slow permeability is apparent in the north-west and southern sectors; and rapid permeability in the middle and south-western sectors (Figure 3.6). Very-low to low (0–7.4%) macroporosity is found in the north-east, while areas of moderate to high macroporosity occur in the mid-section. Pockets of high to very high macroporosity (10–25%) border the rivers in the south-west and central-east areas (Figure 3.7).

Low salinity soils dominate Zone B, mainly centred in the south with some pockets in the north-west. Medium salinity soils (0.15–0.29%) are found in the mid-sections while pockets of high salinity (0.3 - 0.69%), totalling 12% of the zones, are found in the middle and south-western sections (Figure 3.8, Table 3.9). Much of Zone B also has very low PRAW, although low readings (25–49mm) are found in the northern sectors. Small pockets, covering 200ha, of moderate PRAW (50–74mm) are found in the southern sectors (Figure 3.9, Table 3.10).

Zone C

Zone C is smaller (approx. 590ha) and the last of the currently irrigated areas. It is dominated by shallow to moderately deep, semiarid–argillic soils (Tables 3.2 & 3.3). Much of Zone C has well drained soils with a shallow potential rooting depth between 250–400mm (Figures 3.4 & 3.5).

The majority of this zone has moderate permeability and low macroporosity, covering 72% and 80% of the area respectively (Table 3.7 & 3.8). High salinity soils dominate Zone C covering 66% of the area, with a band of low salinity soils on the eastern border (Figure 3.8, Table 3.9). Similarly, a band of low PRAW lies on the eastern border, while the rest of the zone has very low PRAW (Figure 3.9).

Zone D

Zone D rises above 300m elevation and covers an area of approximately 1770ha. Half of Zone D consists of semiarid-anthropic or argillic soils. Of what remains, 30% are pallic-argillic, and 9% are gley-organic (Table 3.2). The soil depths are evenly distributed between moderately deep, shallow and stony (Table 3.3). Zone D has the largest areas of deep potential rooting depth covering 479ha (27% of this zone). However, large pockets of shallow rooting depth soils are interspersed between these (Table 3.4).

This zone is predominantly moderately well drained (66%), with small pockets of both well and poorly drained soils (Table 3.6). The permeability follows a similar pattern, being moderate/slow with small pockets of both moderate and slow permeability (Table 3.7). The majority of the soils found in this zone have moderate to high macroporosity, with very-low to low macroporosity covering only 15% of the area (Table 3.8).

Very low salinity soils cover 85% of Zone D, with fingers of low salinity soils in central and north-eastern sections (Figure 3.8, Table 3.9). This zone appears to have the most varied PRAW of the whole study area (Figure 3.9). While very-low PRAW covers half of the area, bands of low to moderately-high PRAW are also present.

Zone E

Zone E is the smallest zone (approx. 146ha) and consists of semiarid, mainly impeded moderately-well drained, shallow soils with low salinity (Tables 3.2, 3.3, 3.5 & 3.9). However, the potential rooting depth of this area is estimated to be 600–890mm (Table 3.4). The permeability is mainly moderate/slow, and much of this area is of low to moderate macroporosity except for a 22ha pocket of high macroporosity in the north (Tables 3.7 & 3.8). Similarly the PRAW of this zone is mainly low with a 22ha section of moderate (50–74mm) PRAW in the north.

Zone F

Zone F is approximately 630ha, half of which consists of semiarid-argillic and impeded soils, with gley-organic and recent soils occupying the rest of the area (Table 3.2). The recent soil tends to be stony, while the other soils range between shallow and moderately-deep. Very shallow potential rooting depths are found along the saddle of the hill dissecting the zone. Slightly deeper soils are found on either side of this, and a moderately deep pocket (600–890mm) is found to the east (Tables 3.3 & 3.4). This zone consists of mainly moderately well-drained soils, with poorly drained soils on the north-western limit. The permeability of these soils are moderate/rapid on the hill saddle and moderate/slow either side. This pattern repeated with high macroporosity on the saddle and low either side (Figures 3.6 & 3.7).

The western half of Zone F is comprised of low salinity soils while the other half contains bands of medium, high, and very-low salinity soils, reducing in size respectively towards the east (Figure 3.8). The higher elevations of this zone have a very-low PRAW which rises to 25–49mm at lower elevations (Figure 3.9).

Zone G

Zone G is small (approx. 200ha) and rises above 300m elevation. It consists of mainly semiarid, impeded, moderately-well to well-drained soils (Table 3.2 & 3.6). 60% of the zone has shallow soil depths, with small pockets of both stony and moderately deep soils (Table 3.3). The soils in this zone predominantly have a moderately deep potential rooting depth (600–890mm), moderate/slow permeability, and a moderate to low macroporosity (Table 3.4, 3.7 & 3.8). Low salinity soils with very low PRAW cover the eastern third of Zone G, while medium to high salinity, low PRAW soils dominate the west (Figure 3.8 & 3.9).

Zone H

Zone H is approximately 662ha, much of which is semiarid-argillic hill soil and therefore of unclassified depth (Table 3.2). There is a 44ha pocket of recent deep soil beside the Manuherikia River. However, this is associated with an estimated very shallow potential rooting depth (Table 3.3 & 3.4). Shallow to stony soil depths and shallow rooting depths are present in the southern reaches of this zone. Some of the unclassified hill country soils are estimated to have moderately deep potential rooting depths with slow to moderate permeability (Table 3.4 & Figure 3.6). High macroporosity is found in this zone closest to the river, while moderate and very low macroporosity is found in the hill soils and towards the southern sectors (Figure 3.7).

Low salinity soils cover 80% of Zone H, although a 106ha pocket of high salinity soil is apparent within the mid section (Figure 3.8, Table 3.9). This pattern is reflected in the PRAW with the majority of the zone having very-low readily available water with a pocket of low PRAW in the mid section (Figure 3.9).

4 Climate

Irrigation is essential to maintaining agricultural production especially with the intensification and diversification of agriculture. Determining the amount of water naturally available to sustain crops requires an understanding of the spatial and temporal distribution of both rainfall and evapotranspiration.

A critical element in the working of any environmental system is the availability of water. It determines plant type, plant growth, and agricultural production as well as a range of other environmental attributes. Until the full seasonal pattern of water availability is appreciated it is difficult to determine what water resources may be present, or needed, for human activities.

At high application rates, much of the irrigation water often flows through the macropores in the soil, bypassing the root zone, and simply recharging the groundwater. This costs a significant amount of money with little return in terms of increased productivity. It also decreases the water resources available to others for no practical purpose. On the other hand, if water applied to the soil surface evaporates before being used by the crops then this is also an inefficient practice. Understanding the irrigation requirements of crops and soils in the study area, and the most efficient methods of applying this water, are therefore of critical importance to the long-term management of the water resources of this area.

A water balance or budget assesses the availability of water throughout the year. Water enters the budget in the form of precipitation and is lost through evapotranspiration. Potential evapotranspiration (PE) losses are a function of the incoming solar radiation, the vapour pressure deficit, and the wind. PE represents the maximum amount of water which will be lost if water is in unlimited supply. However, while potential evapotranspiration is the potential loss of water this is not always attained because of limitations on the availability of the water. The actual evapotranspiration (AE) rate, therefore, represents the amount of water that is lost, and is a function of both the potential evapotranspiration and the water availability. Potential evapotranspiration will use up the incoming precipitation and if this is insufficient to satisfy the demand then the soil moisture will be utilised (Hawke *et al*., 2000).

Thus, the soil moisture represents a limited storage capacity within the pores of the soil. When inputs of water exceed outputs the storage is recharged. Alternatively, when outputs potentially exceed inputs the soil moisture acts as a buffer to reduce stress on plants.

Determining the amount of water available to sustain crops as a result of the climate is therefore the first step when considering the need for irrigation, and the amount of water that must be applied. Quantification of both inputs and outputs of moisture from the system (the rainfall and evapotranspiration) is required, as is the amount of water which can be held in the soil. Understanding the amount and distribution of this naturally available water is critical for efficient irrigation allocation. It represents the component of crop water which does not need to be supplied through augmentation strategies i.e. irrigation.

4.1 Location of rainfall sites

Rainfall data from 27 sites were obtained from NIWA climatological archive. As with many parts in New Zealand, the rainfall network in the Manuherikia has been reduced since the 1980's, through station closures. Although there is still reasonably good spatial coverage, the majority of sites are in the valleys, and near the towns and dams (Figure 4.1). There are few sites at higher elevations.

When using rainfall data there is often considerable variability over the length of the station records (Table 4.1). This variability needs to be considered when determining rainfall trends, averages, minimums, and temporal variability.

Pan evaporation data and potential evapotranspiration data were each obtained from 4 sites. Despite a sparse spatial coverage, losses over summer will be expected to be higher than at other times of the year because of increased energy and dry winds. Potential evapotranspiration has also been known to be relatively consistent across wide areas because of limited variability in the major controlling factors.

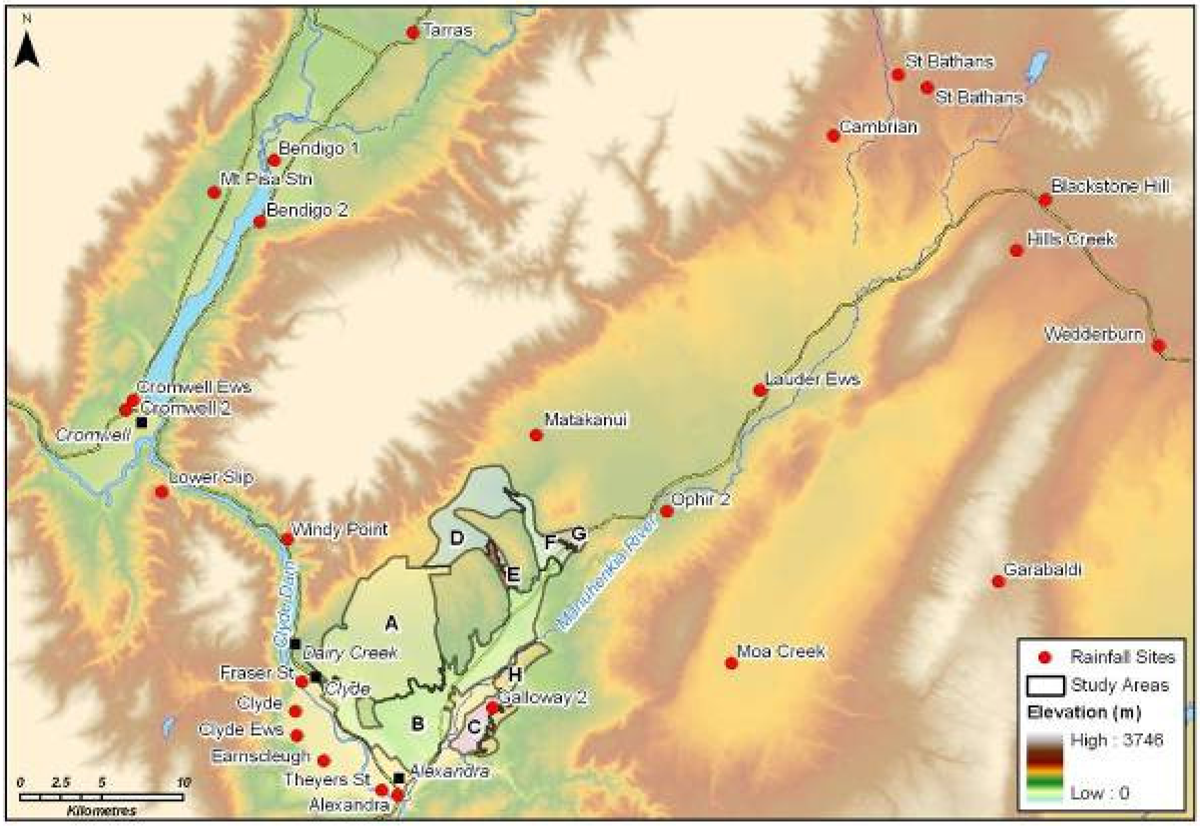

Figure 4.1 Location of the rainfall sites.

Table 4.1 Length of record of rainfall stations.

Site Name	Site Number	Length of Record of Rainfall Stations																								Total Years	Years
		95	0	5	10	15	20	25	30	35	40	45	50	5	60	65	70	75	80	85	90	95	00	05	10		
Alexandra, Theyers St	I59238																									11	1983-1994
Alexandra	I59236																									80	1929-2009
Earnscleugh D.S.I.R.	I59232																									36	1947-1983
Clyde	I59235																									13	1983-1996
Clyde Ews	I59239																									14	1995-2009
Galloway 2	I59241																									61	1922-1983
Clyde, Fraser St	I59131																									93	1896-1989
Bendigo 2	I49932																									31	1978-2009
Bendigo 1	I49931																									24	1955-1979
Cromwell Ews	I59013																									3	2006-2009
Cromwell 2	I59024																									23	1984-2007
Mt Pisa Station	I49921																									16	1908-1924
Tarras	I49841																									84	1902-1986
Ophir 2	I59161																									85	1924-2009
Matakanui	I59051																									62	1947-2009
Lauder Ews	I59065																									24	1985-2009
Windy Point	590115																									20	1989-2009
Lower Slip	590144																									20	1989-2009
Moa Creek	I59162																									71	1913-1984
St Bathans	I49881																									39	1892-1931
Cambrian	I49971																									37	1936-1973
Blackstone Hill	I49991																									92	1915-2007
St Bathans	I49883																									20	1989-2009

4.2 Average annual rainfall

Three rainfall stations with long records were used to assess the variation in annual precipitation about the long-term median. Median values were used because they are a more robust measure than the mean, and less subject to the effect of extreme values. Annual precipitation varies about the long-term median by around 100mm where this fluctuation is relatively short lived (Figure 4.2). While random variability is apparent about the median rainfall there is no indication of either cyclic behaviour, or a consistent trend. It would appear that the annual rainfall at Blackstone Hill is significantly more varied than at the other stations. This site is approximately 50km to the northeast of the others and the rainfall variability may include a regional trend in rainfall. This site is also significantly higher that the others and the high degree of temporal variability may also be a function of the orographic effect. The lack of rainfall stations means that the cause of this variability cannot be confirmed with any greater precision.

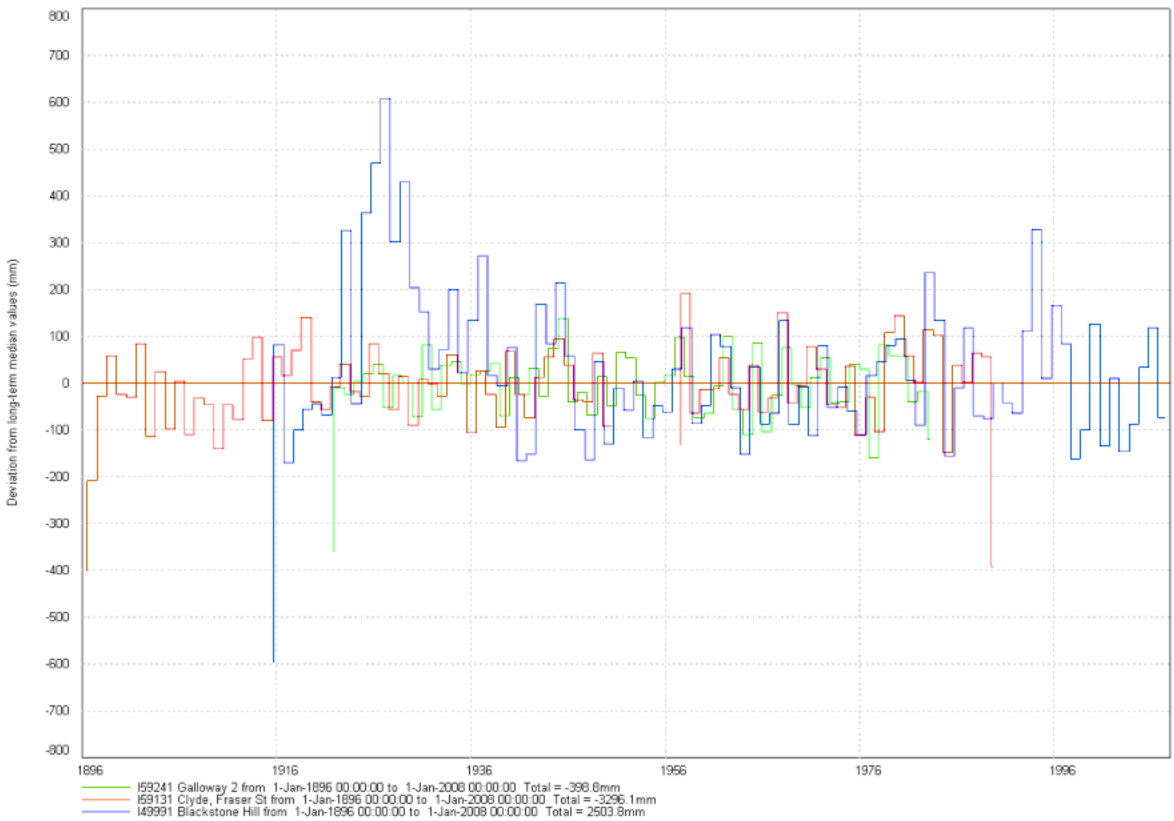

Figure 4.2 Annual deviation from the long-term average rainfall.

4.3 Spatial distribution

The spatial distribution of the annual mean and median rainfall shows a strong rainfall gradient associated with the influence of the Dunstan Mountains (Table 4.2). The highest rainfalls are experienced along the axial range. There is also a rain shadow effect caused by the mountains which reduces the rainfall significantly on the plains and valleys below (Figure 4.3).

Table 4.2 Average annual rainfall (mm), median (mm) and height (m) for selected sites in the Manuherikia region.

Site Number	Site Name	Mean Annual Rainfall (mm)	Median Annual Rainfall (mm)	Height (m)
I59238	Alexandra, Theyers St	345	354	141
I59236	Alexandra	314	297	150
I59232	Earnscleugh D.S.I.R.	360	360	152
I59235	Clyde	432	400	171
I59239	Clyde Ews	383	370	171
I59241	Galloway 2	359	359	177
I59131	Clyde, Fraser St	402	402	183
I49932	Bendigo 2	414	415	200
I49931	Bendigo 1	442	440	202
I59013	Cromwell Ews	332	355	213
I59024	Cromwell 2	446	416	213
I49921	Mt Pisa Station	420	420	263
I49841	Tarras	475	467	290
I59161	Ophir 2	409	406	305
I59051	Matakanui	528	513	357
I59065	Lauder Ews	409	406	375
590115	Windy Point	490	463	410
590144	Lower Slip	396	382	425
I59162	Moa Creek	400	397	427
I49881	St Bathans	767	732	538
I49971	Cambrian	707	713	549
I49991	Blackstone Hill	629	596	637
I49883	St Bathans	653	594	640

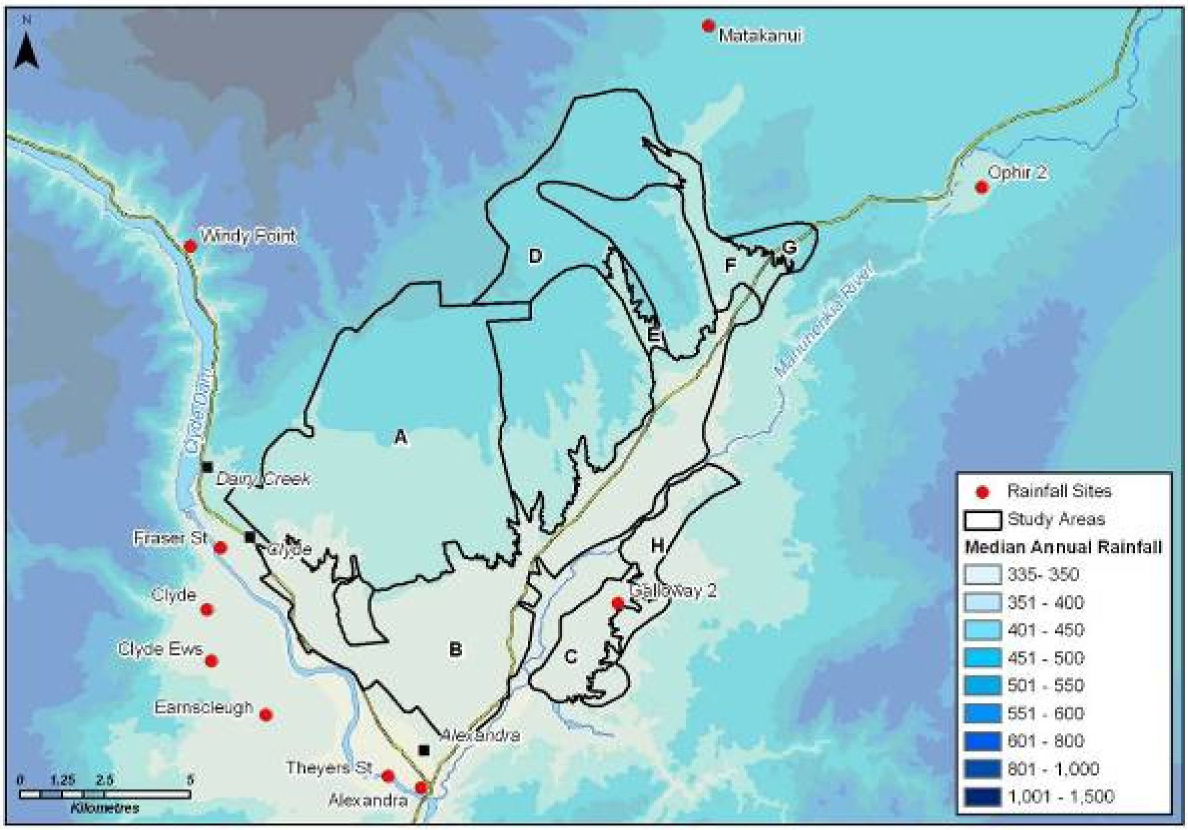

Figure 4.3 Median annual rainfall (mm).

4.4 Summer 'growing season' rainfall

When estimating irrigation water demands the amount of rainfall between September and the end of April, the "growing season", is critical. It is during this growing season that irrigation is most commonly needed, especially in the peak months of December-February. During the September-April period the highest rainfall totals are found on the Dunstan Mountains decreasing into the basin near Alexandra (Figure 4.4). This is a function of the orographic effect discussed previously.

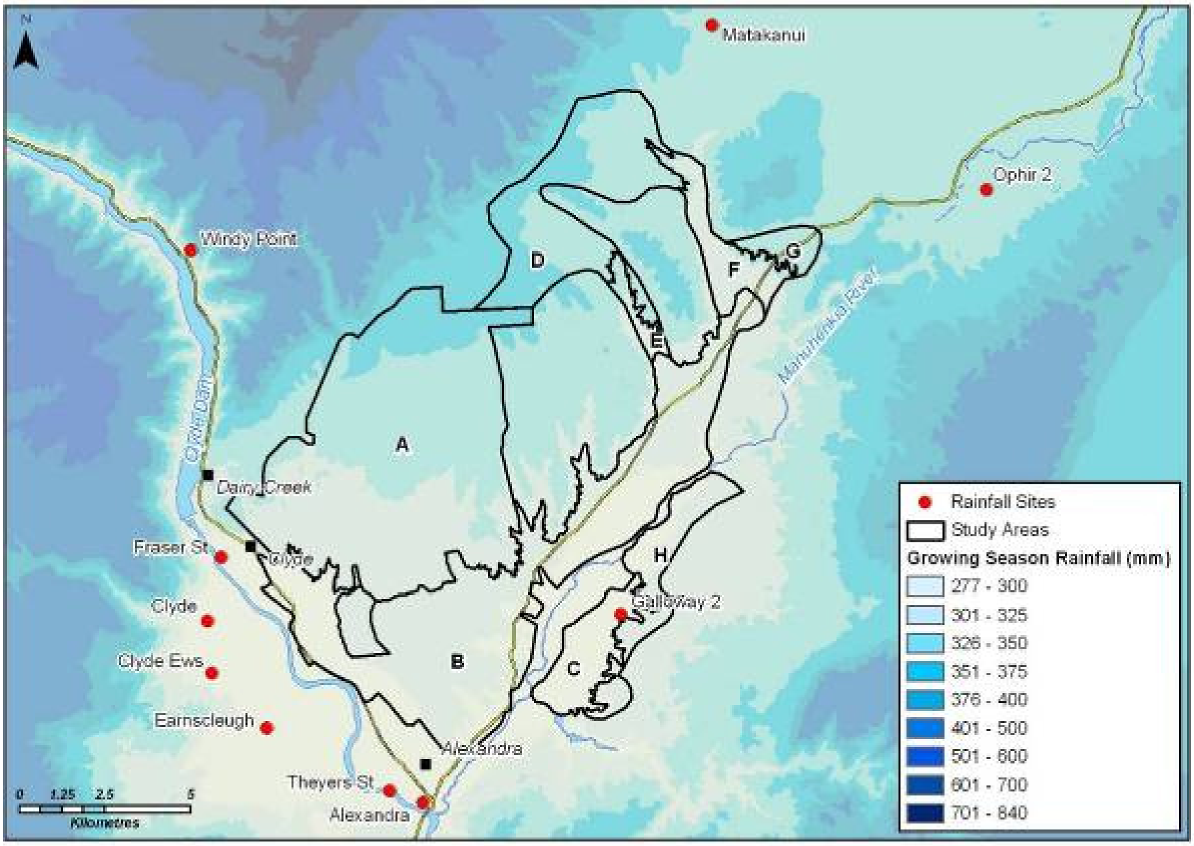

Figure 4.4 Growing season median annual rainfall (mm).

The variability apparent in the annual rainfall also extends to the monthly patterns. To ensure sustainable water resource management and risk mitigation this variability needs to be considered.

Therefore, the one-in-five year (Q_5) minimum and one-in-ten-year (Q_{10}) minimum summer growing season rainfall for each site was determined (Figures 4.5 & 4.6). This analysis is based on the assumption that historical records are a reasonable model upon which future rainfall can be estimated (Pearson and Davies, 1997). The discussion relating to Figure 4.2, and the lack of any consistent trend in rainfall, suggests that the assumption is reasonable. It has also been suggested that the Q_5 and Q_{10} growing season rainfalls can be used as a standard return period that farmers can use for planning. Analysis of data used the best of three statistical distributions to fit the data; Gumbel, GEV (Generalised Extreme Value) and Pearson 3. The Q_5 and Q_{10} summer rainfalls were then estimated from this distribution.

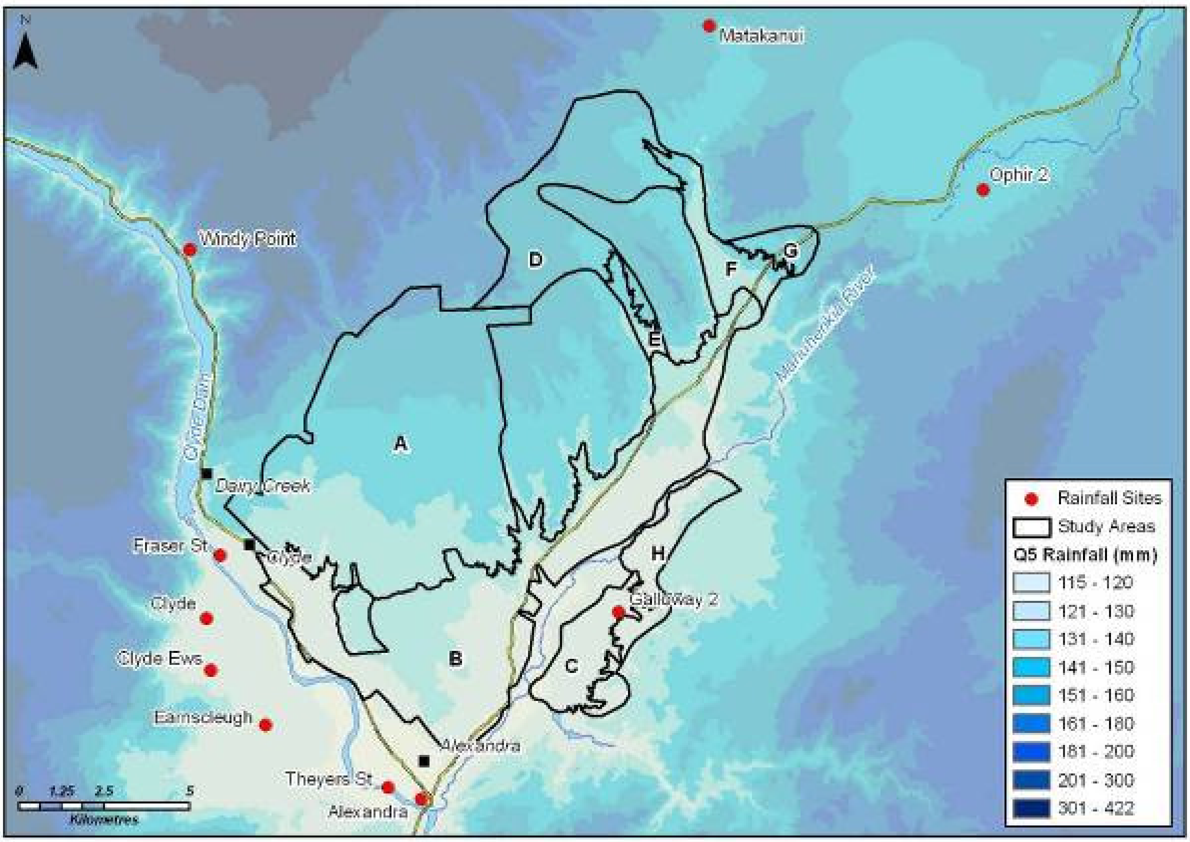

Figure 4.5 One-in-five year (Q_5) minimum growing season rainfall (mm).

The difference between the average summer growing season rainfall and the minimum one-in-five year growing season rainfall (Q_5) ranged between 131.6 and 218.1mm. The Q_5 rainfall is approximately 45% of the average summer growing season precipitation (Table 4.3). The Q_5 rainfall can be used as a relatively robust measure on which to estimate naturally available precipitation. This is known as the 'dependable rainfall'.

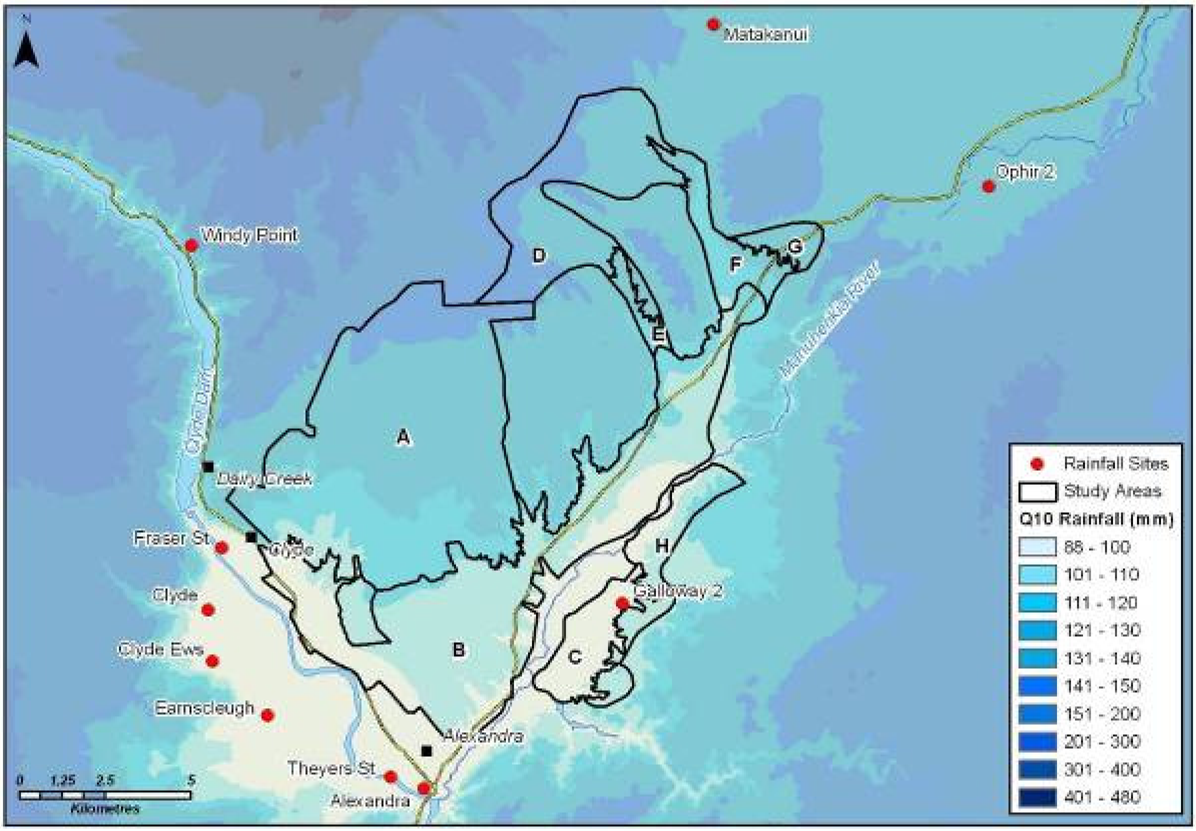

Figure 4.6 One in ten-year (Q_{10}) minimum growing season rainfall (mm).

The difference between the average summer growing season rainfall and the minimum one in ten-year growing season rainfall (Q_{10}) has a range of approx. 400mm for the region. The Q_{10} rainfall is approximately 41.5% of the average summer growing season precipitation (Table 4.3). When compared with the Q_5 rainfall, the Q_{10} is 3.5% smaller which equates to approximately 10mm less rainfall. This means a longer, more severe dry season. Like the Q_5, the Q_{10} rainfall can be used as a relatively robust measure on which to estimate naturally available precipitation.

Table 4.3 The difference between the median growing season rainfall and the Q_5 and Q_{10} events.

Site Name	Site Number	Median growing season rainfall (mm)	Q_5 (mm)	Difference (mm)	% of median	Q_{10} (mm)	Difference (mm)	% of median
Windy Point	590115	354.8	155.8	199.0	44	144.7	210.1	41
Tarras	I49841	317.0	142.4	174.6	45	131.9	185.1	42
Blackstone Hill	I49991	423.0	204.9	218.1	48	193.4	229.6	46
Cromwell 2	I59024	286.0	154.4	131.6	54	146.2	139.8	51
Matakanui	I59051	354.0	156.6	197.4	44	141.7	212.3	40
Lauder Ews	I59065	340.0	147.6	192.4	43	143.1	196.9	42
Clyde, Fraser St	I59131	287.0	107.3	179.7	37	90.3	196.7	31
Ophir 2	I59161	310.5	144.9	165.6	47	134.4	176.1	43
Clyde	I59235	308.0	150.1	157.9	49	146.8	161.2	48
Clyde Ews	I59239	257.0	113.2	143.8	44	101.2	155.8	39
Galloway 2	I59241	272.0	105.9	166.1	39	93.6	178.4	34

4.5 Evapotranspiration

Pan evaporation data, Penman open water evaporation, Penman potential evapotranspiration, and Priestly-Taylor potential evapotranspiration data are all recorded at a number of sites within the region. Priestly-Taylor potential evapotranspiration estimations are available at most sites providing good spatial coverage. This measure is commonly used in evaporation studies and so was also used in this study. Data showed a good correlation (0.88) between elevation and evapotranspiration enabling the creation of a map showing the spatial distribution of potential evapotranspiration (Figure 4.7) over the growing season. Low evapotranspiration values during the winter months are most likely the result of the very low temperatures experienced in this region. These low temperatures cause the water to freeze thus producing little or no evaporation.

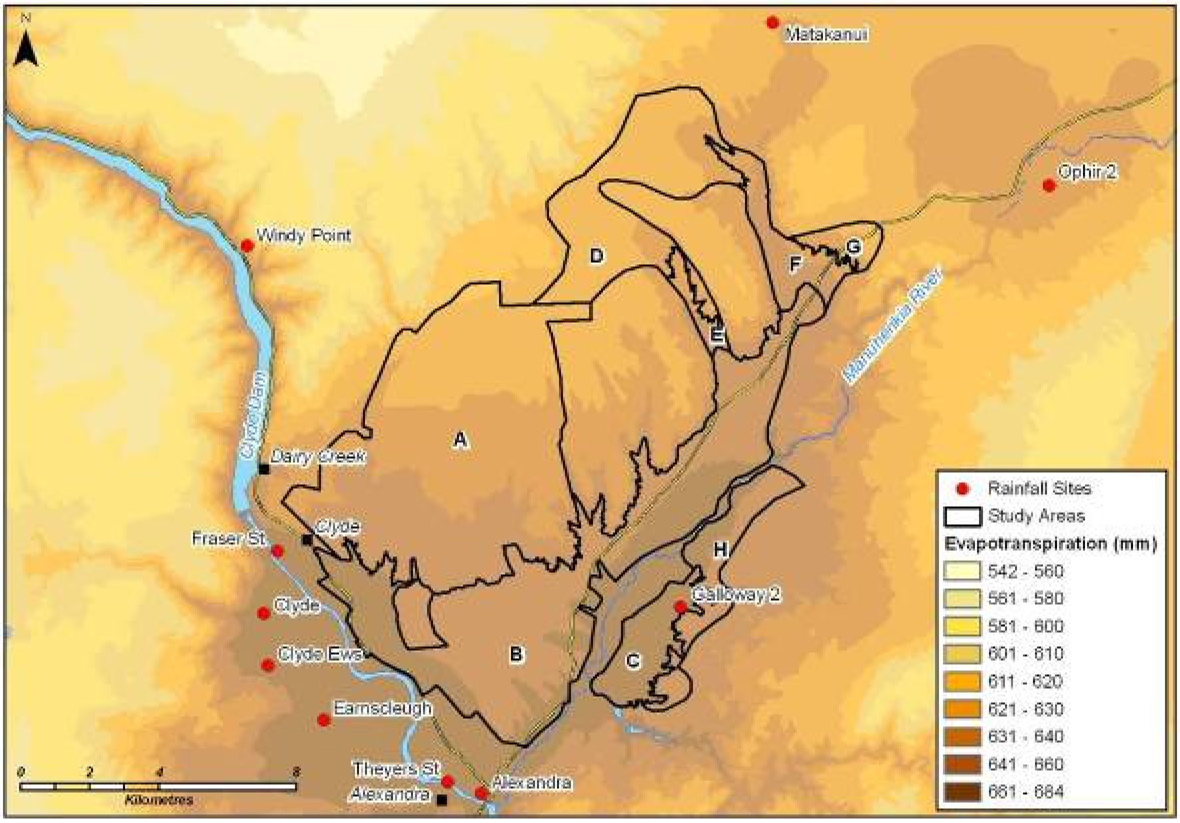

Figure 4.7 Growing season Priestly-Taylor potential evapotranspiration (mm).

4.6 Effective precipitation

The difference between rainfall and potential evapotranspiration losses determines the effective precipitation. If evaporation losses are greater than the rainfall over any period the shortfall will be made up of any available soil moisture. If there is not enough moisture in the soil then a deficit occurs and plants will become stressed unless irrigated.

The lower Manuherikia Valley is the most susceptible to the occurrence of deficits (Figure 4.8). This area receives the least amount of rain and has the highest evapotranspiration rates. A period of surplus in rainfall is needed to ensure that at some time of the year water is available to recharge the soil moisture storage. If soil moisture replenishment is low, or the soil has a low storage capacity, the moisture in soil storage may be depleted over the growing season resulting in water stress (Hawke *et al*, 2000).

In the valley the average summer growing season effective precipitation ranges between 300mm and -400mm. Thus, the effective precipitation is severely limited by the high evapotranspiration (Figure 4.8). During the minimum one-in-five and one-in-ten year rainfall season not even the higher elevation areas experience an effective precipitation surplus (Figures 4.9 & 4.10). Therefore, irrigation is required over the entire area to avoid moisture stress in plants.

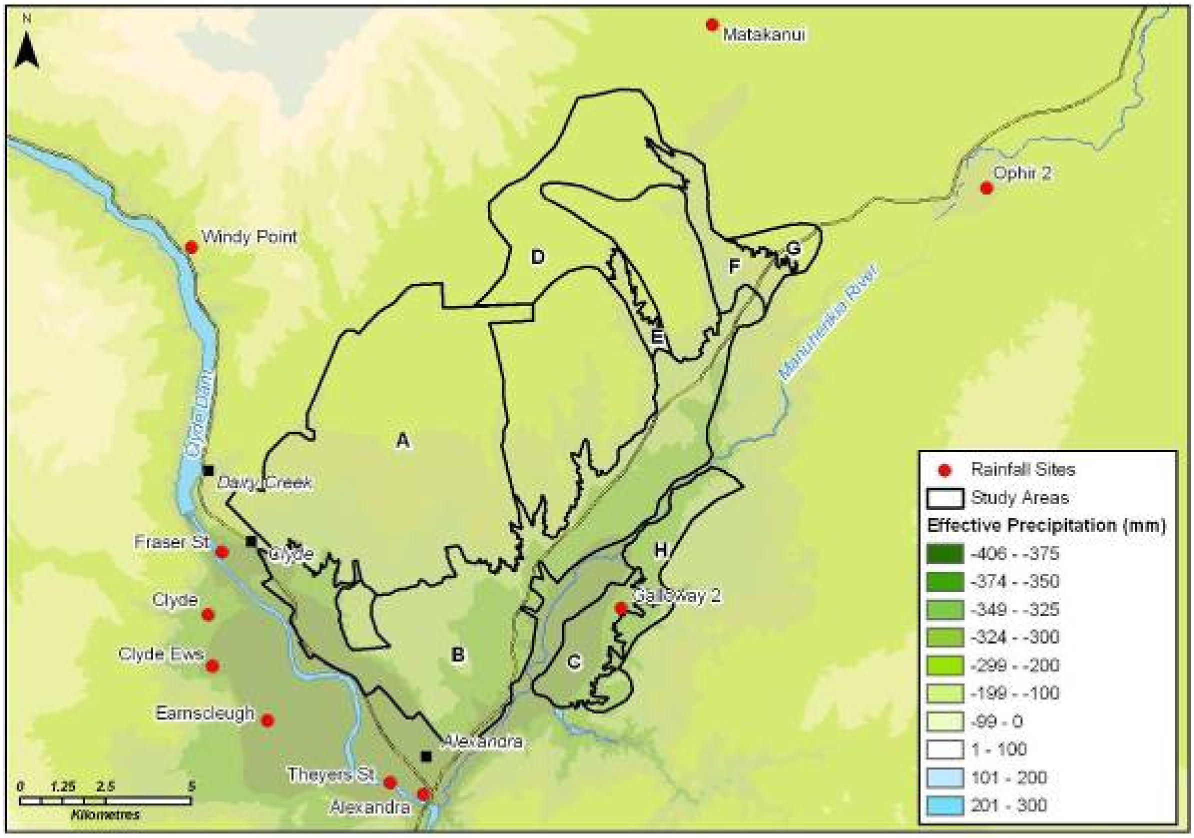

Figure 4.8 Growing season effective precipitation (mm).

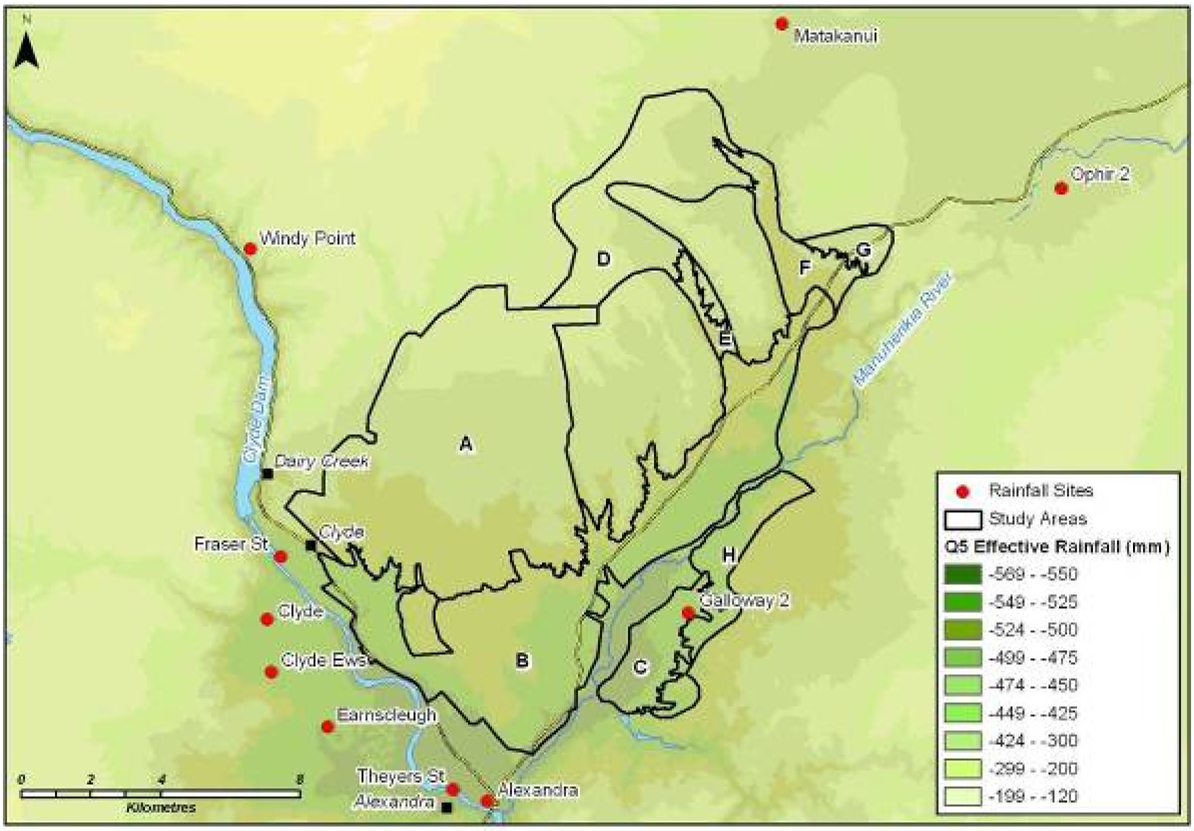

Figure 4.9 One-in-five year minimum growing season effective precipitation (mm).

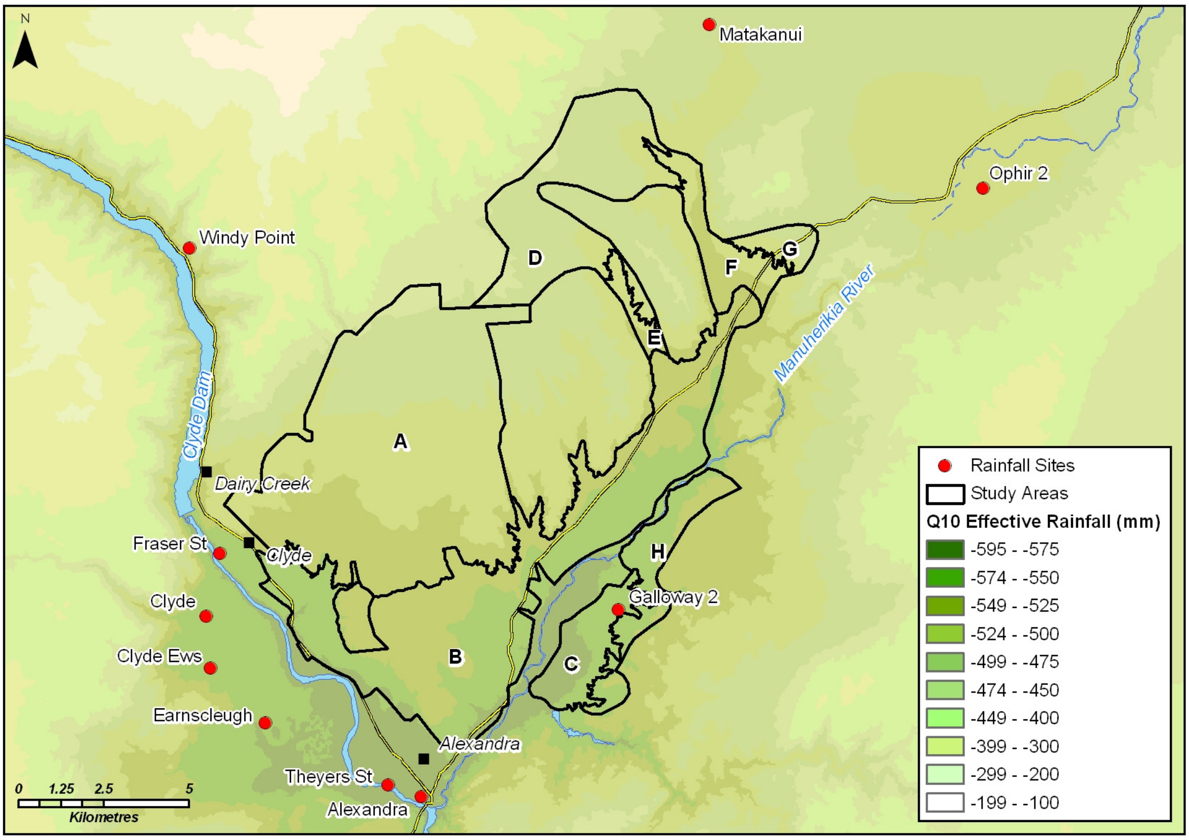

Figure 4.10 One-in-ten year minimum growing season effective precipitation (mm).

4.7 Soil moisture deficit

Soil moisture is essentially the moisture in the soil that is available to supply plant growth. If evaporation losses are greater than the rainfall, the shortfall will be made up of any available soil moisture. If there is not enough moisture in the soil, then a deficit occurs and plants will become stressed unless irrigated.

Figure 4.11 shows the growing season soil moisture deficit where 0 is totally saturated soil and 150 is completely dry soil. The figure shows that only the lower part of the study area has a small amount of soil moisture available during the early part of the growing season. It should be noted that the assumption of a 150mm soil moisture capacity for the study area is overly optimistic. As shown in the analysis of soil properties, the correct measure is likely to be less than half of this for the soils of the study area. However, 150mm is the standard value used in the NIWA climatological archive, and it does indicate the spatial variability across the area

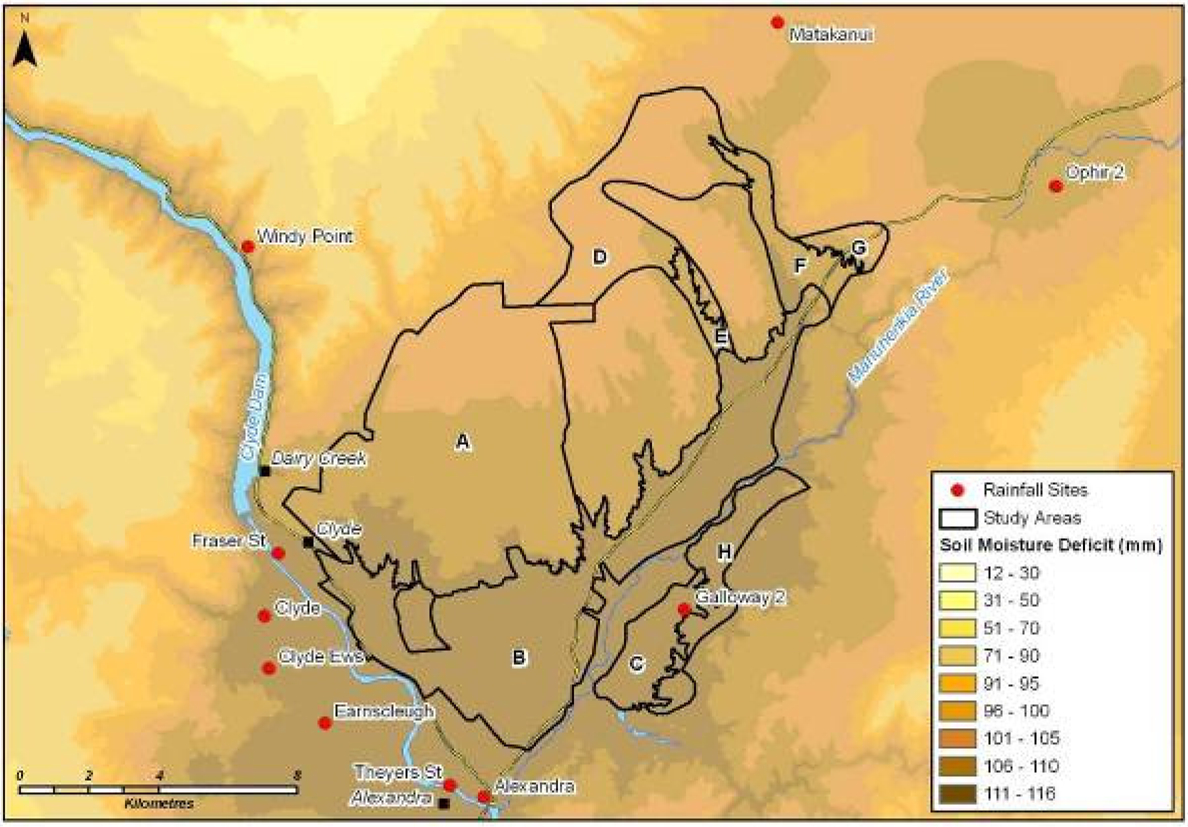

Figure 4.11 The growing season soil moisture deficit (mm).

5 The soil moisture balance

A soil moisture balance was used to estimate the availability of water within the soils of the study area throughout each month of the year. This is a simple conceptual model of the soil's water budget which accounts for water added, stored and removed from the system. This model can be used to estimate the irrigation needs of an area to maintain adequate water within the root zone (Morgan, 1997).

Water enters the system as precipitation (P) and is lost through evapotranspiration and runoff. Potential evapotranspiration (PE) is the maximum amount of water lost to the system (assuming an unlimited supply) as a result of solar radiation, wind speed and vapour pressure deficit (McConchie, 2000). However, because of limitations to water availability, this maximum is often not achieved. Actual evapotranspiration (AE) is a function of PE and water availability, and therefore quantifies the actual amount of water lost to the system.

In the water balance, precipitation is initially used to meet the PE. If precipitation is sufficient, then AE will equal PE. Any excess water will recharge the soil water storage (ST), or when that reaches capacity, become surplus (S) runoff. Water is therefore stored in the pores of the soil. This moisture is released to the plants and atmosphere when water supply from precipitation is short. However, moisture within the soil may not be sufficient to meet PE, resulting in a water deficit (D) which places plants under stress. During these times the soil must be irrigated to prevent lost production or ultimately death of the plant.

5.1 Inputs

Only the Galloway 2 rain-gauge is situated within the study area. However, data from the sites surrounding the study area all show that the monthly proportion of the annual median rainfall is very similar. It appears that elevation is the major control on the amount of rain received at any given point (Figure 5.1). That is the annual pattern of rainfall is consistent across the study area. It is only the amount of rainfall that varies.

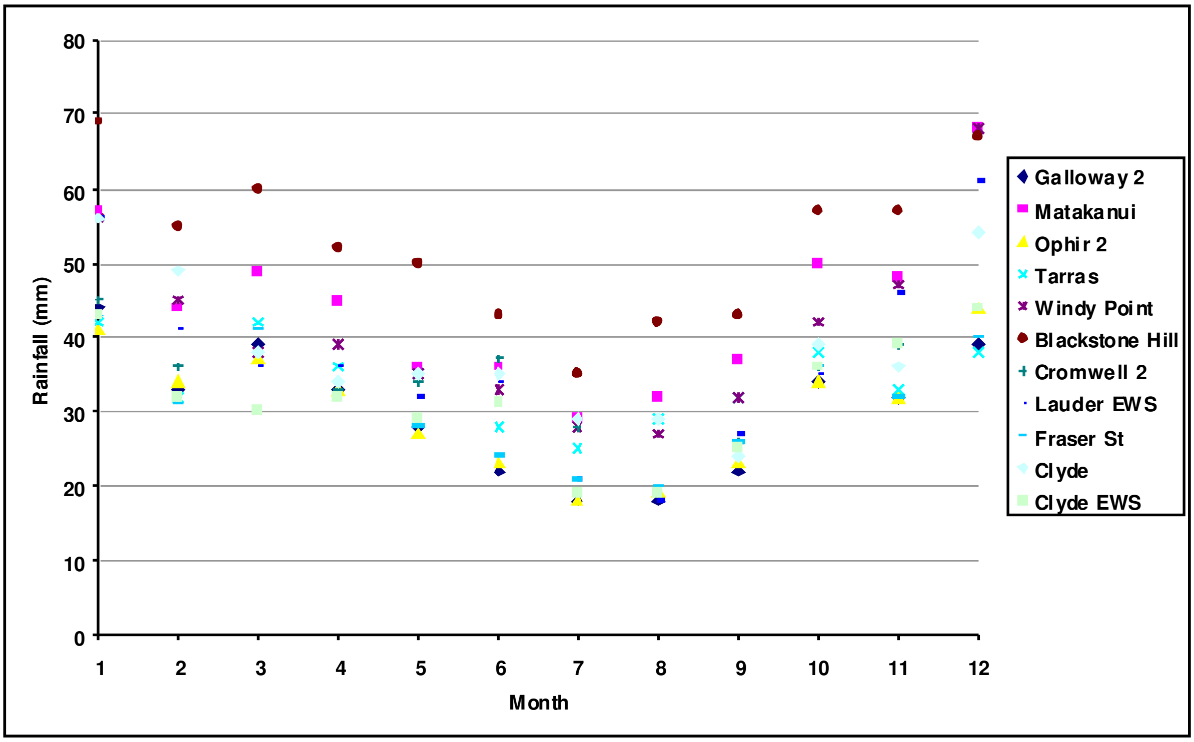

Figure 5.1 Monthly median rainfall for selected sites in the Manuherikia region.

Having established a relationship between elevation and median annual rainfall (Figure 4.3) the mean elevation of each of the specific zones was used to predict the monthly median rainfall. The Q_5 Clyde rainfall data (elevation 171m, median annual rainfall 150mm) was used as the baseline data to adjust the predicted rainfalls. This rainfall site has good quality data, without gaps, and is at the bottom of the valley from which elevations could be scaled. The mean elevation of each zone was calculated using GIS.

The annual Q_5 rainfall of each zone (R_{ZQ5A}) was calculated using Equation 5.1.

$$R_{ZQ5A} = ((E_Z - E_C) \times 0.1679) + R_{CQ5A}$$ **Equation 5.1**

Where E_Z is the mean elevation of the zone; E_C is the elevation of the Clyde rain-gauge; 0.1679 is derived from the slope of a linear regression of the median annual rainfall vs. elevation of all rain-gauge data ($R^2 = 0.72$); and R_{CQ5A} is the Q_5 median annual rainfall at Clyde rain-gauge.

Results are shown in Table 5.1. The modelled Q_5 annual median rainfall for Zone C is 46mm higher than that calculated using the rainfall record for Galloway 2 (177m elevation) in Table 4.3. This difference is a function of modelling the data across the whole study area; moving from point to areal data; and some uncertainty in the regression equation. However, this error is minor when spread over the whole year (4mm/month). This provides some indication of the error inherent in the analysis.

Table 5.1 Mean elevation and Q_5 median rainfall of specific zones.

Zone	Mean Height (m)	Q_5 Annual median rainfall (mm)
A	307	173
B	199	155
C	174	151
D	352	180
E	271	167
F	261	165
G	333	177
H	212	157

Monthly Q_5 Clyde rainfall (R_{CQ5M}) was calculated using the proportionality of the Q_5 Clyde annual median data to the monthly Clyde median rainfall data as in Equation 5.2

$$R_{CQ5M} = R_{CQ5A} / R_{CA} \times R_{CM}$$ **Equation 5.2**

Where R_{CA} is the median Clyde annual rainfall data, and R_{CM} is the monthly Clyde median rainfall data.

The monthly Q_5 rainfall of each zone (R_{ZQ5M}) was then calculated using Equation 5.3

$$R_{ZQ5M} = R_{ZQ5A} / R_{CQ5A} \times R_{CQ5M}$$ **Equation 5.3**

Results show Zone D to be consistently the wettest over all months, while Zone C is the driest (Table 5.2). As Zone D has the highest elevation and Zone C the lowest, these results seem to be reasonable given the acknowledged orographic effect.

Table 5.2 Q_5 monthly median rainfall of specific zones.

Zones	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
A	21.2	18.5	14.4	12.8	13.2	13.2	11.0	11.0	9.1	14.7	13.6	20.4	173
B	19.0	16.6	12.9	11.5	11.8	11.8	9.8	9.8	8.1	13.2	12.2	18.3	155
C	18.5	16.2	12.5	11.2	11.5	11.5	9.6	9.6	7.9	12.9	11.9	17.8	151
D	22.0	19.3	14.9	13.4	13.8	13.8	11.4	11.4	9.4	15.3	14.1	21.2	180
E	20.4	17.9	13.9	12.4	12.8	12.8	10.6	10.6	8.8	14.2	13.1	19.7	167
F	20.2	17.7	13.7	12.2	12.6	12.6	10.4	10.4	8.6	14.1	13.0	19.5	165
G	21.6	18.9	14.7	13.1	13.5	13.5	11.2	11.2	9.3	15.1	13.9	20.9	177
H	19.2	16.8	13.0	11.7	12.0	12.0	9.9	9.9	8.2	13.4	12.3	18.5	157

5.2 Outputs

It was assumed that the PE rates were consistent across the whole study area. As such the measured monthly average PE data from Clyde climate station were used to achieve a water balance based on conservative estimates of evapotranspiration. The use of the raised pan AE data was also considered, however, this is believed to be too high. The water balance results using this parameter were in deficit for the entire year. This scenario would create an extremely harsh environment for vegetation. It is also known that raised pan rates are artificially high because of heating through the walls of the pan. These data were therefore not considered further.

5.3 Storage

The storage capacities of the soils differ within the zones across the study area. It was decided that the PRAW was the best indication of the soil's water storage capability. This was because the calculation of PRAW took into account the soil depth, potential rooting depth, and soil moisture properties. The pore volume was also calculated as an indication of the soil's ability to hold moisture. However, it was considered to be of less use for the water balance as the main contributing factor was macroporosity. These large pores can effectively assist water to flow out of the soil and into the groundwater as will be discussed below.

To give a range of scenarios the mid values and upper limits of each of the PRAW classes were used in the assessment of the water balance. The mid value of the PRAW classes were 11mm, 37mm, 62mm and 87mm for very low, low moderate and moderately high PRAW respectively. The upper limits of these classes were 24mm, 49mm, 74mm and 99mm. Not all zones had all four classes. The same water balances were achieved when the potential storage was not met, therefore results for these classes have been grouped together.

5.4 Water balances

The water balances of various soil storage capacities were calculated for each zone using the Q_5 modelled rainfall. These results therefore are a conservative indication of water deficit. The general pattern emerges that the soils with a storage capacity of 11–24mm remain in deficit for all months except May to August. However, soils with a storage capacity >37mm also remain out of deficit for September.

Zone A

Very-low PRAW (0–24mm) covers 82% of Zone A. The yearly deficit for this zone will be 494–507mm and will require irrigation from September to April (

Table 5.3). The deficit for the deeper soils within this zone is only slightly lower at 483mm. Irrigation is still required from October to April. Lower deficits are found in the deeper soils in the spring months until November when they become the same as for the other soils (Figure 5.2). However, the deficit patterns remain the same for all depths from summer and into winter.

Table 5.3 Water balance for various storage capacities within Zone A.

Water balance for 11mm storage capacity													
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
P	21	19	14	13	13	13	11	11	9	15	14	20	173
PE	125	90	62	23	1	0	1	11	37	76	104	126	656
P-PE	-104	-71	-48	-10	12	13	10	0	-28	-61	-90	-106	
∆ST	0	0	0	0	11	0	0	0	-11	0	0	0	
ST	0	0	0	0	11	11	11	11	0	0	0	0	
AE	21	19	14	13	1	0	1	11	20	15	14	20	
D	-104	-71	-48	-10	0	0	0	0	-17	-61	-90	-106	-507
S	0	0	0	0	1	13	10	0	0	0	0	0	24
Water balance for 24mm storage capacity													
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
P	21	19	14	13	13	13	11	11	9	15	14	20	173
PE	125	90	62	23	1	0	1	11	37	76	104	126	656
P-PE	-104	-71	-48	-10	12	13	10	0	-28	-61	-90	-106	
∆ST	0	0	0	0	12	12	0	0	-24	0	0	0	
ST	0	0	0	0	12	24	24	24	0	0	0	0	
AE	21	19	14	13	1	0	1	11	33	15	14	20	
D	-104	-71	-48	-10	0	0	0	0	-4	-61	-90	-106	-494

S	0	0	0	0	0	1	10	0	0	0	0	0	11
Water balance for 37 - 74mm storage capacity													
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
P	21	19	14	13	13	13	11	11	9	15	14	20	173
PE	125	90	62	23	1	0	1	11	37	76	104	126	656
P-PE	-104	-71	-48	-10	12	13	10	0	-28	-61	-90	-106	
∆ST	0	0	0	0	12	13	10	0	-28	-7	0	0	
ST	0	0	0	0	12	25	35	35	7	0	0	0	
AE	21	19	14	13	1	0	1	11	37	22	14	50	
D	-104	-71	-48	-10	0	0	0	0	0	-54	-90	-106	-483
S	0	0	0	0	0	0	0	0	0	0	0	0	0

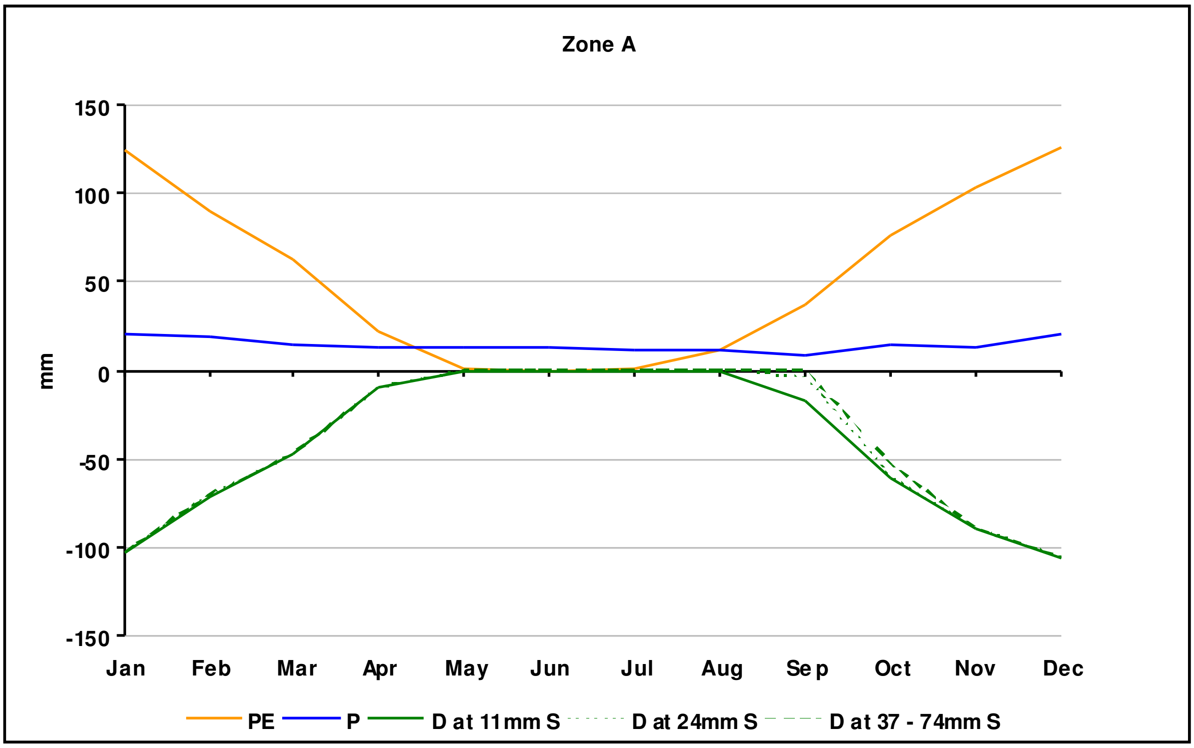

Figure 5.2 PE, P and D curves for Zone A.

Zone B

Very-low PRAW (0–24mm) covers 78% of Zone B. The yearly deficit for this zone will be 508–521mm and will require irrigation from September to April (Table 5.4). The deficit for the deeper soils within this zone is only slightly lower at 500mm with irrigation being required from October to April. Lower deficits are found in the deeper soils in the spring months until November when they become the same as for the other soils (Figure 5.3). However, the deficit patterns remain the same for all depths from summer and into winter.

Table 5.4 Water balance for various storage capacities within Zone B.

Water balance for 11mm storage capacity													
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
P	19	17	13	12	12	12	10	10	8	13	12	18	155
PE	125	90	62	23	1	0	1	11	37	76	104	126	656
P-PE	-106	-73	-49	-11	11	12	9	-1	-29	-63	-92	-108	
ΔST	0	0	0	0	11	0	0	-1	-10	0	0	0	
ST	0	0	0	0	11	11	11	10	0	0	0	0	
AE	19	17	13	12	1	0	1	11	18	13	12	18	
D	-106	-73	-49	-11	0	0	0	0	-19	-63	-92	-108	-521
S	0	0	0	0	0	12	9	0	0	0	0	0	21
Water balance for 24mm storage capacity													
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
P	19	17	13	12	12	12	10	10	8	13	12	18	155
PE	125	90	62	23	1	0	1	11	37	76	104	126	656
P-PE	-106	-73	-49	-11	11	12	9	-1	-29	-63	-92	-108	
ΔST	0	0	0	0	11	12	1	-1	-23	0	0	0	
ST	0	0	0	0	11	23	24	23	0	0	0	0	
AE	19	17	13	12	1	0	1	11	31	13	12	18	
D	-106	-73	-49	-11	0	0	0	0	-6	-63	-92	-108	-508
S	0	0	0	0	0	0	8	0	0	0	0	0	8
Water balance for 37-74mm storage capacity													
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
P	19	17	13	12	12	12	10	10	8	13	12	18	155
PE	125	90	62	23	1	0	1	11	37	76	104	126	656
P-PE	-106	-73	-49	-11	11	12	9	-1	-29	-63	-92	-108	
ΔST	0	0	0	0	11	12	9	-1	-29	-2	0	0	
ST	0	0	0	0	11	23	32	31	2	0	0	0	
AE	19	17	13	12	1	0	1	11	37	15	12	18	
D	-106	-73	-49	-11	0	0	0	0	0	-61	-92	-108	-500

S	0	0	0	0	0	0	0	0	0	0	0	0	0

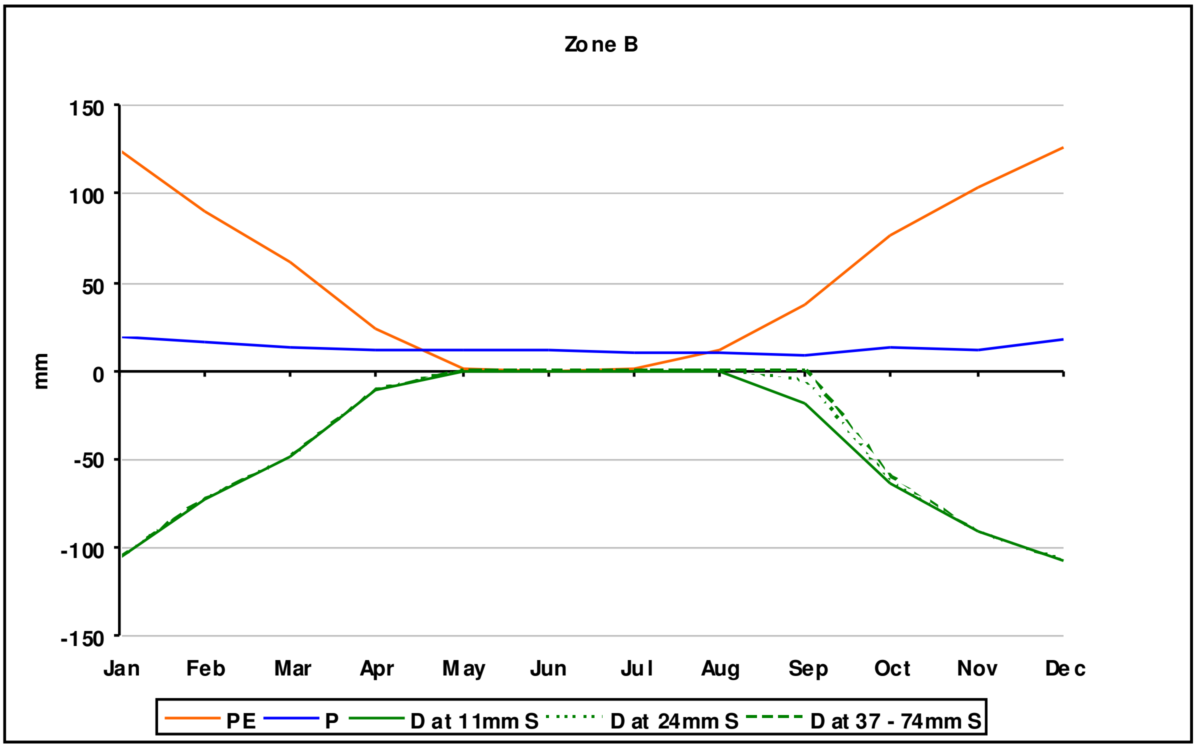

Figure 5.3 PE, P and D curves for Zone B.

Zone C

Very-low PRAW (0–24mm) covers 82% of Zone C. The yearly deficit for this zone will be 511–524mm and will require irrigation from September to April (Table 5.5). The deficit for the deeper soils within this zone is only slightly lower at 503mm with irrigation being required from October to April. Lower deficits are found in the deeper soils in the spring months until November when they become the same as for the other soils (Figure 5.4). However, the deficit patterns remain the same for all depths from summer and into winter.

Table 5.5 Water balance for various storage capacities within Zone C.

Water balance for 11 mm storage capacity													
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
P	18	16	13	11	12	12	10	10	8	13	12	18	151
PE	125	90	62	23	1	0	1	11	37	76	104	126	656
P-PE	-107	-74	-49	-12	11	12	9	-1	-29	-63	-92	-108	
∆ST	0	0	0	0	11	0	0	-1	-10	0	0	0	
ST	0	0	0	0	11	11	11	10	0	0	0	0	
AE	18	16	13	11	1	0	1	11	18	13	12	18	
D	-107	-74	-49	-12	0	0	0	0	-19	-63	-92	-108	-524
S	0	0	0	0	0	12	9	0	0	0	0	0	21
Water balance for 24 mm storage capacity													
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
P	18	16	13	11	12	12	10	10	8	13	12	18	151
PE	125	90	62	23	1	0	1	11	37	76	104	126	656
P-PE	-107	-74	-49	-12	11	12	9	-1	-29	-63	-92	-108	
∆ST	0	0	0	0	11	12	1	-1	-23	0	0	0	
ST	0	0	0	0	11	23	24	23	0	0	0	0	
AE	18	16	13	11	1	0	1	11	31	13	12	18	
D	-107	-74	-49	-12	0	0	0	0	-6	-63	-92	-108	-511
S	0	0	0	0	0	0	8	0	0	0	0	0	8
Water balance for 37 - 49 mm storage capacity													
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
P	18	16	13	11	12	12	10	10	8	13	12	18	151
PE	125	90	62	23	1	0	1	11	37	76	104	126	656
P-PE	-107	-74	-49	-12	11	12	9	-1	-29	-63	-92	-108	
∆ST	0	0	0	0	11	12	9	-1	-29	-2	0	0	
ST	0	0	0	0	11	23	32	31	2	0	0	0	
AE	18	16	13	11	1	0	1	11	37	15	12	18	
D	-107	-74	-49	-12	0	0	0	0	0	-61	-92	-108	-503
S	0	0	0	0	0	0	0	0	0	0	0	0	0

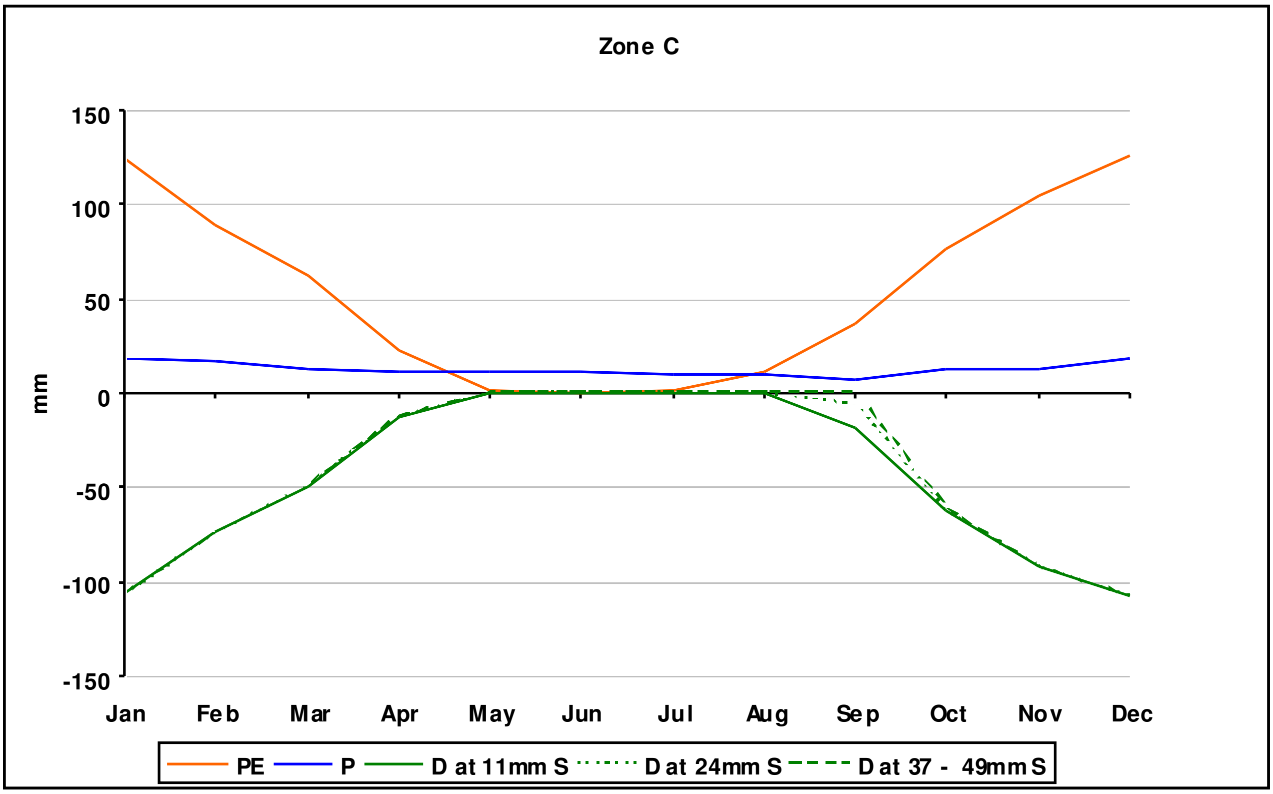

Figure 5.4 PE, P and D curves for Zone C.

Zone D

Very-low PRAW (0–24mm) covers 51% of Zone D. The yearly deficit for this zone is 491-504mm and will require irrigation from September to April (Table 5.6). The other half of the zone contains soils of low to moderately high PRAW, all of which have the same water deficit of 478mm from October to April. Lower deficits are found in the deeper soils in the spring months until November when they become the same as for the other soils (Figure 5.5). However, the deficit patterns remain the same for all depths from summer and into winter.

Table 5.6 Water balance for various storage capacities within Zone D.

Water balance for 11mm storage capacity													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	22	19	15	13	14	14	11	11	9	15	14	21	180
PE	125	90	62	23	1	0	1	11	37	76	104	126	656
P-PE	-103	-71	-47	-10	13	14	10	0	-28	-61	-90	-105	
ΔST	0	0	0	0	11	0	0	0	-11	0	0	0	
ST	0	0	0	0	11	11	11	11	0	0	0	0	
AE	22	19	15	13	1	0	1	11	20	15	14	21	
D	-103	-71	-47	-10	0	0	0	0	-17	-61	-90	-105	-504
S	0	0	0	0	2	14	10	0	0	0	0	0	26

Water balance for 24mm storage capacity													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	22	19	15	13	14	14	11	11	9	15	14	21	180
PE	125	90	62	23	1	0	1	11	37	76	104	126	656
P-PE	-103	-71	-47	-10	13	14	10	0	-28	-61	-90	-105	
ΔST	0	0	0	0	13	11	0	0	-24	0	0	0	
ST	0	0	0	0	13	24	24	24	0	0	0	0	
AE	22	19	15	13	1	0	1	11	33	15	14	21	
D	-103	-71	-47	-10	0	0	0	0	-4	-61	-90	-105	-491
S	0	0	0	0	0	3	10	0	0	0	0	0	13

Water balance for 37 - 99mm storage capacity													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	22	19	15	13	14	14	11	11	9	15	14	21	180
PE	125	90	62	23	1	0	1	11	37	76	104	126	656
P-PE	-103	-71	-47	-10	13	14	10	0	-28	-61	-90	-105	
ΔST	0	0	0	0	13	14	10	0	-28	9	0	0	
ST	0	0	0	0	13	27	37	37	9	0	0	0	
AE	22	19	15	13	1	0	1	11	37	24	14	21	
D	-103	-71	-47	-10	0	0	0	0	0	-52	-90	-105	-478
S	0	0	0	0	0	0	0	0	0	0	0	0	0

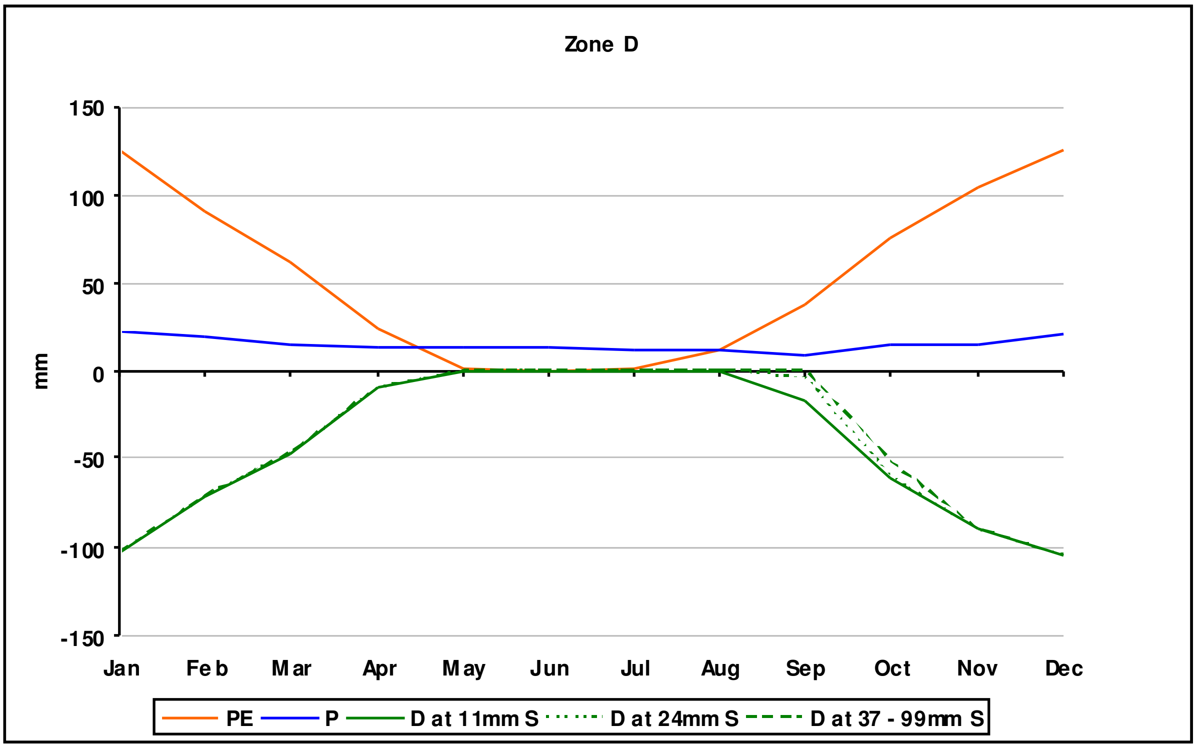

Figure 5.5 PE, P and D curves for Zone D.

Zone E

Very-low PRAW (0–24mm) covers only 26% of Zone E. The yearly deficit for this zone will be 499-512mm and will require irrigation from September to April (Table 5.7). The remainder of the zone has a low to moderate PRAW (25-74mm), all of which have the same water deficit of 488mm from October to April. Lower deficits are found in the deeper soils in the spring months until November when they become the same as for the other soils (Figure 5.6). However, the deficit patterns remain the same for all depths from summer and into winter.

Table 5.7 Water balance for various storage capacities within Zone E.

Water balance for 11mm storage capacity													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	20	18	14	12	13	13	11	11	9	14	13	20	167
PE	125	90	62	23	1	0	1	11	37	76	104	126	656
P-PE	-105	-72	-48	-11	12	13	10	0	-28	-62	-91	-106	
ΔST	0	0	0	0	11	0	0	0	-11	0	0	0	
ST	0	0	0	0	11	11	11	11	0	0	0	0	
AE	20	18	14	12	1	0	1	11	20	14	13	20	
D	-105	-72	-48	-11	0	0	0	0	-17	-62	-91	-106	-512
S	0	0	0	0	1	13	10	0	0	0	0	0	24
Water balance for 24mm storage capacity													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	20	18	14	12	13	13	11	11	9	14	13	20	167
PE	125	90	62	23	1	0	1	11	37	76	104	126	656
P-PE	-105	-72	-48	-11	12	13	10	0	-28	-62	-91	-106	
ΔST	0	0	0	0	12	12	0	0	-24	0	0	0	
ST	0	0	0	0	12	24	24	24	0	0	0	0	
AE	20	18	14	12	1	0	1	11	33	14	13	20	
D	-105	-72	-48	-11	0	0	0	0	-4	-62	-91	-106	-499
S	0	0	0	0	0	1	10	0	0	0	0	0	11
Water balance for 37 - 74mm storage capacity													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	20	18	14	12	13	13	11	11	9	14	13	20	167
PE	125	90	62	23	1	0	1	11	37	76	104	126	656
P-PE	-105	-72	-48	-11	12	13	10	0	-28	-62	-91	-106	
ΔST	0	0	0	0	12	13	10	0	-28	-7	0	0	
ST	0	0	0	0	12	25	35	35	7	0	0	0	
AE	20	18	14	12	1	0	1	11	37	21	13	20	
D	-105	-72	-48	-11	0	0	0	0	0	-55	-91	-106	-488
S	0	0	0	0	0	0	0	0	0	0	0	0	0

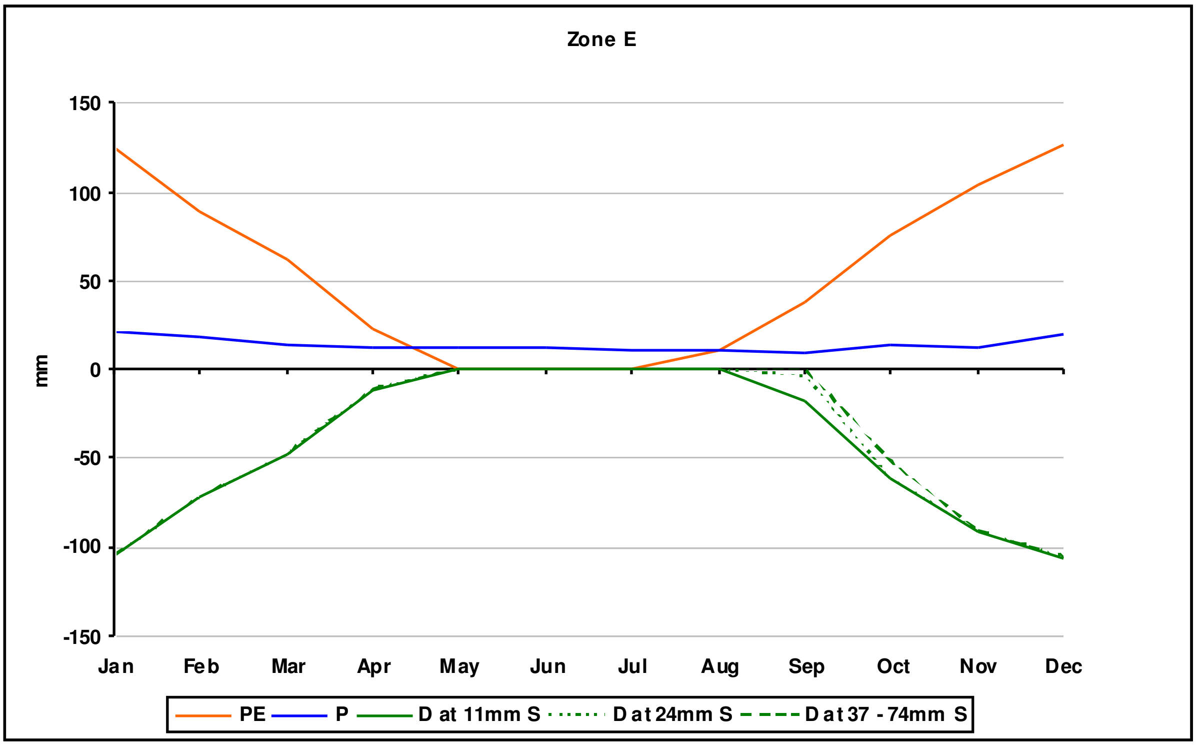

Figure 5.6 PE, P and D curves for Zone E.

Zone F

Very-low PRAW (0–24mm) covers 42% of Zone F. The yearly deficit for this zone is 501-514mm and will require irrigation from September to April (Table 5.8). The remainder of the zone has a low to moderate PRAW (25-74mm), all of which have the same potential water deficit of 491mm from October to April. Lower deficits are found in the deeper soils in the spring months until November when they become the same as for the other soils (Figure 5.7). However, the deficit patterns remain the same for all depths from summer and into winter.

Table 5.8 Water balance for various storage capacities within Zone F.

Water balance for 11mm storage capacity													
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
P	20	18	14	12	13	13	10	10	9	14	13	19	165
PE	125	90	62	23	1	0	1	11	37	76	104	126	656
P-PE	-105	-72	-48	-11	12	13	9	-1	-28	-62	-91	-107	
ΔST	0	0	0	0	11	0	0	-1	-10	0	0	0	
ST	0	0	0	0	11	11	11	10	0	0	0	0	
AE	20	18	14	12	1	0	1	11	19	14	13	19	
D	-105	-72	-48	-11	0	0	0	0	-18	-62	-91	-107	-514
S	0	0	0	0	1	13	9	0	0	0	0	0	23
Water balance for 24mm storage capacity													
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
P	20	18	14	12	13	13	10	10	9	14	13	19	165
PE	125	90	62	23	1	0	1	11	37	76	104	126	656
P-PE	-105	-72	-48	-11	12	13	9	-1	-28	-62	-91	-107	
ΔST	0	0	0	0	11	13	0	-1	-23	0	0	0	
ST	0	0	0	0	11	24	24	23	0	0	0	0	
AE	20	18	14	12	1	0	1	11	32	14	13	19	
D	-105	-72	-48	-11	0	0	0	0	-5	-62	-91	-107	-501
S	0	0	0	0	1	0	9	0	0	0	0	0	10
Water balance for 37-74mm storage capacity													
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
P	20	18	14	12	13	13	10	10	9	14	13	19	165
PE	125	90	62	23	1	0	1	11	37	76	104	126	656
P-PE	-105	-72	-48	-11	12	13	9	-1	-28	-62	-91	-107	
ΔST	0	0	0	0	12	13	9	-1	-28	-5	0	0	
ST	0	0	0	0	12	25	34	33	5	0	0	0	
AE	20	18	14	12	1	0	1	11	37	19	13	19	
D	-105	-72	-48	-11	0	0	0	0	0	-57	-91	-107	-491
S	0	0	0	0	0	0	0	0	0	0	0	0	0

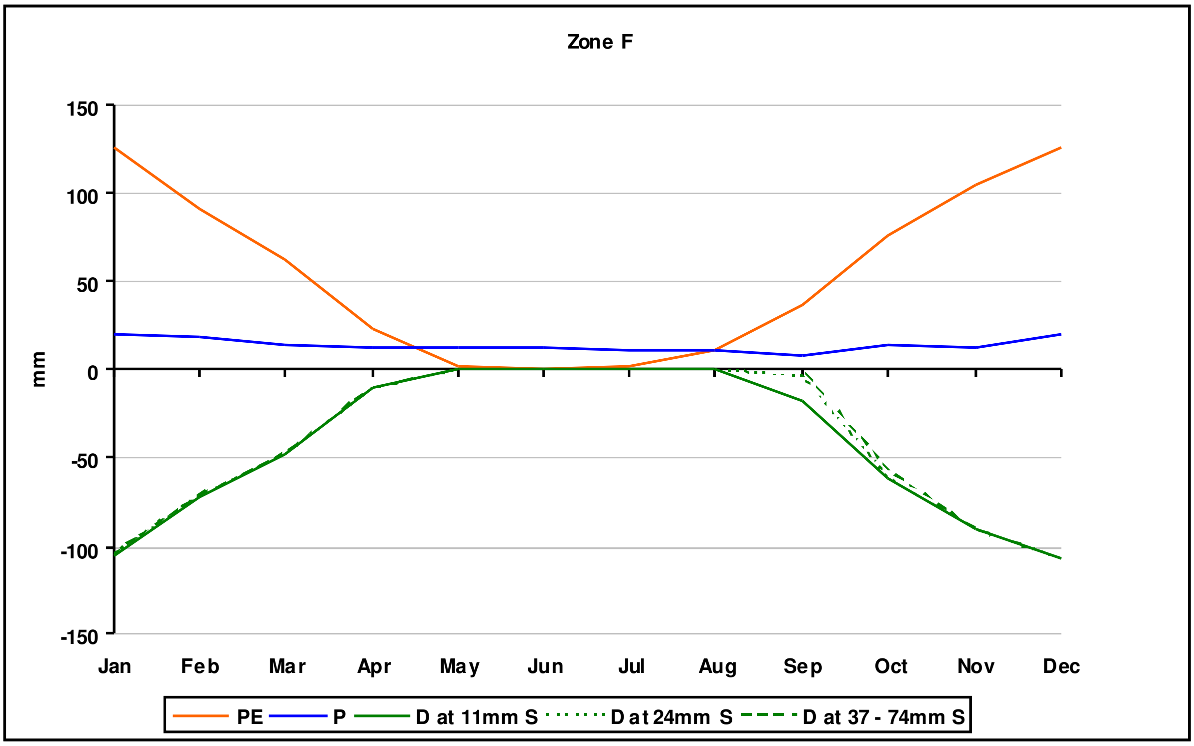

Figure 5.7 PE, P and D curves for Zone F.

Zone G

Very-low PRAW (0-24mm) covers only 32% of Zone G. The yearly deficit for this zone will potentially be 491-504mm and will require irrigation from September to April (Table 5.9). The remainder of the zone has a low PRAW (25-49mm), the moisture deficit of which will be 478mm from October to April. Lower deficits are found in the deeper soils in the spring months until November when they become the same as for the other soils (Figure 5.8). However, the deficit patterns remain the same for all depths from summer and into winter.

Table 5.9 Water balance for various storage capacities within Zone G.

Water balance for 11mm storage capacity													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	22	19	15	13	14	14	11	11	9	15	14	21	177
PE	125	90	62	23	1	0	1	11	37	76	104	126	656
P-PE	-103	-71	-47	-10	13	14	10	0	-28	-61	-90	-105	
∆ST	0	0	0	0	11	0	0	0	-11	0	0	0	
ST	0	0	0	0	11	11	11	11	0	0	0	0	
AE	22	19	15	13	1	0	1	11	20	15	14	21	
D	-103	-71	-47	-10	0	0	0	0	-17	-61	-90	-105	-504
S	0	0	0	0	2	14	10	0	0	0	0	0	26
Water balance for 24mm storage capacity													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	22	19	15	13	14	14	11	11	9	15	14	21	177
PE	125	90	62	23	1	0	1	11	37	76	104	126	656
P-PE	-103	-71	-47	-10	13	14	10	0	-28	-61	-90	-105	
∆ST	0	0	0	0	13	11	0	0	-24	0	0	0	
ST	0	0	0	0	13	24	24	24	0	0	0	0	
AE	22	19	15	13	1	0	1	11	33	15	14	21	
D	-103	-71	-47	-10	0	0	0	0	-4	-61	-90	-105	-491
S	0	0	0	0	0	3	10	0	0	0	0	0	13
Water balance for 37-49mm storage capacity													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	22	19	15	13	14	14	11	11	9	15	14	21	177
PE	125	90	62	23	1	0	1	11	37	76	104	126	656
P-PE	-103	-71	-47	-10	13	14	10	0	-28	-61	-90	-105	
∆ST	0	0	0	0	13	14	10	0	-28	-9	0	0	
ST	0	0	0	0	13	27	37	37	9	0	0	0	
AE	22	19	15	13	1	0	1	11	37	24	14	21	
D	-103	-71	-47	-10	0	0	0	0	0	-52	-90	-105	-478
S	0	0	0	0	0	0	0	0	0	0	0	0	0

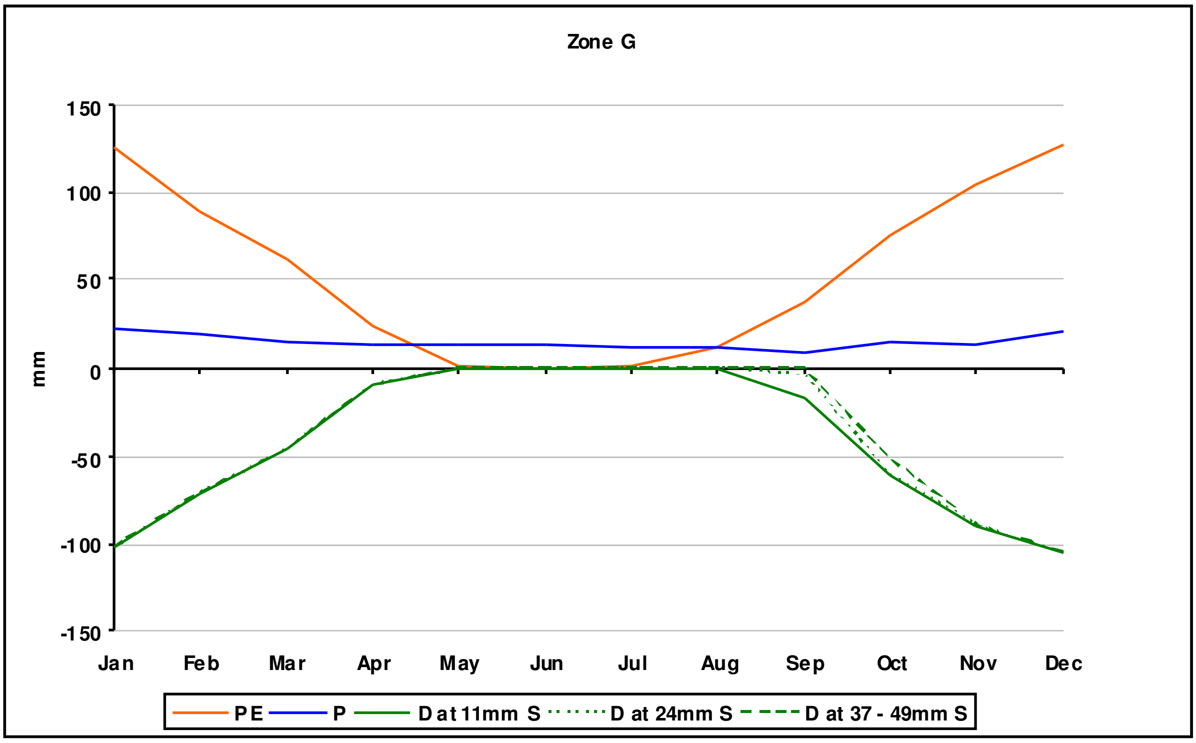

Figure 5.8 PE, P and D curves for Zone G.

Zone H

Very-low PRAW (0–24mm) covers 77% of Zone A. This is the only zone that differs between the mid-value (11mm) and the upper limit (24mm) of very-low PRAW. The yearly deficit for the mid value will be 520mm and will require irrigation from September to April (Table 5.10). The upper limit deficit acts in a similar way to soils with low (25–49mm) PRAW. They have a lower deficit of 499 from September to April. Lower deficits are found in the deeper soils in the spring months until November when they become the same as for the other soils (Figure 5.9). However, the deficit patterns remain the same for all depths from summer and into winter.

Table 5.10 Water balance for various storage capacities within Zone H.

Water balance for 11mm storage capacity													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	19	17	13	12	12	12	10	10	8	13	12	19	157
PE	125	90	62	23	1	0	1	11	37	76	104	126	656
P-PE	-106	-73	-49	-11	11	12	9	-1	-29	-63	-92	-107	
∆ST	0	0	0	0	11	0	0	-1	-10	0	0	0	
ST	0	0	0	0	11	11	11	10	0	0	0	0	
AE	19	17	13	12	1	0	1	11	18	13	12	19	
D	-106	-73	-49	-11	0	0	0	0	-19	-63	-92	-107	-520
S	0	0	0	0	0	12	9	0	0	0	0	0	21
Water balance for 24-49mm storage capacity													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
P	19	17	13	12	12	12	10	10	8	13	12	19	157
PE	125	90	62	23	1	0	1	11	37	76	104	126	656
P-PE	-106	-73	-49	-11	11	12	9	-1	-29	-63	-92	-107	
∆ST	0	0	0	0	11	12	9	-1	-20	0	0	0	
ST	0	0	0	0	11	23	32	31	2	0	0	0	
AE	19	17	13	12	1	0	1	11	37	15	12	19	
D	-106	-73	-49	-11	0	0	0	0	0	-61	-92	-107	-499
S	0	0	0	0	0	0	0	0	0	0	0	0	0

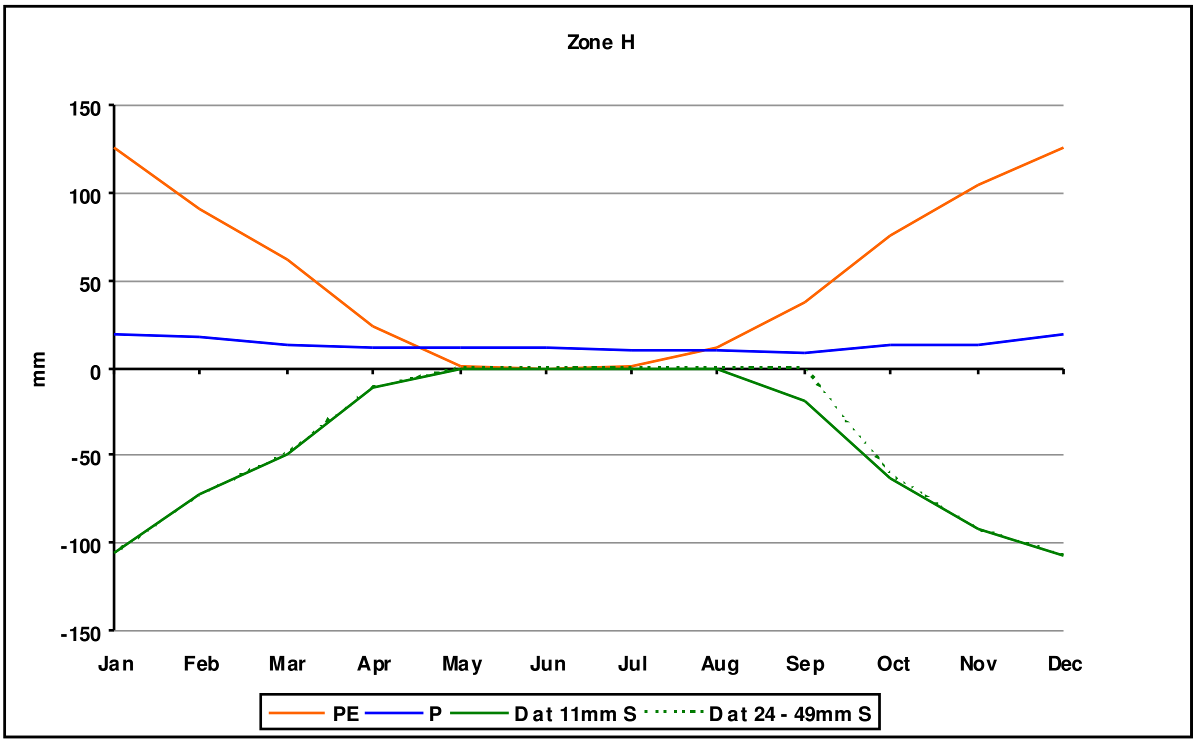

Figure 5.9 PE, P and D curves for Zone H.

5.5 Pore volume

Pore volume was calculated for each zone within the study area. As porosity as defined in the NZFSL is an indication of macroporosity, this is an indication of the volume of macropores within the soils. These can either aid the soil's ability to store water, or be so large that water flows through them, quickly bypassing the root zone. The role of the macropores depends on their actual size, with larger pores having less ability to retain moisture. The pore volume was calculated using Equation 5.4.

$$PV = D \times Por$$ **Equation 5.4**

Where PV is pore volume; D is depth; and Por, the porosity. The porosity values were assigned to 8 classes, and the area of each PV class calculated. The depth of the soil was taken from the mean depth figures for each potential rooting depth class, and the porosity as the proportion of macropores. For the majority of the study area the pore volume is low, lying between 26 -39 mm (classes 6 & 7) (Figure 5.10, Table 3.1). However, areas of higher pore volume (156mm) are apparent in Zones B and D, covering 200 and 277ha respectively. It may be wise to further investigate the areas of apparently higher pore volume to assess the potential effectiveness of irrigation.

Table 5.11 Pore volume of specific zones.

Pore Volume (area in hectares)									
CLASS	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**TOTAL**
ZONE	**156mm**	**104mm**	**74-78mm**	**51-55mm**	**49mm**	**34-39mm**	**26-29mm**	**19mm**	
A				328.46		2062.35	1896.32	196.53	4483.66
B	200.26			1037.41	424.62	694.46	722.78	1083.05	4162.59
C		2.69		31.33	6.31	116.90	424.44	8.07	589.74
D	276.62	202.47	111.80	185.65		914.51	78.21		1769.25
E	21.79			85.90		38.75			146.44
F			0.31	141.12		228.41	159.16		529.01
G				97.57		99.65	10.90		208.12
H			32.72		5.76	412.54	96.97	88.91	636.90
TOTAL	498.67	205.16	144.84	1907.44	436.69	4567.57	3388.78	1376.56	12525.71
% TOTAL	3.98	1.64	1.16	15.23	3.49	36.47	27.05	10.99	100

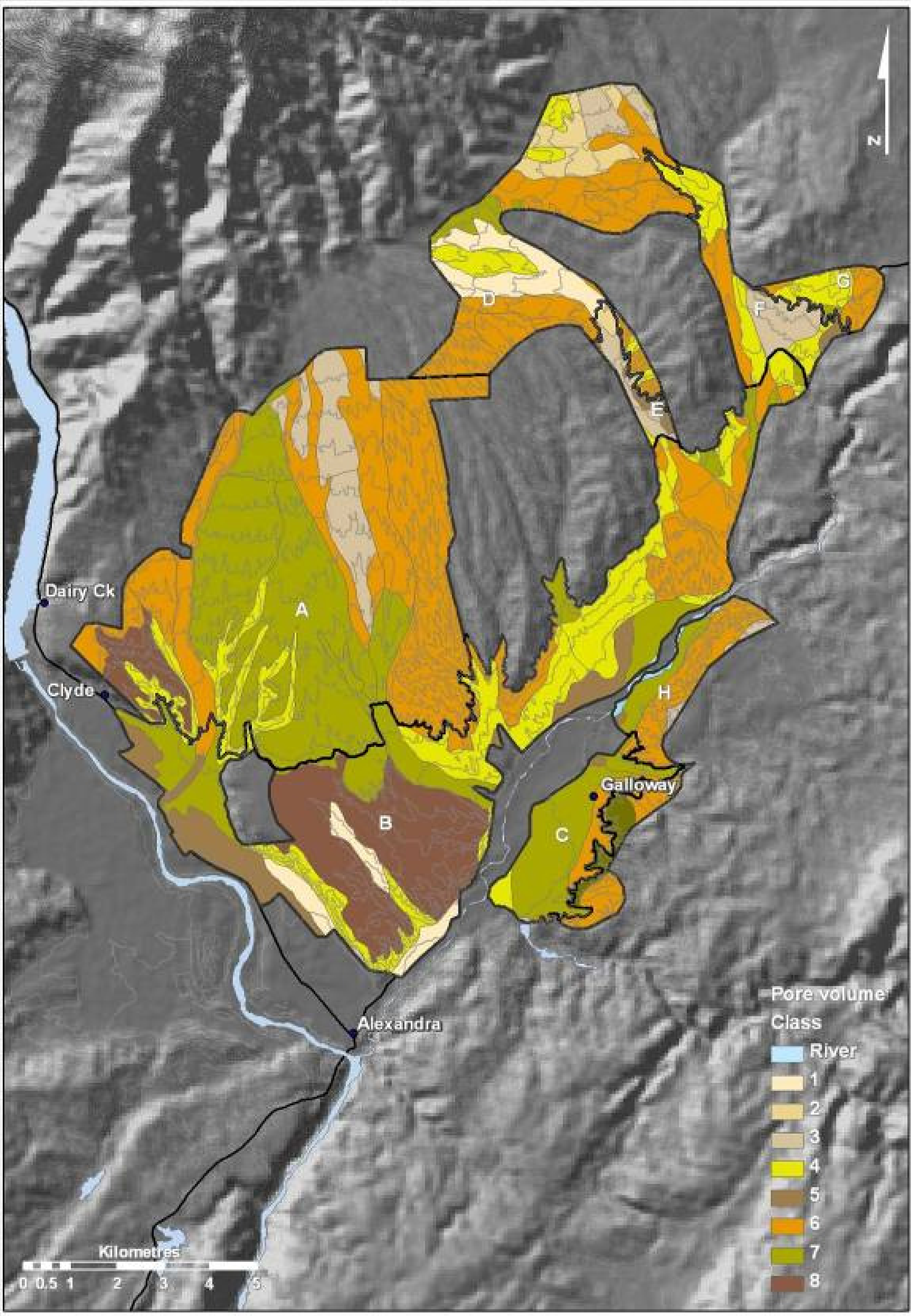

Figure 5.10 Pore volume classes of the study area.

5.6 Irrigating to offset periods of deficit

The above discussion of the water balances for the study area highlight two specific issues with regard to irrigation. First, the soils in general have very low soil moisture storage potential. Therefore, any irrigation regime will need to add water in small amounts regularly. To add water either too quickly, or in too great a volume, will lead to any surplus moisture moving rapidly below the root zone. Since the soil provides only a limited ability to buffer moisture availability this will need to be provided via the irrigation system itself. Second, over a year, approximately half a metre of water needs to be applied to offset the potential soil moisture deficit. This is about three times the amount of water that arrives naturally as rainfall during the 1-in-5 year event.

The volume of water that would need to be applied to offset the soil moisture deficit in each of the zones can be estimated by multiplying the monthly deficit by the area. This was then reduced to a daily and continuous rate to provide an indication of the amount of water that would need to be applied each month to avoid plant stress (Table 5.12 & Figure 5.11). In general, irrigation would need to begin in September with the addition of relatively small amounts of water. The rate at which water needs to be supplied then increases rapidly to a peak during December and January. This is also the period when evapotranspiration rates are highest. Rates would then decrease by about 30mm a month until the end of April. While there are subtle differences between the various zones and different soil types, the irrigation pattern would appear to be relatively consistent across the study area. Storage facilities would be required to hold water to supplement the months where the irrigation needs are over the maximum consented take of $4m^3/s$.

Given the quality of some of the data, as discussed in previous sections, these results should be regarded as indicative only. More accurate analyses would require further study and more reliable soil data.

Table 5.12 Indicative monthly irrigation volumes for the various zones

Monthly Irrigation Volumes													
Zones	**Rates**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
A	**m³/day**	165326	124960	76305	16427	0	0	0	0	27925	96970	147840	168506
	m³/sec	1.914	1.446	0.883	0.190	0	0	0	0	0.323	1.122	1.711	1.950
B	**m³/day**	142348	108535	65802	15264	0	0	0	0	26366	84603	127665	145034
	m³/sec	1.648	1.256	0.762	0.177	0	0	0	0	0.305	0.979	1.478	1.679
C	**m³/day**	20365	15593	9326	2360	0	0	0	0	3737	11990	18093	20555
	m³/sec	0.236	0.180	0.108	0.027	0	0	0	0	0.043	0.139	0.209	0.238
D	**m³/day**	58776	44857	26820	5897	0	0	0	0	10024	34809	53070	59918
	m³/sec	0.653	0.498	0.298	0.066	0	0	0	0	0.111	0.387	0.590	0.666
E	**m³/day**	4945	3754	2261	535	0	0	0	0	827	2920	4429	4992
	m³/sec	0.057	0.043	0.026	0.006	0	0	0	0	0.010	0.034	0.051	0.058
F	**m³/day**	8773	6660	4010	950	0	0	0	0	1554	5180	7856	8940
	m³/sec	0.102	0.077	0.046	0.011	0	0	0	0	0.018	0.060	0.091	0.103
G	**m³/day**	6911	5274	3154	693	0	0	0	0	1179	4093	6240	7045
	m³/sec	0.080	0.061	0.036	0.008	0	0	0	0	0.014	0.047	0.072	0.082
H	**m³/day**	21781	16608	10069	2336	0	0	0	0	4034	12945	19535	21987
	m³/sec	0.252	0.192	0.117	0.027	0	0	0	0	0.047	0.150	0.226	0.254
Total	**m³/day**	429225	326241	197746	44462	0	0	0	0	75646	253511	384728	436976
	m³/sec	4.941	3.755	2.276	0.512	0	0	0	0	0.871	2.918	4.428	5.030

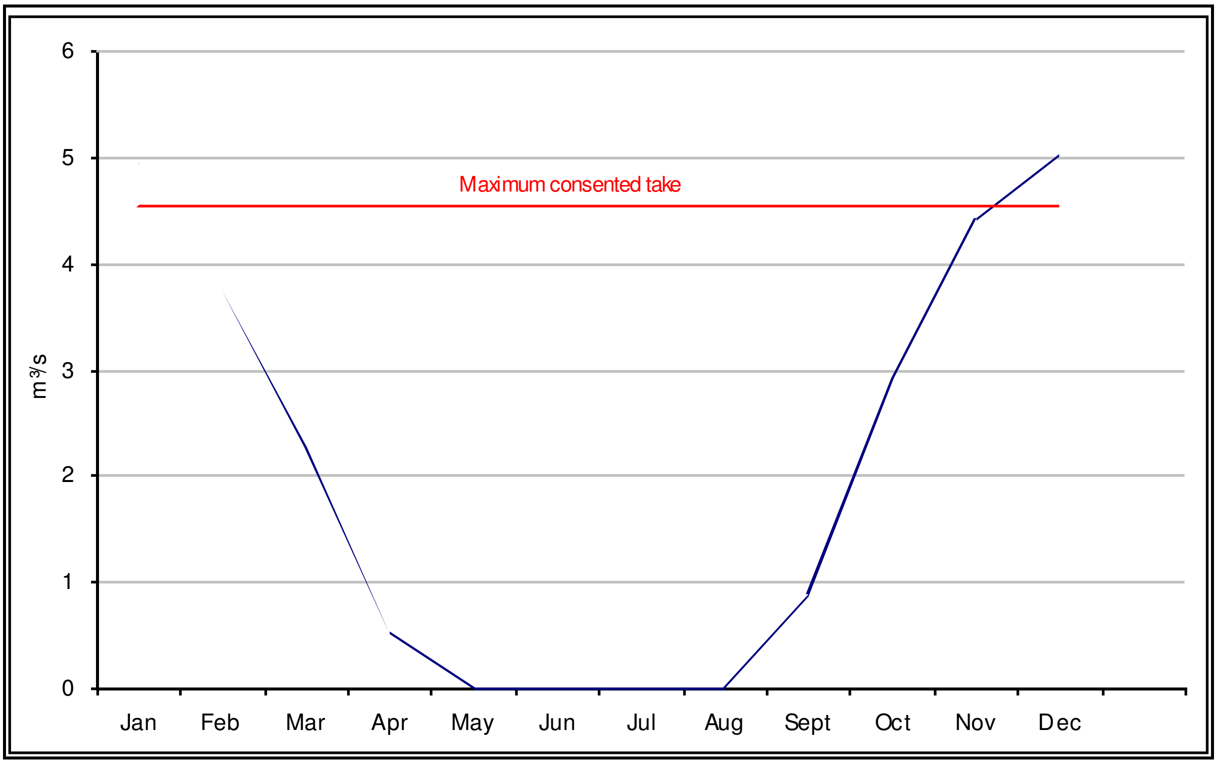

Figure 5.11 Monthly demand for water to offset soil moisture deficit

5.7 Crop-specific irrigation

The above analysis focuses on the worst case scenario where irrigation is required to offset the total soil moisture deficit that might arise during the 1-in-5 year event. Obviously the actual soil moisture that has to be maintained to sustain plant growth and productivity depends on the particular plant. Some plants can resist soil moisture stress better and for longer than others. These plants would require less irrigation intervention than more moisture demanding crops. Therefore, it might be necessary to tailor the demand for irrigation to specific crops, however, this level of detail was considered to be beyond the requirements of this initial study.

To maximise the potential effectiveness of any rainfall in a given season, management of irrigation is required. Continually irrigating to maintain a completely full soil profile would result in any rainfall being lost as runoff. To maximise the potential benefit of any rainfall it is recommended that any water added through irrigation should not completely fill the soil. A soil moisture deficit should be maintained so as to store any rainfall that arrives, and reduce reliance on irrigation. The NZSA (1973) recommend that a conservative general depletion of 50% is adequate to maintain sufficient root zone water to prevent crop stress (Morgan, 1997).

To predict the irrigation needs of soils for specific crops the Equation 5.5 is used:

$$IR = Et_{CROP} - (P - D - R) + 50\%\ ASM \quad \text{OR} \quad IR = Et_{CROP} - P_E + 50\%\ ASM$$ **Equation 5.5**

Where IR (mm) is the irrigation requirements; Et_{CROP} (mm) is crop water requirement; P is precipitation; D is loss through drainage; R is runoff and P_E, effective precipitation.

This equation requires data on the water requirements of crops proposed for the study area, and is an example of analysis which can be performed in future studies.

6 References

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Appendix A
Supplementary Soil Maps

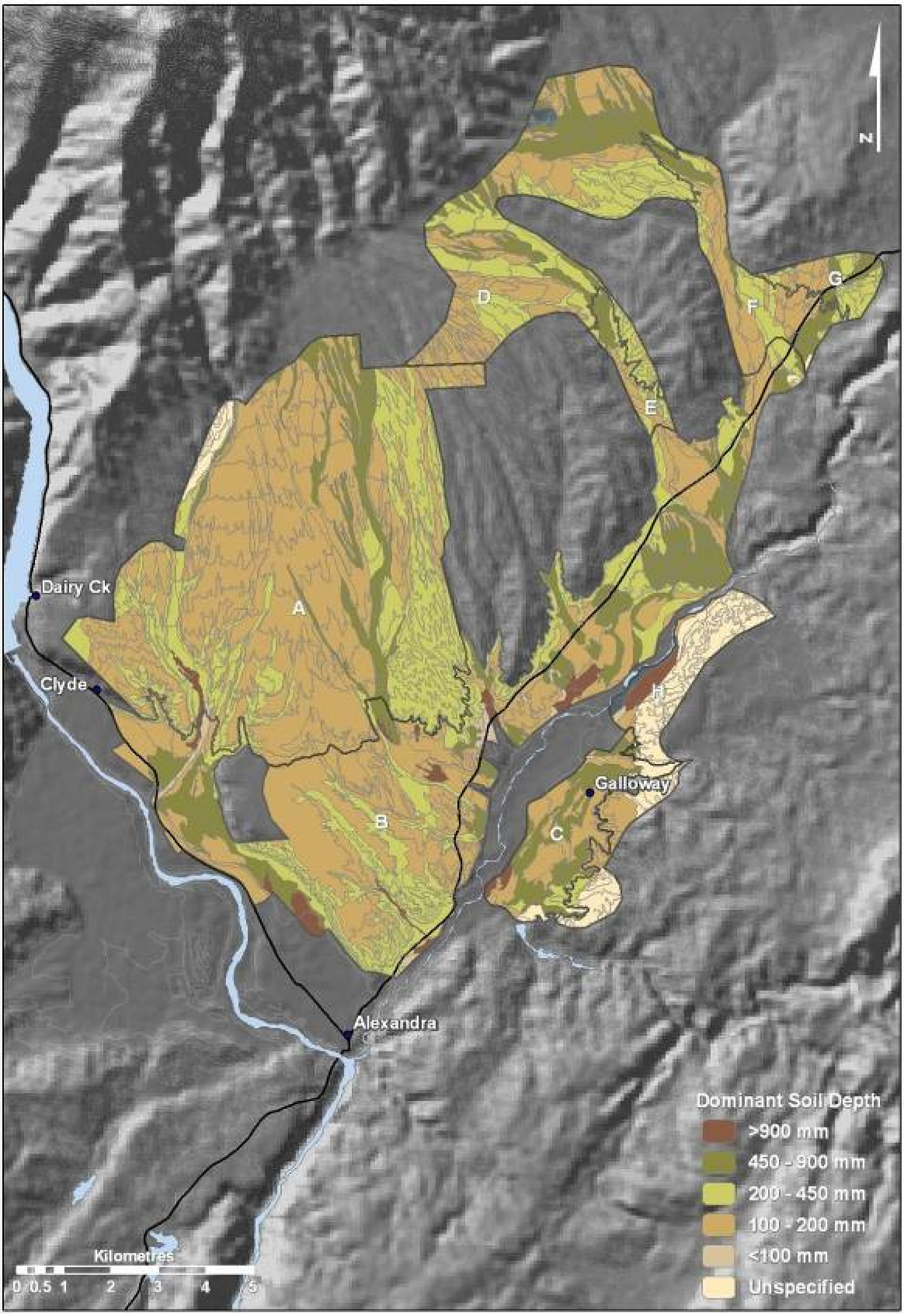

Figure A.1 Dominant soil depth of the study area.

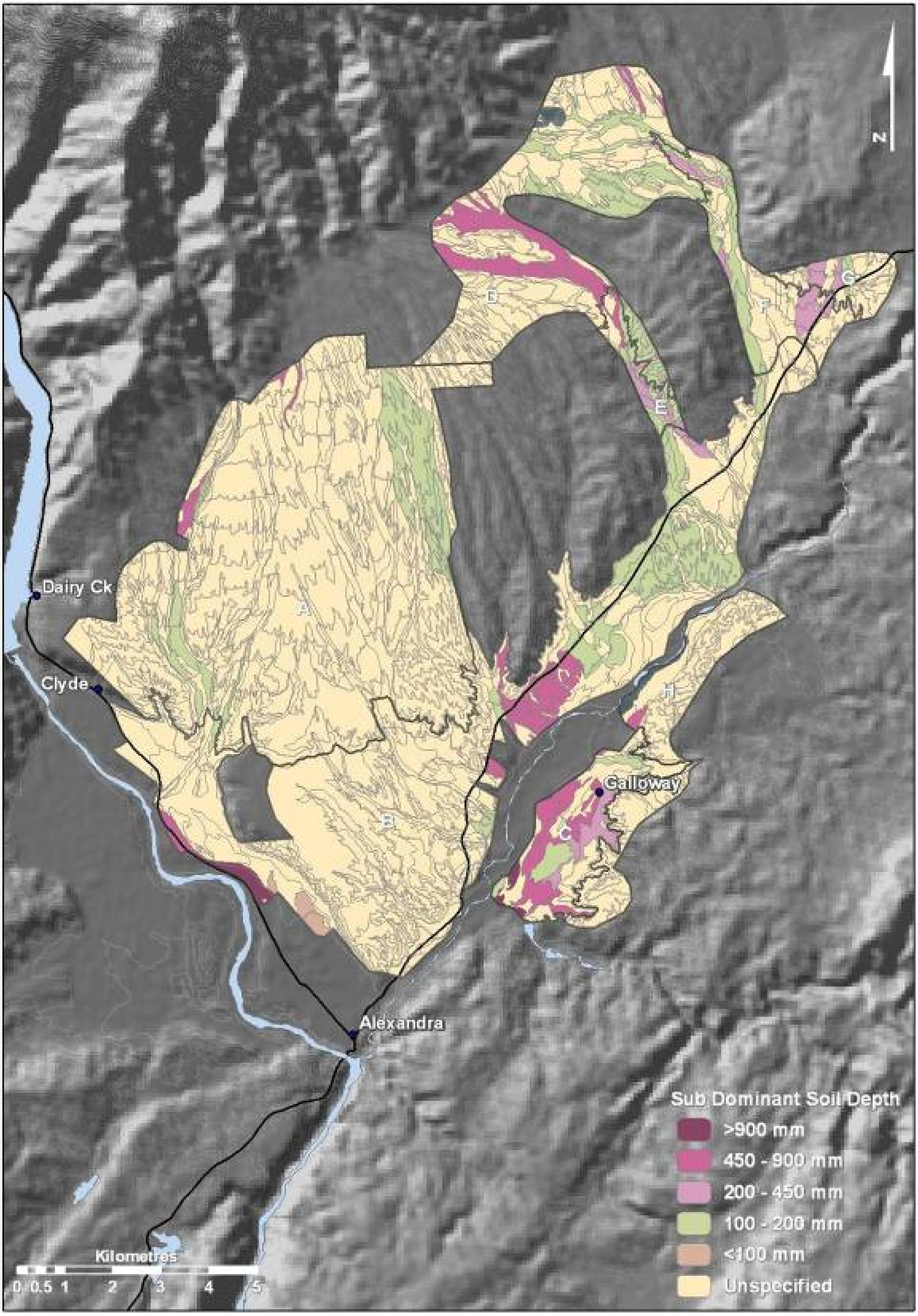

Figure A.2 Subdominant soil depth of the study area.

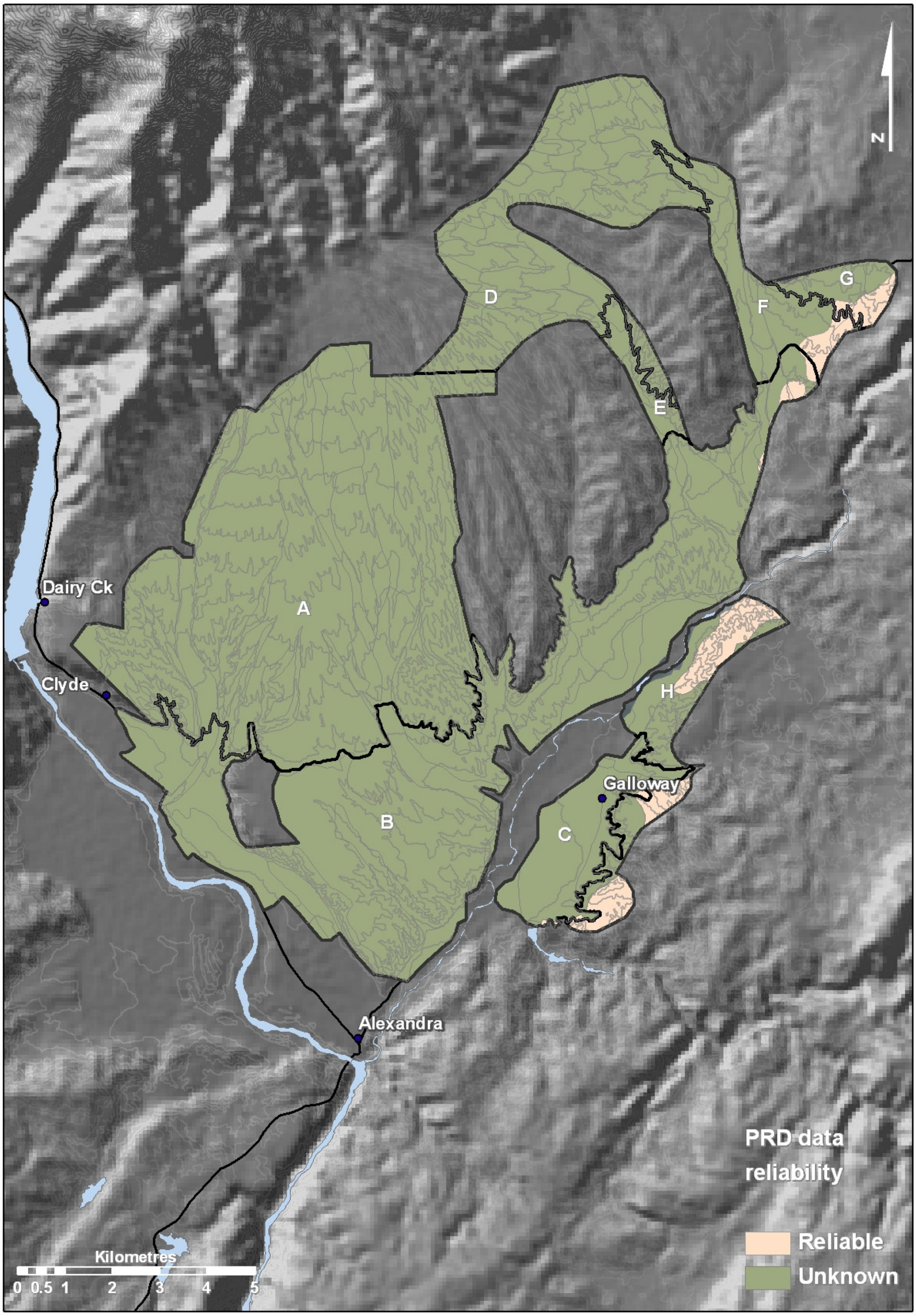

Figure A.3 Potential rooting depth data reliability.

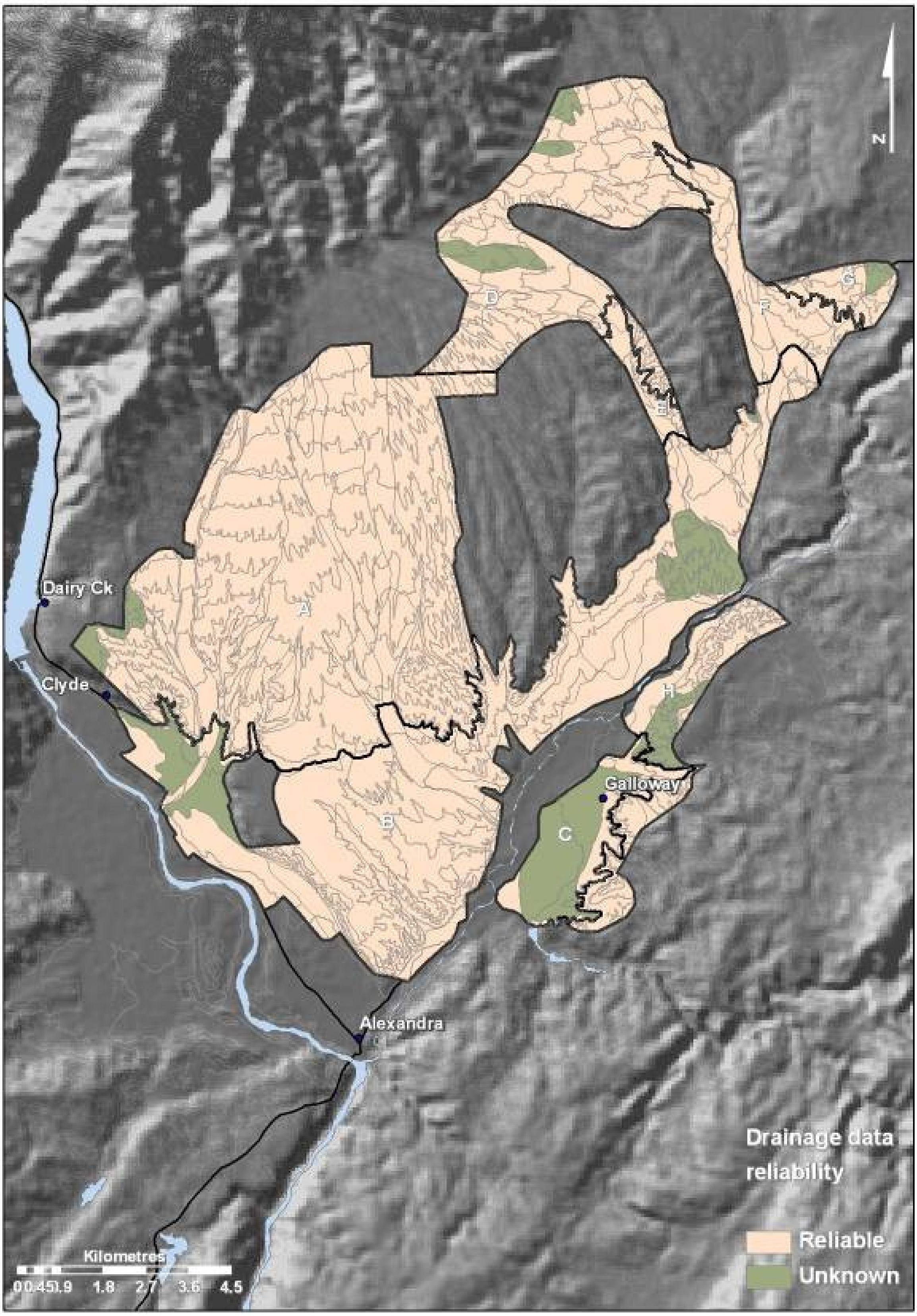

Figure A.4 Drainage data reliability.

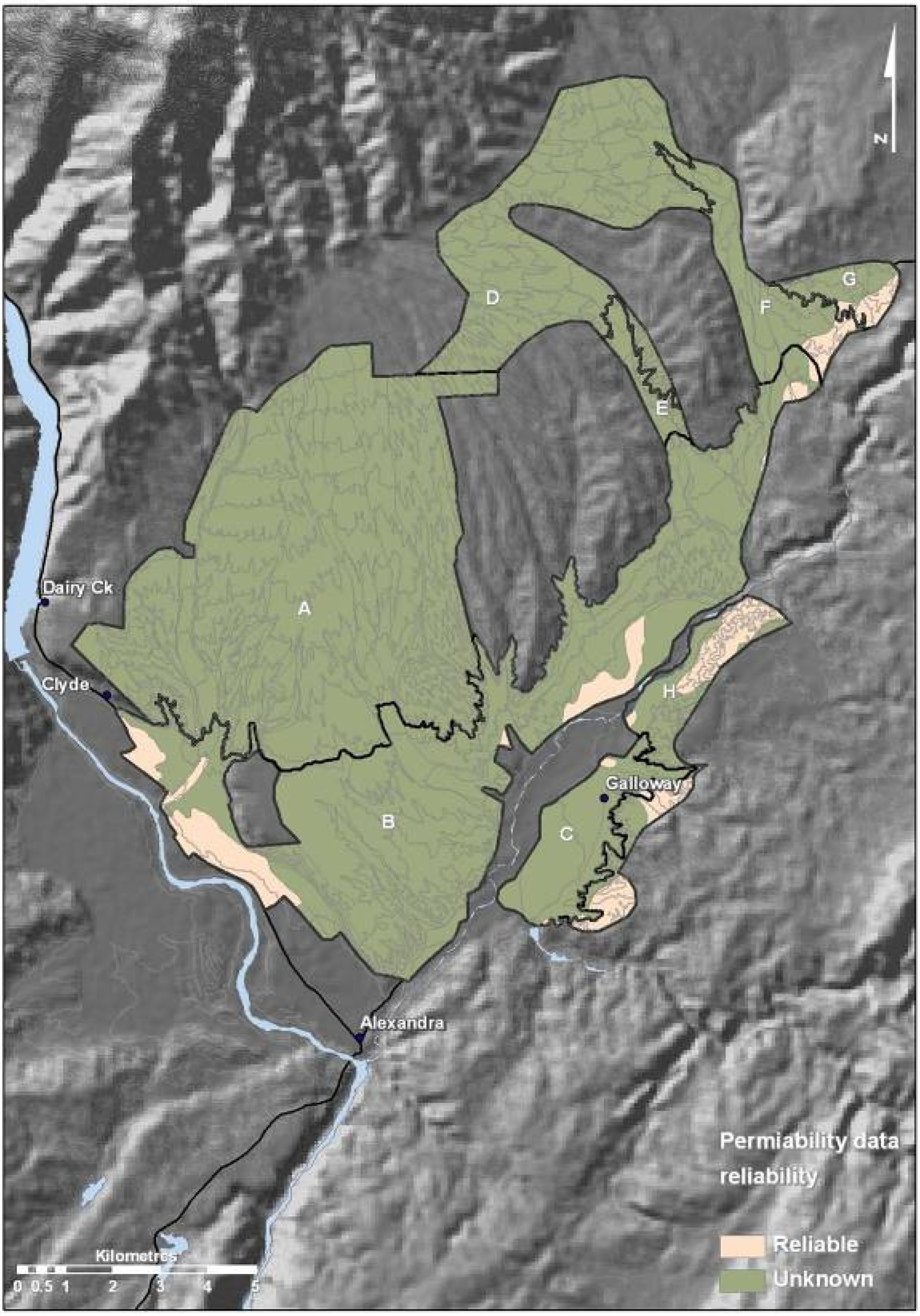

Figure A.5 Permeability data reliability.

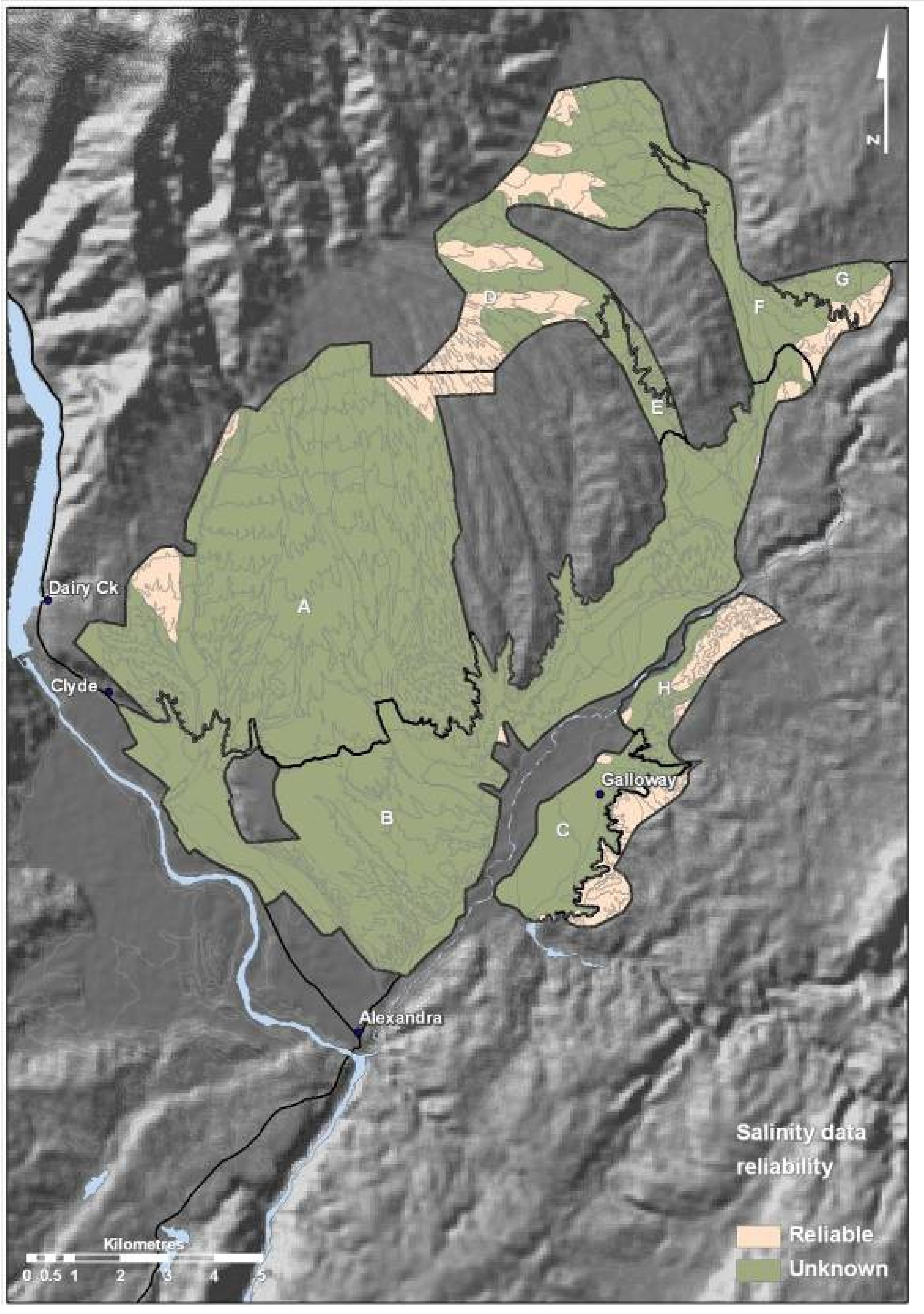

Figure A.6 Salinity data reliability.

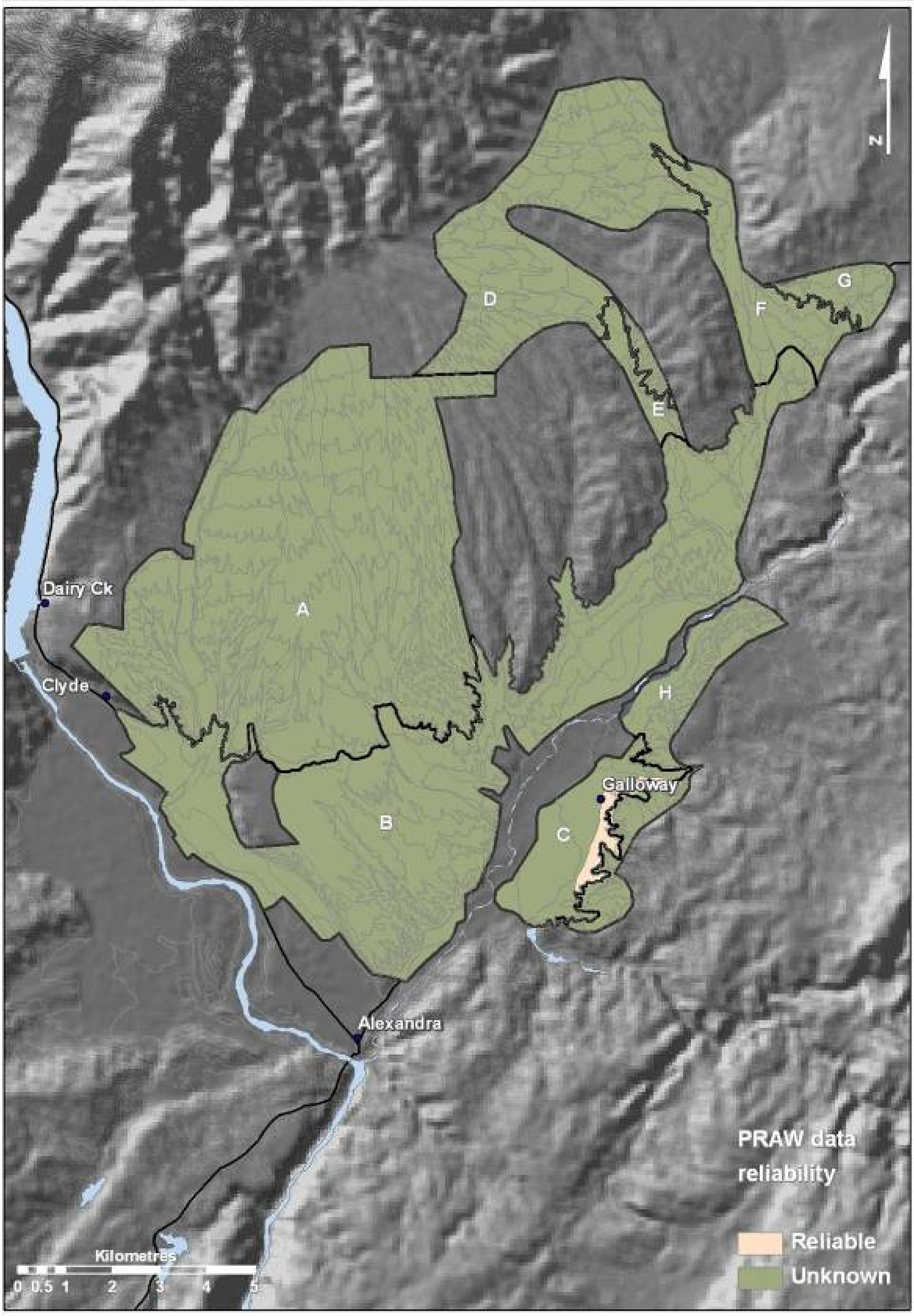

Figure A.7 Profile readily available water data reliability.

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