ORC Rainfall, Climate and Soil Moisture Network Review

Prepared for Otago Regional Council

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Executive summary

Climatically, the Otago region is one of the most diverse in the country with the country's driest, and one of the wettest areas, located in the region, separated by a few tens of kilometres. On behalf of the Otago Regional Council (ORC), the National Water and Atmospheric research limited (NIWA) undertook a review of the region's **rainfall, climate and soil moisture monitoring networks**, to understand how well they fulfil current information demands and their adequacy in fulfilling projected future information needs. The review only considered the adequacy of the climate network with respect to drought monitoring in the region, as per ORC's request. Previously ORC had assessed the adequacy of their climate and weather networks for flood warning and monitoring. Findings from that assessment, done internally by ORC, were not considered in our review.

Overall, the existing network is considered to be adequate for current ORC information needs. However, there are some clear gaps in the networks and several aspects of data collection management that could be improved to meet anticipated future information needs.

The region has four major agencies that collect weather and climate (including rainfall) data – ORC, NIWA, Meteorological Service of New Zealand Limited (MetService), and Fire and Emergency New Zealand (FENZ). Each agency has their own monitoring objectives which dictate their observation practices and procedures. However, a difference in their monitoring purpose, does not preclude the sharing of data and information among the agencies. The region could benefit if data from all agencies could be made accessible under one portal, through data sharing agreements. This will not only minimise data duplication but may also reduce redundancy of resources and duplicated investment in monitoring networks.

The interpolated data from NIWA's Virtual Climate Station (VCS) Network help fill an important gap in the region's daily weather information and data needs. While the accuracy of VCS data has been demonstrated as reliable at low altitudes, it has been found to be less reliable at higher altitudes due to a lack of availability of observations to improve interpolation.

Over time, and like most regions nationally, many of the Otago region's manual monitoring sites have been phased out, with many being closed and some being automated. While this allows for a greater use of data, there are potentially negative impacts on the homogeneity of the climate record if not well managed.

Whilst acknowledging the different mandates of each monitoring agency, and with continued collaboration between the agencies, there are minimal additional recommendations to enhance climate monitoring of the Otago region.

We also note that there are existing planned incremental improvements by ORC and NIWA, for example addition of soil moisture and temperature at various locations, and solid precipitation in alpine locations.

Key recommendations are summarised as:

- ORC, NIWA and MetService continue to collaborate in ensuring regional consistency in the monitoring methodologies used.
- The accuracy of the operational VCS data would be significantly improved if:
  - ORC rainfall data were included into the NIWA climate database (CliDB) in real time and/or for inclusion in the monthly revision. This would substantially

  improve the accuracy of the VCS rainfall estimates throughout the region (and beyond).

  - There were additional measurements of climate variables at higher elevations.
  - Some temporary sites would be very useful in verifying VCS data and determining whether or not a more permanent (and costly) site would be useful. (Note, such temporary site installations and data comparisons are beyond the scope of this study.)

- The addition of ORC rainfall data into CliDB would ensure that adequate coverage of rainfall climatological normals is maintained as the manual network continues to reduce.
- ORC and NIWA consider adding temperature to some of the higher altitude precipitation sites. This applies not only to climatic region M but any sites above 500 m altitude. This would have the added benefit of improving coverage in the Manuherekia and Upper Lakes Rohe.
- ORC, NIWA and MetService continue to collaborate on improving the measurement of solid precipitation.
- It is recommended that NIWA and ORC look to enhance wind measurements above 500 m, as well as explore data available from other providers not considered in this study (e.g., ski fields, wind farms and others). The current soil moisture network is largely focused on the agricultural areas of the region and not all FMUs (Freshwater Management Units), Rohe and climatic regions are well covered. Further expansion should consider upgrading existing automatic rainfall and climate stations to include soil moisture sensing. To expand the usability and applicability of soil moisture data, it should be considered in context with other national and regional products such as the NIWA Soil Moisture Deficit maps and New Zealand Drought Indices, to maximise the network value.
- Considering the probable extent and impact of a changing climate on the region, it is time to develop a long-term climate monitoring plan for the region. For example, the significant spatial variability of projected changes in precipitation will require as many as possible of the current rain gauge sites to remain open, particularly those in the areas projected to experience the greatest change.

1 Introduction and background

The need for reliable climate related science information is broadening as Regional Council needs evolve. Council information requirements may include, but are not limited to, flood warning, water resource and water quality management, state of the environment reporting, land use change planning, drought monitoring and understanding climate change impacts.

Otago Regional Council (ORC) is seeking a review of its environmental monitoring network related to rainfall, climate and soil moisture measurements. This will assist it in future planning and managing of the region's Freshwater Management Units (FMUs) and Rohe during extreme events such as droughts, and to assess the impact of climate change and variability on the region's water resources.

It is understood that ORC's requirements for the measurement of climatic variables are evolving and that current monitoring information may not adequately satisfy future needs. The network review presented in this report has considered the comprehensiveness of the current network and how, if any, shortfalls and gaps could be addressed. As well as providing a commentary on the network design, the review includes advice on the adequacy of instrumentation and field installations, to ensure measurements continue to be of an appropriate standard.

The review presented in the report only considers the adequacy of the climate network with respect to drought monitoring in the region, as per ORC's request. However, ORC had previously assessed the adequacy of their climate and weather networks for flood warning and monitoring, and this assessment was carried out by ORC internally. Findings from that internal assessment were not considered or included in this report.

The network review considers all open and publicly available, rainfall, climate and soil moisture monitoring sites across the region, including those operated by agencies such as ORC, National Institute of Water and Atmospheric Research Limited (NIWA), Meteorological Service of New Zealand Limited (MetService), and Fire and Emergency New Zealand (FENZ).

The report covers the following broad themes, primarily based on Otago region's climate and freshwater management units (FMUs and Rohe):

1) Adequacy of current climate installations and data collected to provide detailed advice to ORC on current and future requirements
2) Adequacy of the climate network for refining national scale networks, such as NIWA's Virtual Climate Station (VCS), and recommendations on how to use the VCS network to complement the climate network of the ORC region
3) Adequacy of the spatial coverage of rainfall for a range of uses
4) Adequacy of the current soil moisture monitoring network
5) Appropriate instrumentation for soil moisture monitoring (co-located with rainfall monitoring sites, where possible)
6) Usefulness of the soil moisture data in relation to the nationally published soil moisture deficit map
7) Drought monitoring, and
8) Suggestions to obtain consistency between agencies, of measurement of climate variables.

In 2015, NIWA produced a report on the diversity and variability of Otago's weather and climate (Macara, 2015). This network review complements the 2015 report.

2 Review methods

This section presents information on the availability of climate, rainfall and soil moisture data from various agencies along with their spatial locations.

2.1 Information collation

Station information for this review was assembled from the data supplied by ORC, NIWA's climate database (CliDB) and NIWA's Stations Information Management System (SIMS).

Stations have been broadly assembled under three categories:

1. Rainfall – any station recording rainfall data on a daily or sub-daily basis. It includes both telemetered and non-telemetered stations.

2. Climate – any station providing air temperature and/or soil moisture on a daily or sub-daily basis. Note that climate stations recording rainfall will also appear as rainfall stations. Both telemetered and non-telemetered stations were included.

3. Soil moisture – any station recording soil moisture on an hourly or sub-hourly basis. All soil moisture stations in the region are telemetered.

Initially all stations registered in either CliDB or SIMS, within the Otago region, were selected, regardless of their current status (open/closed), type (manual/telemetered) or data type (rainfall/ climate/soil moisture). These lists were then merged with the station list supplied by ORC for this review.

When selecting stations from CliDB, the following selection criteria were used:

1. Rainfall – any station with data in the Daily Rain table (code 181) regardless of station type (closed/open; telemetered/non-telemetered; recording authority)

2. Climate – any station with air temperature data in the Max_Min_Temp table (code 202) and classed as a climate station regardless of station type code

2.2 Recording authorities and data availability

There are five broad categories of data providers in the ORC region used throughout this report: FENZ, MetService, NIWA, ORC, and Other. The "other" category captures the manual rainfall and climate station network operated by volunteers and organisations other than those named.

The four main providers of automated stations (referred to as recording authorities in the tables and figures in the report) NIWA, MetService, ORC and FENZ, all have different purpose(s), sometimes overlapping, for their networks, and this dictates the type of equipment used, telemetry and siting. For example,

- NIWA core network stations are intended to monitor long-term climate, and are part of national and international networks

- MetService stations are primarily used for forecasting purposes. A key responsibility is aviation hence many stations are at aerodromes. These are also part of national and international networks.

- ORC stations are primarily used for SOE reporting or flood warning, and to understand regional climate and freshwater resources.

- FENZ stations are primarily used for monitoring fire weather conditions and estimating fire weather indices. These are also part of the national network.

NIWA and MetService data are archived in the publicly accessible tables in CliDB. FENZ data are also archived in CliDB, but in a separate table, thus not available to the general public. ORC is able to access the FENZ data. There is minimal ORC data archived in CliDB.

While FENZ stations are now under a single umbrella, this was not always the case. In terms of ownership, stations were operated by the regional Rural Fire Authority (RFA). Each RFA had multiple members and some stations have multiple "owners" such as the Department of Conservation, forest owners, and District or City Councils. The two main providers of the stations were Scott Technical Instruments and Harvest Electronics. Both NIWA and MetService also contribute to the wider FENZ network.

Data from commercial networks such as the New Zealand Transport Agency (NZTA) state highway meteorological stations operated by MetService or wind only stations operated for various projects were not considered. Similarly, stations operated by hydropower companies were not considered in this review, as they are not available for public access. However, it may be possible for ORC to access data from those stations if required.

The review is based on the assumption that data from multiple agencies will be pooled or made accessible via federated data systems to provide a unified view of weather systems and climate across the region. It needs to be kept in mind that such collation of data from multiple sources should account for differences in instruments used, accuracy of data collected, availability of data in (near) real-time, frequency of data collection, QA/QC procedures applied, and data archival and retrieval. We also found inconsistencies in metadata between data providers especially with station names, station identifiers (station numbers), geographic coordinates, and others. These all add to the complexity. For instance, while working on compiling information on climate and rainfall stations in the Otago region, we found many sites that have multiple identifiers and names.

In early 2000, as a part of growOTAGO campaign, approximately 490 climate sites were installed temporarily for three years across the Otago region. These sites were used to describe the climate variability across the region. These sites have since been discontinued and thus are not included in this report. More information on the campaign and its outputs and outcomes can be accessed at https://www.royalsociety.org.nz/assets/113-Alpha-Series-Climate-variability-and-regional-development.pdf

2.3 Purpose and use of data collected

Climate data sources include numerous meteorological and related observational networks, and systems that provide data for various purposes such as weather forecasting, agricultural, aviation, and environmental impact assessments. Requirements of data quality and timeliness for these applications strongly depend on the use. The requirement for climate-relevant observations is to describe the long-term aspects variability of the climate system, while the focus of weather observations is to describe the current state of the atmosphere and its short-term variations.

Not all weather-related data are suitable for climatological purposes. This is an important distinction and can be due to several reasons:

- The length of record is (or is still) too short, although, in some circumstances, a well-equipped station can still contribute to validate other stations in a tiered approach, or be used in gridded analyses
- The station is equipped with non-standard (low quality and/or resolution) instruments, or is located in a site characterised by the presence of nearby obstacles affecting the representativeness and/or stability of the measured variables

- Lack of maintenance that could potentially introduce artificial biases in the data series (due to unrecognised drift of sensors that were not periodically verified or calibrated, or due to instrument change without specific procedures in place to compare old and new systems)
- Biased by changes in the methods and schedules of data collection
- Influenced by changes in the local environment and station surroundings and, therefore, biased to reliably support long-term climate assessments, products, or services.

Specific requirements differentiating weather observations from climatological observations include:

- A reference climatological period provides context for comparison of climatic variables over time. Climatological normals are derived based on these reference periods (see section 2.4 on climatological statistics). In order to derive a satisfactory climatological reference for a particular climate element, a sufficient period record of homogeneous, continuous and good quality observations is essential. A long period of record is also key if the data are to be useful for supporting assessments of climate variability and change.
- A climate observation must be associated with an adequate set of metadata that will provide users with information on how, where, when and by whom the observations were recorded, and on how it should be interpreted and used.
- The time resolution of data is also a point of difference between weather and climatological data. In the modern era, with many observations made by automatic weather stations, which have a high observation frequency (often 1-minute). Weather forecasting applications have limited use for data with hourly time resolution. However, data with only one or two observations per day, as long as they are consistent and reliable, can still be very useful for climatological purposes.

2.4 Derivation of climate statistics

Observations from climate and rainfall monitoring stations are used to derive a range of statistics such as daily mean temperature, number of rain days, growing degree days, winter chill units, soil moisture deficit and others. As noted earlier, a long period of record is key if the data are to usefully support assessments of climate variability and change. Long-term climate data are essential to identifying climatic indicators and understanding long-term regional trends.

The methods used to derive these statistics are also important. For example, historically, climate observations were made only once per day at 0900 NZDT. To calculate daily mean temperature, conventionally, daily maximum and minimum temperatures were added and divided by 2. Today modern automated stations record temperature at sub-hourly intervals, and thus average temperatures could be calculated with more data. However, average based on fine resolution temperature observations may vary significantly from that derived from the conventional method. Thus, the conventional methods are still continued to be used in combination with more modern methods to ensure continuity.

Another important statistic derived from long term climate observation is the climatological normal, a 30-year global standard product produced every ten-years. The normals for the 1991-2020 period are currently being reviewed at time of writing this report. For consistency, normals and long-term averages from the 1981 to 2010 period are included in the report.

Normals are available for the following variables:

- Total rainfall (mm)
- Mean air temperature (°C)
- Total sunshine hours

Climate normals are used for two principal purposes. They serve as a benchmark against which recent or current observations can be compared to generate anomalies. They are also widely used, implicitly and explicitly, to predict conditions that are most likely to be experienced at a given location (WMO, 2017a, 2018a). A list of all open and closed stations used for calculating "normals" has been assembled in Appendix A. Maps showing the 1981-2010 normals are included in section 4.

Long-term daily averages are also available for many variables. They include, but are not limited to:

- Solar radiation (Mj m^{-2})
- Penman potential evapotranspiration (mm)
- Soil temperature at 10 cm depth (°C)
- Wind speed at 10 m above ground level (m s^{-1})
- Soil moisture deficit (mm).

A count of average number of wet days (daily rainfall, $\geq$ 0.1 mm) per annum is also published.

2.5 Data measurement - Considerations and assumptions

Measurement consistency and awareness of differing data collection methods (instrumentation, quality control, archival and others) are crucial (see also section 6). There are subtle yet important differences between the providers as well as changes that could occur over the lifetime of a site. Instrument make and model, exposure, and data logging methods can influence the data recorded. Changes to any one of these can result in changes to measured variables and subsequent interpretations. Examples of few of those changes for a range of climate variables are included below:

- Changes to instrumentation: A change in instrument could change data *resolution* (the smallest change that can be measured), *sensitivity* (change in output to the change in the variable measured), *dynamic and operational ranges* (minimum and maximum measurable), *time response* (time it takes to record the change in the variable measured) and *linearity* (extent to which measured data is exactly proportional to its cause). With the change from Munro mechanical anemometers to Vector anemometers for measuring wind speed there are now fewer calm periods recorded because the start up speed was approximately 2.5 m/s for the Munro and is 0.15 m/s for the Vector sensor.

- Changes to measurement (site) exposure: Structures installed or removed nearby can impact the variable measured. WMO and others have documented the effects of sensor exposure on air temperature measurements. These include the proximity of heat sources such as roads. The type of radiation screens or shields used can also affect the measurement (WMO 2018b). For this latter reason, NIWA and MetService still continue to use wooden Stevenson screens at their key network sites.

- Changes to data logging procedures: Air temperature is recorded in many ways. For example, hourly data are logged differently by different data providers. The procedures range from measurement of instantaneous value on the hour, a 1-minute average prior to the hour, a 10-minute average prior to the hour, or an average over the entire hour. In addition, the scan rate of the data logger for these readings could be anywhere from less than a second to a minute.

  Another example is the recording of wind gusts. Some data providers use the maximum gust value over the whole hour and others use measurement from 10 minutes prior to the hour. With some data providers the maximum gust is a discrete 3-second value but for others it is a moving 3-second value.

Manual rainfall and climate stations provide vital long-term records for climate purposes. They have remained until recently, the main contributors to the derivation of climate normals. This review focuses mostly on stations providing near real-time data unless specifically mentioned (i.e., telemetered sites). The main reason for this is the frequency and timeliness of data. Manual stations provide only daily data and are often received months after being measured.

The number of stations with 30 or more years of data are limited, or many stations have gaps in their record. Where possible normals have been estimated using a complex set of rules. These rules are accessible via Cliflo (cliflo.niwa.co.nz) and in WMO (2017a).

The climate at a site is often based on monthly statistics for many variables. These statistics in turn are based on regular daily measurements, nominally at 0900 local time. The ideal is that no daily measurements are missed due to data logging problems, instrument problems, calibration problems, communications loss to data logger, observer absence, lost data entry forms, and many others. Occasionally an accumulated measurement has a period greater than one day (for instance, an observer for whatever reason, may record rainfall after a period of few days of accumulation). While the totals and extremes are unaffected by this, it can affect the daily data and in turn the monthly statistic. The following rules have been applied in the creation of statistics (WMO 2018a):

- TOTAL: all daily values must be present for the month, either on the day or implied where an accumulated period occurs
- EXTREME (Maximum or Minimum): all daily values must be present for the month, either on the day or implied where an accumulated period occurs. No date is given if the extreme value for the month occurs within an accumulation.
- MEAN: up to 10 daily values may be missing, but no more than 5 consecutive days.

In this report, no correlation analysis of historic information with nearby open, primary recorder sites was conducted, to assess their effectiveness in identifying sub climatic regions. However, we recommend that if new stations are going to be installed then temporary installations should be used first, followed by an evaluation of the temporary data against the VCS values for that location. This analysis will determine if the temporary site “adds any value” to the network, or whether interpolation from nearby sites is sufficient. Section 3 discusses the use of tiered networks and the feasibility of temporary stations.

Redundancy of stations was not considered in this review. Where duplication does exist, it is the view of the authors that nearby stations mostly have a different core purpose and complement each other by providing backup, as well as providing validation for models and a greater understanding of performance of differing instrument makes and models. However, the review did not delve into the purpose and instrumentation available at every site in the network.

This report did not consider the potential to reopen previously closed stations. Many closed stations were manual stations (especially climate) that have since been automated. Other reasons include decisions by the station operators to cease operations due to lack of resources (mainly funding), the end of the projects that led to the original installation (e.g., growOTAGO climate sites), and changes to land-use (e.g., property development). Where consideration is given to reopening stations, differences in instrumentation, and thus collected data, and changes to ambient conditions (e.g., land use change) need to be reviewed before linking old and new datasets.

3 Assessment of current climate network design

This section discusses network design principles and provides an assessment of the current Otago region network based on recognised criteria including the different climate types. For climate variable specific assessment see section 5.

Networks continuously evolve. Changing data requirements, along with ever changing technology, present a complex challenge for climate network managers. Climate networks are expensive to install and operate, and the consistency of measurement method is a vital performance requirement.

When considering a climate network, there are a series of logical and recurring questions: *What are the key purposes for monitoring the climate? Why are the stations there? What type of station is required - Ordinary, Principal, Agrometeorological and/or Urban climate station? What variables need to be measured?* Even within these station types, the levels of complexity vary.

WMO provides guidance on Network Design Principles (WMO, 2021). For convenience, these principles are repeated here and are translatable at a regional, national, and global level. A summary of the recommendations is provided below:

1. Multi-purpose station: Where practicable, observing networks should be designed and operated in such a way that the needs of multiple applications are addressed. It is acknowledged that different applications have different, and sometimes conflicting, requirements; when an observing network is implemented primarily to serve the needs of one application, compromises may be needed in its ability to serve others. Nevertheless, the requirements of other applications should be actively considered during network design.

2. Responding to user requirements: User communities should be involved in the observing network design. To ensure that observing networks respond to the key needs of the user communities, specific decisions about observing network design should include a consultation stage with appropriate application area representatives. A procedure should be implemented to allow a documented collection and synthesis of detailed user requirements.

3. Designing appropriately spaced networks: When considering priorities for additional observations, attention should be given to data-sparse regions and domains, poorly observed variables, regions sensitive to change and regions which experience environmental phenomena that place people and properties at risk.

4. Designing cost-effective networks: Partnerships with other organisations responsible for observations should be established and maintained to build on potential synergies, share costs and provide more cost-effective multi-purpose networks.

5. Achieving homogeneity in observational data: When stations are relocated or instruments upgraded, a sufficient period of overlap between the old and new systems should be provided, considering the targeted application areas.

6. Designing using a tiered approach: A network of other stations can be interspersed with a subset of high-quality stations for more complete coverage.

7. Designing reliable and stable networks: For climate monitoring, special attention should be given to maintaining stations with long, uninterrupted records and to

maintaining their homogeneity in location, instrumentation, and observation procedures.

8. Making observational data available: All raw data and agreed subsets of processed data should be collected into a document (permanent data and metadata) following commonly accepted standards.

9. Providing information so that the observations can be interpreted: Observation networks should be designed and operated in such a way that the station details and history of instruments, environments and operating conditions, data processing procedures and other factors pertinent to the understanding and interpretation of the observational data (i.e., metadata) are documented and treated with the same care as the data themselves.

10. Achieving sustainable networks

11. Managing change: Only observing technologies with adequately characterized performance should be deployed to ensure that levels of observational quality consistent with user requirements are attained.

Along with the station purpose, other critical factors in establishing a climate site are exposure and instrumentation. Even with the best instruments, if the exposure is poor, then the data quality suffers. Equally, good exposure but poor, or different, instrumentation will compromise data quality. Site exposure and instrumentation are further discussed in Section 6.

The New Zealand government reforms of the Public sector in the mid-1980s saw a large reduction in climate and rainfall stations that were operated by various departments. This necessitated a rethink and some key design criteria were developed to ensure the weather and climate of New Zealand were monitored as representatively as possible, and to meet as wide a range of uses as possible. See sub-headings in this section for further explanation on these criteria:

- Urban areas (population centres)
- Climatic regions (see NZMS, 1983)
- Areas of significant primary industry presence
- Altitude (added around 2008)

Where applicable some regional aspects have also been included such as:

- Land and water management units such as FMUs, Rohe, Whaitua (Greater Wellington Regional Council) and others but these have tended to be regionally specific and a result of specific needs or requests.

Nationally, the climate network is thought to be adequate for long-term climate monitoring with key criteria being met except for high-altitude stations (> 500 m above mean sea level). Technological improvements are now making this possible but there are also financial considerations with high altitude stations being very expensive to install, maintain and operate.

WMO provides guidance on the most common surface climate variables. Table 3-1 presents a subset of the climate variables for various station types from the Guide to Climatological Practices (WMO, 2018a).

Table 3-1: Examples of surface (above ground) and subsurface (below ground) elements for different station types.

Element	Ordinary Climate	Principal Climate	Hydrometeorological	Agrometeorological	Urban
Air Temperature	X	X		X	X
Soil Temperature				X	
Water Temperature			X		
Precipitation	X	X	X	X	X
Weather		X		X	X
Clouds		X		X	X
Pressure		X		X	X
Visibility		X		X	X
Humidity		X		X	X
Wind		X		X	X
Solar Radiation		X		X	X
Sunshine		X		X	X
Evaporation			X	X	X
Soil Moisture			X	X	X

In the New Zealand context, cloud and visibility measurements are almost exclusively made at airports only. Sunshine and solar radiation are commonly used as surrogates for cloudiness.

The following sub-sections are a more detailed outline of the current national network design reduced to a regional scale. Note that all maps and lists in this section are for open climate stations only. In this section, we did not focus on the variables measured at these stations. These are covered elsewhere in the report.

3.1 Urban areas

Urban stations are of high importance in climate networks for providing long lasting data series, and for monitoring the climate conditions in locations where people live. In a more practical sense, people want to know what it is going on around them. Climatologically, the value of urban stations is in the time extent of the recorded data though the metrological quality of the measurements may be subject to degradation due to many factors such as urban sprawl, vegetation cover (e.g., tree coverage), buildings, human traffic and so on.

In 2014, based on a previously published report from 2004 (Statistics New Zealand, 2004), Statistics New Zealand produced an update on the country's urban and rural profile (Statistics New Zealand, 2014), using 2006 Census data. The method used in the 2014 publication differs from previous definitions, where urban areas are defined as areas with population greater than 20,000.

In the ORC region, the greater Dunedin region and Queenstown Lakes qualify as urban areas as per StatNZ 2014 report (Statistics New Zealand, 2014). The current list of open climate stations for Dunedin and the Queenstown Lakes is provided in Table 3-2 and Figure 3-1. Note that further metadata on these sites and other lists in the document can be found in the appendices and are also freely available on CLIFLO (cliflo.niwa.co.nz), hence are not included here.

Table 3-2: Open climate sites within the urban areas of the Otago region.

Urban area	Site name	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Telemetered	Recording authority
Greater Dunedin region	Swampy Summit AWS	2313752	5486642	716	Yes	MetService
	Dunedin Aero AWS	2292444	5471955	2	Yes	MetService
	Dunedin, Musselburgh EWS	2317005	5475563	10	Yes	NIWA
	Dunedin RAWS	2292461	5471699	1	Yes	FENZ
	Highcliff RDNZ	2323185	5477483	351	Yes	FENZ
Queenstown Lakes	Queenstown Aero RAWS	2175748	5568075	346	Yes	FENZ
	Queenstown Aero AWS	2174345	5568034	357	Yes	MetService
	Queenstown EWS	2168420	5565818	322	Yes	NIWA

3.1.1 Conclusions

- There is good station coverage and a range of core uses in the urban areas.

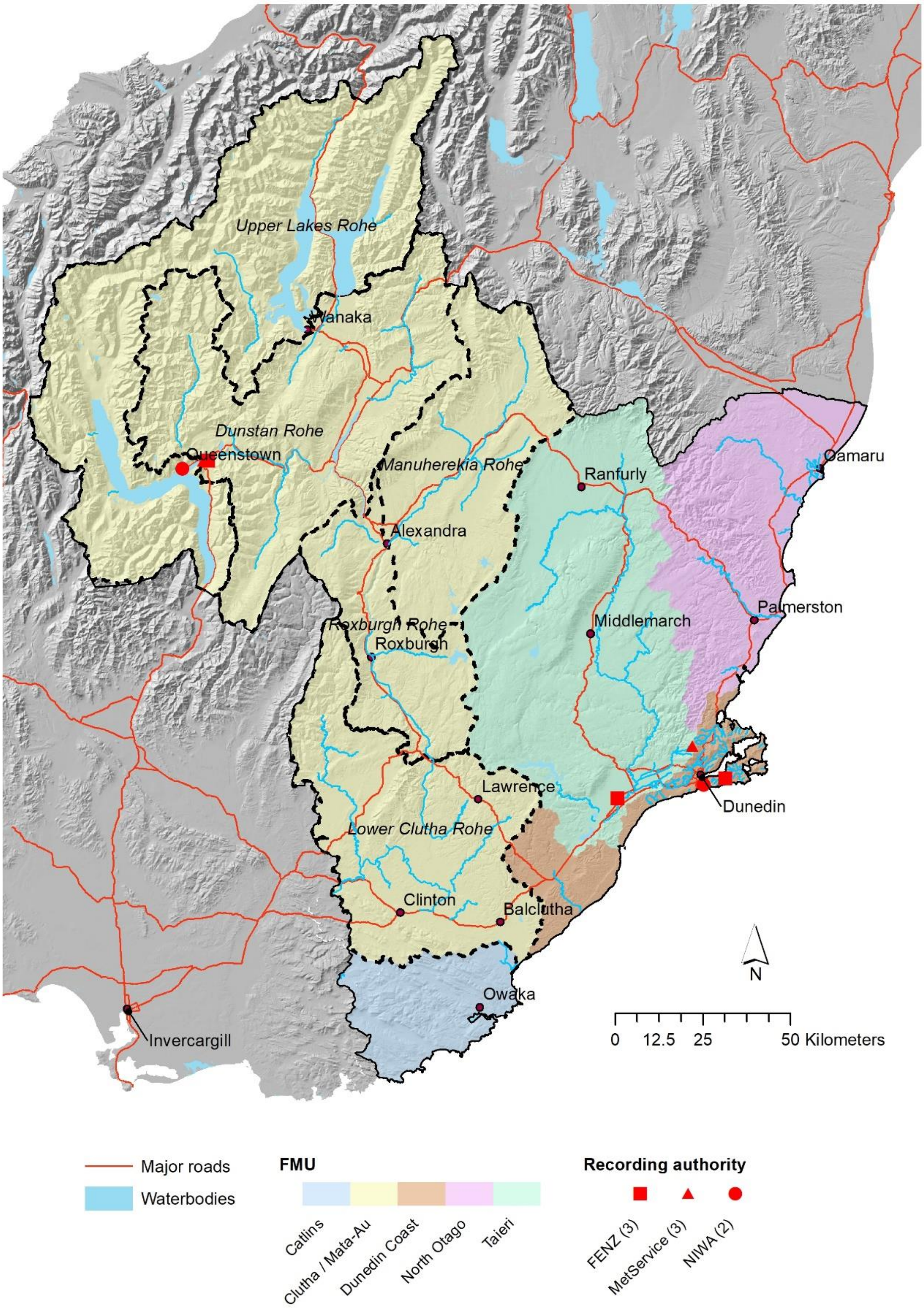


Figure 3-1: Open climate sites within the urban areas of the ORC region, shown by FMUs.

3.2 Climatic regions

The regional climatology report by Macara (2015) describes Otago's climate as below -

"The climate of Otago is perhaps the most diverse of any region in New Zealand. The region is in the latitudes of prevailing westerlies, and exposed coastal locations often experience strong winds, but the winds are lighter inland. Winter is typically the least windy time of year, as well as for many but not all areas, the driest.

Annual precipitation in Otago typically decreases with increasing distance from the western ranges and the east coast. Indeed, Central Otago is the driest region of New Zealand, receiving less than 400 mm of rainfall annually. Dry spells of more than two weeks occur relatively frequently in Central Otago, but less so elsewhere. Temperatures are on average lower than over the rest of the country with frosts and snowfalls occurring relatively frequently each year. However daily maximum temperatures in summer can exceed 30°C, especially about inland areas of Otago.

On average, coastal Otago receives less sunshine than many other parts of New Zealand."

The climate of Otago is perhaps the most diverse of any region in New Zealand. The main divide of the Southern Alps in the west of the region acts as a barrier to the prevailing westerlies and has a profound effect on the weather and climate of Otago. This is highlighted in that the divide separates New Zealand's wettest region (West Coast) from the driest (Central Otago). Central Otago's climate is characterised by hot dry summers and cold dry winters. The climate of coastal areas of eastern Otago are tempered by relatively cool sea surface temperatures.

The climatic regions for New Zealand have been defined in New Zealand Meteorological Service (1983). This describes 17 distinct climate types across New Zealand of which the Otago region has six types as shown here in Table 3-3.

Table 3-3: Dominant climatic regions of Otago.

Source: New Zealand Meteorological Service (1983)

Climatic region	Description
F1	Low annual rainfalls of 500 to 800 in south. Slightly more in winter than in other seasons. Warm summers with occasional hot foehn northwesterlies giving temperatures above 30 °C. Cool winters with frequent frosts and occasional snow. Northeasterlies prevail with northwesterlies more frequent inland.
F2	Cooler and wetter than F1 with rainfall 800 to 1,500 mm. Northwesterlies predominate with occasional very strong gales especially along river valleys. Snow may lie for weeks in winter.
F3	Semi-arid areas with annual rainfall 300 to 500 mm. Very hot summers and cold winters.
G1	Warm summers and cool winters. Rainfall 500 to 900 mm evenly distributed but slight winter minimum.
G2	Wetter than G1 with rainfall 900 to 1,300 mm. Generally windier with frequent showers in coastal districts.
M	High rainfall mountain climates. Conditions vary greatly with altitude and exposure.

A list of all open climate stations organised by climatic regions are available in Table 3-4.

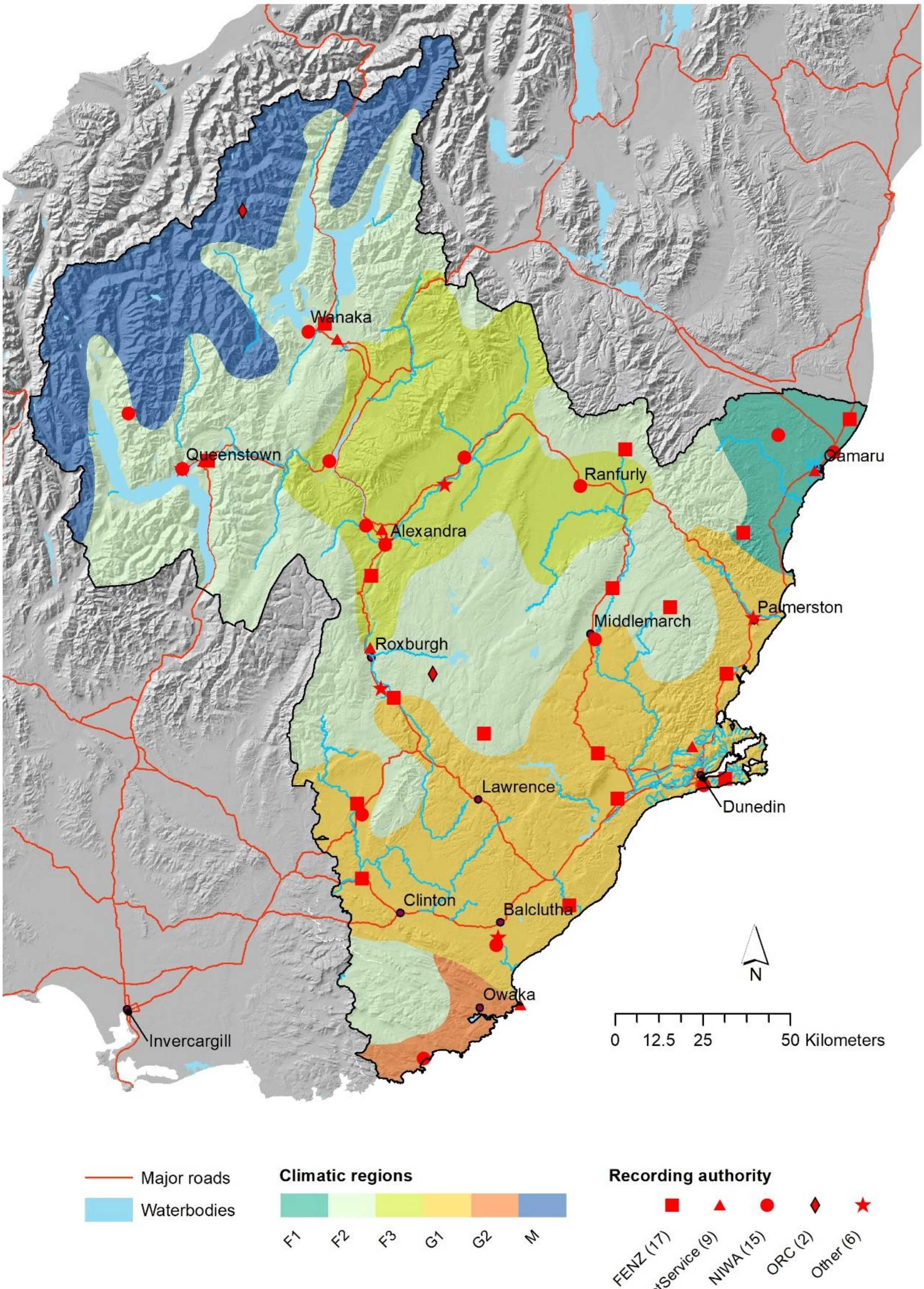


Figure 3-2: Open climate sites in the Otago region, shown by climatic regions.

Refer to Table 3-3 for an explanation of the climatic regions.

Table 3-4: Open climate sites in the Otago region listed by climatic regions.

Total number of sites, 49.

Climatic region	Site name	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Telemetered	Recording authority
F1	Herbert RAWS	2328300	5547657	572	Yes	FENZ
F1	Oamaru RAWS	2358658	5579998	41	Yes	FENZ
F1	Oamaru AWS	2348651	5565348	40	Yes	MetService
F1	Oamaru Airport AWS	2358595	5579964	30	Yes	MetService
F1	Oamaru EWS	2354201	5570499	20	Yes	NIWA
F1	Windsor EWS	2338333	5575447	81	Yes	NIWA
F2	Glendhu RAWS	2254447	5490223	660	Yes	FENZ
F2	Mcraes RAWS	2307562	5526325	633	Yes	FENZ
F2	Rock and Pillar RAWS	2291091	5531815	270	Yes	FENZ
F2	Queenstown Aero RAWS	2175748	5568075	346	Yes	FENZ
F2	Dansey Pass RAWS	2294691	5571315	495	Yes	FENZ
F2	Hawera Flats RAWS	2209092	5607157	307	Yes	FENZ
F2	Roxburgh Wxt AWS	2221926	5514752	160	Yes	MetService
F2	Queenstown Aero AWS	2174345	5568034	357	Yes	MetService
F2	Wanaka Aero AWS	2212511	5602778	352	Yes	MetService
F2	Queenstown EWS	2168420	5565818	322	Yes	NIWA
F2	Mt Larkins EWS	2153094	5581629	1900	Yes	NIWA
F2	Wanaka CWS	2204381	5604889	331	Yes	NIWA
F2	Mt Teviot EWS	2239756	5507383	960	Yes	NIWA
F2	Ettrick No.2	2225164	5503123	91	No	Other
F2	Queenstown	2168420	5565818	322	No	Other
F3	Butchers Dam RAWS	2222331	5535265	383	Yes	FENZ
F3	Alexandra AWS	2225317	5548567	231	Yes	MetService
F3	Alexandra EWS	2226217	5544151	132	Yes	NIWA
F3	Clyde 2 EWS	2220767	5549601	170	Yes	NIWA
F3	Ranfurly EWS	2281864	5560831	450	Yes	NIWA
F3	Cromwell EWS	2210270	5567979	213	Yes	NIWA
F3	Lauder EWS	2248801	5568999	375	Yes	NIWA
F3	Alexandra	2226574	5545121	150	No	Other
F3	Ophir 2	2243270	5561387	305	No	Other
G1	Toko Mouth RAWS	2278792	5441218	127	Yes	FENZ
G1	Waipahi RAWS	2219674	5448888	115	Yes	FENZ
G1	Tapanui RAWS	2218205	5470326	200	Yes	FENZ
G1	Dunedin RAWS	2292461	5471699	1	Yes	FENZ
G1	Highcliff Rdnz	2323185	5477483	351	Yes	FENZ
G1	Traquair RAWS	2286906	5484627	425	Yes	FENZ
G1	Millers Flat RAWS	2228737	5500452	93	Yes	FENZ
G1	Bucklands RAWS	2323551	5507397	75	Yes	FENZ
G1	Dunedin Aero AWS	2292444	5471955	2	Yes	MetService
G1	Swampy Summit AWS	2313752	5486642	716	Yes	MetService
G1	Balclutha, Telford EWS	2257972	5429980	11	Yes	NIWA
G1	Tapanui EWS	2219690	5467167	180	Yes	NIWA

Climatic region	Site name	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Telemetered	Recording authority
G1	Dunedin, Musselburgh EWS	2317005	5475563	10	Yes	NIWA
G1	Middlemarch EWS	2286136	5517182	213	Yes	NIWA
G1	Balclutha, Finegand	2258464	5432204	6	No	Other
G1	Palmerston	2331212	5523309	21	No	Other
G2	Tautuku EWS	2237176	5397601	25	Yes	NIWA
G2	Nugget Point AWS	2264841	5413020	131	Yes	MetService
M	Albert Burn	2185504	5639415	1280	Yes	NIWA

3.2.1 Conclusions

- Each climatic region has at least one station
- The small isolated region (but also classed as F2) wedged between G1 and G2 in the south of the region (see Figure 3-4) does not have any climate station
- Climatic region M is poorly covered by the climate network although of note is that Mt Larkins EWS is 700 m higher in altitude than Albert Burn but is in region F2 under this classification
- Operationally, and for water resource management, region M is potentially under-represented.

3.3 Primary industry

Otago is topographically diverse consisting of large mountain blocks and relatively low elevation basins. The climate of these inland basins lends itself to a burgeoning viticulture industry, whilst horticulture and agriculture have a long history within the region.

Stations within this category were arbitrarily selected yet still ensure good coverage across the region. In addition to more typical rainfall and air temperature, these stations tend to measure variables such as soil temperature (multiple depths), soil moisture, solar radiation and evaporation/potential evapotranspiration, which are all important for this sector. A listing of stations that are located within the primary sector region of ORC can be found in Figure 3-3, Figure 3-4 and Table 3-5.

Table 3-5: Open climate sites in the Otago region, listed by primary sector region.

Total number of sites, 29.

Name	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Recording authority
Rock and Pillar RAWS	2291092	5531997	270	FENZ
Butchers Dam RAWS	2222329	5535447	383	FENZ
Traquair RAWS	2286907	5484808	425	FENZ
Dansey Pass RAWS	2294691	5571498	495	FENZ
Tapanui RAWS	2218203	5470506	200	FENZ
Glendhu RAWS	2254446	5490403	660	FENZ
Mcraes RAWS	2307563	5526507	633	FENZ
Herbert RAWS	2328301	5547840	572	FENZ
Bucklands RAWS	2323553	5507578	75	FENZ
Waipahi RAWS	2219672	5449067	115	FENZ
Hawera Flats RAWS	2209089	5607341	307	FENZ
Queenstown Aero RAWS	2175744	5568257	346	FENZ
Oamaru RAWS	2358661	5580182	41	FENZ
Dunedin RAWS	2292462	5471880	1	FENZ
Millers Flat RAWS	2228735	5500633	93	FENZ
Toko Mouth RAWS	2278793	5441398	127	FENZ
Highcliff RDNZ	2323187	5477664	351	FENZ
Nugget Point AWS	2264841	5413198	131	MetService
Windsor EWS	2338334	5575630	81	NIWA
Ranfurly EWS	2281864	5561014	450	NIWA
Middlemarch EWS	2286136	5517363	213	NIWA
Cromwell EWS	2210267	5568161	213	NIWA
Lauder EWS	2248799	5569182	375	NIWA
Clyde 2 EWS	2220764	5549782	170	NIWA
Balclutha, Telford EWS	2257973	5430159	11	NIWA
Tautuku EWS	2237176	5397779	25	NIWA
Mt Teviot EWS	2239755	5507563	960	NIWA
Palmerston	2331213	5523491	21	Other
Ettrick No.2	2225163	5503303	91	Other

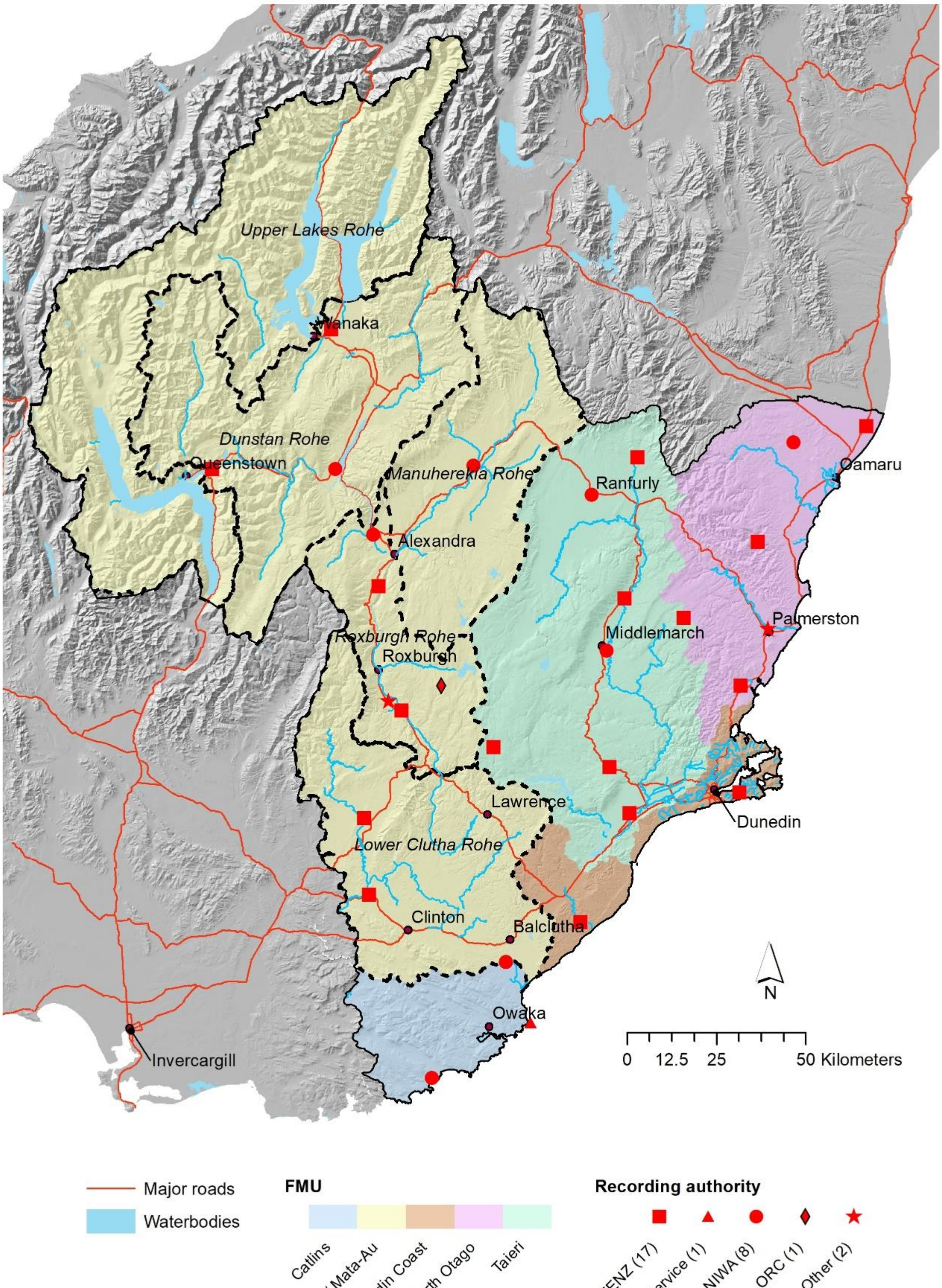


Figure 3-3: Open climate sites listed by primary sector region withn various FMUs.

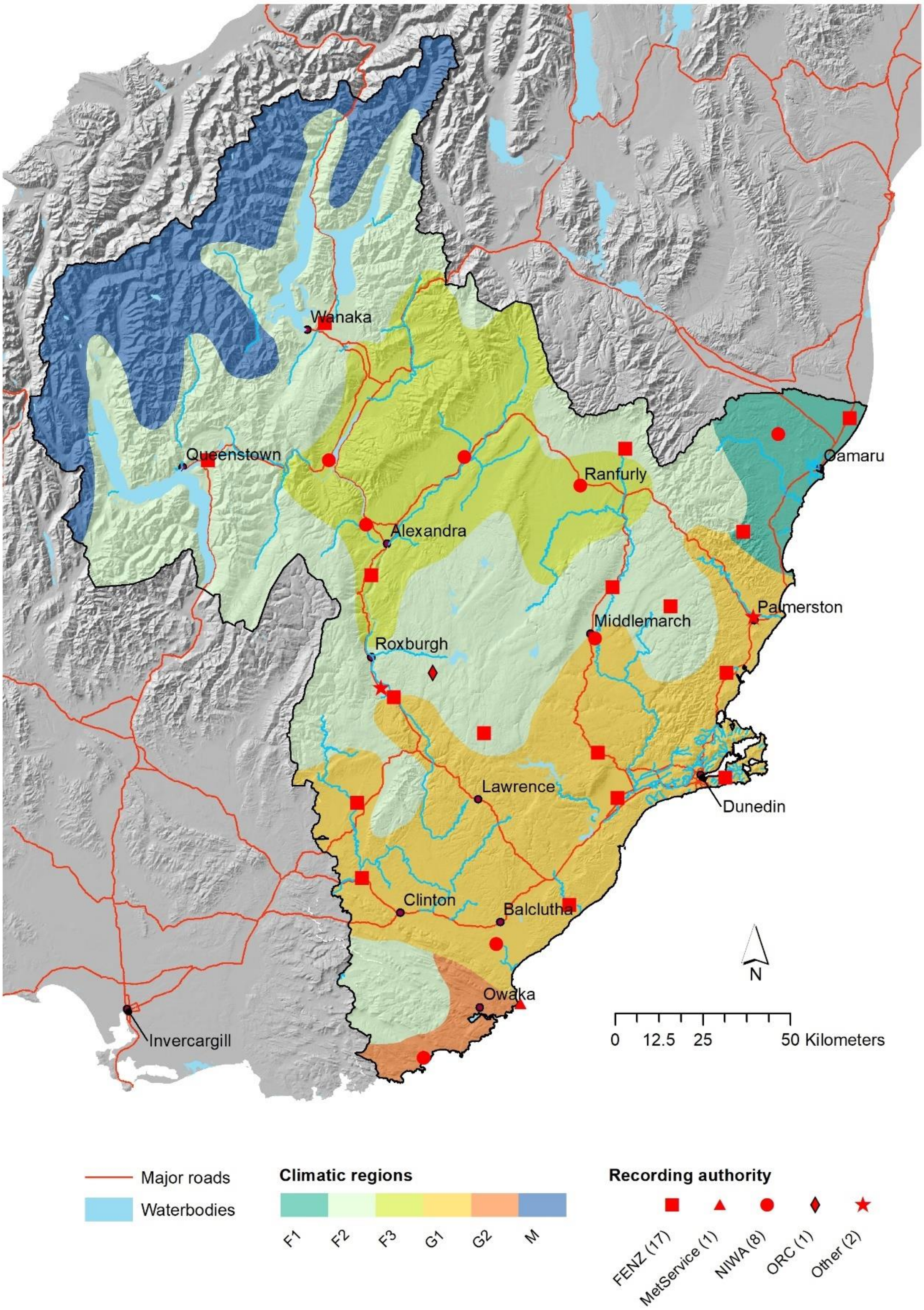


Figure 3-4: Open climate sites listed by primary sector region within various climatic regions. Refer to Table 3-3 for an explanation of the climatic regions.

3.3.1 Conclusions

- There appears to be a good station coverage of primary sector land use for most variables.

3.4 Altitude

As previously stated, Otago is topographically diverse, yet there is tendency to have sites at locations that are near population centres and easy to access. These centres all tend to be at relatively low elevations, yet a significant percentage of Otago is above 500 m.

While elevations above 500 m tend to be unpopulated, they are significant climatologically and are underrepresented. This criterion is to ensure a range of elevations is considered. Of 49 climate stations in the region, only seven are above 500 m. Figure 3-5 and Table 3-6 highlight this lack of sites above 500 m altitude.

Table 3-6: Open climate sites at or above 500 m above mean sea level in the Otago region.

Total number of sites, 7.

Site name	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Telemetered	Recording authority
Mt Larkins EWS	2153094	5581629	1900	Yes	NIWA
Albert Burn	2185504	5639415	1280	Yes	NIWA
Mt Teviot EWS	2239756	5507383	960	Yes	NIWA
Swampy Summit AWS	2313752	5486642	716	Yes	MetService
Glendhu RAWS	2254447	5490223	660	Yes	FENZ
Mcraes RAWS	2307562	5526325	633	Yes	FENZ
Herbert RAWS	2328300	5547657	572	Yes	FENZ

3.4.1 Conclusions

- A significant percentage of the region is above 500 m, however, the current climate network does not sufficiently capture areas above 500 m.

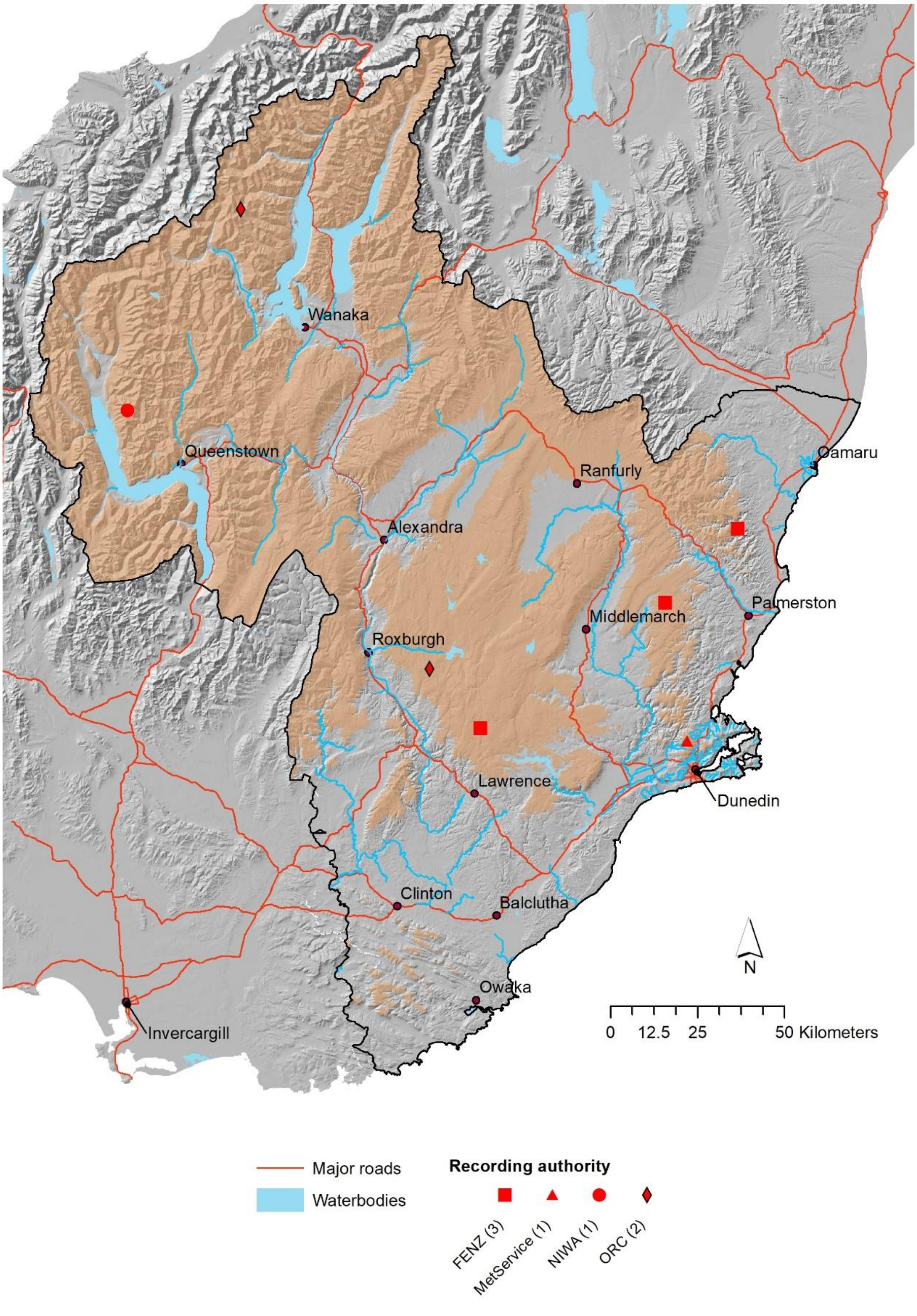


Figure 3-5: Open climate sites at or above 500 m above mean sea level.

Areas shown in brown colour are at or above 500 m above mean sea level.

3.5 FMUs and Rohe

A Freshwater Management Unit (FMU) is a water body, or multiple water bodies, that ORC has assigned as an appropriate management unit for setting of freshwater objectives and limits (refer, https://www.orc.govt.nz/plans-policies-reports/regional-plans-and-policies/water/freshwater-management-units). This can be a river catchment, part of a catchment, or a group of catchments.

The region has been divided into five FMUs:

- Catlins
- Clutha/Mata-Au
- Dunedin Coast
- North Otago
- Taieri

As the Clutha/Mata-Au FMU is large, it has been further divided into five Rohe (areas):

- Upper Lakes
- Dunstan
- Manuherekia
- Roxburgh
- Lower Clutha

The purpose of this sub-section is to investigate the general coverage of climate stations across each FMU and Rohe. All open climate stations arranged by FMUs and Rohe are shown in Figure 3-6, Table 3-7 and

Table 3-8.

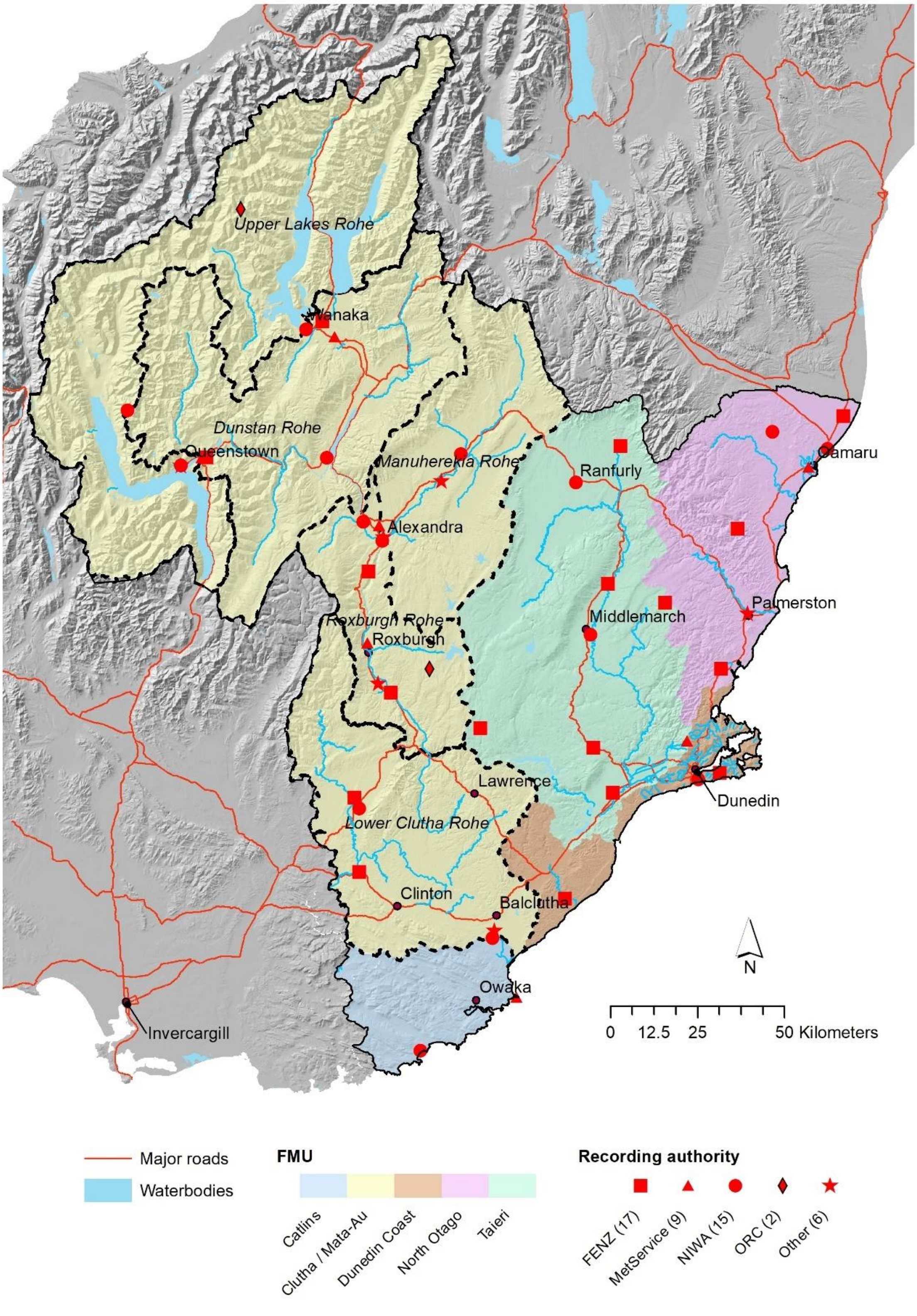


Figure 3-6: Open climate sites in the Otago region, shown by FMUs.

Table 3-7: Open climate sites in the Otago region listed by FMUs.

Total number of sites, 49.

FMU	Site name	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Recording authority
Catlins	Nugget Point AWS	2264841	5413020	131	MetService
Catlins	Tautuku EWS	2237176	5397601	25	NIWA
Catlins	Balclutha, Telford EWS	2257972	5429980	11	NIWA
Clutha / Mata-Au	Waipahi RAWS	2219674	5448888	115	FENZ
Clutha / Mata-Au	Tapanui RAWS	2218205	5470326	200	FENZ
Clutha / Mata-Au	Millers Flat RAWS	2228737	5500452	93	FENZ
Clutha / Mata-Au	Butchers Dam RAWS	2222331	5535265	383	FENZ
Clutha / Mata-Au	Queenstown Aero RAWS	2175748	5568075	346	FENZ
Clutha / Mata-Au	Hawera Flats RAWS	2209092	5607157	307	FENZ
Clutha / Mata-Au	Roxburgh Wxt AWS	2221926	5514752	160	MetService
Clutha / Mata-Au	Alexandra AWS	2225317	5548567	231	MetService
Clutha / Mata-Au	Queenstown Aero AWS	2174345	5568034	357	MetService
Clutha / Mata-Au	Wanaka Aero AWS	2212511	5602778	352	MetService
Clutha / Mata-Au	Tapanui EWS	2219690	5467167	180	NIWA
Clutha / Mata-Au	Alexandra EWS	2226217	5544151	132	NIWA
Clutha / Mata-Au	Clyde 2 EWS	2220767	5549601	170	NIWA
Clutha / Mata-Au	Queenstown EWS	2168420	5565818	322	NIWA
Clutha / Mata-Au	Cromwell EWS	2210270	5567979	213	NIWA
Clutha / Mata-Au	Lauder EWS	2248801	5568999	375	NIWA
Clutha / Mata-Au	Mt Larkins EWS	2153094	5581629	1900	NIWA
Clutha / Mata-Au	Wanaka CWS	2204381	5604889	331	NIWA
Clutha / Mata-Au	Albert Burn	2185504	5639415	1280	NIWA
Clutha / Mata-Au	Mt Teviot EWS	2239756	5507383	960	NIWA
Clutha / Mata-Au	Balclutha, Finegand	2258464	5432204	6	Other
Clutha / Mata-Au	Ettrick No.2	2225164	5503123	91	Other
Clutha / Mata-Au	Alexandra	2226574	5545121	150	Other
Clutha / Mata-Au	Ophir 2	2243270	5561387	305	Other
Clutha / Mata-Au	Queenstown	2168420	5565818	322	Other
Dunedin Coast	Toko Mouth RAWS	2278792	5441218	127	FENZ
Dunedin Coast	Highcliff RDNZ	2323185	5477483	351	FENZ
Dunedin Coast	Dunedin, Musselburgh EWS	2317005	5475563	10	NIWA
North Otago	Bucklands RAWS	2323551	5507397	75	FENZ
North Otago	Mcraes RAWS	2307562	5526325	633	FENZ
North Otago	Herbert RAWS	2328300	5547657	572	FENZ
North Otago	Oamaru RAWS	2358658	5579998	41	FENZ
North Otago	Oamaru AWS	2348651	5565348	40	MetService
North Otago	Oamaru Airport AWS	2358595	5579964	30	MetService
North Otago	Oamaru EWS	2354201	5570499	20	NIWA
North Otago	Windsor EWS	2338333	5575447	81	NIWA
North Otago	Palmerston	2331212	5523309	21	Other
Taieri	Dunedin RAWS	2292461	5471699	1	FENZ

FMU	Site name	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Recording authority
Taieri	Traquair RAWS	2286906	5484627	425	FENZ
Taieri	Glendhu RAWS	2254447	5490223	660	FENZ
Taieri	Rock and Pillar RAWS	2291091	5531815	270	FENZ
Taieri	Dansey Pass RAWS	2294691	5571315	495	FENZ
Taieri	Dunedin Aero AWS	2292444	5471955	2	MetService
Taieri	Swampy Summit AWS	2313752	5486642	716	MetService
Taieri	Middlemarch EWS	2286136	5517182	213	NIWA
Taieri	Ranfurly EWS	2281864	5560831	450	NIWA

Table 3-8: Open climate sites arranged by Rohe within Clutha/Mata-Au FMU.

Rohe	Site name	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Telemetered	Recording authority
Dunstan	Queenstown Aero RAWS	2175748	5568075	346	Yes	FENZ
Dunstan	Hawera Flats RAWS	2209092	5607157	307	Yes	FENZ
Dunstan	Queenstown Aero AWS	2174345	5568034	357	Yes	MetService
Dunstan	Wanaka Aero AWS	2212511	5602778	352	Yes	MetService
Dunstan	Cromwell EWS	2210270	5567979	213	Yes	NIWA
Dunstan	Mt Larkins EWS	2153094	5581629	1900	Yes	NIWA
Lower Clutha	Waipahi RAWS	2219674	5448888	115	Yes	FENZ
Lower Clutha	Tapanui RAWS	2218205	5470326	200	Yes	FENZ
Lower Clutha	Tapanui EWS	2219690	5467167	180	Yes	NIWA
Lower Clutha	Balclutha, Finegand	2258464	5432204	6	No	Other
Manuherekia	Lauder EWS	2248801	5568999	375	Yes	NIWA
Manuherekia	Alexandra	2226574	5545121	150	No	Other
Manuherekia	Ophir 2	2243270	5561387	305	No	Other
Roxburgh	Millers Flat RAWS	2228737	5500452	93	Yes	FENZ
Roxburgh	Butchers Dam RAWS	2222331	5535265	383	Yes	FENZ
Roxburgh	Roxburgh Wxt AWS	2221926	5514752	160	Yes	MetService
Roxburgh	Alexandra AWS	2225317	5548567	231	Yes	MetService
Roxburgh	Alexandra EWS	2226217	5544151	132	Yes	NIWA
Roxburgh	Clyde 2 EWS	2220767	5549601	170	Yes	NIWA
Roxburgh	Mt Teviot EWS	2239756	5507383	960	Yes	NIWA
Roxburgh	Ettrick No.2	2225164	5503123	91	No	Other
Upper Lakes	Queenstown EWS	2168420	5565818	322	Yes	NIWA
Upper Lakes	Wanaka CWS	2204381	5604889	331	Yes	NIWA
Upper Lakes	Albert Burn	2185504	5639415	1280	Yes	NIWA
Upper Lakes	Queenstown	2168420	5565818	322	No	Other

3.5.1 Conclusions

- Each FMU is generally well covered
- Each Rohe has at least three climate stations
- The Manuherekia and Upper Lakes Rohe could benefit from further review as to the adequacy of coverage or whether stations near the boundaries in neighbouring Rohe are sufficient.

4 Assessment of climate network for refining the virtual climate station (VCS) network

Virtual climate station (VCS) data are estimates of daily rainfall, potential evapotranspiration, air and vapour pressure, maximum and minimum air temperature, soil temperature, relative humidity, solar radiation, wind speed and soil moisture on a regular grid (0.05 degrees latitude/longitude, ~5 km), covering the whole of New Zealand (see Figure 4-1, which shows the VCS network nodes for the Otago region). The estimates are produced every day, based on the spatial interpolation of actual observations made at approximately 280 climate sites located around the country.

A thin-plate smoothing spline model is used for the spatial interpolations. This model incorporates two location variables (latitude and longitude) and a third "pattern" variable. For example, for rainfall the 1951–80 mean annual rainfall digitised from an expert-guided contour map is used to aid the interpolation (Tait et al. 2006; Tait et al. 2012). The software used for the interpolations is ANUSPLIN (Hutchinson 2012).

The underlying usefulness of spatial interpolation methods is directly related to the quality and quantity of the surface observations. In addition to the daily production run, a monthly update is run using data from a further 250 manual rainfall sites across the country. Rainfall data from Regional Councils is also used to bias correct the VCS rainfall data periodically on demand. Data from FENZ stations are not used to produce VCS data.

Figure 4-2 shows the current open rain gauge network for the Otago region, and Figure 4-3 shows the current open climate site network.

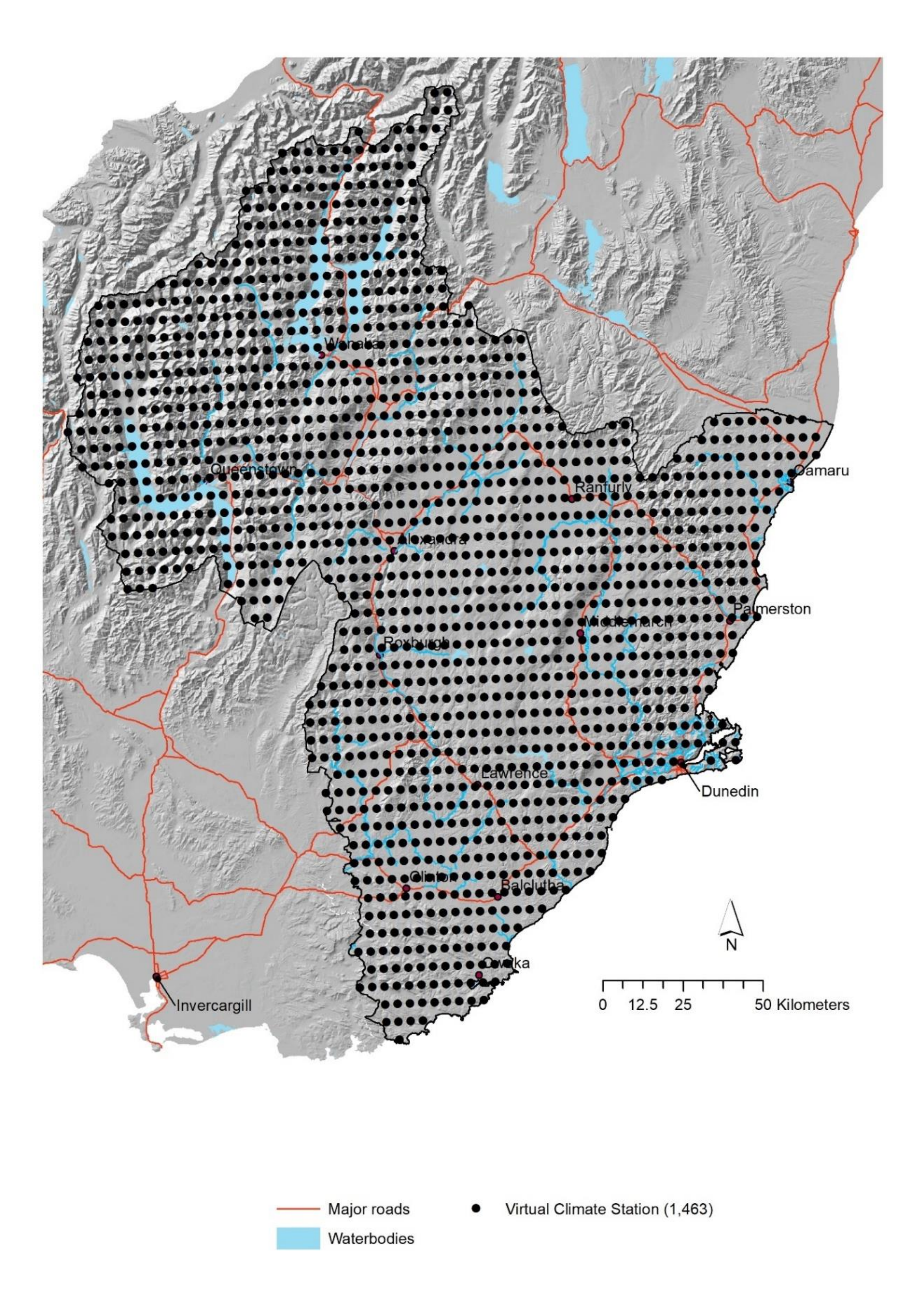


Figure 4-1: Virtual Climate Station nodes within the ORC region.

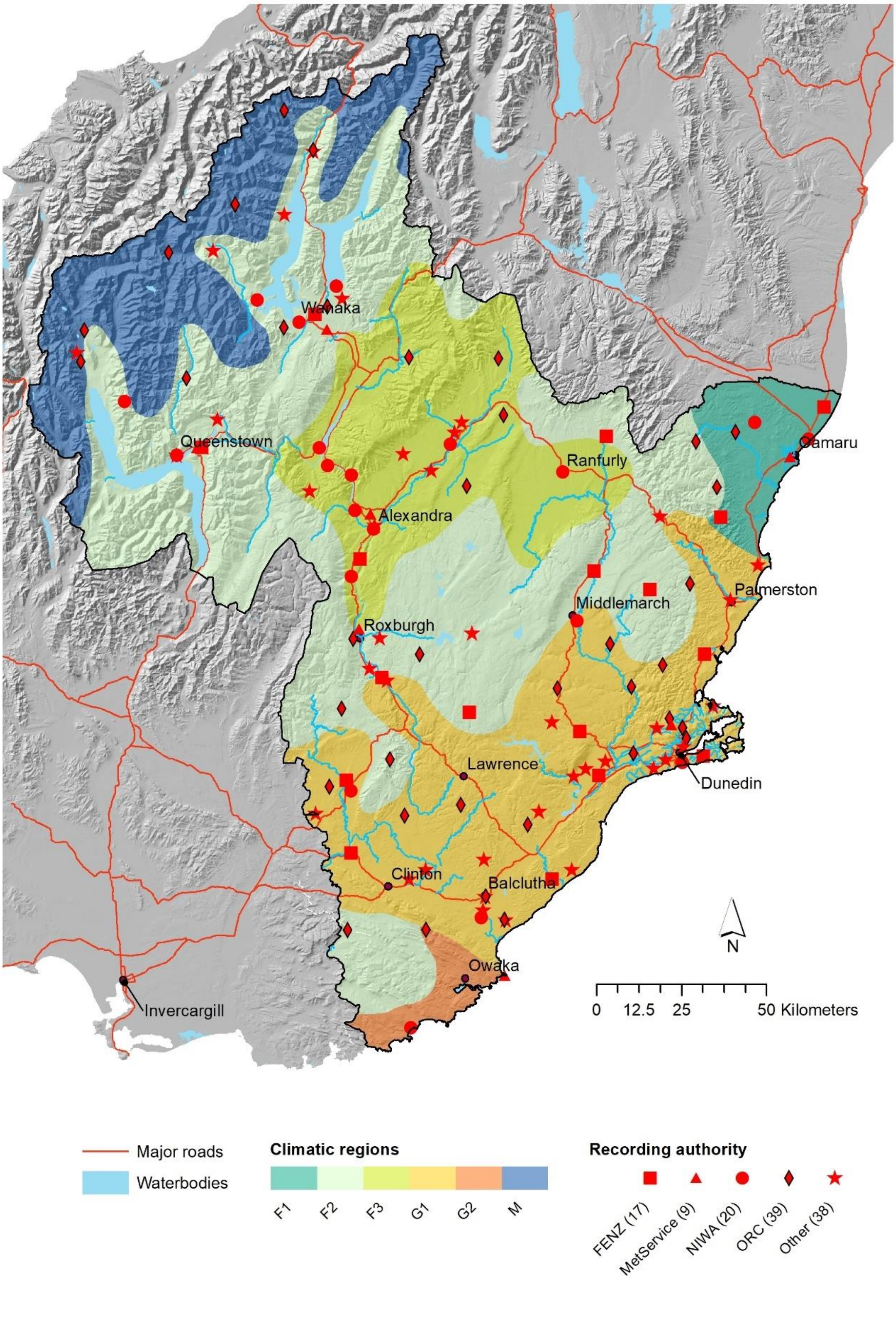


Figure 4-2: Open rainfall sites across various climatic regions within the Otago region. Refer to Table 3-3 for an explanation of the climatic regions. Only NIWA sites are used in developing VCS dataset.

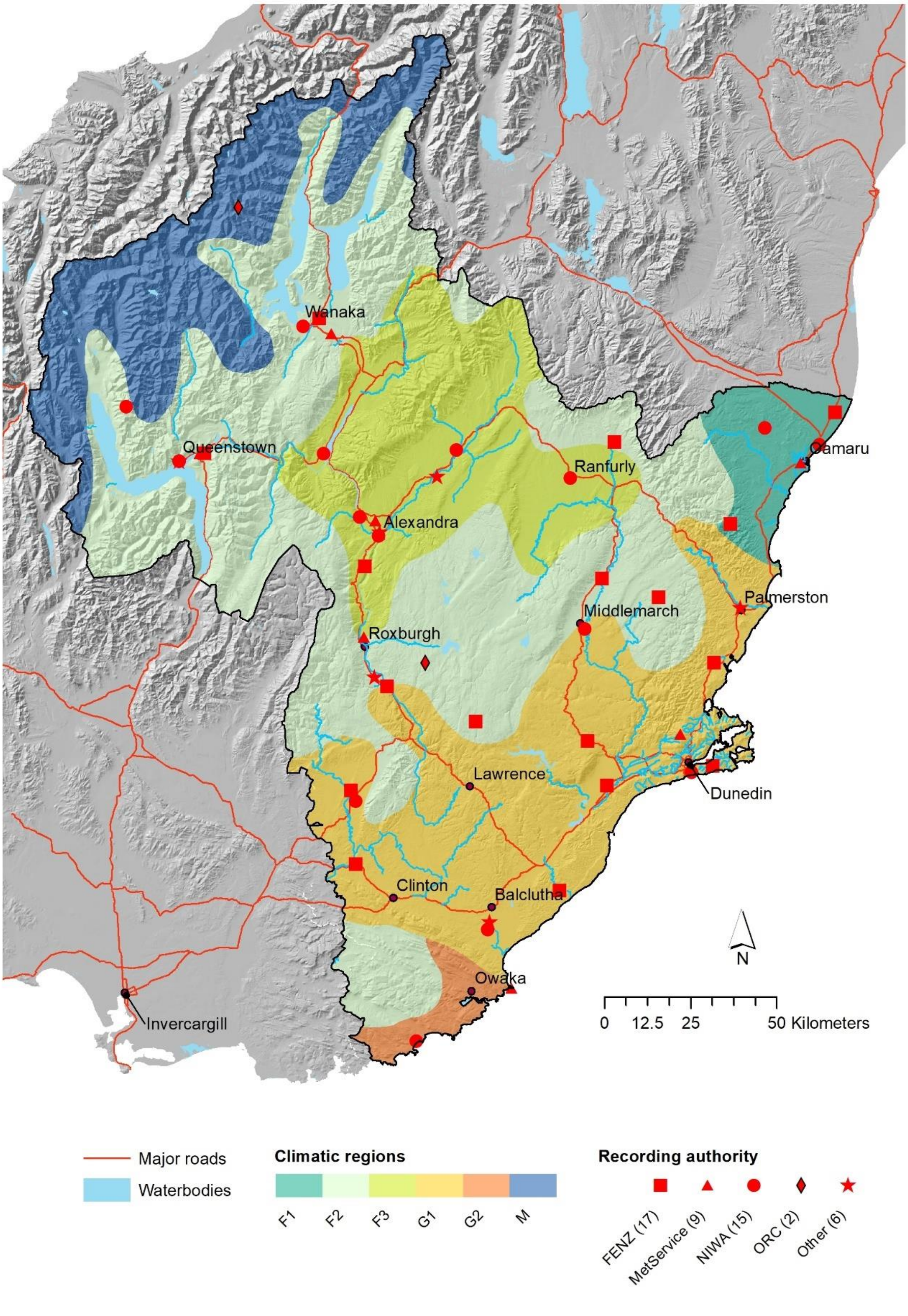


Figure 4-3: Open climate sites across various climatic regions within the Otago region. Refer to Table 3-3 for an explanation of the climatic regions. Only NIWA sites are used in developing VCS dataset.

The coverage of rainfall measurements (rain gauges) in the Otago region is considered to be very good, with all the sub-climatic regions well represented with a good density of observations (Figure 4-2). There is a good mix of coastal and inland sites, as well as sites at different elevations up to approximately 2,000m above mean sea level. However, not all these sites are telemetered, and, as the gauges are of mixed ownership, not all data are available in real-time to the ORC environmental database or NIWA's climate database (CliDB).

Based on the distribution of these observation sites, and whether they are automated or not, and our understanding of the principal causes of uncertainty in the spatial interpolation of daily climate data, our conclusions and recommendations for rainfall and climate are given in the following two sub-sections.

4.1 Rainfall

- Real-time VCS rainfall data (produced daily) for all of New Zealand are derived from NIWA and MetService automatic climate site data only (see the corresponding sites in the Otago region in Figure 4-3). As a result, there are a number of gauges shown in Figure 4-2 that do not contribute to the VCS rainfall data interpolation. Despite this, VCS rainfall values are likely to be reasonably representative of actual rain gauge data in all but the mountain climatic region M of the region, where there are few observations.
- Every month (at around the 20th of the month), the previous month's VCS data are re-generated and overwritten. This is done to accommodate the rainfall observations received from manual sites (the number of manual rainfall sites in New Zealand is currently around 280).
- Recently NIWA in collaboration with ORC has worked on refining the VCS rainfall dataset by including rainfall data from ORC stations listed in Table 4-1.

Table 4-1: List of ORC rain gauges used in developing region specific Virtual Climate Network rainfall data. Total number of sites, 30.

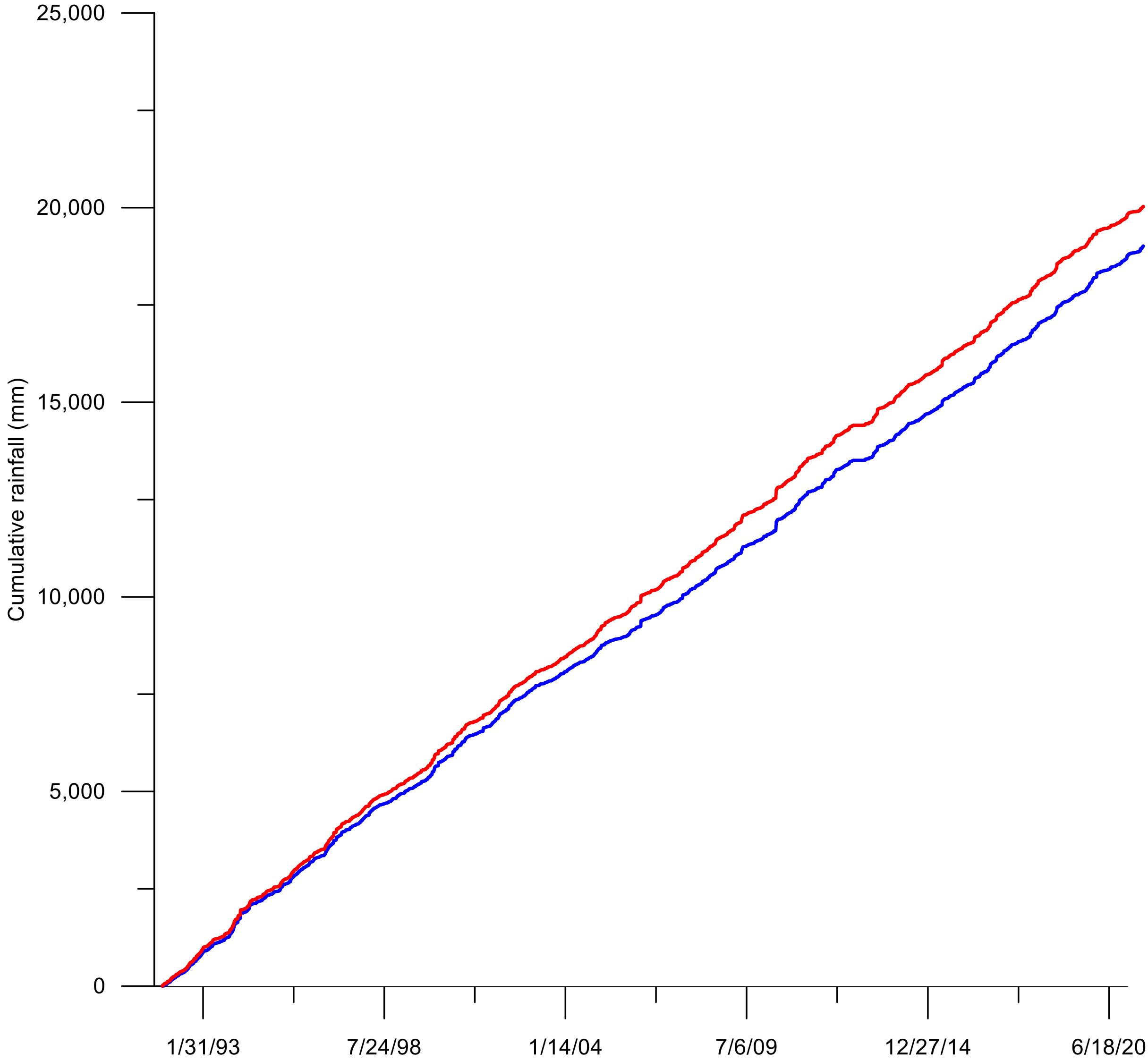
Site name	Easting (NZMG)	Northing (NZMG)
Matukituki at Cascade Hut	2166000	5625399
Matukituki at Raspberry Flat	2173201	5624763
Dart at Paradise	2141200	5602499
Dart at The Hillocks	2140100	5593299
Albert Burn at DragonFly	2185500	5639599
Shotover at Peats	2171200	5588499
Young North Branch at Dam	2200000	5667099
Makarora at Makarora	2208500	5655499
Manuherikia at Tunnel Hill	2262900	5594299
Ida Burn at Hills Creek	2264500	5577599
Kakanui at Clifton Falls Bridge	2332700	5572699
Kauru at The Dasher	2327200	5556499
Shag at Stoneburn	2319300	5528099
Nenthorn at Mt Stoker Road	2295700	5510399
Deep Stream at SH87	2280300	5497299
Waikouaiti at Mt Misery	2311253	5504267

Site name	Easting (NZMG)	Northing (NZMG)
Leith at Pinehill	2318200	5482699
3 OClock Stream at Lambhill	2302000	5497799
Silverstream at Swampy Spur	2313241	5488523
Silverstream at Taieri Depot	2302100	5478299
Leith at Sullivans Dam	2317100	5485799
Poolburn at Merino Ridges	2253600	5556799
Pomahaka at Moa Flat	2216800	5491399
Heriot Burn at Blue Mountains	2231030	5476549
Waitahuna at Clarks Flat	2251900	5463099
Tokomairiro at Tablehill Road	2271500	5457299
Waipahi at The Cairn	2219400	5428599
Clutha at Balclutha	2259200	5436199
Inchclutha Soils	2264656	5429380
Puerua at Lochindorb	2241605	5426436

4.2 Comparison of VCS and observed rainfall data

Comparisons of VCS and observed rainfall data are shown in Figure 4-4 to Figure 4-9. These results confirm that there is a general adequacy of the rainfall station network for VCS interpolations in low altitude areas, but the general inadequacy of the station network in the mid and high altitudes.

The density of the observation network is the primary deficiency for interpolation methods. In lowland areas with relatively uncomplicated terrain (i.e., where most of the population reside), there is generally an adequate coverage of climate (particularly rainfall) data, for the purposes of the daily VCS interpolations. On the other hand, observations in areas of mountainous terrain are often sparse and records are often relatively short with many missing values. This is not uncommon for many areas around the world. Interpolation of climate observations into these areas based on data from lower elevation sites, sometimes several kilometres in distance, can cause significant discrepancies.



Blue trace – Observed rainfall; Red trace – VCS rainfall

Figure 4-4: Comparison of cumulated Virtual Climate Station (VCS) and observed daily rainfall data at Dunedin Airport.. Station located at sea level.

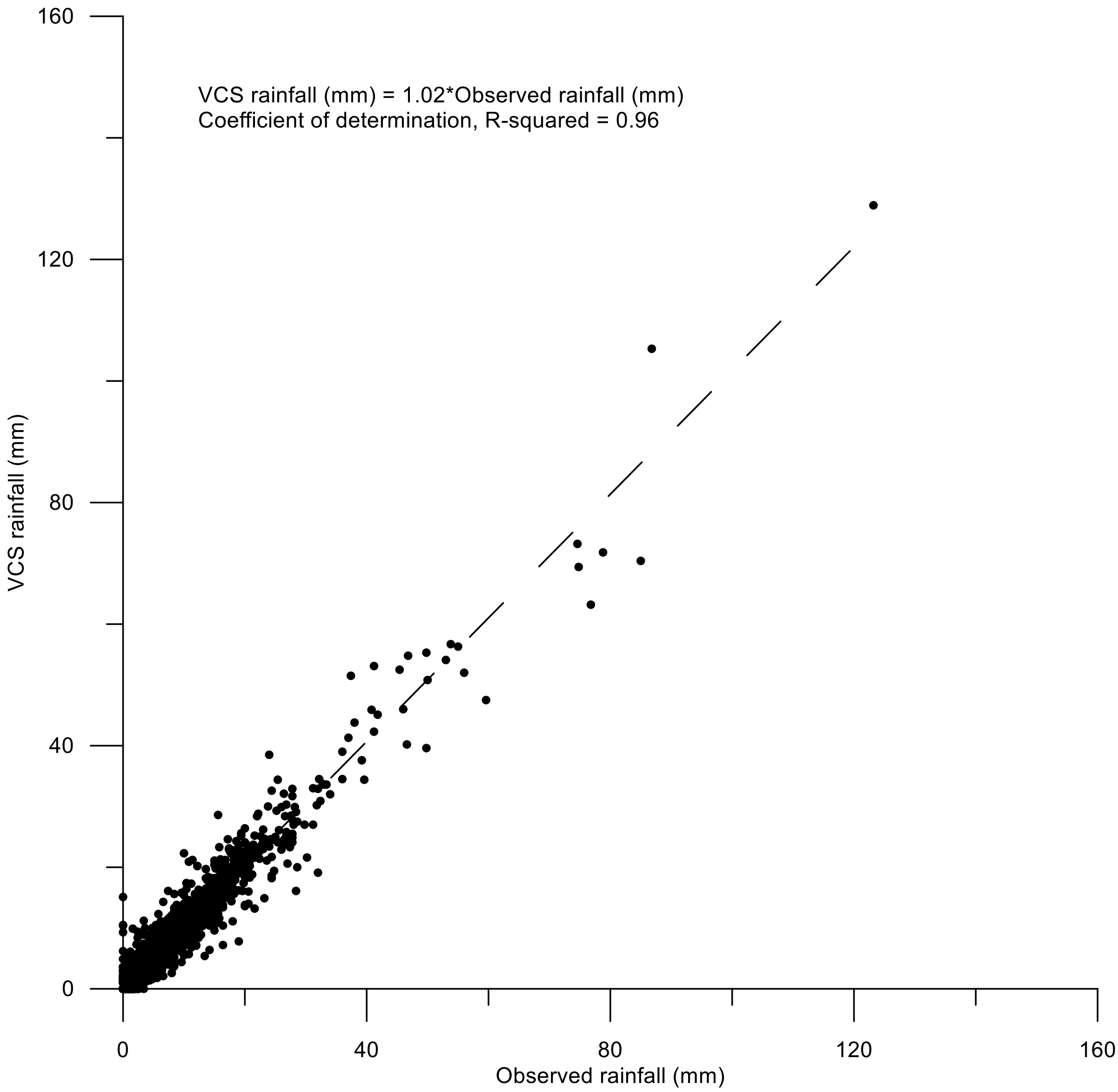
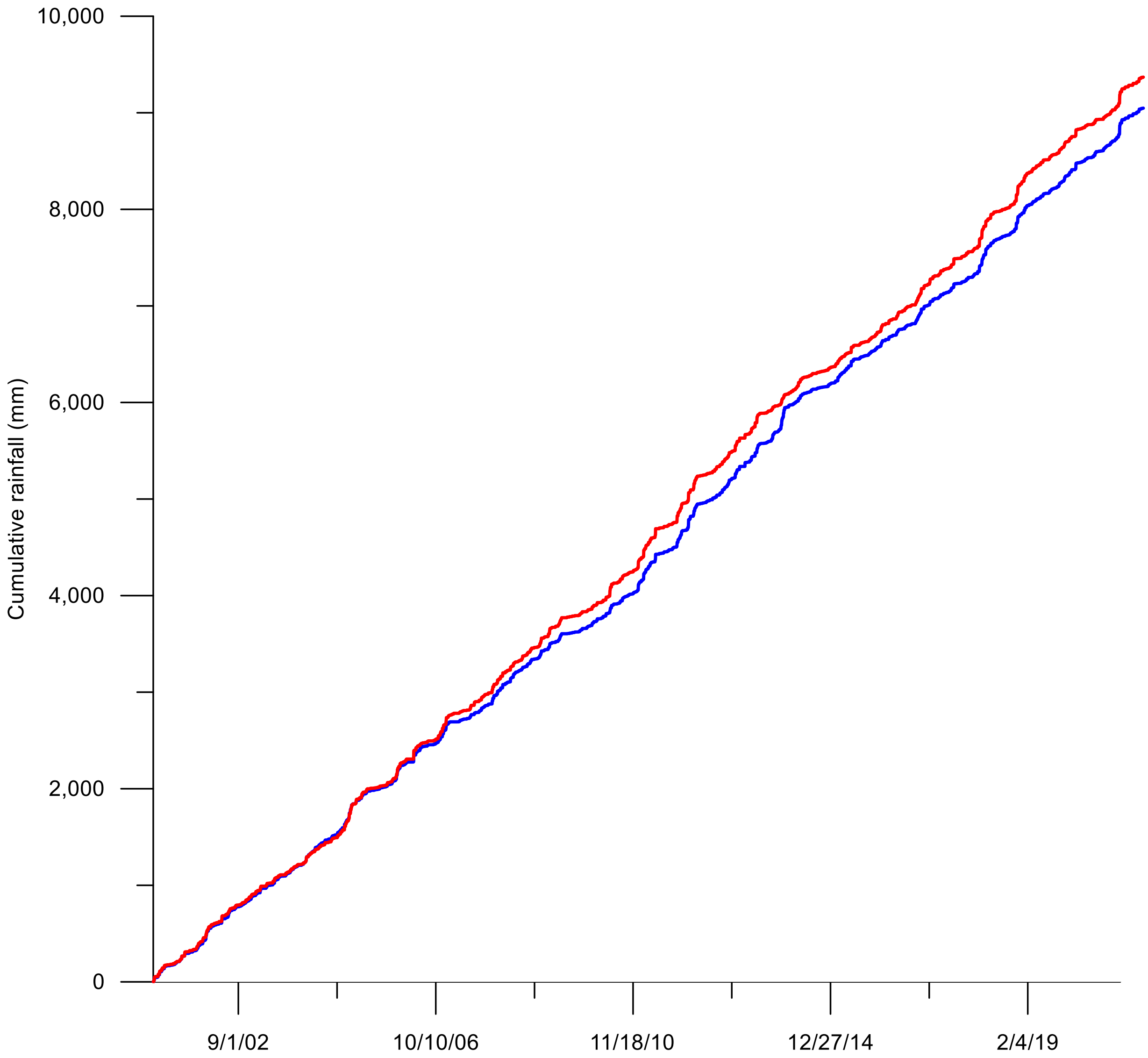


Figure 4-5: Scatter plot of Virtual Climate Station and observed daily rainfall data at Dunedin Airport site. Station located at sea level.



Blue trace – Observed rainfall; Red trace – VCS rainfall

Figure 4-6: Comparison of cumulated Virtual Climate Station (VCS) and observed daily rainfall data at Ranfurly EWS. Station located at 450 m above mean sea level.

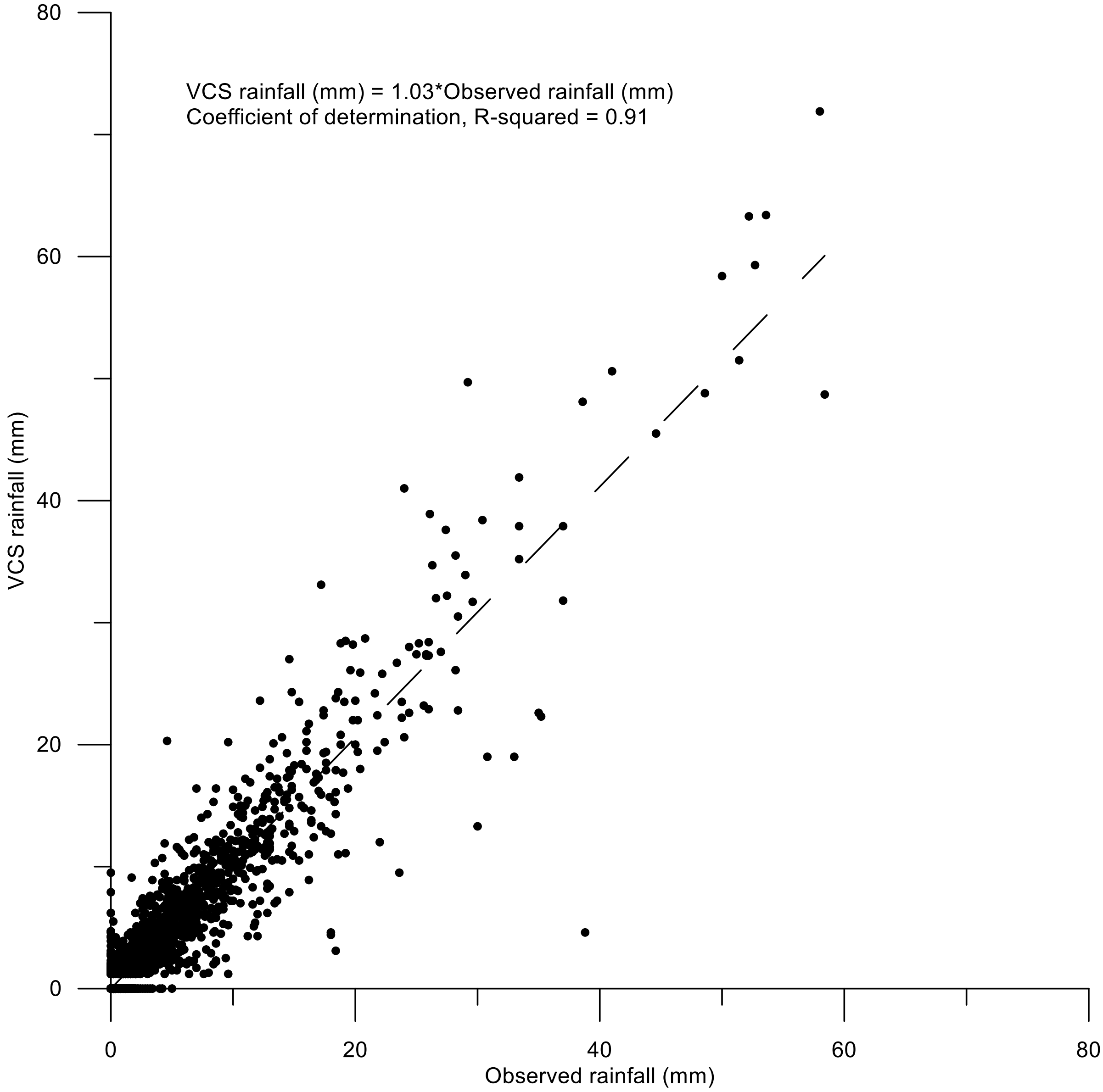
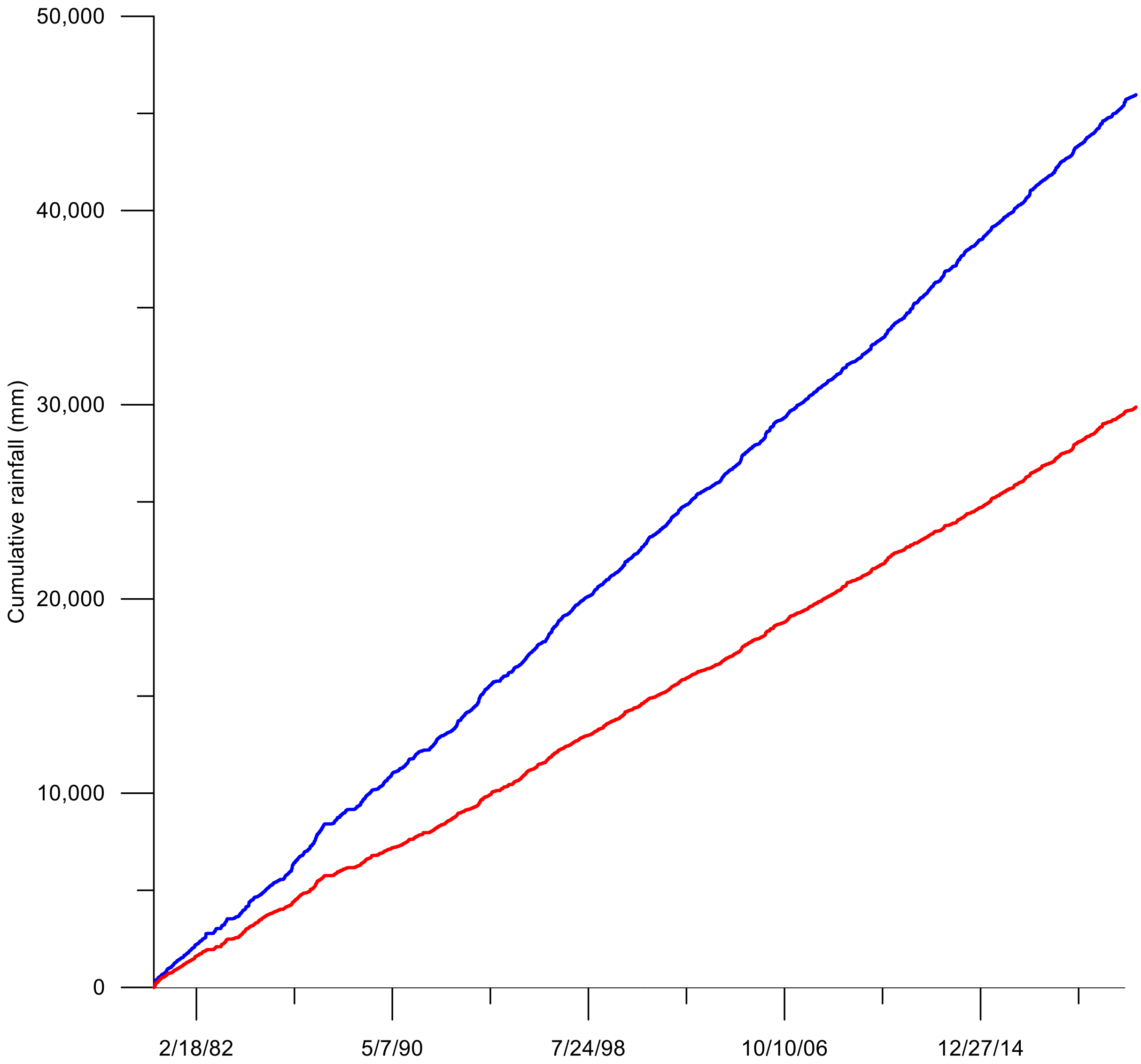


Figure 4-7: Scatter plot of Virtual Climate Station and observed daily rainfall data at Ranfurly EWS site . Station located at 450 m above mean sea level.



Blue trace – Observed rainfall; Red trace – VCS rainfall

Figure 4-8: Comparison of cumulated Virtual Climate Station (VCS) and observed daily rainfall data at Elbow Creek @ Plateau site. Station located at 1,042 m above mean sea level.

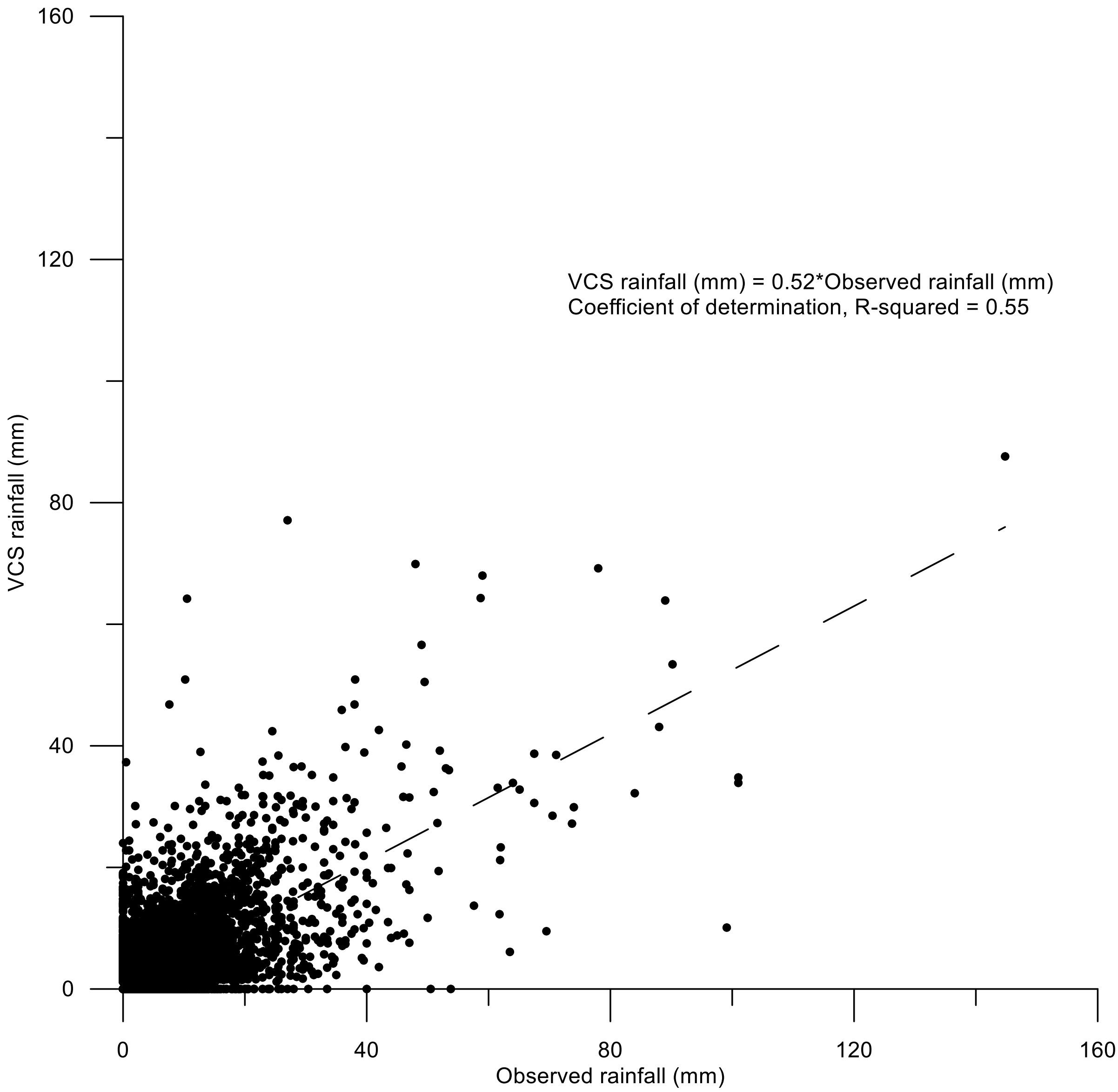


Figure 4-9: Scatter plot of Virtual Climate Station and observed daily rainfall data at Elbow Creek @ Plateau site . Station located at 1,042 m above mean sea level.

4.2.1 Conclusions and recommendations

- Inclusion of ORC rainfall data into the NIWA climate database in real time and/or for inclusion in the monthly VCS data revision would substantially improve the accuracy of the VCS rainfall values throughout the region (and beyond). As we prepare the report, NIWA and ORC are already working on this.

4.3 Climate

Following on from the discussion above regarding the suitability of the current rainfall network for VCS interpolations, we also conclude that:

- Real time VCS interpolations (and monthly revisions) are also produced for several climate variables as noted above (based on NIWA and MetService data entered into CliDB), but as there are only a handful of manual climate sites across the country, the monthly revised VCS data are very similar to the real time data.

- Looking at Figure 4-3, there is a poor representation of climate in the mountain climatic region M.

4.3.1 Conclusions and recommendations

- While no direct comparisons can be made due to the overall lack of observation sites, the accuracy of VCS climate values would be significantly improved if there were additional climate sites/variables in the Southern Alps.

5 Assessment of current climate variables to provide detailed advice to ORC on current and future requirements

In this section we discuss climate variables rather than climate network types. For this reason, the “rainfall” network is discussed as precipitation in this section as it is also a climate variable.

This section also only briefly touches on instrumentation differences as the core purpose of the various measurements, mean there are at times differences in the methods used between providers which need to be recognised. Section 6 discusses some of these various methods and the associated challenges in further detail.

Guidance on horizontal spatial resolution is available from WMO. Guidance on recommended vertical resolutions are less clear. These differ depending on the variable measured. These are defined as minimum and maximum requirements recognizing that the ideal spacing can be somewhat cost prohibitive and that a suitable compromise is somewhere in between. These minimum and maximum requirements can be seen in the series of maps along with further explanation in Appendix B.

5.1 Air temperature and relative humidity

There are currently 49 open climate stations measuring air temperature and relative humidity in the region (Figure 5-1 and Figure 5-2). Forty-three of these are telemetered and six are non-telemetered. The 18 FENZ stations are available to NIWA and MetService in real-time. ORC currently does not have access to FENZ sites in real-time. There are 66 closed stations with temperature measurements (see Appendix H). Data from nine open and 13 closed stations were used to calculate normals for the 1981-2010 period (Figure 5-3 and Figure 5-4).

With few exceptions, re-establishing closed stations is not practical. Many closed stations were manual stations that have since been automated. Other reasons include decisions by the station operators to cease or changes to land-use (e.g., property development).

Four open manual stations are scheduled for automation. Queenstown and Alexandra have already been automated with parallel measurements still being maintained.

Daily maximum and minimum air temperature are an important climatological measurement. This is still used today to determine a daily mean temperature ((max + min)/2) to ensure consistency with historical data. Of note is that from a climatological perspective the FENZ stations do not typically record daily maximum or minimum temperature. While this is important climatologically, it is less important for real-time applications.

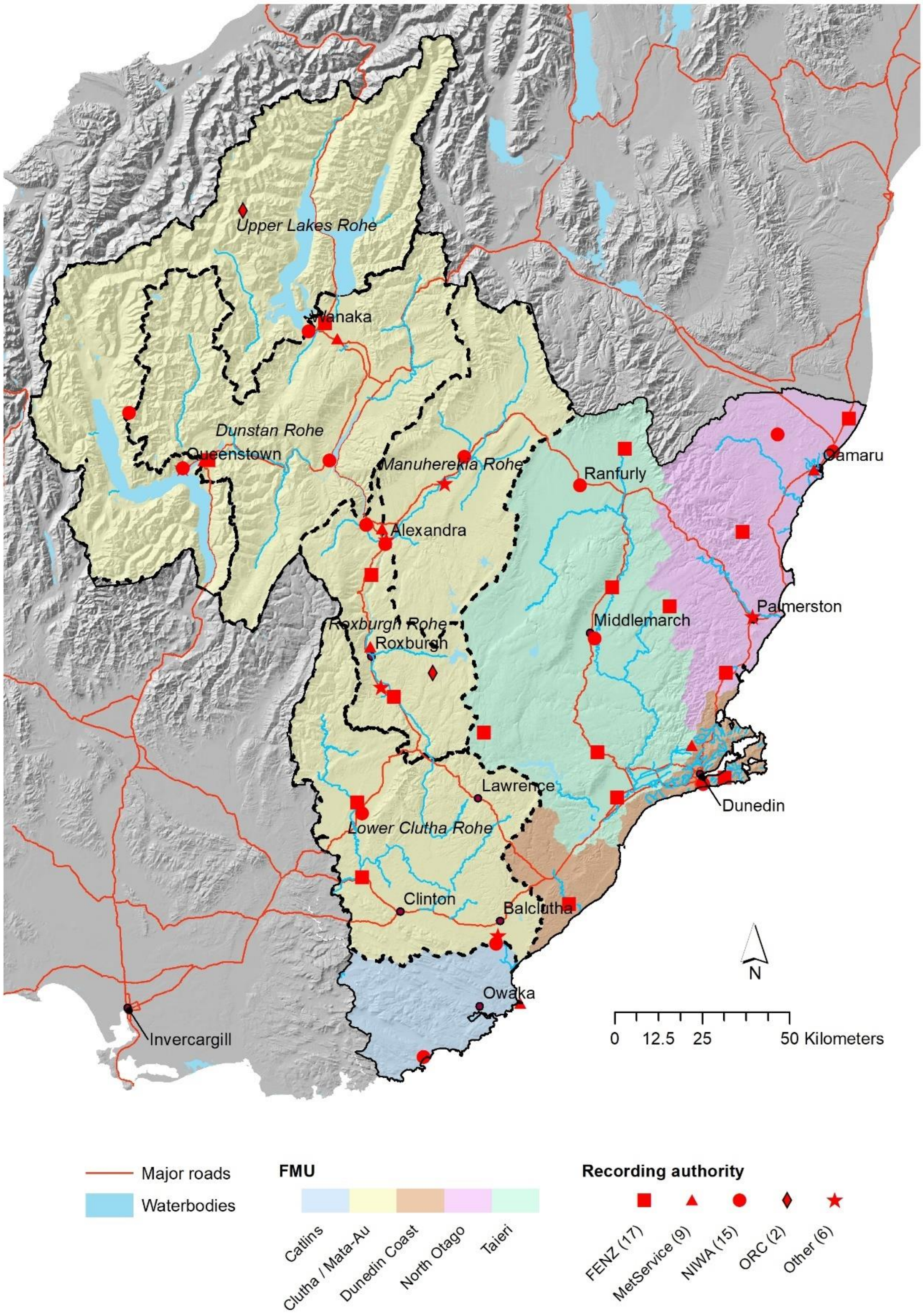


Figure 5-1: Open climate sites recording air temperate and relative humidity, shown by FMUs.

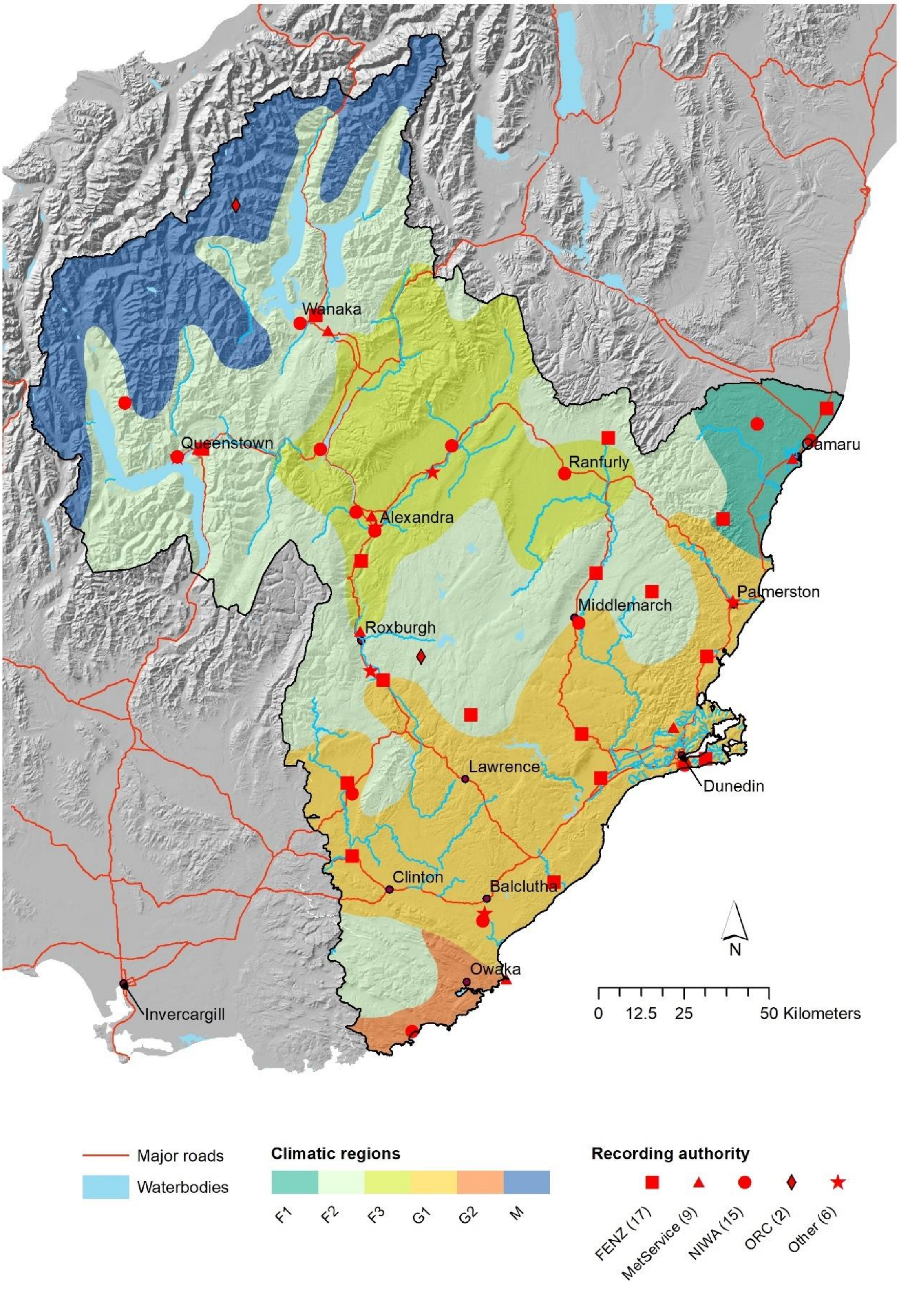


Figure 5-2: Open climate sites recording air temperature and relative humidity, shown by climatic regions. Refer to Table 3-3 for an explanation of the climatic regions.

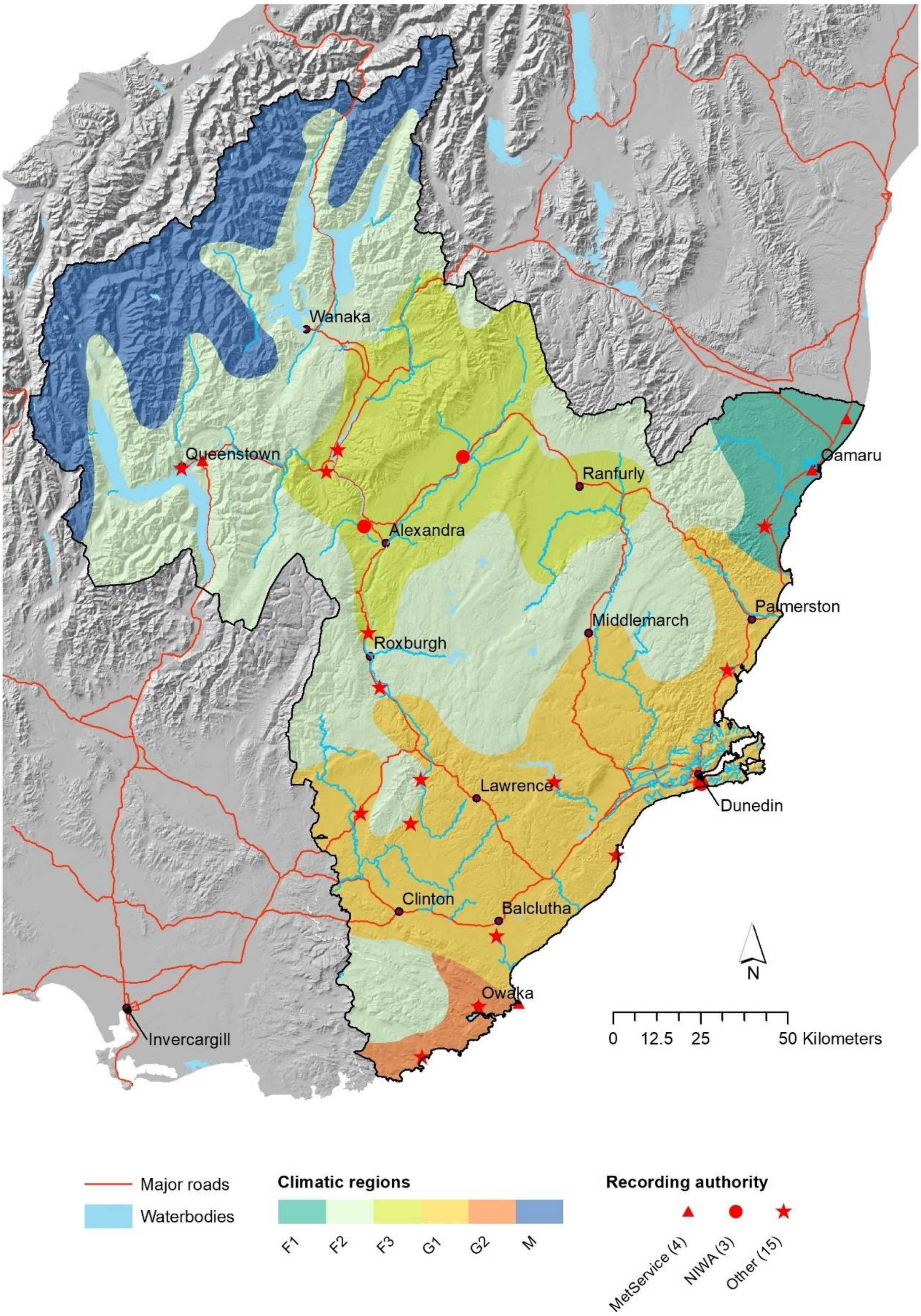


Figure 5-3: Climate stations used to derive air temperature normals for 1981-2010 period, shown by climatic regions. Refer to Table 3-3 for an explanation of the climatic regions.

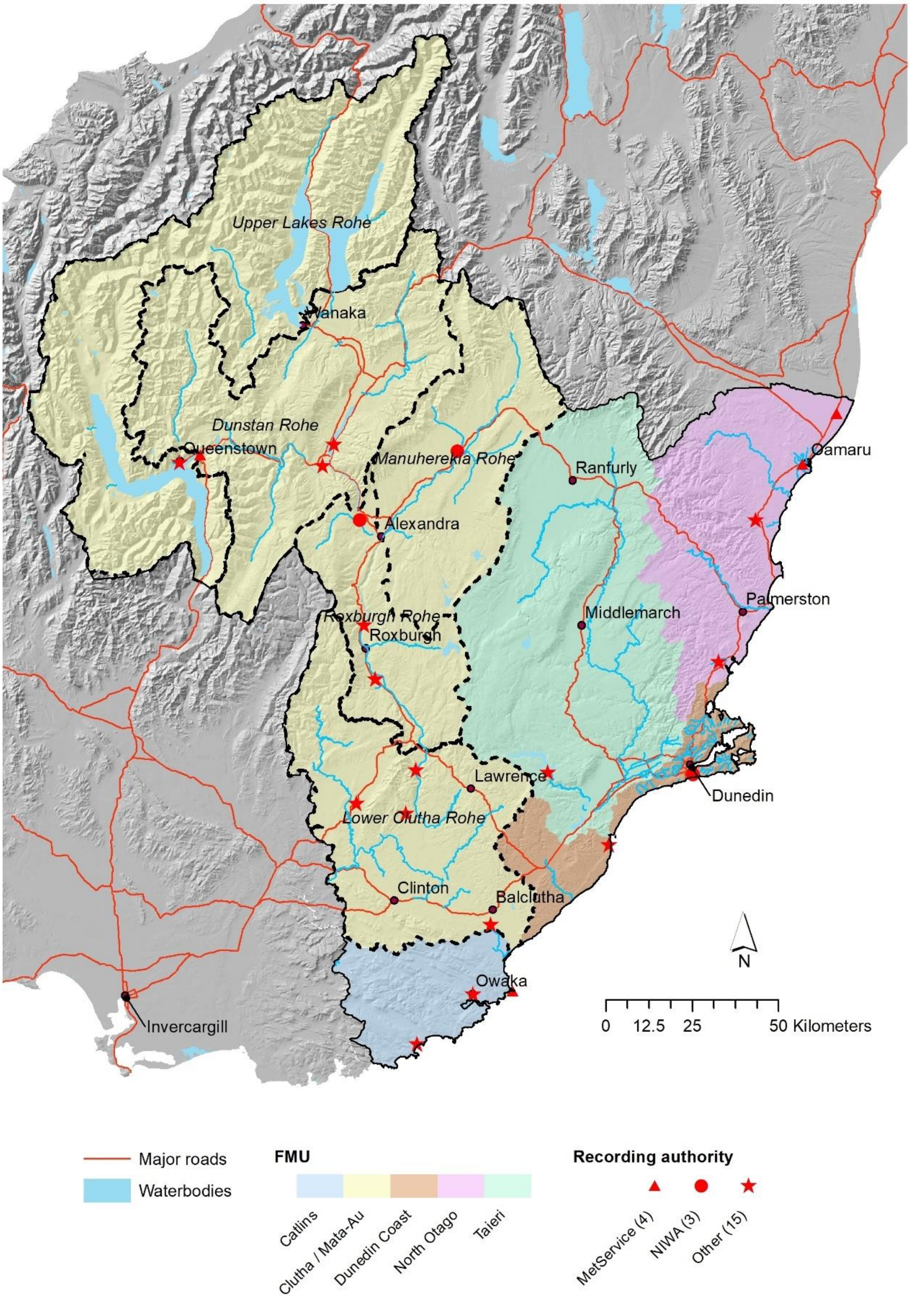


Figure 5-4: Stations used to derive air temperature normals for 1981-2010 period, shown by FMUs.

5.1.1 Conclusions

- While each climatic region and FMU/Rohe has at least one station currently measuring air temperature and relative humidity, there are limited measurements above 500 m
- All climatic regions and FMU/Rohe have at least one site included in calculating current temperature normals
- Not all stations record daily maximum and minimum air temperature (e.g., FENZ stations). While important in a climatological sense, this is less important for real-time applications.
- There is a range of methods used for the recording of air temperature. This largely depends on the purpose of the measurement
- The 1991-2020 normals have not been released at time of writing this report but the coverage will be similar to the 1981-2010 normals. Some climatic regions have nil or limited current temperature normals. Some gaps are filled with earlier normals
- There is no quick fix for the gaps in normals due to the length of record required and strict rules on their compilation in terms of missing record
- The remaining manual stations are scheduled to be automated and therefore adding real-time coverage.

5.1.2 Recommendations

For building climatologies, the current network is mostly adequate for national and regional scales with some enhancements. However, some improvements can be made.

- It is recommended that ORC and NIWA consider adding temperature to some of the higher altitude precipitation sites. This applies not only to climatic region M but any sites above 500 m altitude.

5.2 Soil temperature

Soil temperature (also referred to as earth temperature) is typically measured at 10, 20, 50 and 100 cm depths on automatic weather stations (AWS). Manual stations continue to use the earlier standard of 30 cm for consistency at those sites.

There are only 14 open stations currently measuring soil temperature. For simplicity, maps (Figure 5-5 and Figure 5-6) only show sites where soil temperature is recorded at 20 cm depth as this is also the nominal depth for soil moisture. As a rule of thumb if a site has a 20 cm soil temperature, there is always a sensor at 10 cm, but the reverse is not always true. That is, there are fewer 20 cm depth measurement sites than 10 cm.

Soil temperature measurements from soil moisture sensors are currently not being archived in CliDB as these measurements are typically an ancillary measurement and their method of measurement and quality are unknown. See section 6 for further discussion on this.

Note that not all sites are suitable for soil temperature profiles. For example, soil temperature measurements are not appropriate if ground has been disturbed or re-filled, irrigated, mountainous (no soil). Similarly, soil temperature measurement may not be of any value if the measured soils are not representative of the region.

5.2.1 Conclusions

- Not all climatic regions have current soil temperature measurements
- The Upper Lakes Rohe has no current coverage of soil temperature
- The Dunedin Coast and Catlins FMU have little or no current coverage of soil temperature

5.2.2 Recommendations

- ORC and NIWA, where practicable, should consider the inclusion of 10, 20, 50 and 100 cm soil temperatures at climate sites within FMU or Rohe with little to no coverage. Noting that:
  - NIWA already plans to automate the manual stations at Ettrick and Palmerston and include soil temperature measurement
  - The addition of soil temperature to the NIWA stations at Tapanui and Tautuku is very straightforward though not planned yet
  - There are practical reasons such as limited soil depth for the limited coverage in the Upper Lakes Rohe.

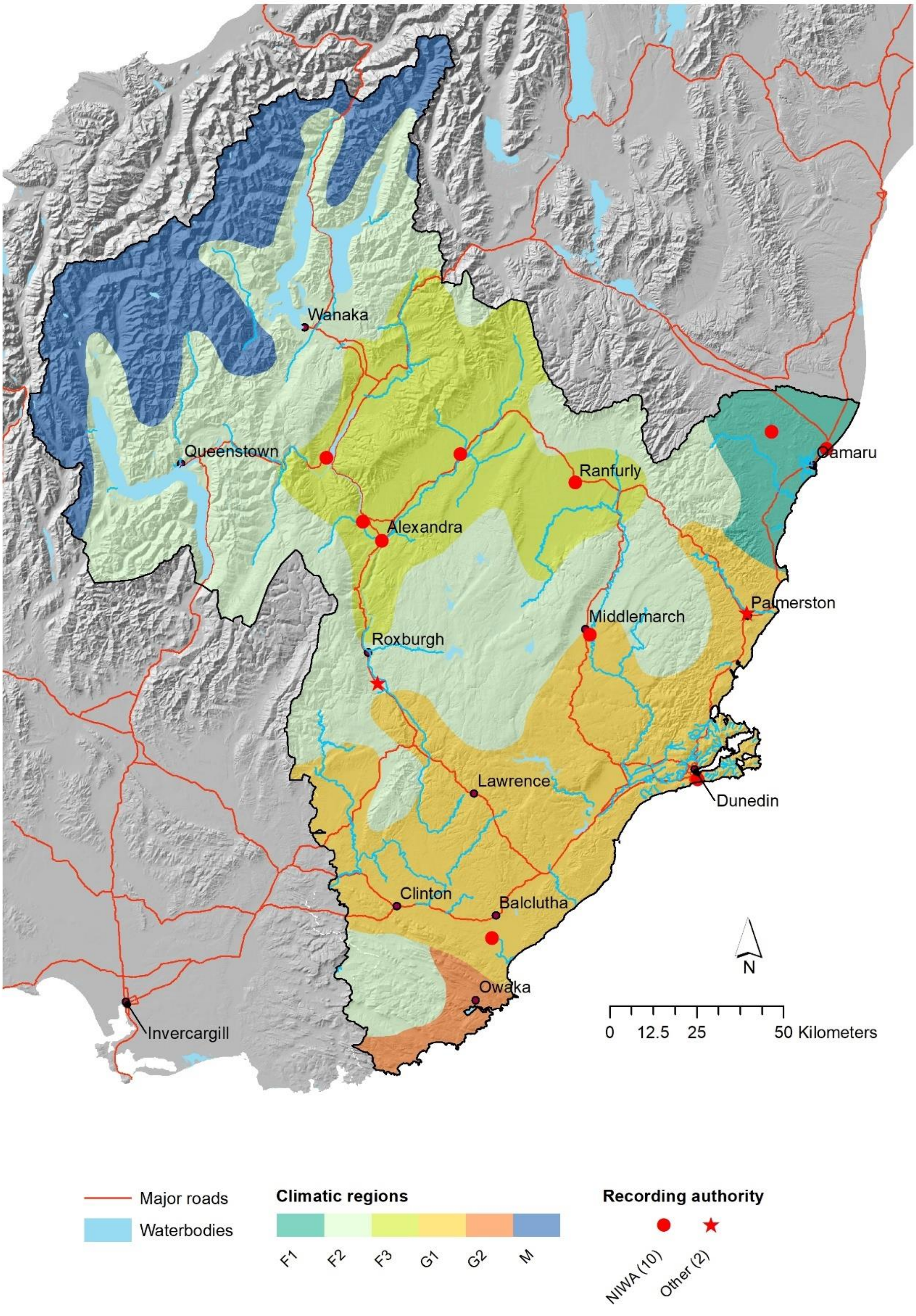


Figure 5-5: Open climate sites recording soil temperature at 20 cm, shown by climatic regions. Refer to Table 3-3 for an explanation of the climatic regions.

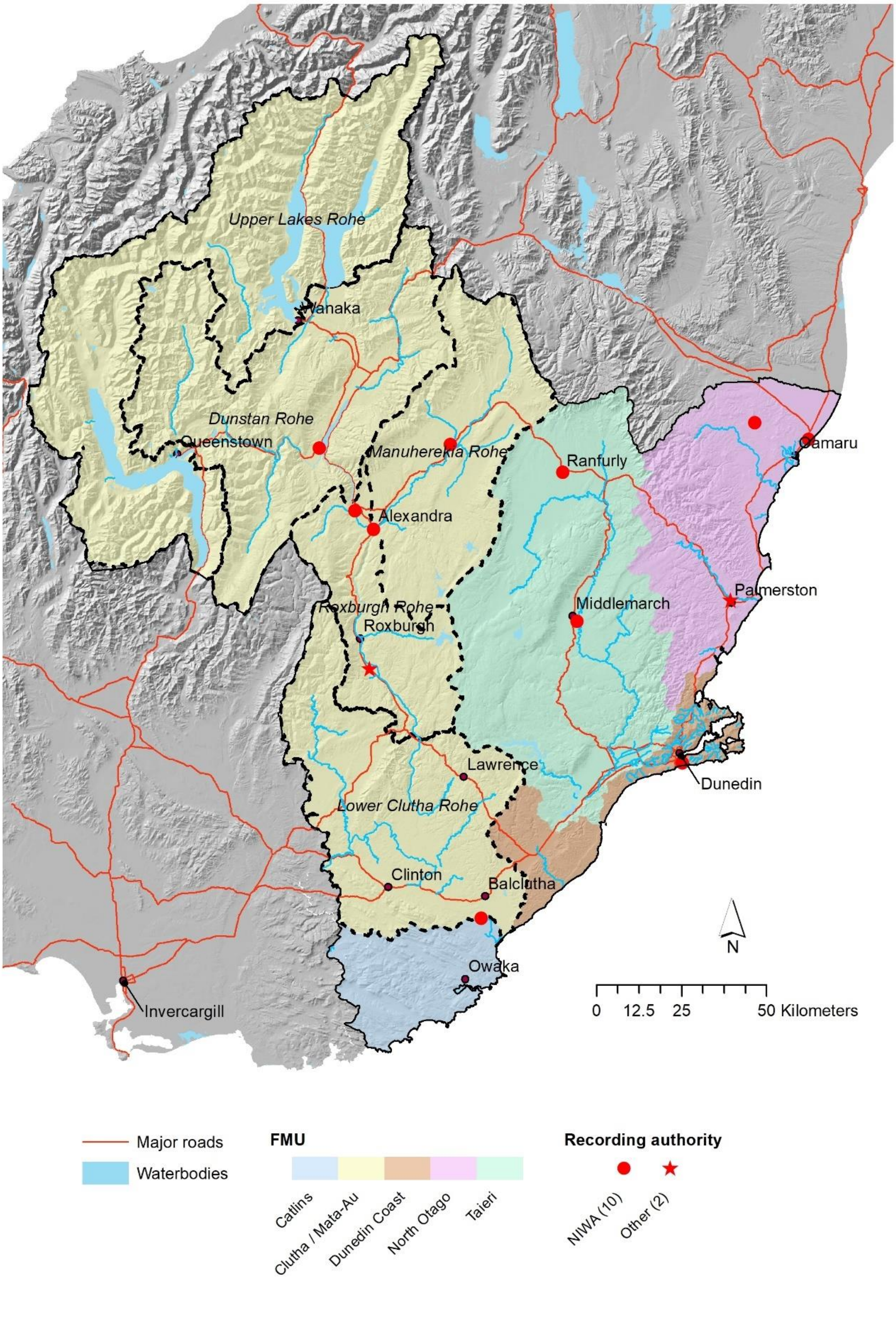


Figure 5-6: Open climate sites recording soil temperature at 20 cm, shown by FMUs.

5.3 Precipitation

The measurement of rainfall accumulation has long been the mainstay of climate monitoring and reached a peak in the mid-1990s during many investigations and studies by various Government departments for hydropower generation, irrigation, and other agricultural uses. The historic climate record is compiled mostly from daily (0900 to 0900) data, and normals are compiled from daily data. For some sites, records extend for over 100 years.

Figure 5-7 shows current manual and automated (telemetered) gauges that record daily precipitation. All open stations that record daily rainfall and rainfall sites that were used to develop long term normals are shown in **Error! Reference source not found.**,

Figure **5-9**, Figure 5-10 and Figure 5-11.

Solid precipitation makes a significant contribution to the water resource of the region and is a key factor for water and risk management. However, historically the measurement of solid precipitation has not been generally well measured in New Zealand although some melt will be captured by the rain gauges it has generally been under recorded. Reasons for this include suitable technology and the lack of infrastructure at high altitudes and difficulty in accessing sites in winter. Some instruments and methods for liquid and solid precipitation and intensity are only touched on briefly in this section but are discussed in greater detail in section 6, as is the topic of homogeneity.

This is beginning to change. NIWA has weighing gauges for solid precipitation at Lauder and Mt Larkins. ORC have recently installed a weighing gauge at their new Lauder Basin site in the Dunstan Mountains. NIWA and MetService are looking to enhance their networks to better measure solid precipitation.

Historically, rainfall intensity has generally been well measured with the use of chart recorders and more recently automated rain gauges. Although quantitative amounts of liquid and solid precipitation have been the basis for many practices, the intensity of precipitation has become a variable of almost equal significance. Rainfall and snowfall intensity data are extremely relevant in cases of severe weather (WMO, 2006). Application areas using precipitation intensity include:

- Road and urban meteorology (damages to buildings, roads and urban infrastructure)
- Climatology (with ongoing climate change, localised showers of extreme intensities are expected to become more frequent)
- Hydrology (flood warning, design and modelling of run-off systems, timely forecasts)
- Agricultural meteorology - primary sector (crop damage, soil erosion, drainage and leaching)

Snow and ice are two resources already showing significant changes and this is likely to continue. These changes will have substantial impacts on the long-term planning for water resources, operation of hydro-electricity generation, agriculture, and tourism/skiing industries. These changes will also affect all aspects of the alpine and downstream environments with influences on the hydrological cycle, erosion, landslide and land stability, biodiversity, and recreation (Hendrikx and Harper, 2013).

Currently there are only two stations where snow depth measurements are made (Albert Burn and Mt Larkins) although ORC have a consent to include snow depth at their Lauder Basin site in the Dunstan Mountains. We also note that recently WMO have made snow depth a mandatory requirement for stations reporting on the Global Basic Observing Network. MetService and NIWA are considering how to respond to this new requirement

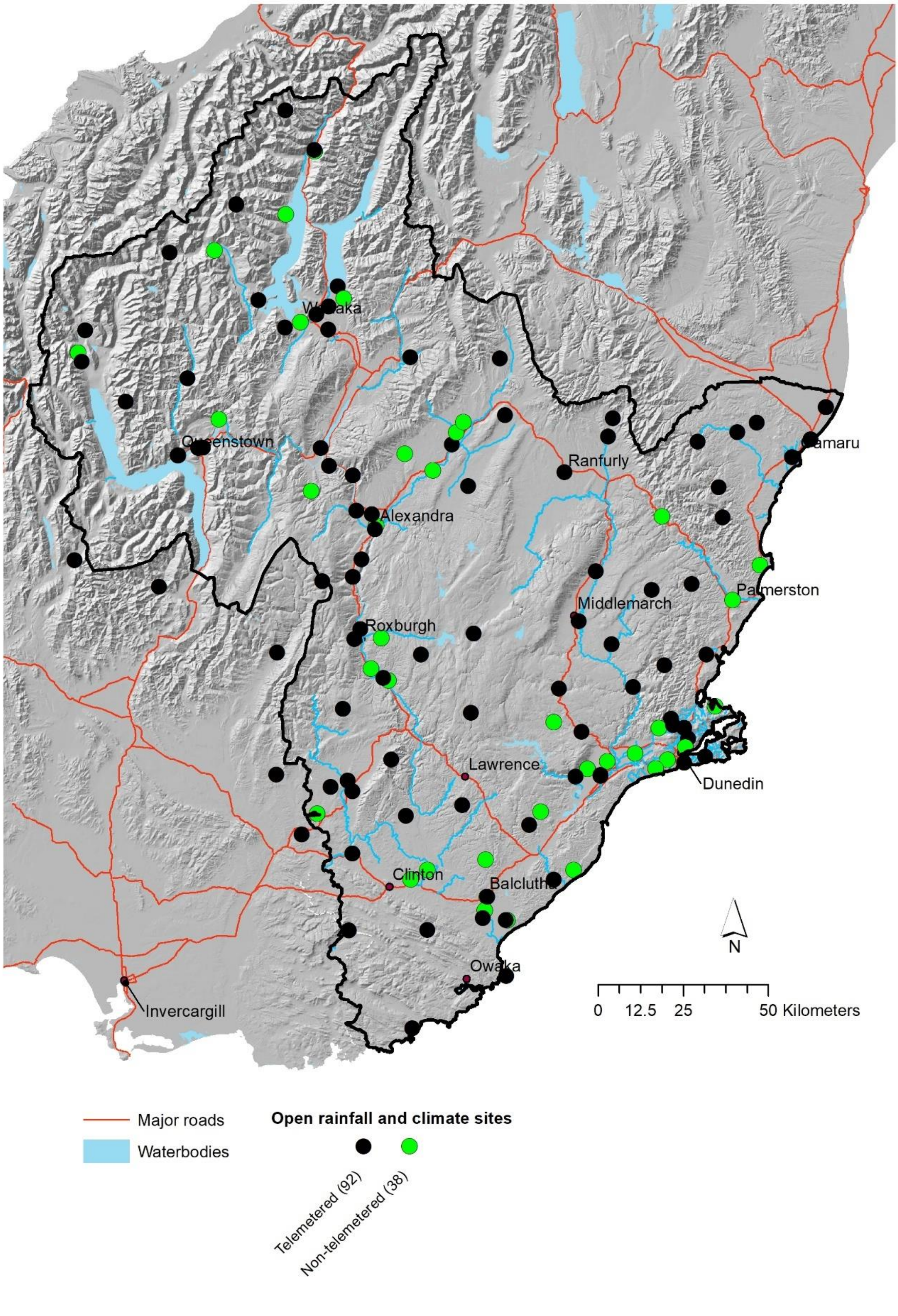


Figure 5-7: Open rainfall sites in the ORC region and their telemetry status.

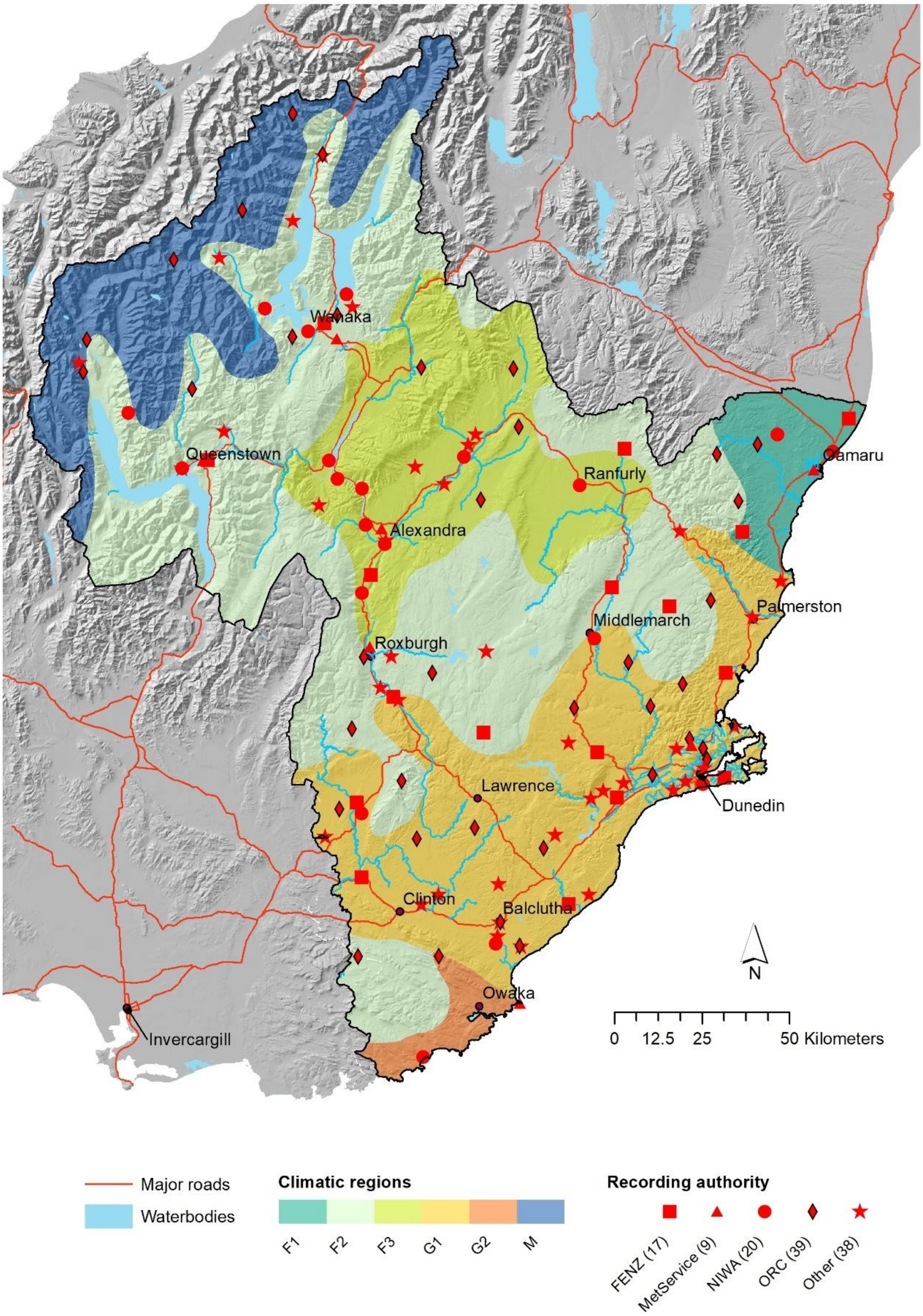


Figure 5-8: Open stations that record daily precipitation, shown by climatic regions. Refer to Table 3-3 for an explanation of the climatic regions.

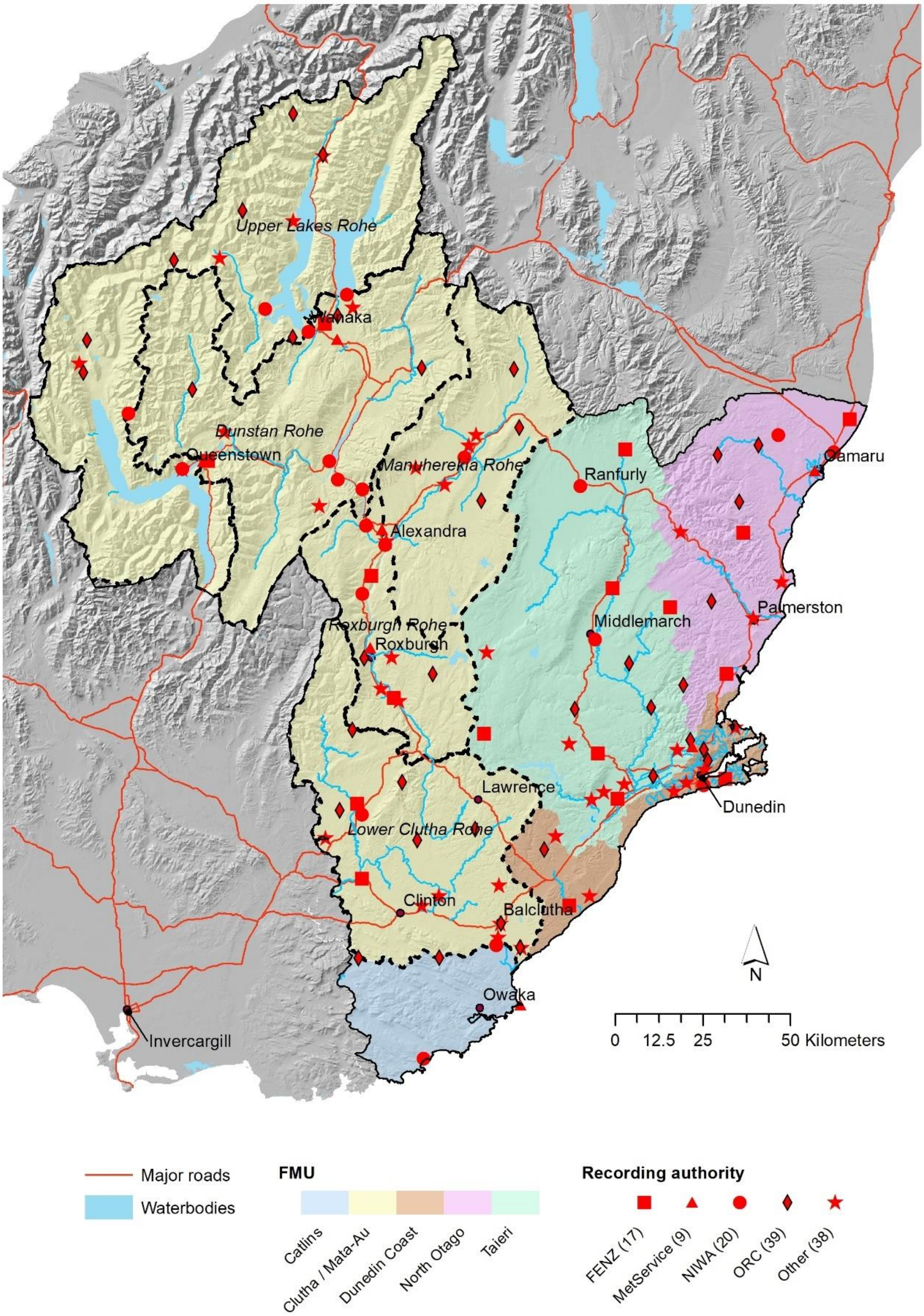


Figure 5-9: Open stations that record daily precipitation, shown by FMUs.

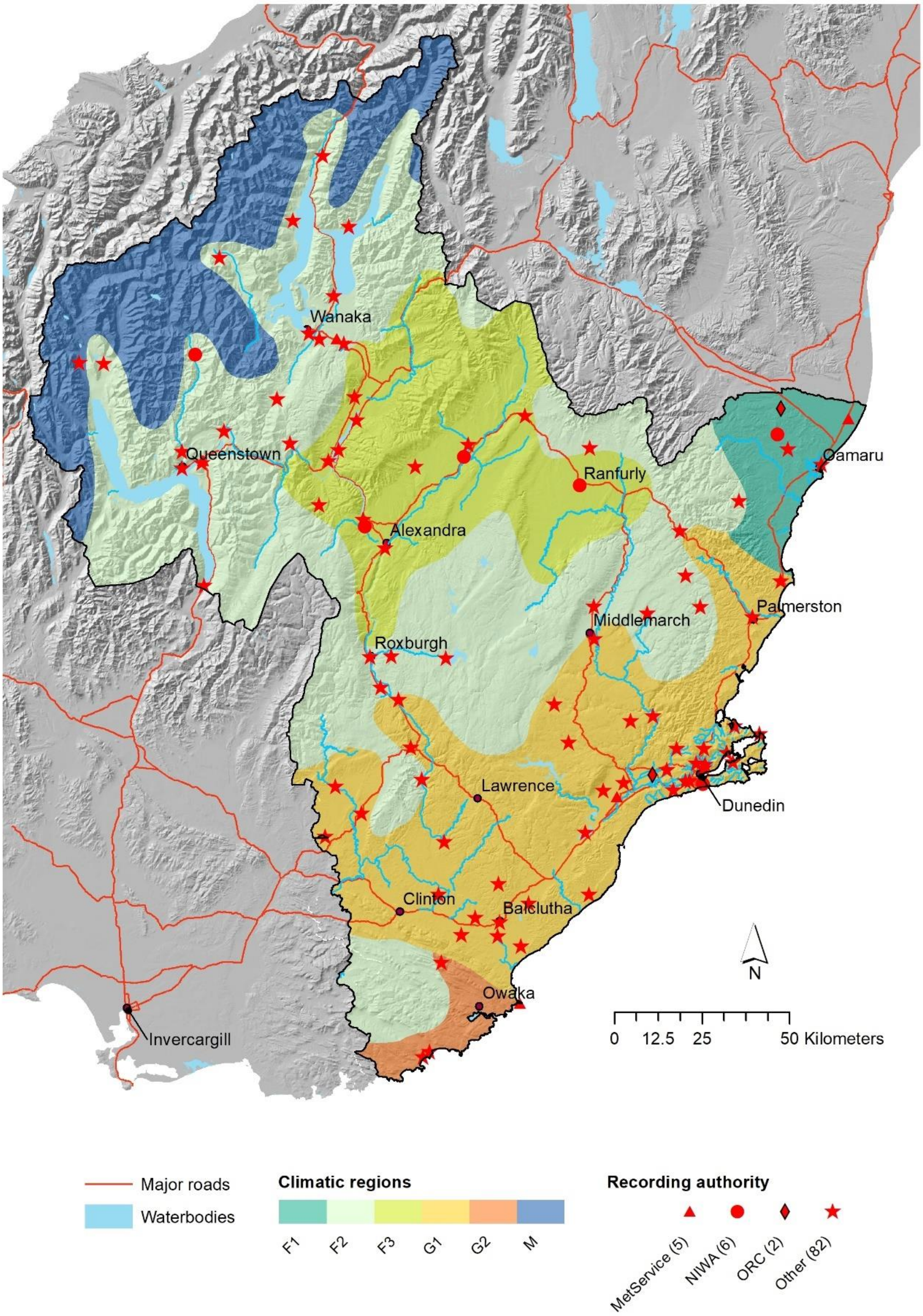


Figure 5-10: Stations used to derive 1981-2010 rainfall normals, shown by climatic regions. Refer Table 3-3 for an explanation of the climatic regions.

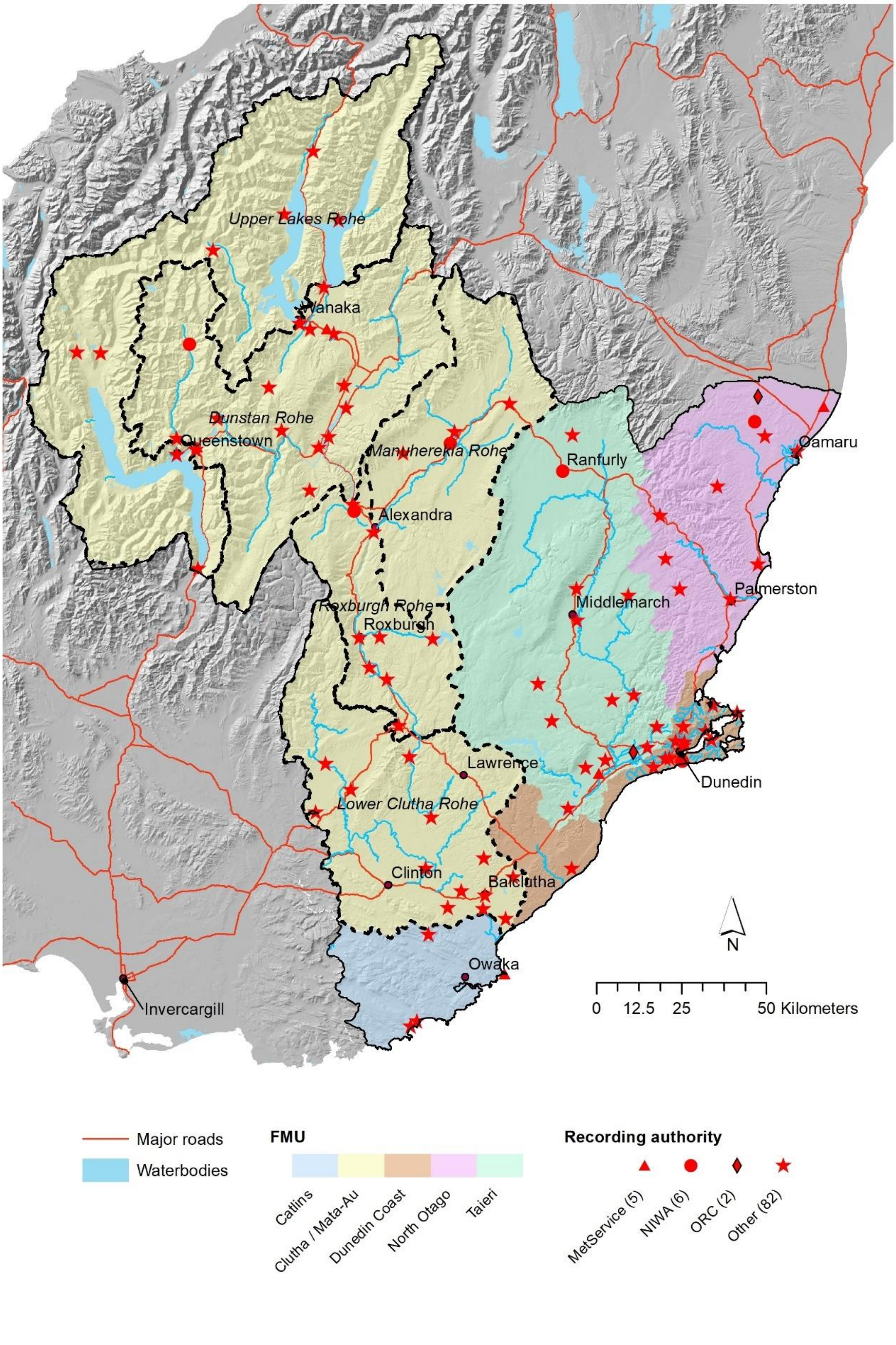


Figure 5-11: Stations used to derive 1981-2010 rainfall normals, shown by FMUs.

5.3.1 Conclusions

- Daily rainfall is well covered across the region, despite many site closures
- Rainfall (hourly and sub-hourly) is well covered
- Solid precipitation is not well measured
- The normals are dominated by data from the manual stations, which is likely to change in the coming decades
- Data are stored in multiple databases depending on the owner/operator which at times limits their usability. On-going discussions on data sharing may help resolve this. For example, there are 17 rainfall sites managed by FENZ whose data are not available to ORC in real-time. Data and indices can be viewed at https://fireweather.niwa.co.nz/region/Otago. It might be advantageous for ORC to obtain real-time access through the National Rural Fire Officer.

5.3.2 Recommendations

- We recommend that ORC data be added to CliDB to enable a greater number of normals to be created
- There are 17 rainfall sites managed by FENZ whose data are not available to ORC in real-time. Data and indices can be viewed at https://fireweather.niwa.co.nz/region/Otago. It might be advantageous for ORC to obtain real-time access through the National Rural Fire Officer.

5.4 Pressure

Surface pressure can be measured at any altitude. However, when barometric pressure is primarily used for forecasting it is reported at mean sea level. This is done to bring measurements to a common datum, as pressure changes with altitude. However, measurement uncertainty increases with altitude due to assumptions on the temperature of the air column from the sensor to sea level. Therefore, mean sea level pressure is not measured at stations above 800 m.

Climatologically, pressure is used to produce long-term and seasonal anomaly maps. These maps are produced as part of NIWA's seasonal outlook discussion each month. See an example at, https://niwa.co.nz/climate/seasonal-climate-outlook/seasonal-climate-outlook-april-june-2022.

Surface pressure is also an Essential Climate Variable (ECV) as defined by the Global Climate Observing System (GCOS) (https://gcos.wmo.int/en/essential-climate-variables).

ORC is proposing to add pressure sensors to their air quality stations at Arrowtown, Alexandra, Mosgiel and Dunedin.

5.4.1 Conclusions

- Despite there being limited mean sea level pressure in the Upper Lakes Rohe, it is considered there is adequate spatial coverage across the entire region (Figure 5-12 and Figure 5-13).

5.4.2 Recommendation

- Noting that NIWA plans to add pressure sensor to Ranfurly, Palmerston and Ettrick stations, and ORC plan to add pressure sensors to their Air Quality sites in Arrowtown, Alexandra, Mosgiel and Dunedin, there will be significant improvements in the spatial resolution. It is still recommended that NIWA and ORC consider adding pressure measurements to the alpine sites within the Upper Lakes Rohe as station level pressure is used in some models.

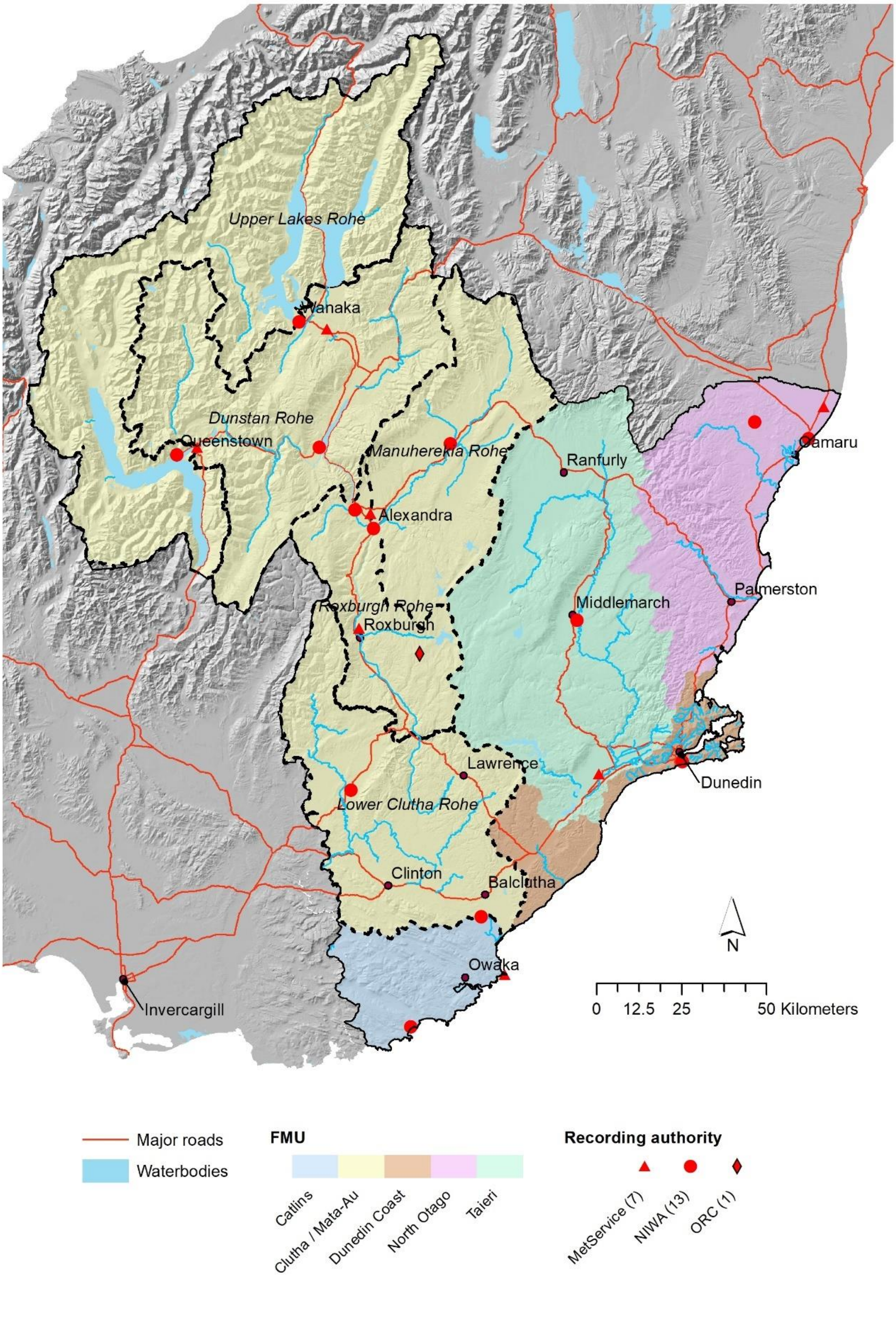


Figure 5-12: Open stations that record barometric pressure, shown by FMUs.

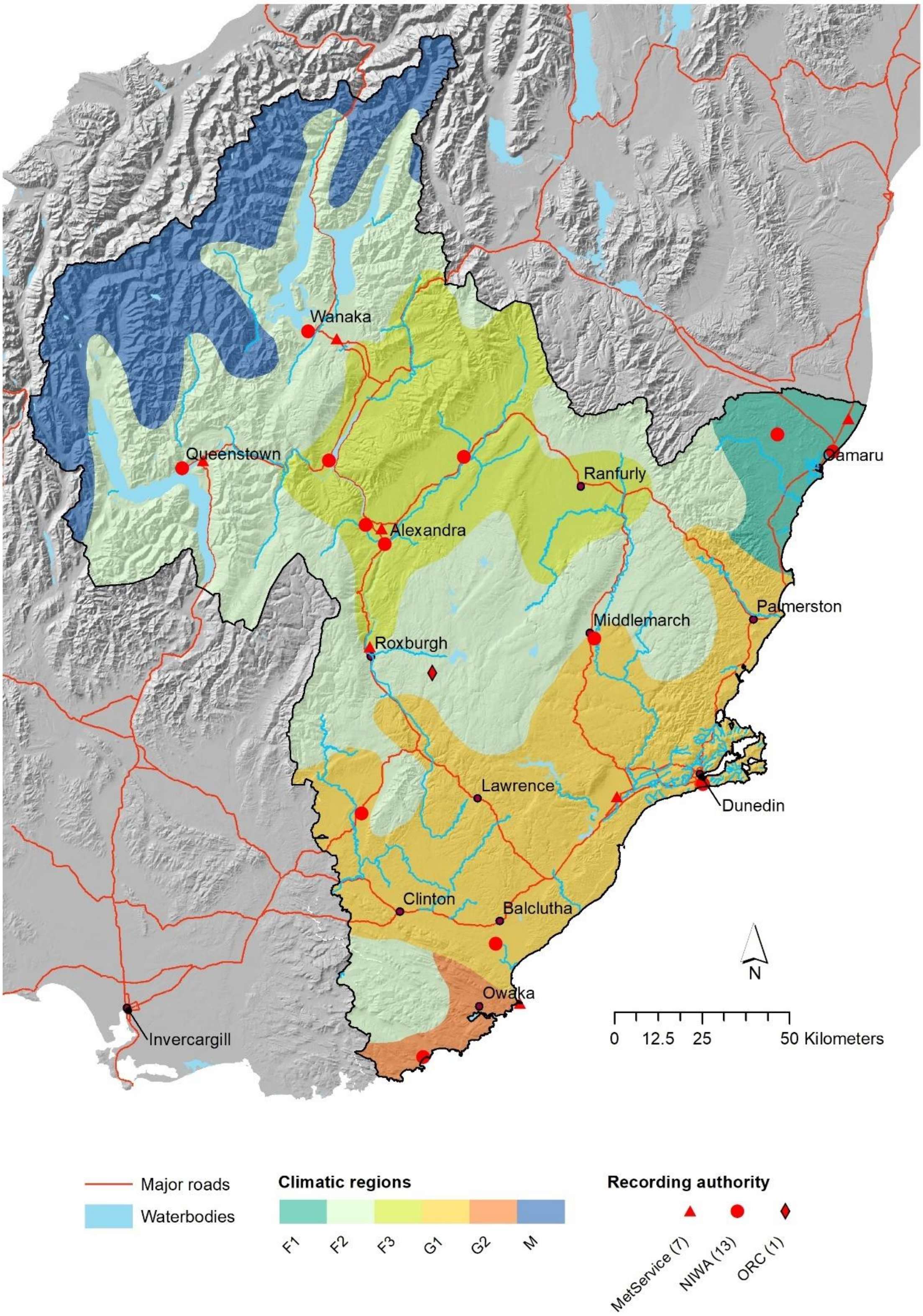


Figure 5-13: Open stations that record barometric pressure, shown by climatic regions. Refer to Table 3-3 for an explanation of the climatic regions.

5.5 Wind

There are 39 open wind speed and direction measurement stations in the region (Figure 5-14 and Figure 5-15). All, except the FENZ sites (seventeen of them), measure maximum gust. Most locations monitoring wind are at low elevations, either at airports or near population centres.

Wind is a variable that gets used for a range of purposes with varying requirements. The WMO guideline for the standard height for wind measurement is 10 m above ground but this assumes that any requirements around sheltering and heights and distances to obstructions are also met. However, wind is also used as an ancillary parameter for many other measurements where the usual siting requirements are not needed, for example, the measurement of air quality. This results in a variety of heights used at the sites shown in Figure 5-14 and Figure 5-15.

As well as the effects of surface conditions and nearby obstructions, wind patterns in the region are also greatly influenced and modified by topography especially in inland areas.

While not considered in this report, there are other providers monitoring wind in the region. These include ski-fields, wind prospecting for wind farms, major infrastructure projects such as Clyde Dam and Lake Dunstan, and tourism ventures. Many of these are also located at altitudes greater than 500 m.

5.5.1 Conclusions

- Measurement methods are not fully consistent between the providers, however, there is good consistency at the core climate stations allowing good climatologies to be compiled
- While there are inconsistencies, these have been planned for and selected to fit the purpose
- There are few long-term stations above 500 m.

5.5.2 Recommendations

- It is recommended that NIWA and ORC look to enhance wind measurements above 500 m, as well as explore data available from other providers not considered in this study (e.g., ski fields, wind farms and others)

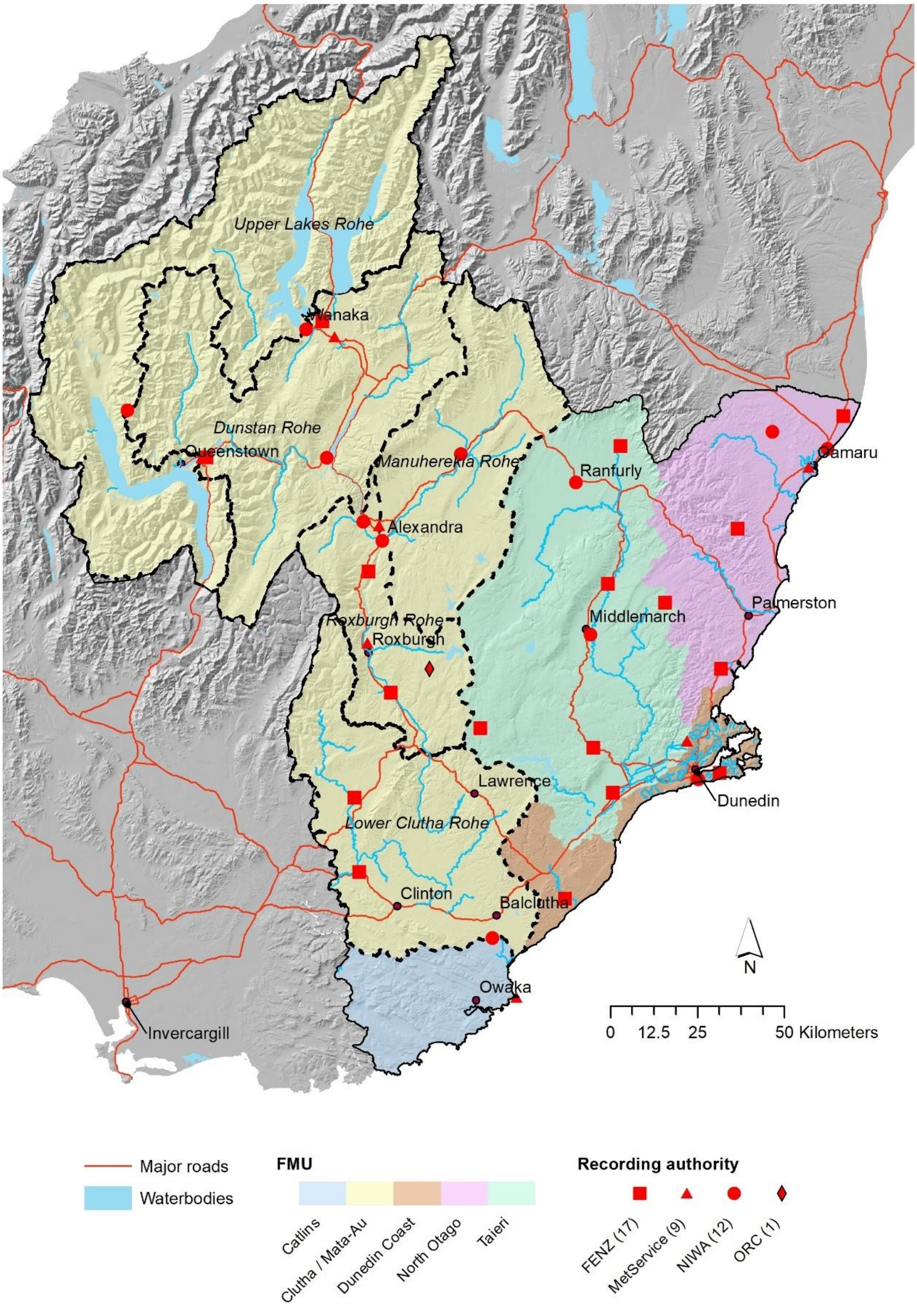


Figure 5-14: Open stations recording hourly wind speed and direction, shown by FMUs.

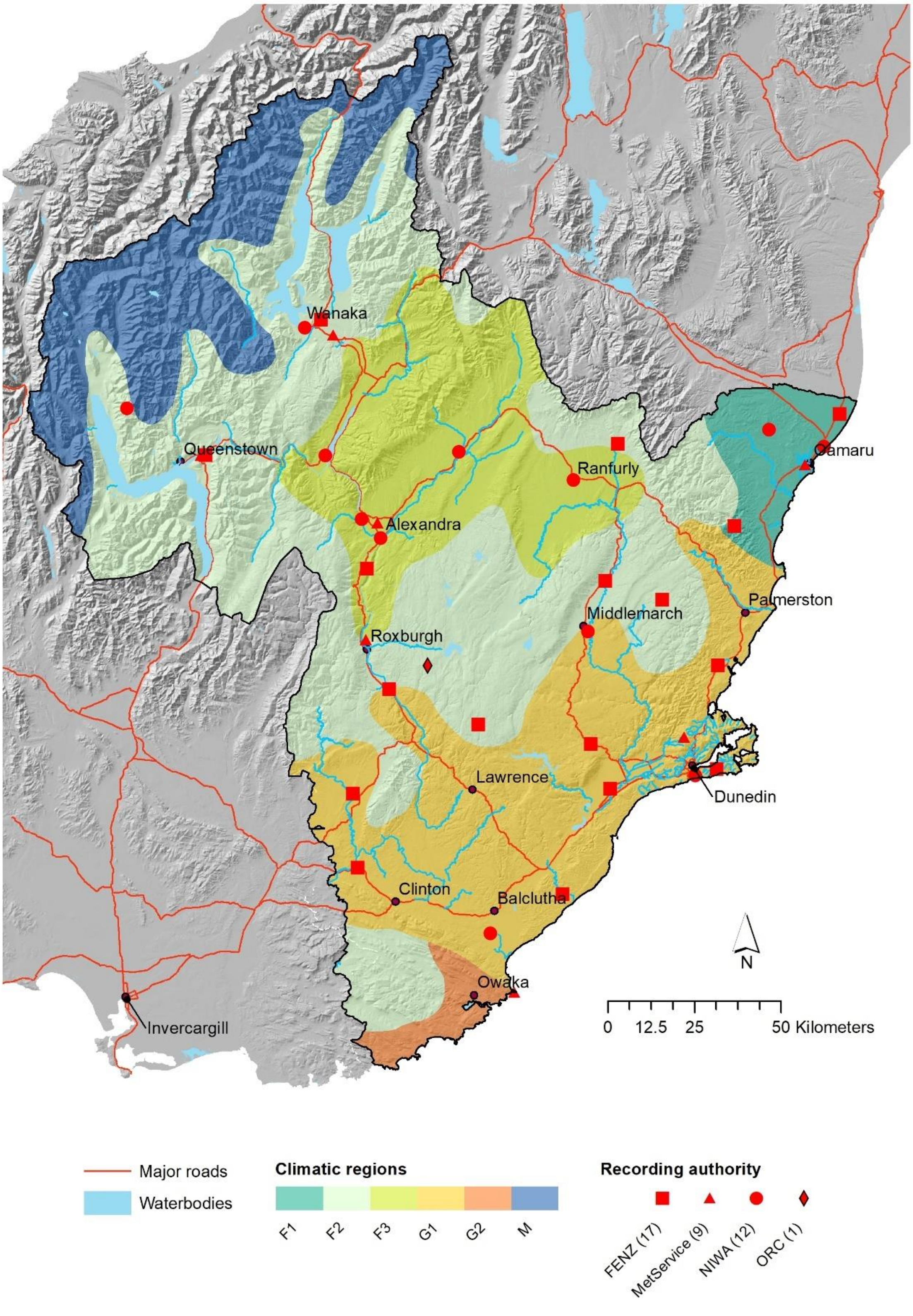


Figure 5-15: Open stations recording hourly wind speed and direction, shown by climatic regions. Refer to Table 3-3 for an explanation of the climatic regions.

5.6 Solar radiation and sunshine

Solar radiation and sunshine duration are two distinct climate variables. Solar radiation is a measure of incoming energy. It can be used as an indication of cloudiness. Sunshine duration is a direct measure of sunshine hours. Global solar radiation can be inferred from sunshine but not the reverse. However, direct solar radiation can be used for calculating sunshine.

Lauder is a primary network site and measures global, direct and diffuse solar radiation. All other sites measure global solar radiation. Lauder is also the sole New Zealand site that is a part of the World Radiation Monitoring Centre – Baseline Surface Radiation Network (BSRN).

In New Zealand, we see that the results on sunshine duration measurement with the electronic sensor differ from that of conventional "glass ball and suncard" method (Srinivasan et al. 2019). Investigations at different sites by WMO showed that the threshold irradiance for burning the card varied between 70 and 280 Wm^{-2}. However, further studies, especially those performed by the IRSR in France, resulted in a mean value of 120 Wm^{-2}, which was adopted as the threshold of direct solar irradiance to distinguish bright sunshine. Due to this change in technology and method, we see big differences between methods, with the biggest difference occurring when it is partly cloudy. A clear horizon (excluding natural features such as mountains) at all times of the year is crucial for accurate measurements otherwise the usefulness of the data is limited.

There are 17 solar radiation and 11 sunshine duration stations that are currently operating in the region (Figure 5-16, Figure 5-17, Figure 5-18 and Figure 5-19). Stations used to derive 1981-2010 sunshine normals are shown in Figure 5-20 and Figure 5-21.

5.6.1 Conclusions

- The minimum spatial requirements for regional definition of sunshine hours and solar radiation are being met.

5.6.2 Recommendations

- Noting that NIWA plans to install a solar radiation sensor at Ettrick and a solar radiation and sunshine sensor at Palmerston, and that ORC plan to install solar radiation sensors at their air quality sites in Arrowtown, Alexandra, Dunedin and Mosgiel, there are no additional recommendations to make

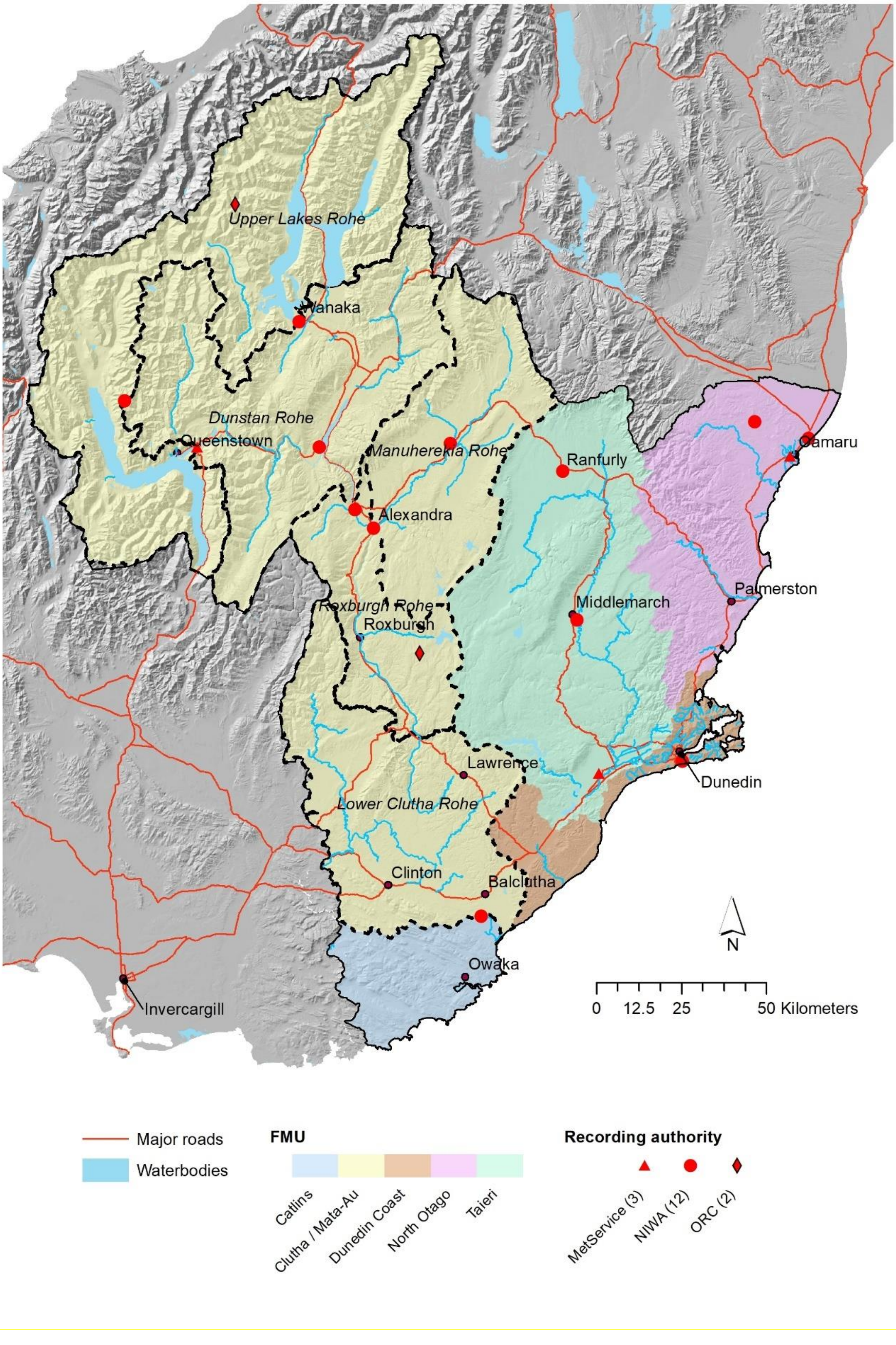


Figure 5-16: Open stations that record solar radiation, shown by FMUs.

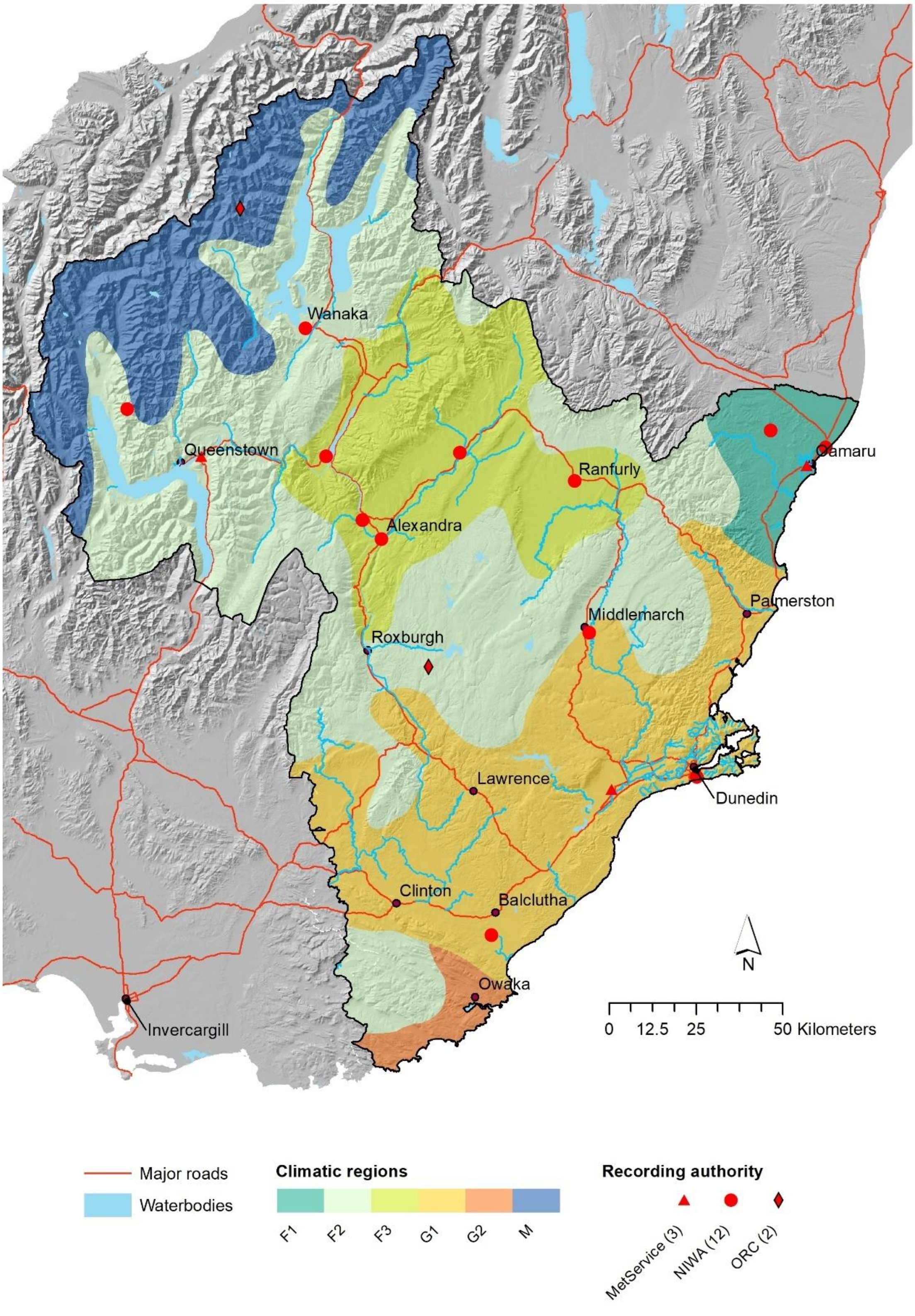


Figure 5-17: Open stations that record solar radiation, shown by climatic regions. Refer to Table 3-3 for an explanation of the climatic regions.

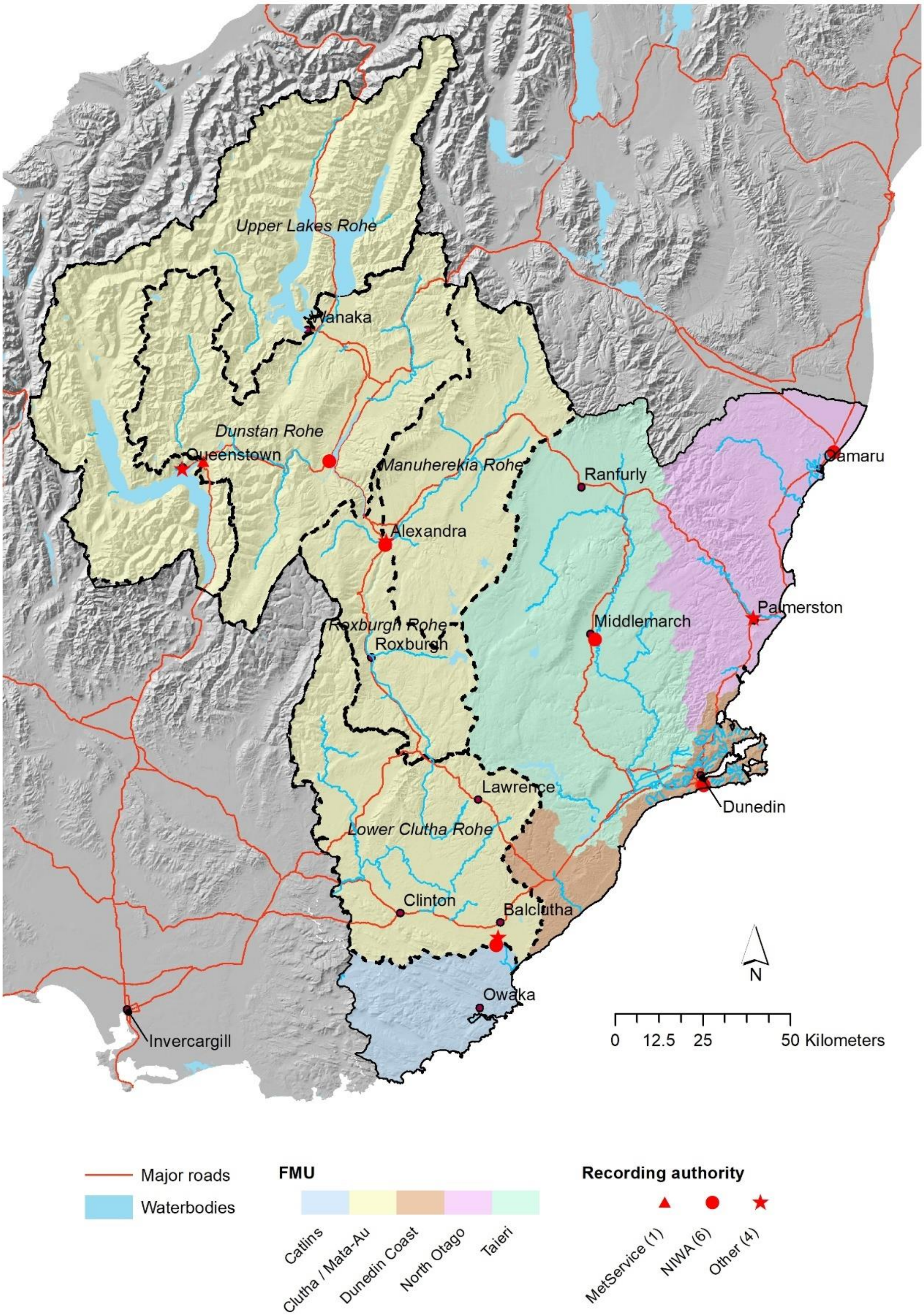


Figure 5-18: Open stations that record sunshine duration, shown by FMUs.

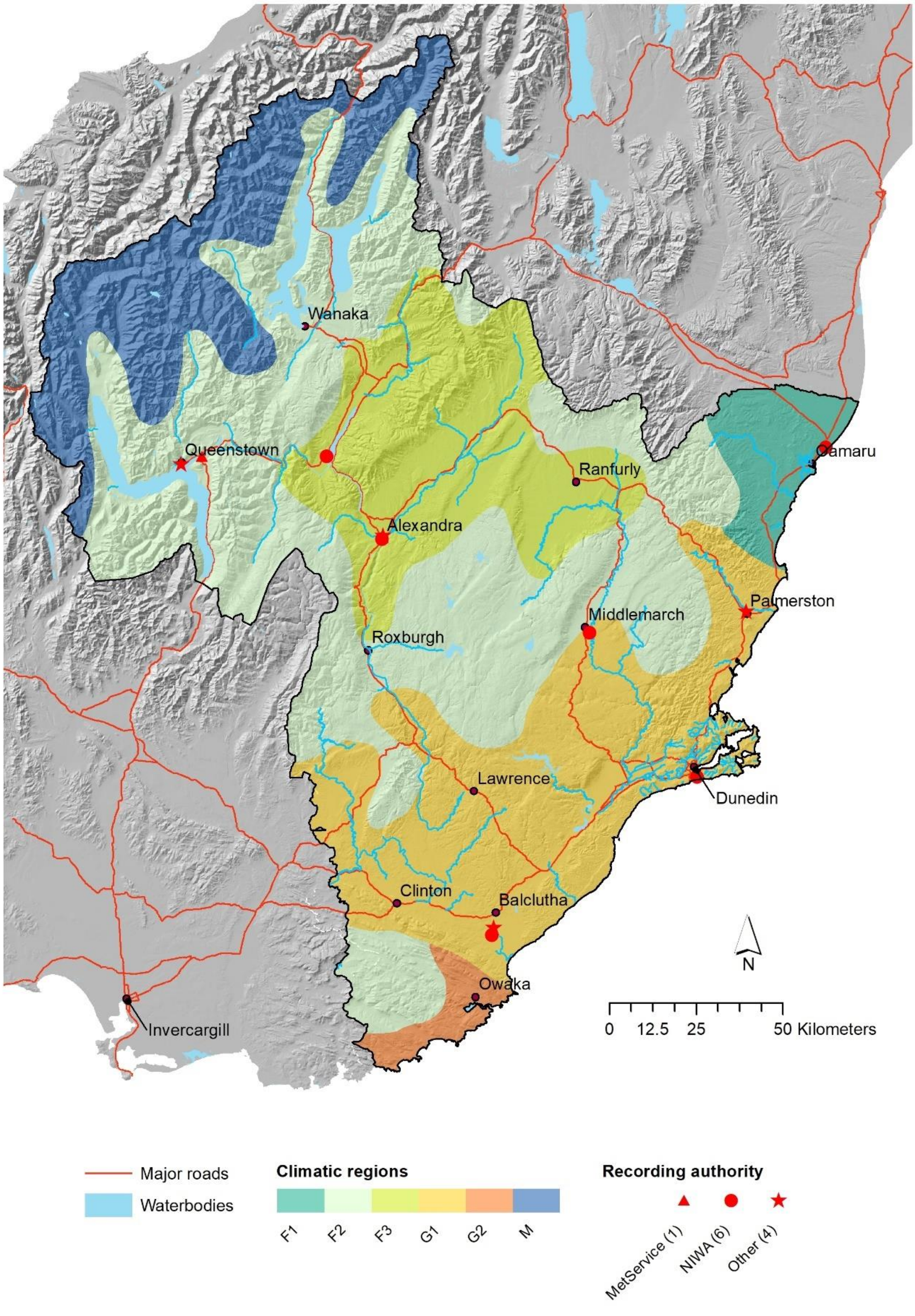


Figure 5-19: Open stations that record sunshine duration, shown by climatic regions.
Refer to Table 3-3 for an explanation of the climatic region.

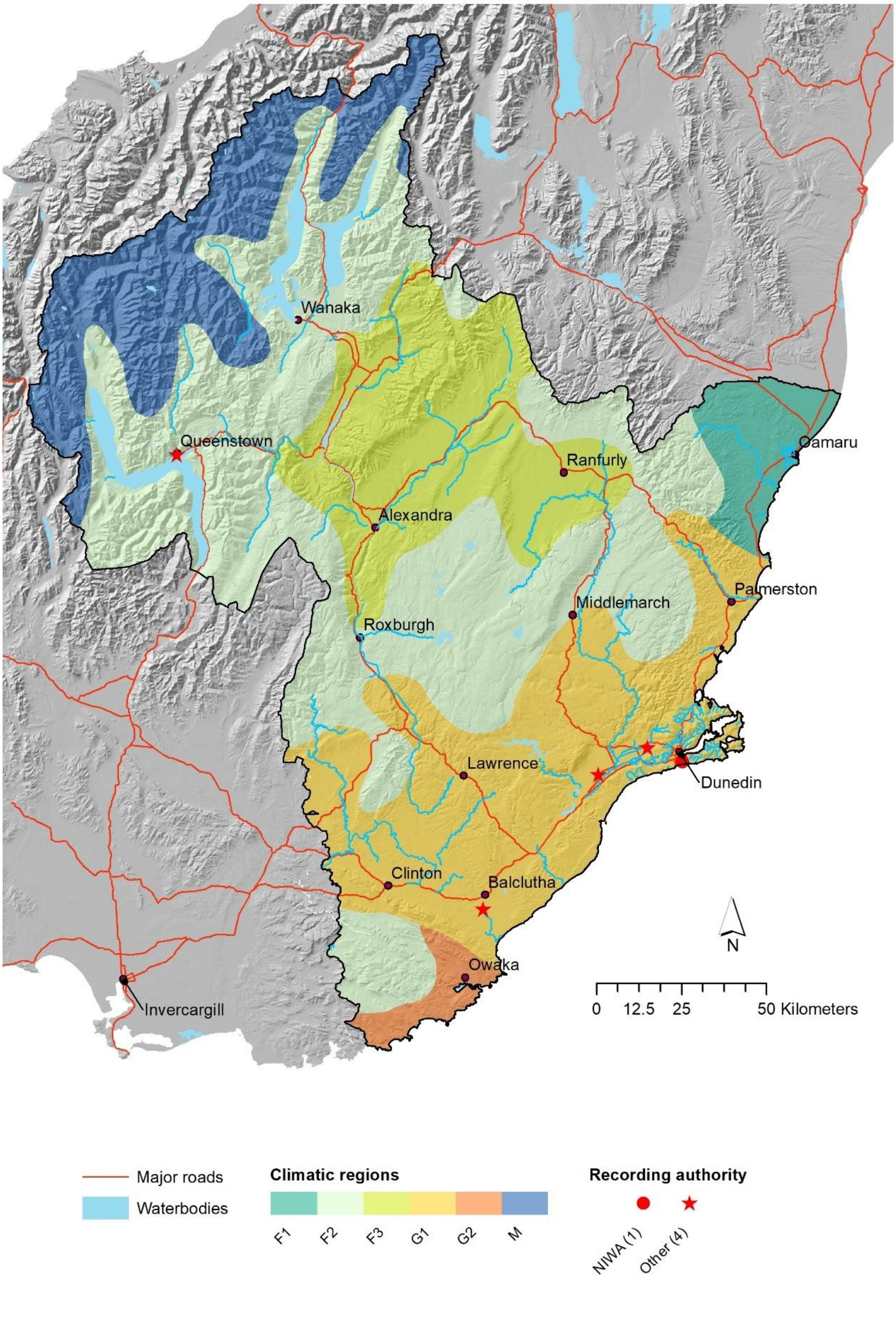


Figure 5-20: Climate sites used to derive 1981-2010 sunshine normal, shown by climatic regions. Refer Table 3-3 for an explanation of climatic regions.

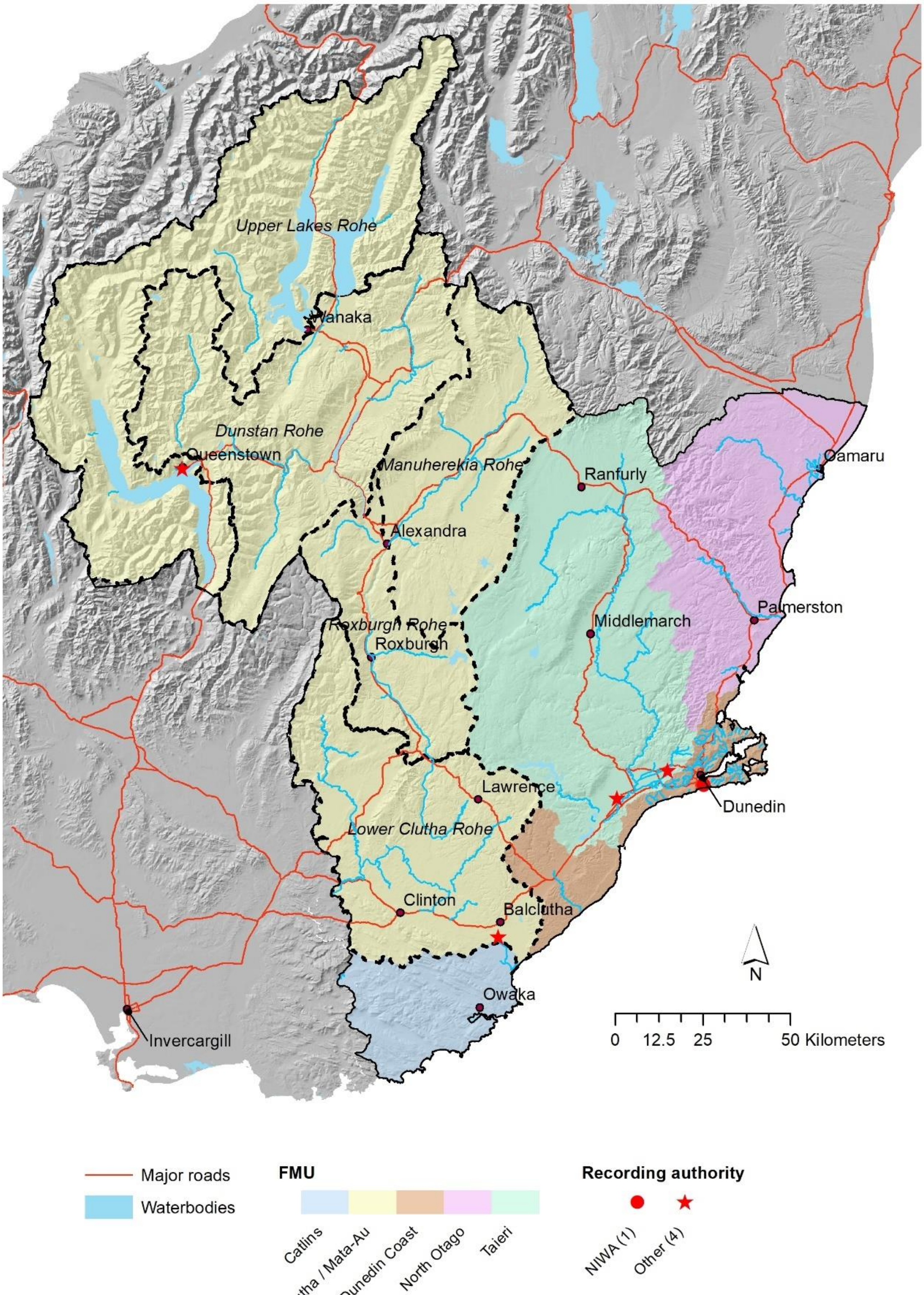


Figure 5-21: Climate sites used to derive 1981-2010 sunshine normal, shown by FMUs.

5.7 Evaporation and evapotranspiration

While historically there have many evaporation monitoring sites, Ettrick is the only remaining site in the region that continues to have a manually read pan evaporimeter. Pan evaporimeters are difficult to maintain and require constant maintenance for accurate readings. While it is possible to automate, the accuracy obtained is limited and outside recognised specifications. NIWA has chosen not to continue with pan evaporimeters and now calculates evaporation and potential evapotranspiration (PET) using standardised formulae such as Priestley-Taylor and Penman.

The calculation of Penman PET, Priestley-Taylor PET and Penman Open Water Evaporation is done for stations below 500 m using other variables (wind, solar radiation, precipitation, air temperature and humidity). These are available at the sites shown in Figure 5-22 and Figure 5-23.

As PET is a derived value, the input data must be of good quality. It is very easy to have a poor estimate due to a poorly exposed (e.g., raingauge on a roof, temperature/relative humidity over concrete) or poor quality instruments. For this reason, there is little value in calculating PET from a station that may be used for air quality where the exposure may be compromised, yet the measurements may be perfect for their intended purpose.

Penman PET estimates are also generated in the VCSN. As for other VCSN variables, the more data, and closer to the grid point, the more reliable the estimate.

5.7.1 Conclusions

- There are well established methods for calculating PET and evaporation
- Reliable PET estimates are reliant on good quality meteorological measurements
- PET estimates are generated in the VCS network

5.7.2 Recommendations

- If recommendations in earlier sections (addition or upgrade of climate sites as well as use of temporary climate sites) are implemented, then coverage of PET will be greatly enhanced across the entire region
- It is considered there is no requirement to install further pan evaporimeters given comments above on maintenance and accuracy of measurement.

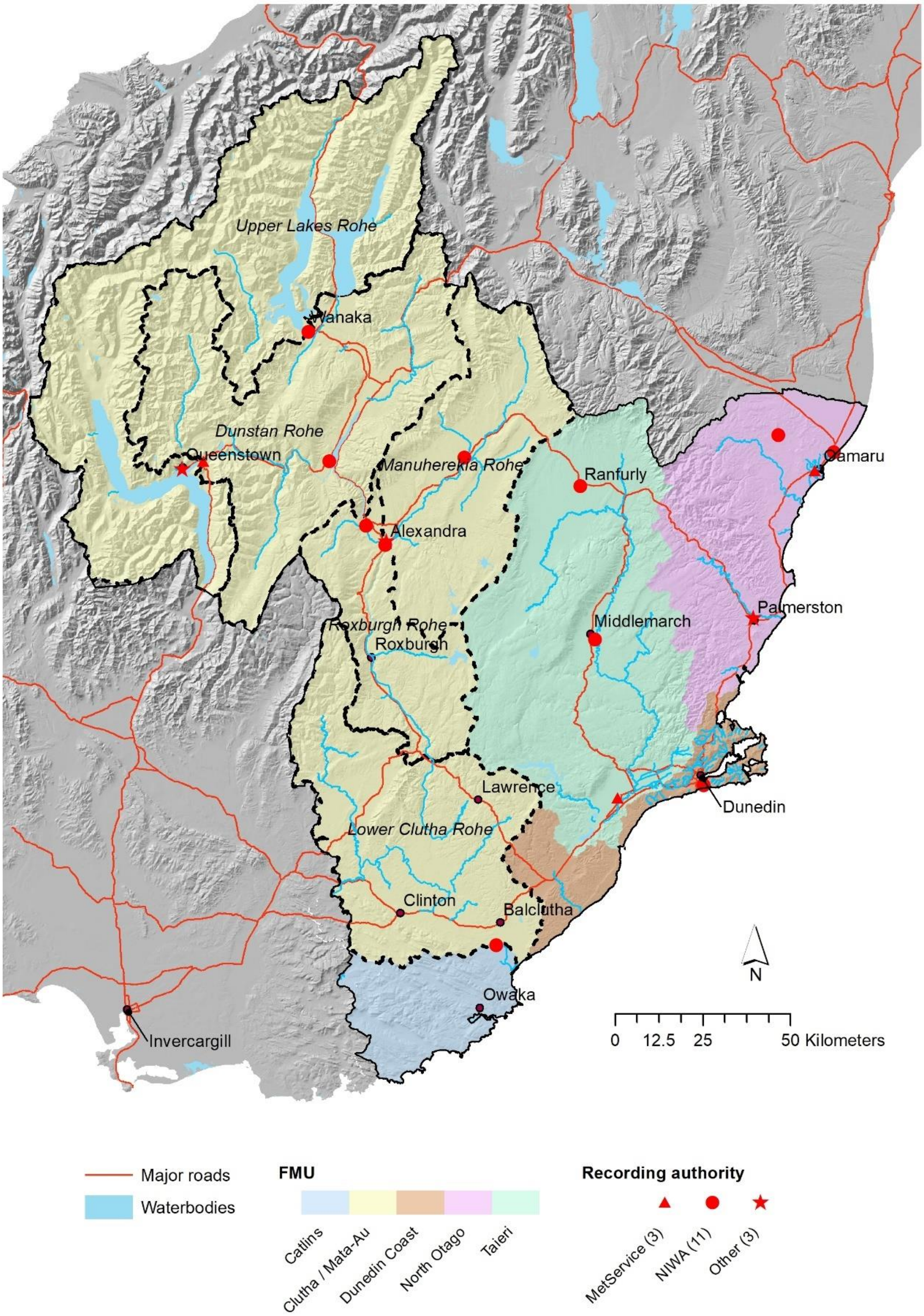


Figure 5-22: Open stations with potential evapotranspiration estimates, shown by FMUs.

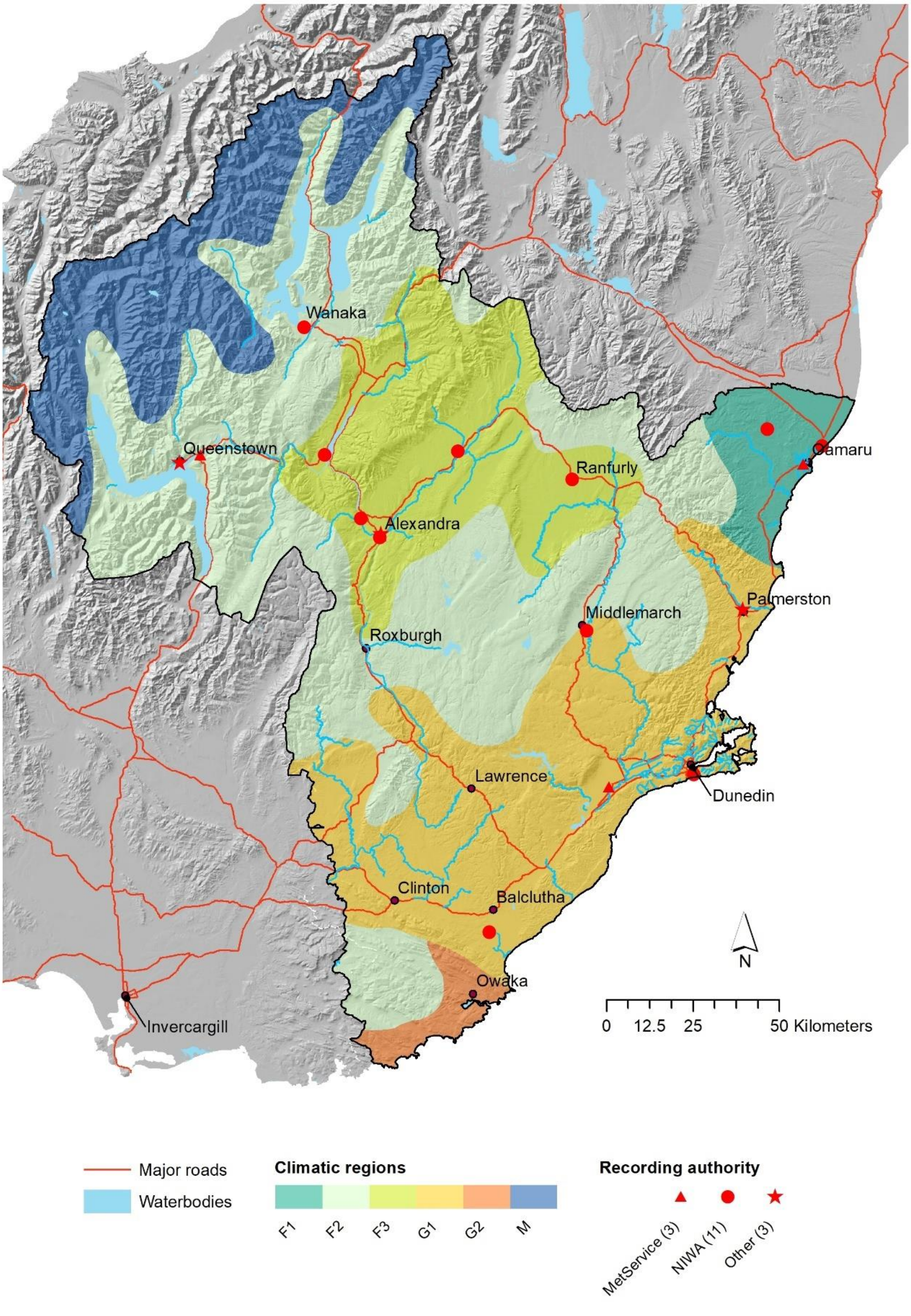


Figure 5-23: Open stations with potential evapotranspiration estimates, shown by climatic regions. Refer to Table 3-3 for an explanation of the climatic regions.

6 Assessment of instrumentation, site exposure and site maintenance

Whilst recognising ORC's commitment to adopting National Environmental Standards (NEMS), these have not yet been formalised for meteorological variables, except for rainfall (specific to hydrological purpose) and soil moisture.

A NEMS for "Meteorological Variables for baseline Air Quality" measurements is under production but is limited to Air Quality observations and does not cover general meteorological or climatological observations.

In the absence of NEMS for other meteorological variables and noting that NIWA and MetService are obligated to follow WMO requirements and monitoring guidelines, this section provides some commentary on general monitoring principles, guidance from WMO, and assessment of different methods used in the region.

Automatic weather stations (AWSs), are playing a prominent role in observation networks. They offer numerous advantages in weather applications such as:

- Data availability: Allowing observations at a high time resolution to be received in real time
- Data frequency: Many locations that previously had observations only once per day now record data every minute
- Data are collected in areas where there is no permanent human settlements, and in locations that are not readily accessible by human observers

On the other hand, automated stations typically require more-frequent and specialized maintenance than manual systems, which can place a significant burden on network management in some places, especially regions with limited resources.

Automated stations also introduce challenges for long-term climate monitoring. Any change in an observing system could potentially introduce homogeneity issues into the climate record, which needs to be assessed and adjusted for, if necessary. Assessment of data homogeneity at a site is especially challenging if similar changes occur at multiple sites. In many cases, the introduction of AWSs will also be accompanied by site relocations. In addition, the introduction may lead to the loss of observations of variables that are difficult to measure automatically (or where automatic measurements are not directly comparable with manual observations), such as pan evaporation. (WMO, 2017b).

Maintaining consistency of instrument type or logging schema has also become more difficult as technology evolves. For example, the principles of liquid-in-glass thermometers did not change in over 150 years, yet the electronic equivalents have continually evolved. Technology is changing rapidly and a challenge for network managers is maintaining homogeneity by not changing instruments every time a new product comes on the market.

Siting, or exposure, of instruments is as important as the sensor itself in obtaining appropriate measurement. Even with the best instruments if the exposure is poor, then the data are compromised. Equally, good exposure but poor, or different, instrumentation will also compromise data quality.

The WMO sets technical standards, quality control procedures and guidance for the use of meteorological instruments and observation methods to promote global standardisation. The WMO Guide to Meteorological Instruments and Methods of Observation or commonly known as WMO-No.8 (WMO, 2018b), is one of few internationally recognized guidance publications for instruments and methods of observation. Recent editions are far more comprehensive than earlier editions and it is continually being updated on a 2-yearly cycle. A new volume is currently being developed dedicated to cryosphere measurements.

6.1 Exposure

As indicated previously, siting and exposure of instruments is crucial to achieve good quality measurements. Whilst in most situations it is true that if the exposure is poor then the data are compromised, this is not necessarily true in all situations. A good example is meteorological variables at Air Quality sites. The exposure may be significantly compromised but the measurement is of the quality as required by the application.

Similarly, a site may not meet all the requirements for a network site but is more than adequate for other purposes such as a short-term study. It may be that such a site may be classed as poor for wind and temperature yet have other variables such as rainfall or solar radiation that meet class 1 requirements.

WMO-No.8 provides guidance on exposure of instruments for optimal collection of environmental variables as well as guidance on siting classification and how exposure affects measurement of variables. (WMO, 2018b).

Some requirements include:

- Outdoor instruments should be installed on a level piece of ground
- The ground should be covered with short grass or a surface representative of the locality and surrounded by open fencing or palings
- A bare patch of ground for observations of the state of the ground and of soil temperature at depths of equal to or less than 20 cm. Soil temperatures at depths greater than 20cm can be measured outside this bare patch
- There should be no steeply sloping ground in the vicinity, and the site should not be in a hollow
- The site should be well away from trees, buildings, walls or other vertical obstructions. The distance of any such obstacle (including fencing) from the raingauge should not be less than twice the height of the object above the rim of the gauge, and preferably four times the height
- Very open sites which are satisfactory for most instruments are unsuitable for raingauges. For such sites, the rainfall catch is reduced in conditions other than light winds and some degree of shelter is needed
- At coastal sites, it is desirable that the site command a view of the open sea. However, the site should not be too near the edge of a cliff as the eddies created by the cliff will affect the wind and precipitation measurements.

Data collected also need to be representative of the general area. A good exposure that is representative on scales from a few metres to 100 km is difficult to achieve. A site in a hilly or coastal area is unlikely to be representative of a large spatial scale, however good homogeneity over time may enable such data from unrepresentative sites to be used in regional climate studies.

In the case of urban sites, general exposure rules are virtually impossible to meet and compromise is thus required. WMO-No.8, Vol III, Chapter 9 gives excellent guidance for monitoring in urban settings.

WMO-No.8 also refers to agriculture meteorology which is covered in more detail in the Guide to Agricultural Meteorology WMO-134 (WMO, 2010).

6.2 Instruments and data logging

WMO-No.8, Vol I, Chapter 1, Annex 1.A provides a table of operational measurement uncertainty requirements and instrument performance requirements for different variables.

Most instrumentation and methods used by NIWA and MetService are similar but differences do exist. Mostly these are related to data requirements for differing purposes e.g., aviation vs climate, but they are well known and documented. NIWA and MetService continue to work closely to ensure the networks complement each other.

There is an increase in uncertainty on the instruments and data loggers used with the FENZ sites as many of these have made changes over the past two years and the methods used are not fully known or documented.

Care must also be taken when changing data logger types as sometimes programming instructions differ between logger brands and models. An example of potential differences a change in data logger can have is demonstrated in this plot of monthly mean wind speed clearly showing such a change (see Figure 6-1). This is likely due to the processing instruction being different and not following established methods (vector averaging) in the new logger.

An underlying climate monitoring principle to managing change is that only observing technologies with adequately characterized performance should be deployed to ensure that levels of observational quality consistent with user requirements are attained. This includes appropriate periods of parallel measurements. Guidance provided by WMO recommend a minimum of 12 months for wind speed and direction, 24 months for temperature, humidity, sunshine and evaporation, and 60 months for precipitation whilst also noting that “a useful compromise would be an overlap period of 24 months”.

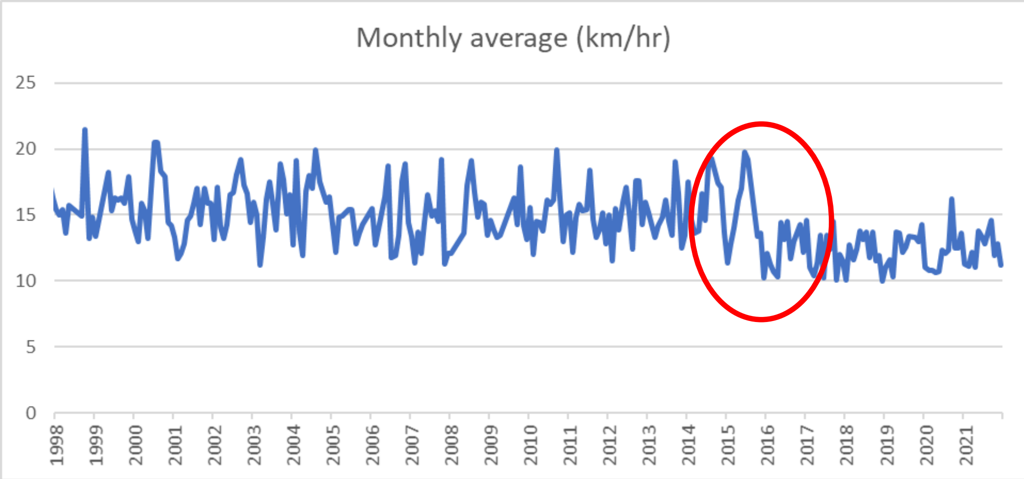


Figure 6-1: An example showing the error introduced (shown by red oval) by a change to the averaging methodology.

6.3 Air temperature and relative humidity

While temperature has been a direct measurement – that is using a sensor designed to measure temperature e.g., thermometer, thermistor, platinum resistance thermometer - relative humidity has historically been a derived parameter calculated from dry and wet bulb thermometer readings and subject to ability of the observer to correctly maintain the wet bulb for accurate readings. This is particularly so when the temperature is below zero and the wet bulb is frozen. The advent of automated systems has seen the introduction of capacitive methods for measuring relative humidity. Early systems were subject to significant drift and also were less accurate in the 90 – 100% range but nowadays these are very reliable including at sub-zero temperatures.

As indicated earlier, there are also variations in the instrumentation and methods used between data providers. These are summarized here in Table 6-1.

One of reasons for the difference results from the WMO guidelines which are quite broad and open to interpretation especially when not read in full. For example, WMO-No.8 states “Sensors situated inside a screen should be mounted at a height determined by the meteorological service (within 1.25 m to 2.0 m) as indicated in the World Meteorological Organisation (WMO, 2018b). The height should never be less than 1.25 m. The higher limit requirement is less stringent, as the temperature gradient versus height is decreasing with height. For example, the difference in temperature measured by sensors located between 1.5 and 2.0 m is less than 0.2 °C.”

Table 6-1: Differences in temperature data collection procedures among the major providers.

	WMO-No.8	ORC	NIWA	MetService	FENZ
Double louvered wooden screen	Type not specified		√	√	
Disk type radiation shield	Type not specified	√	At EWS sites		√
Height above ground level	1.25 m to 2 m	1.5 m	1.2 m, 2.5 m at CWS sites	1.2 m	1.5 m
1-minute mean (on the hour)	√		√	√	
10-minute mean	From 1-minute data	√	√	√	√
Hourly average	From 1-minute data	√	√	√	
Maximum and minimum	√	√	√	√	

The measurement heights above ground level at most sites meet this requirement; however, the key point is consistency of exposure (see section 6.1), and as stated above "…mounted at a height determined by the meteorological service…". Note that historically (internationally adopted in 1873) the height was 4ft (~1.2m) adopted by MetService and NIWA for network sites.

The 2.5 m height at the NIWA sites are from the CWS (Compact Weather Station), or "Tier-2" sites, that use a combined all-in-one weather sensor. Sites with temperatures at this height should only be considered for special investigations rather than long term climate applications.

The type of housing or radiation shield also affects the measurements, especially the extremes and around dawn and dusk, with many reports from WMO and others on this. While using alternative screens at certain installations within their networks, both MetService and NIWA use the double louvered wooden screen (also known as a Stevenson screen) for their "network" sites.

6.4 Soil temperature

Historically, soil temperature measurements have been made using liquid-in-glass thermometers at depths of 10, 20, 30 and 100 cm. At some locations, 5 cm is also included. These were read once a day at 0900 NZDT. At Dunedin Airport, the 10 cm was also read at 1800 NZDT. With the introduction of AWS and a change from liquid-in-glass thermometers to electronic methods, the 30 cm depth was changed to 50 cm in line with new requirements from WMO.

A potential challenge is measuring soil temperature from soil moisture instruments. Most soil moisture instruments (see Section 7) measure soil temperature as an ancillary variable. However, as older soil moisture technologies often do not meet the recommended accuracy as stated in WMO-No.8 (WMO, 2018b), the soil temperature measurements from soil moisture instruments are not currently archived on CliDB. This could potentially change as technological improvements could mean that some of the newer instruments may meet the WMO requirement and be suitable for soil temperature measurements, but these will need a period of evaluation first.

6.5 Precipitation

The measurement of precipitation continues to evolve with the aim to improve measurements and enable a homogenous record. Manually read rain gauges are still in use although there is a trend to use more automatic gauges. Within NZ the most common type of automatic precipitation gauge used is a tipping bucket rain gauge although others such as weighing or drop counter type are also used. While each of these has different characteristics (e.g., 0.2 mm tip vs 0.5 mm tip or siphoning vs non-siphoning), these are generally well understood and have been chosen to be fit for purpose.

Spatially, manual gauges fill the gaps that are critical for the compilation of statistics. Loss of any part of a single day of observations results in the loss of the monthly (annual) total for the month (year), unless the data for the missing period are estimated. This problem is most common with tipping bucket rain gauges where a continuous count is required but is less likely to affect the bucket (accumulation) type weighing gauges.

The convention in New Zealand by most providers has been to use unshielded gauge which tends to lead to an under-catch due to wind effects. This is especially pronounced in highly exposed locations. NIWA and ORC are beginning to introduce shielded weighing bucket gauge types in mountain areas to overcome this challenge.

There are significant challenges to recording small precipitation amounts using both manual and automatic instruments. This is especially important for low precipitation areas such as Central Otago. This could introduce biases in the frequency of such small amounts when transitioning from conventional to automatic stations. Experience with manual sites indicates that it is relatively common for small amounts (less than 2 mm, and especially less than 1 mm) not to be reported, if the sites do not have professional observers. Conversely, automatic rain gauges cannot reliably distinguish between rain and dew or frost, which can lead to an exaggerated number of days with small precipitation amounts unless there is manual intervention to remove them (WMO, 2017b). Such a precipitation pattern is typical of very cold climates, where trace amounts can also contribute significantly to total precipitation as experienced in Central Otago and is seen in the frequency of 0.2 mm counts recorded on clear autumn and winter days in that region.

NIWA has three different gauges in use at Lauder – 0.2 mm tipping bucket, drop counter and a tipping weighing bucket with the latter two being introduced as additional technologies and not replacing the tipping bucket.

NIWA participated in the WMO Solid Precipitation Experiment (SPICE). One of the main objectives of SPICE was the assessment of a wide range of instruments to measure solid precipitation under various climates. Mueller Hut in the South Island was one of 20 sites worldwide participating in this experiment. A report was produced (WMO, 2018c) and this is being further developed into Volume II of WMO-No.8, “Measurement of Cryospheric Variables” (WMO, 2018b).

As the technology and methods evolve, it is important that any changes adopted are well managed to maintain the integrity of the data collected and the differences are well understood and documented.

6.6 Pressure

MetService are the only authorised provider of pressure measurements to the aviation industry. Technological choices for pressure are limited which meant that there is good consistency between organisations in measuring pressure. The biggest areas of caution is the end purpose of the measurements and the reduction to mean sea level, which are subject to very small changes in height and temperature.

6.7 Wind

Wind is another variable with some important differences between providers. This is mostly around exposure and height above ground. These have been mostly informed decisions and with a purpose in mind. As wind is so influenced by obstructions from hundreds of metres upwind, it is important any users of wind data are fully conversant with the associated metadata.

6.8 Solar radiation and sunshine

There are limited methods for the measurement of sunshine. NIWA and MetService have traditionally used the same internationally accepted method, and this continues today as we transition into automated systems.

There are many different sensors and instruments available for measuring solar radiation, which each one of them have their own characteristics. For this reason, NIWA and MetService continue to use the same methods and instruments for solar radiation in their networks. This is to ensure consistency of measurement and calibration as different types and makes have different operating characteristics and calibration challenges. The measurements collected by NIWA and MetService are all traceable to the International Radiation Reference.

ORC intend to add solar radiation to their Air Quality stations. If traceable measurements are required, then care needs to be taken with the choice of instrument.

6.9 Metadata and homogenisation

A challenge with shared sites from multiple providers is consistency of, and accessibility to metadata. Complete metadata is as important as any other requirement but is often overlooked. Changes to instrumentation, and inspection and maintenance records are vital metadata and need to be kept and made accessible to users. Complete and up-to-date metadata is especially important when federated data systems are used for data sharing between providers.

At times data from other organisations might be suitable for use for certain uses. But because of inadequate metadata this opportunity is missed because there is a greater uncertainty over the quality of data. Guidelines on Climate Metadata and Homogenisation (WMO, 2003b), provides useful guidance on requirements.

A good example of challenges faced was in the preparation of this report when accessing metadata from NIWA's CliDB and SIMS, and from ORC where the same station had three different station identifiers, names, data periods and geographical coordinates. These have all been introduced over time as seemingly small changes (e.g., resolution of coordinates, or "common" use of name) have crept in but have magnified over time. Albert Burn and Albert Burn at Dragon Fly is such an example.

6.10 Inspections and maintenance

Climate sites should be inspected no less than annually. The objectives of the inspection are to ensure the siting and exposure are known and documented; instruments are of approved type and checked or verified against standards as necessary; and to ensure uniformity of measurement. Site maintenance must be done regularly and is mostly preventative. This includes tasks such as trimming the grass, changing any desiccants, and routine sensor exchange.

MetService and NIWA sites all operate a routine sensor exchange programme and ORC has well established processes in place. For the core network stations the measurements, with the exception of wind and soil moisture, from NIWA and MetService stations are all traceable to International

System of Units (SI)I. While FENZ have a maintenance regime, the exact procedures are not known to the authors.

7 Assessment of soil moisture monitoring network

Until the late 1990s, soil moisture monitoring at climate and rainfall sites was uncommon. However, as technology is advancing and the frequency of droughts increasing, soil moisture monitoring has become a common practice.

Soil moisture serves to characterise drought and wet periods. In the upland forested catchments, soil moisture monitoring provides an indication of soil storage status, and thus potential for flows (base flows and storm flows) to downstream areas. Following the 1997-98 El Nino event, NIWA installed several soil moisture monitoring sites across the agricultural regions of New Zealand. Aside from these monitoring sites, NIWA has also been publishing daily soil moisture deficit maps for the country. These are discussed in the sub-section 7.2.

Currently there are 14 soil moisture monitoring sites within the ORC region – eleven of them are operated by NIWA and three by ORC (Figure 7-1, Figure 7-2 and Table 7-1). At the NIWA sites, either EnviroPro^{TM}, Aquaflex^{TM} or Acclima^{TM} soil moisture sensors are used. Where Acclima and Aquaflex sensors are used, the soil moisture measurements are limited to the root zone (40 cm or less). At EnviroPro sites, it extends up to 80 cm below surface.

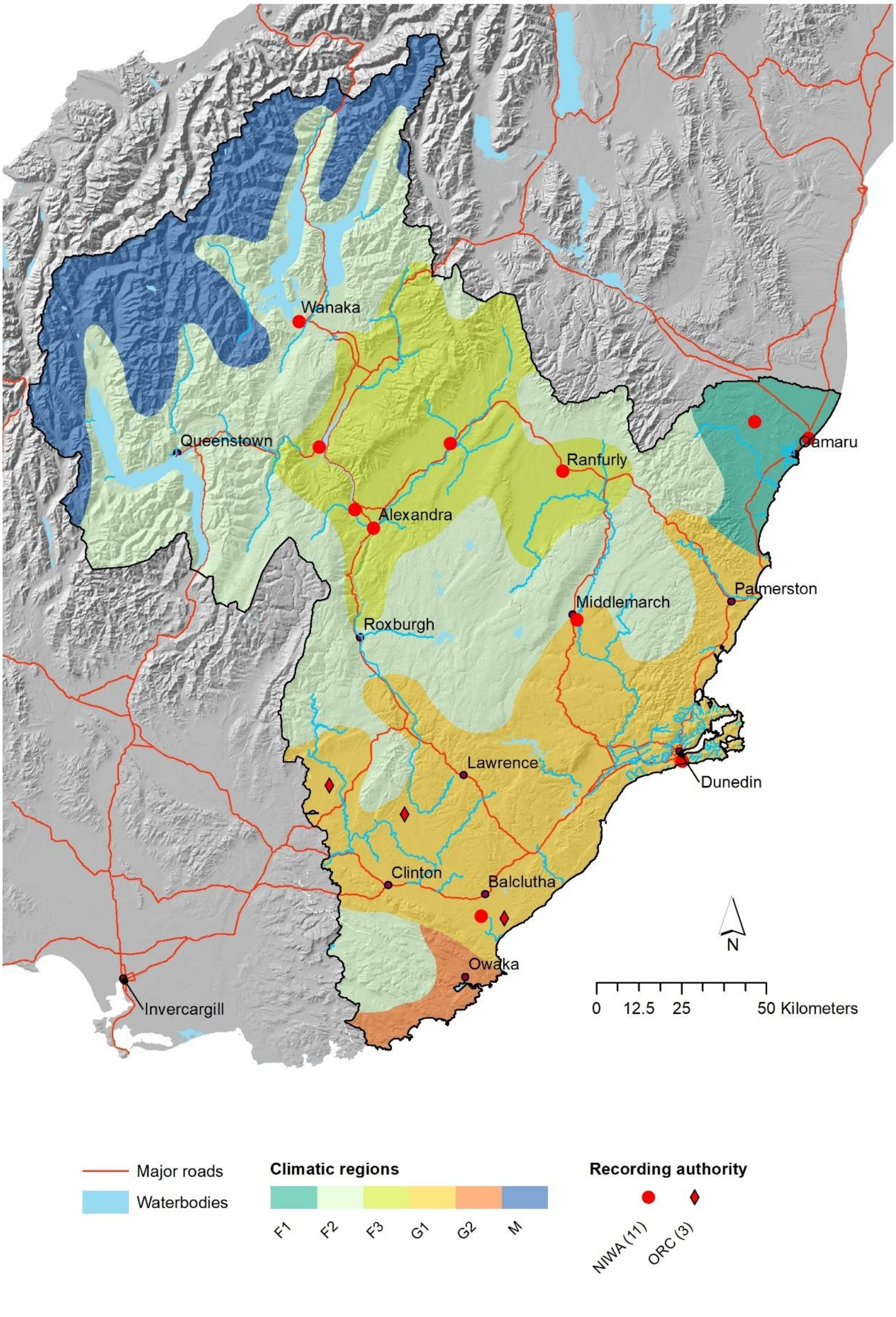


Figure 7-1: Open soil moisture monitoring sites in the ORC region, shown by climatic regions.

Refer to Table 3-3 for an explanation of the climatic regions.

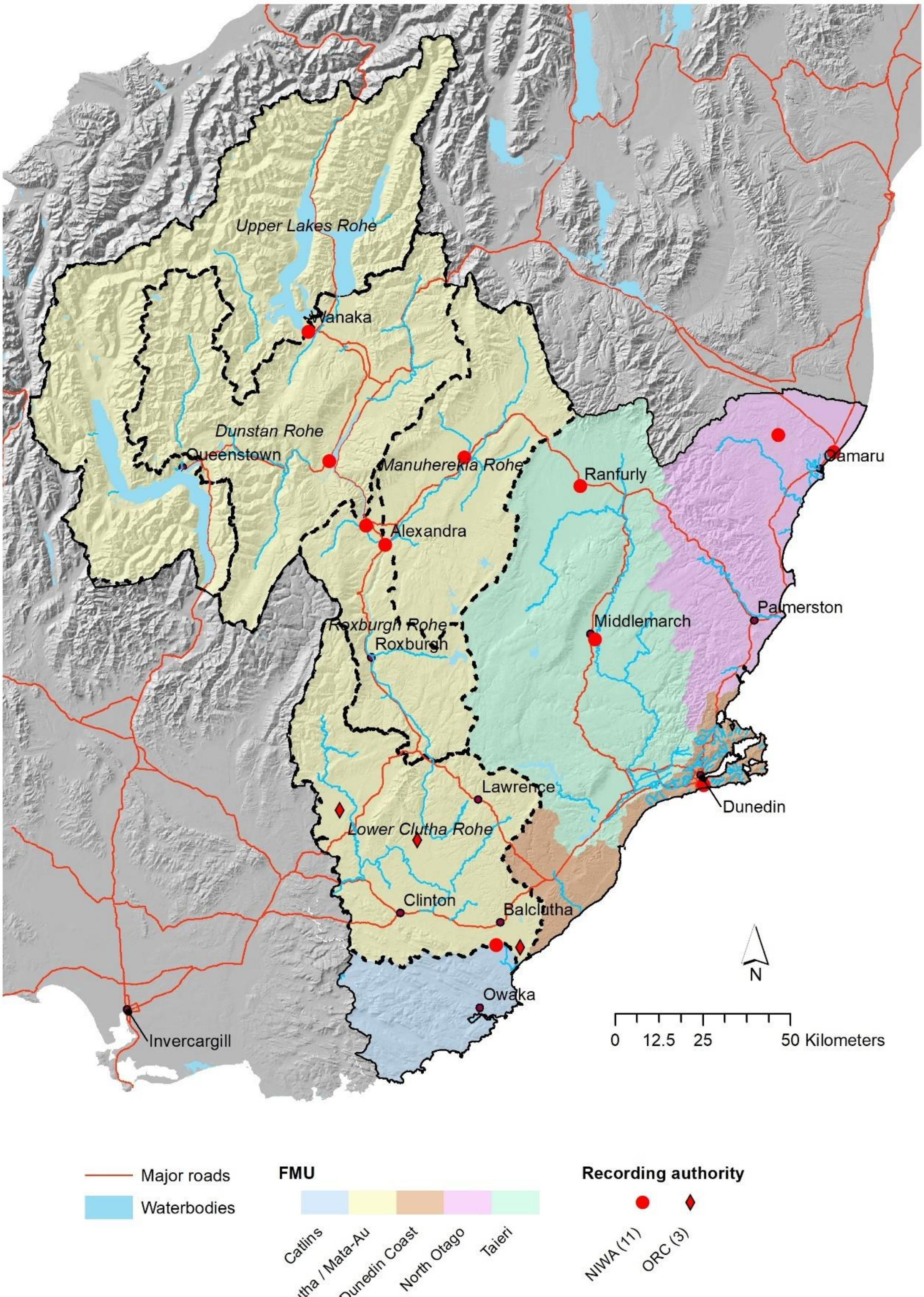


Figure 7-2: Open soil moisture monitoring sites in the ORC region, shown by FMUs.

Table 7-1: List of all open soil moisture monitoring sites in the Otago region, arranged by FMU, Rohe, climatic regions and sensor type.

Total number of sites, 14.

							Soil moisture sensor type					
Site name	Climatic region	FMU	Rohe	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Aquaflex	Acclima	EnviroPro	Other	Telemetered	Recording authority
Windsor EWS	F1	North Otago		2338333	5575447	81	X				Yes	NIWA
Oamaru EWS	F1	North Otago		2354201	5570499	20			X		Yes	NIWA
Ranfurly EWS	F3	Taieri		2281864	5560831	450	X				Yes	NIWA
Middlemarch EWS	G1	Taieri		2286136	5517182	213	X				Yes	NIWA
Dunedin, Musselburgh EWS	G1	Dunedin Coast		2317005	5475563	10	X				Yes	NIWA
Balclutha, Telford EWS	G1	Catlins		2257972	5429980	11	X				Yes	NIWA
Wanaka CWS	F2	Clutha/Mata-Au	Upper Lakes	2204381	5604889	331		X			Yes	NIWA
Wanaka CWS	F2	Clutha/Mata-Au	Upper Lakes	2204381	5604889	331		X			Yes	NIWA
Cromwell EWS	F3	Clutha/Mata-Au	Dunstan	2210270	5567979	213	X				Yes	NIWA
Lauder EWS	F3	Clutha/Mata-Au	Manuherekia	2248801	5568999	375	X				Yes	NIWA
Clyde 2 EWS	F3	Clutha/Mata-Au	Roxburgh	2220767	5549601	170	X				Yes	NIWA
Alexandra EWS	F3	Clutha/Mata-Au	Roxburgh	2226217	5544151	132			X		Yes	NIWA
Pomahaka at Kelso	G1	Clutha/Mata-Au	Lower Clutha	2213200	5468499	0				X	Yes	ORC
Washpool at Lone Hill	G1	Clutha/Mata-Au	Lower Clutha	2235300	5459999	0				X	Yes	ORC
Inchclutha Soils	G1	Clutha/Mata-Au	Lower Clutha	2264656	5429380	0				X	Yes	ORC

7.1 Soil moisture monitoring within FMU and Rohe

When the soil moisture monitoring sites were overlain with FMU-Rohe boundaries (Figure 7-2), the sparseness of the network becomes obvious. There are no soil moisture sites in Catlins FMU and Upper Lakes Rohe. Other FMUs and Rohes have far too few sites with large areas uncovered. The majority of soil moisture sensors are located in sites that contain moderate to well-draining soils, leaving poorly draining soils unrepresented Figure 7-5). When the soil moisture sites were overlain on the SMap-based soil drainage map, no specific inference could be made as the availability of S-map is limited (Figure 7-4). Where practices such as effluent applications occur, it is critical that poorly drained soils are targeted for soil moisture monitoring as those soils are prone to ponding, overland flow and nutrient transport.

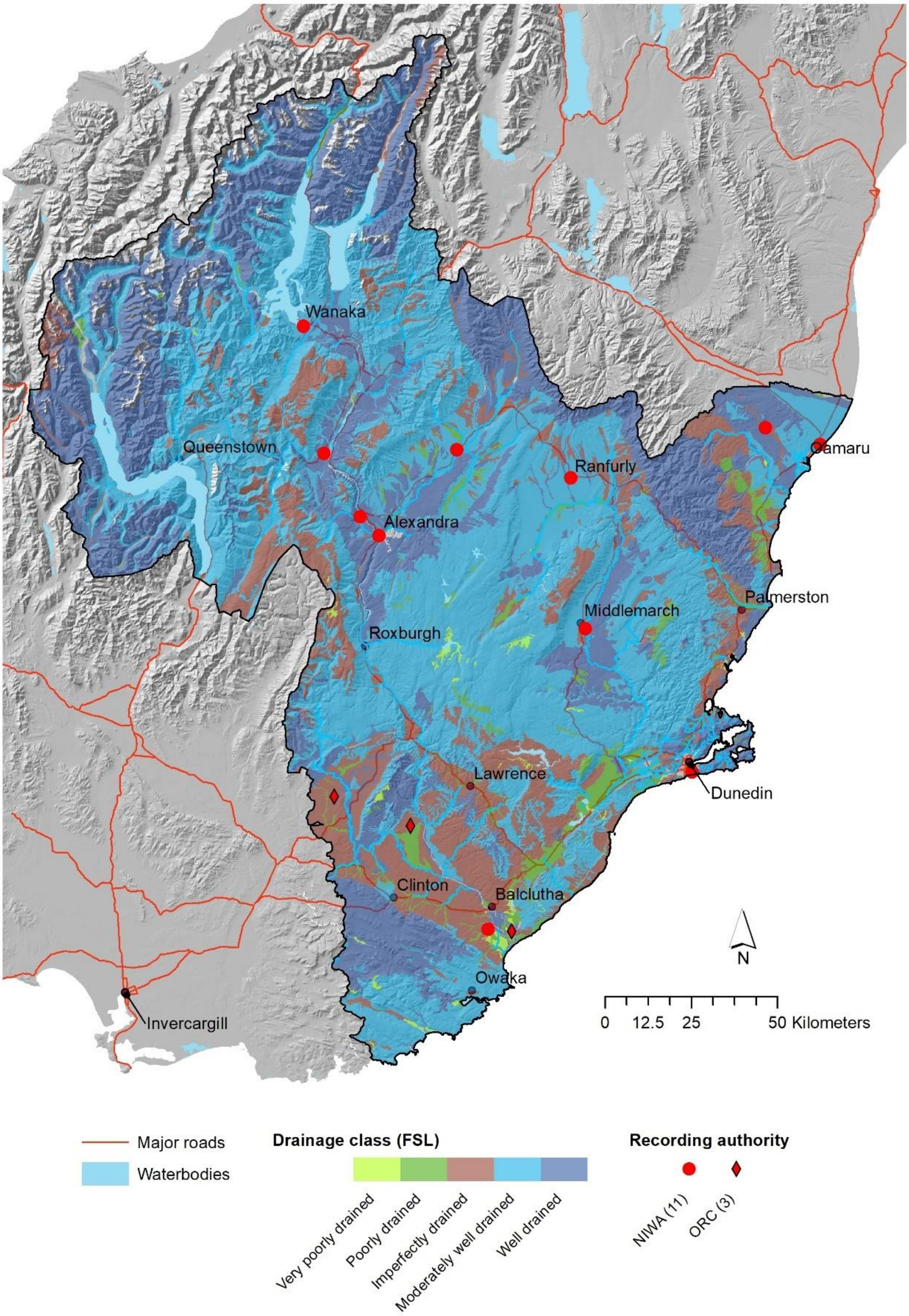


Figure 7-3: Soil moisture monitoring sites in the Otago region, shown based on soil drainage class from the Fundamental Soil Layer.

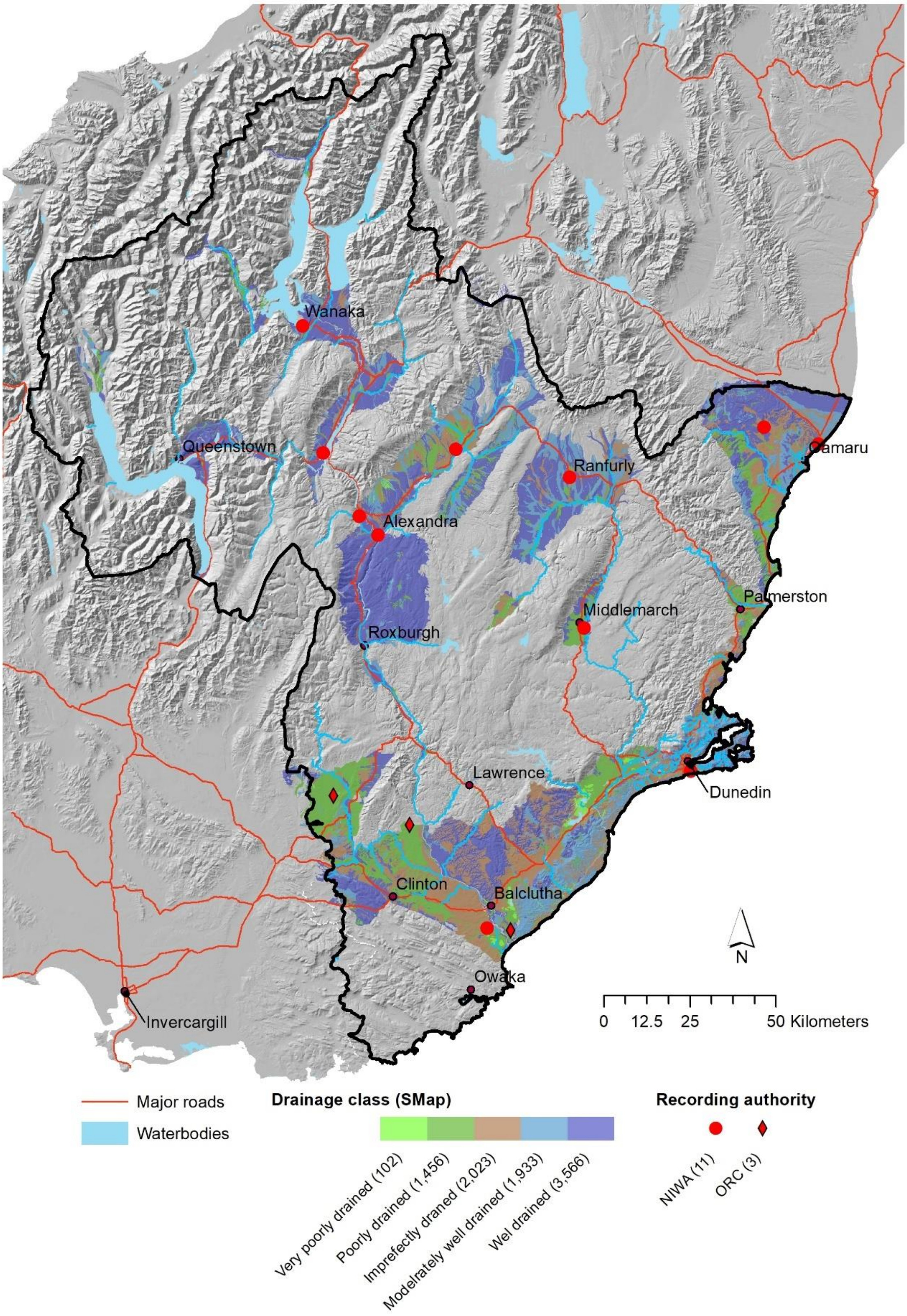


Figure 7-4: Soil moisture monitoring sites in the Otago region, shown by soil drainage class from S-map. S-map data source: Manaaki Whenua Landcare Research Limited and Otago Regional Council.

7.2 Soil moisture monitoring for drought mapping

The adequacy of the current soil moisture network for drought monitoring was assessed. Soil moisture drought is generally expressed as deficit in plant available water (PAW) over normal conditions for that time of the year. The normal conditions vary with season. Near-field capacity condition (PAW at, or near maximum) is normal in winter, while near-zero PAW is normal during peak summer periods when plant water demands are maximum. Since soil moisture droughts are focussed on crop and pasture growth, they account for plant available water within the root zone only. Thus, the soil moisture monitoring at the root zone as is currently done by NIWA and ORC is adequate.

NIWA publishes daily soil moisture deficit (SMD) maps for the entire country (see an example in Figure 7-5). These maps are freely accessible at https://www.niwa.co.nz/climate/daily-climate-maps. The daily SMD maps provide data on long-term normal, along with deficits for the current and previous years. The Greater Wellington Regional Council has developed a similar soil moisture product using VCS data (see, https://graphs.gw.govt.nz/#soilMoistureAnomaly30Day). This can be a potential option for ORC.

A comparison of current SMD against the long term normal and last year conditions provides a useful measure of comparing soil moisture deficit conditions. However, the SMD maps are based on the simplistic assumption of 150 mm of PAW across the entire country. This can result in inaccuracies in soils that have significantly different PAWs from 150 mm. For example, soils with PAW of 100 mm or less (shown in Figure 7-5) are likely to undergo more saturation events than had been predicted in NIWA's daily SMD. Additionally, the SMD values published are deficits from 150 mm storage and not corrected for the normal or expected soil moisture condition for that period of the year. This lack of seasonality in SMD maps may be of less concern when long-term are considered, however, can be of significant importance when used operationally.

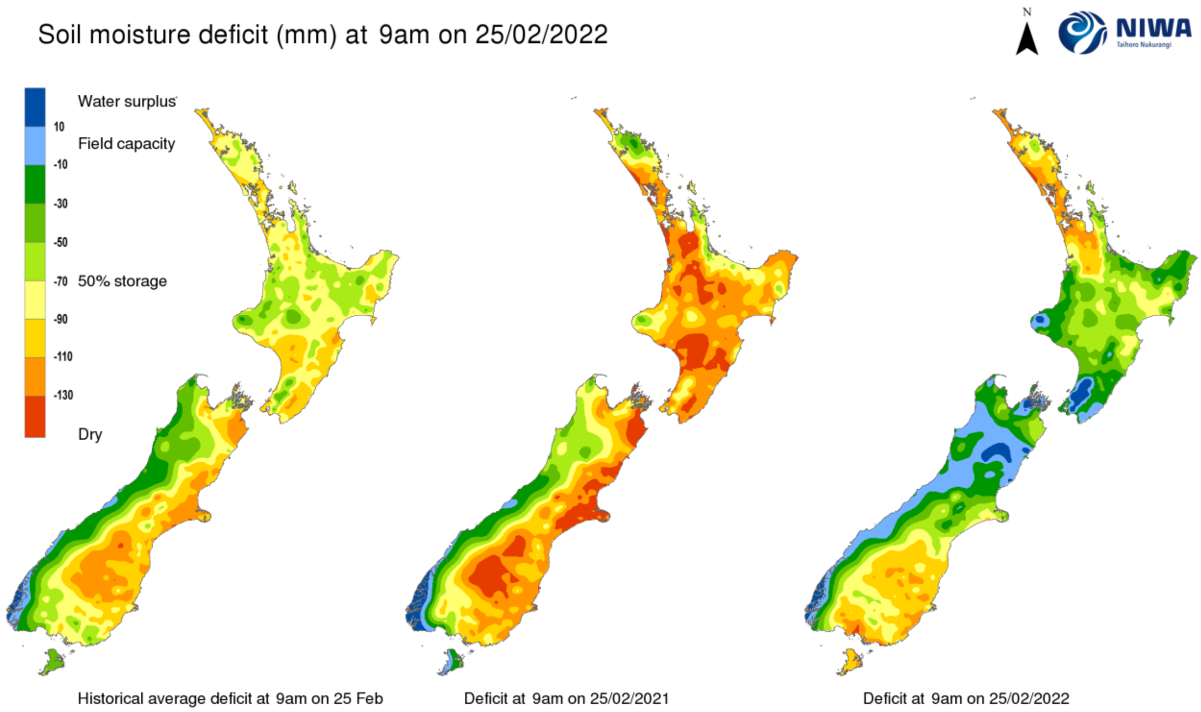


Figure 7-5: An example of daily soil moisture deficit maps published by NIWA.

7.2.1 Conclusions and recommendations

- The region’s current soil moisture network is concentrated around the primary industry areas. Gaps in the soil moisture network has been identified in Figure 7-6. Locating soil moisture monitoring sites in dominant soil and land cover types within each climatic region will be a good start for this network.

- Existing soil moisture sensing sites vary in their instrumentation. Future sites need to consider instrumentation that fits the purpose. NIWA has been using capacitance-based EnviroPro soil moisture sensor which measures top 80-cm of soil profile, that makes up the pasture root zone and drainage zone. Visuals such as the one shown in Figure 7-7 are quite useful in communicating the value of soil moisture sensing to the stakeholders and end-users as well as track instances of drainage for compliance monitoring. Capacitance-based Aquacheck™ (www.aquacheck.co.za) and TDR-based Campbell’s SoilVue 10™ (https://www.campbellsci.com/soilvue10) provide similar data resolution to develop soil moisture plots as shown in Figure 7-7.

- Differences in technology, measurement frequency, sampling volumes and integrity of installation will have an impact on soil moisture readings. Hence it is not advisable to directly compare soil moisture data between various sensor types directly, nor do soil moisture sensors lend themselves for reliable calibration. With soil moisture data, it is most useful to consider the trends as opposed to absolute values, as has been shown in Figure 7-7. Such trends are agnostic of soil moisture sensor types and are only influenced by resolution, sensitivity, time response and linearity as listed in section 2.5.

- NIWA’s daily SMD maps can be improved to provide a realistic representation of soil moisture deficit conditions across the region as described below:

  - *Improved representation of PAW conditions through the use of detailed soil maps such as the S-map:* Currently work is underway within NIWA (funded through NIWA Climate Centre) to investigate the potential for including realistic soil PAW condition based on Fundamental Soil Layer (FSL) data. This work may get extended to include the S-map data though the extent of S-map available for the ORC region may be limited (see Figure 7-4 to see the extent of S-map available for the region).

  - *Increasing the density of soil moisture monitoring network and validating the daily SMD maps using measured data:* When NIWA’s daily SMD maps are compared against these field measurements, it is important to use the PAW from the top 400-500 mm of soil profile. Soil moisture sensors report soil moisture as percentage – volume of water available to the sampling volume. The percent soil moisture needs to be converted to depth units (usually millimetres) to provide a meaningful soil moisture availability (or deficit). Difference between PAW and soil moisture availability yields soil moisture deficit, as presented in NIWA’s daily SMD maps. This requires a knowledge of PAW within the sampling area. This may be obtained from soils maps (S-map or FSL), or through repeated measurements at maximum and minimum PAW using a neutron probe as described in NEMS (2013). Alternatively, soil moisture release characteristics can be determined by a laboratory that undertakes such measurements. Adequate replication and adjustment to represent field conditions would be required.

  - Incorporating seasonality to SMD maps to represent realistic soil moisture conditions.

- Where possible, back-calculate soil moisture deficit based on improved rainfall data to come up with a long-term soil moisture dataset. Such a dataset is useful in contextualising droughts in the region.

- If the soil moisture network is not planned for operational management, then the sites do not need real time telemetry. However, at the times of drought, soil moisture data need to be telemetered at regular intervals (preferably daily) to provide useful updates to the public and stakeholders such as farmers.

- Soil moisture measurements are location, soil, and land cover/land management specific. When establishing a monitoring network in a new climatic region, it is advisable to focus on dominant soil types and land cover/land management units. If the network is designed for drought monitoring, then well-draining soils with dominant agricultural land use need to be targeted.

- Location of soil moisture monitoring sites should be representative of the landscape.

  - Avoiding hollows, valley bottoms and areas where soil wetness and ponding persists

  - Similarly, areas immediately downslope of hillslopes are less desirable as potential overland flow could infiltrate into the soil at the toe of hillslopes biasing the soil moisture measurement

  - In areas where the soils are shallow and/or infested with stones and rocks, soil moisture sensors perform poorly as they cannot make contact with soil

- The current soil moisture monitoring network in the region can be expanded in two ways:

  - In areas where fewer sites exist (see areas outside the red ovals Figure 7-6), existing climate and rainfall sites could be upgraded to include soil moisture sensors. For example, upgrading NIWA site, Tautuku EWS may fill one of the gaps shown in Figure 7-6.

  - Where no soil moisture sensor sites exist (areas shown by red ovals in Figure 7-6), soil moisture sensor sites may be installed by considering soil drainage class, land use type, existing rainfall-climate sites, climatic regions, and FMUs/Rohe. If stand-alone soil moisture sensor sites are to be installed, then it is important that each site includes a rain gauge to measure rainfall.

- NIWA generates drought products (see an example at https://niwa.co.nz/climate/nz-drought-monitor/droughtindicatormaps) that are primarily based on rainfall amounts and potential evaporative losses. They do not include specific soil drainage characteristics, land use type or land management practices. While these products are useful in assessing long term impacts and comparing trends at a site over time, they may still benefit from on-the-ground soil moisture monitoring.

- In setting the scope for this review, the ORC indicated it has no intention of establishing a soil moisture monitoring network to help manage effluent application in intensively farmed areas. This was considered by ORC to be an operational matter that individual landowners should take responsibility for monitoring soil moisture.

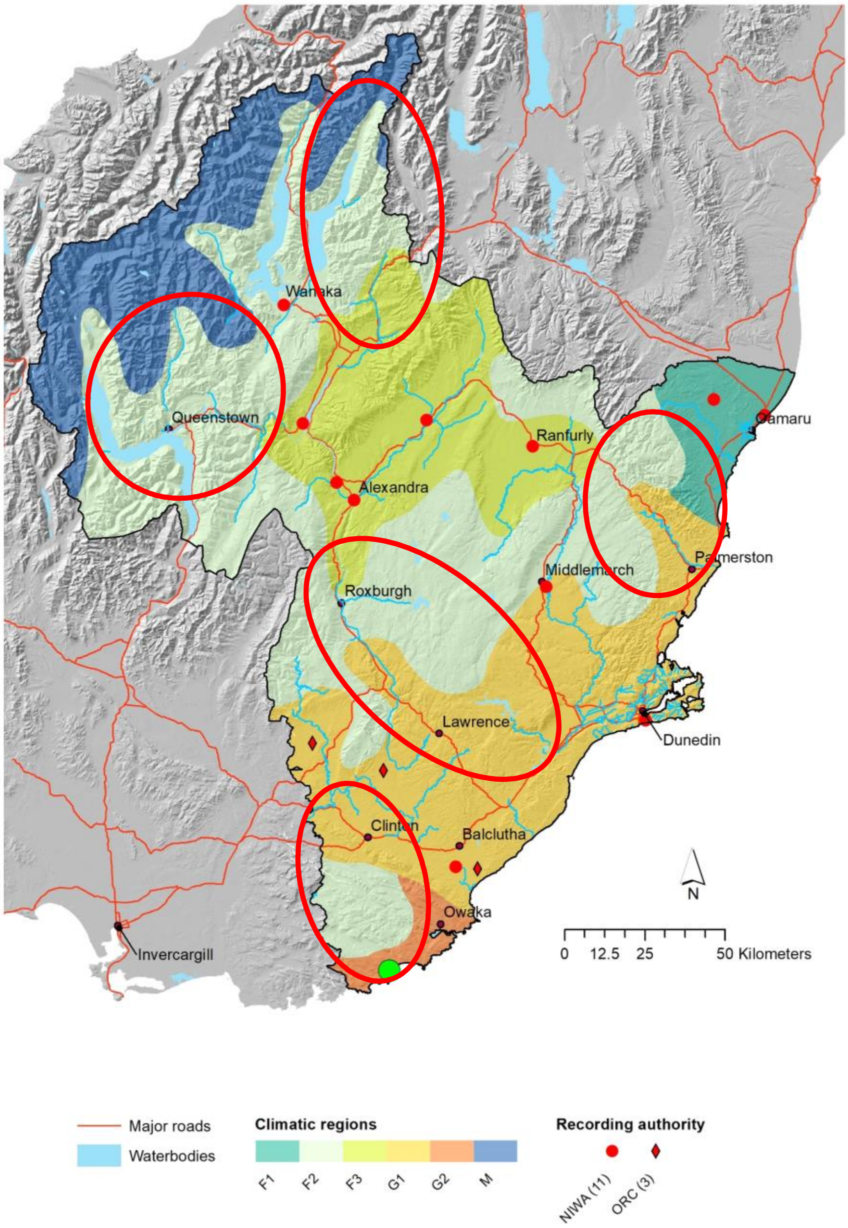


Figure 7-6: Potential areas for expanding the soil moisture monitoring network in the ORC region. Red ovals highlight the gaps in the current network based on climatic regions. Upgrading NIWA climate site Tautuku (shown by a green dot) to include a soil moisture sensor may partially plug the gap in one of the regions.

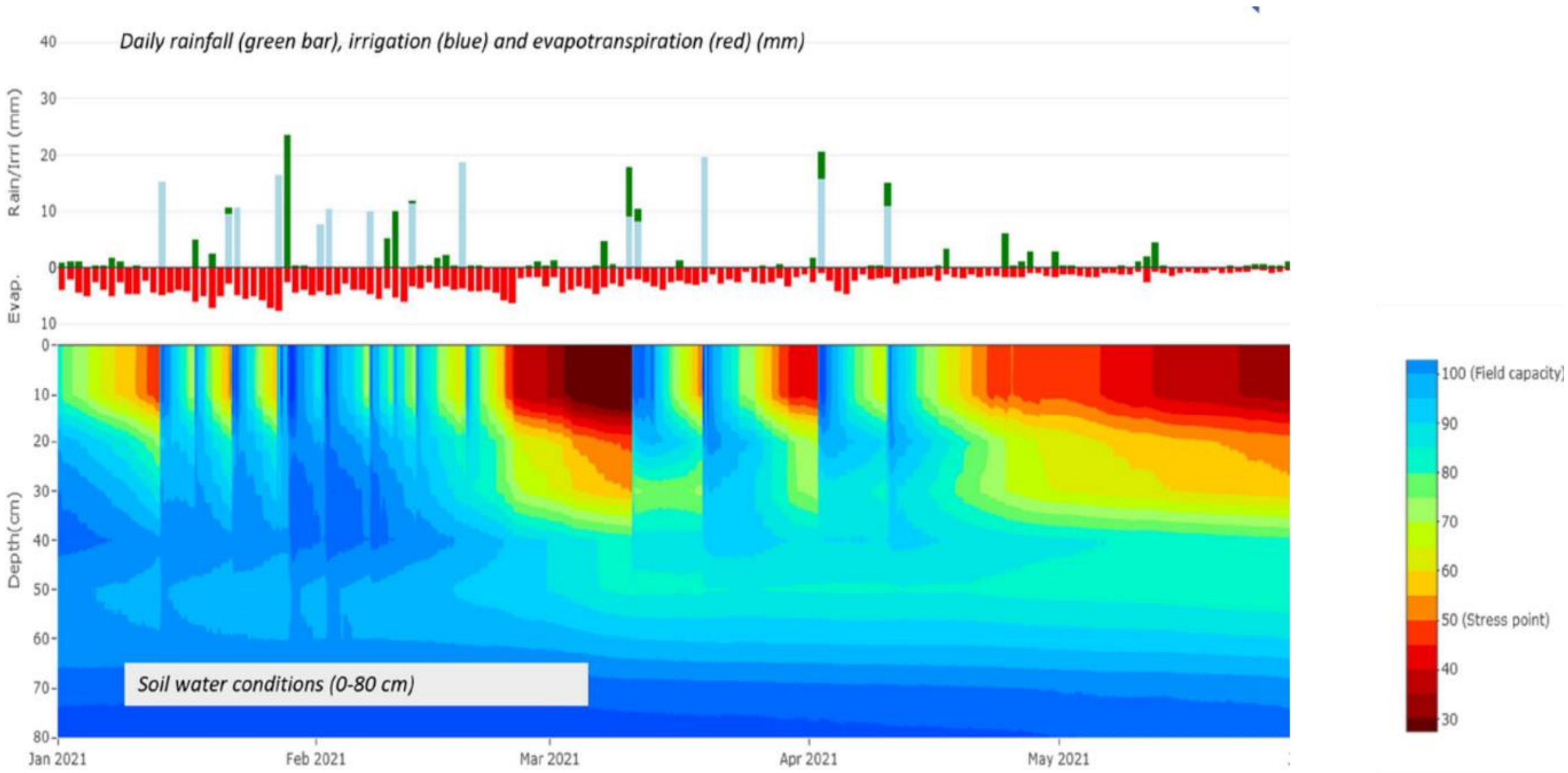


Figure 7-7: Visual reorientation of rainfall, irrigation/effluent application, evaporation and soil moisture for operational and compliance monitoring of drainage. Data based on EnviroPro soil moisture sensor from a site managed by NIWA in Canterbury.

8 Summary of recommendations

This report has reviewed the climate, rainfall and soil moisture monitoring networks in the Otago region against various ORC objectives. Generally the existing network is considered to be adequate for stated ORC information needs. However, there are also some clear gaps in the observational monitoring networks and aspects of the data collection management that could be improved to meet the anticipated future information requirements.

One of the biggest challenges in the region is devising and sustaining a data sharing agreement among the four major regional observing authorities – ORC, MetService, NIWA and FENZ. Through inter-agency cooperation along with (relatively minor) incremental changes by the various providers, the effectiveness of the existing networks can be greatly enhanced for all. An open federated data system could be one of the ways forward but it will rely on accessible, up to date metadata, so that end users can be assured of data quality as well as resources (staff and financial) to set up such systems.

The following is a summary of the observations and recommendations based on the network review.

8.1 Consistency of method of observation

- For climatological purposes, ORC (along with other councils), NIWA and MetService continue to collaborate in ensuring regional and national consistency in methodologies used.

8.2 Improving the accuracy of VCS data

The accuracy of the operational VCS data would be significantly improved if:

- ORC rainfall data were included into the NIWA climate database in real time and/or for inclusion in the monthly revision. This would substantially improve the accuracy of the VCS rainfall estimates throughout the region (and beyond).
- There were additional measurements of climate variables at higher elevations. Some temporary sites would be very useful in verifying VCS data and determining whether or not a more permanent (and resource intensive) site would be useful. (Note, such temporary site installations and data comparisons are beyond the scope of this study).

8.3 Improving rainfall and climate monitoring services

The following recommendations are focussed at enhancing the region's short and long-term rainfall and climate monitoring by considering FMUs, Rohe and climatic regions.

- The distribution of rainfall gauges is excellent, but access to the data by multiple agencies is not ideal because the data are stored in multiple databases. Agreements are in place to allow interagency access as the technical ability to do it, so work should be done to expedite this process.
- The addition of ORC rainfall data into CliDB would ensure that adequate coverage of rainfall normals is maintained as the manual network continues to reduce.
- ORC and NIWA should consider adding temperature to some of the higher altitude (> 500 m) precipitation sites. This applies not only to climatic region M but also to any

sites above 500 m altitude. This will have the added benefit of improving coverage in the Manuherekia and Upper Lakes Rohe.

- ORC, NIWA and MetService should continue to collaborate on improving the measurement of solid precipitation.
- It is recommended that NIWA and ORC look to enhance wind measurements above 500 m, as well as explore data available from other providers not considered in this study (e.g., ski fields, wind farms and others).

8.4 Improving soil moisture monitoring

- Consider increasing the density of soil moisture network by considering soil drainage class and land use type in FMUs and Rohe where there are no monitoring sites.
- Explore the use of products such as drought indicators and soil moisture deficit maps to complement the existing and future soil moisture monitoring networks.
- Instead of measuring soil moisture at one depth, consider multi-depth measurements to track drainage.
- Explore the option of sharing soil moisture data in real time with end-users to manage irrigation and effluent-fertilizer applications

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10 Glossary of abbreviations and terms

AWS	Automatic Weather Station
CliDB	Climate database
ECV	Essential Climate Variable
EWS	Electronic Weather Station
FENZ	Fire and Emergency New Zealand
FMU	Freshwater Management Unit
FSL	Fundamental Soil Layer
GCOS	Global Climate Observing System
NEMS	National Environmental Monitoring Standard
NIWA	National Institute of Water and Atmospheric Research Limited
NZMG	New Zealand Map Grid
NZMS	New Zealand Meteorological Service
NZTA	New Zealand Transport Agency
ORC	Otago Regional Council
RAWS	Rural Automated Weather Station
RFA	Rural Fire Authority
SIMS	Station Information Management System
SOE	State of the Environment
VCS	Virtual Climate Station (Network)
WMO	World Meteorological Organisation

Appendix A Statistics based on long term data

Based on data from climate monitoring sites in the Otago region, NIWA has derived long-term normals and averages for various climatic variables. Long-term normals are based on data from 1981 to 2010 and long-term averages are based on data from 1981 to 2010. In the subsequent pages, the statistics along with climate sites used to derive them for specific climates variables are provided.

Table A-1: List of sites used to derive 1981-2010 rainfall normals in the Otago region.

Total number of sites, 95.

Site name	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Recording authority
Waikoura at Marchwood	2339301	5582899	205	ORC
Oamaru Airport Aws	2358595	5579964	30	MetService
Glenfinnan	2179134	5625982	341	Other
Routeburn Stn	2139110	5595899	381	Other
Earnslaw	2146098	5595737	335	Other
Shotover Branches	2172210	5598258	503	NIWA
Arthurs Point	2168434	5570577	607	Other
Arrowtown No2	2180375	5576424	409	Other
Makarora Station	2208537	5654985	320	Other
Minaret Bay	2200131	5636575	313	Other
Hunter Valley 2	2216077	5634750	360	Other
Lake Hawea	2211718	5614977	350	Other
Wanaka	2204668	5604307	314	Other
Mt Barker	2207679	5602667	305	Other
Luggate	2214634	5601428	295	Other
Wanaka Aero Aws	2212511	5602778	352	MetService
Cardrona	2195579	5585520	518	Other
Queensbury EWS	2217701	5586199	277	Other
Upper Meg Power Stn	2199267	5572904	518	Other
Bendigo 2	2218293	5579512	200	Other
Blackstone Hill	2266287	5580759	637	Other
Naseby Forest 2	2284764	5571636	607	Other
Enfield	2341373	5571222	107	Other
Windsor EWS	2338333	5575447	81	NIWA
Oamaru, Spey st	2350937	5566791	5	Other
Ranfurly EWS	2281864	5560831	450	NIWA
Kauru, The Dasher	2327409	5556498	549	Other
Islay Downs	2310479	5547899	360	Other
Glendale Station	2312122	5535162	550	Other
Trotters Creek	2339283	5533480	30	Other
Kilmory Lug Creek	2286009	5526312	343	Other
Nenthorn	2301180	5524369	360	Other
Stoneburn Cloverdowns	2316385	5526172	260	Other

Site name	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Recording authority
Palmerston	2331212	5523309	21	Other
Middlemarch, Garthmyl	2286124	5516996	200	Other
Lee Flat	2278707	5487466	354	Other
Pinewood	2296401	5493634	351	Other
Hindon, Ardachy	2302897	5495067	120	Other
Long Beach	2326112	5492094	10	Other
Taiaroa Head	2333179	5489843	72	Other
Balmoral, Outram	2294499	5475888	3	Other
Mosgiel Town	2302577	5478264	8	ORC
Invermay Edr	2306807	5479621	30	Other
Dunedin, Balaclava	2313273	5476484	140	Other
Powder Creek, Pump House	2309650	5485715	100	Other
Ross Creek	2315218	5481547	165	Other
Dunedin, Btl Gardens	2317435	5480167	73	Other
Sullivans Dam	2317426	5485727	300	Other
Mooyman Homestead	2317794	5481179	60	Other
Dunedin, Broad bay	2325623	5481850	3	Other
Sawyers Bay Sewage Pl	2323914	5484581	3	Other
Maungatua	2288672	5473690	25	Other
Dunedin Aero Aws	2292444	5471955	2	MetService
Southern Reservoir	2312113	5476338	110	Other
Green Island, Kaikorai Estuary	2308697	5473786	27	Other
Dunedin, Musselburgh EWS	2317005	5475563	10	NIWA
Queenstown	2168420	5565818	322	Other
Queenstown Aero	2173973	5567305	349	Other
Queenstown Aero Aws	2174345	5568034	357	MetService
Kingston	2174689	5532292	310	Other
Northburn	2213088	5571008	210	Other
Cromwell 2	2210236	5567857	213	Other
Matakanui	2235042	5566191	357	Other
Lauder EWS	2248801	5568999	375	NIWA
Lauder Flat	2250105	5572574	366	Other
Bannockburn	2207589	5555276	427	Other
Clyde Dam	2220135	5551065	160	Other
Clyde EWS	2220517	5549165	171	NIWA
Alexandra, Bridge Hill	2226387	5542999	160	Other
Roxburgh	2222119	5511887	97	Other
Roxburgh, Hilltop	2228127	5512152	518	Other
Lake Onslow Auto	2243703	5511590	695	Other
Ettrick No.2	2225164	5503123	91	Other
Tima	2230231	5499674	90	Other
Deep Stream 2	2274729	5498444	366	Other

Site name	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Recording authority
Kelso, The Holt	2212193	5474834	180	Other
Raes Junction	2233703	5486030	152	Other
Beaumont N.z.f.s.	2236897	5476822	46	Other
Tapanui	2219690	5467167	180	Other
Waihola	2283501	5461721	30	Other
Glenledi Rd	2284583	5444074	61	Other
Rosebank	2209269	5460586	168	Other
Tuapeka Mouth	2243230	5459067	116	Other
Baverstock Waiwera	2241665	5443988	91	Other
Hillend	2258786	5447120	261	Other
Warepa	2248188	5432572	70	Other
Te Houka	2252083	5437402	82	Other
Balclutha	2259082	5436122	12	Other
Balclutha, Finegand	2258464	5432204	6	Other
Lovells Flat	2267372	5441446	91	Other
Lochindorb	2242424	5424657	198	Other
Inchclutha, T'graph rd	2265134	5429236	8	Other
Nugget Point Aws	2264841	5413020	131	MetService
Papatowai	2239116	5399149	18	Other
Tautuku	2237176	5397601	25	Other

Table A-2: List of sites used to derive 1981-2010 temperature normals in the Otago region.

Total number of sites, 22.

Site name	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Recording authority
Oamaru Airport Aws	2358595	5579964	30	MetService
Oamaru Aws	2348651	5565348	40	MetService
Herbert Forest	2335183	5549160	61	Other
Cherry Farm Hospital	2324488	5508172	6	Other
Dunedin, Musselburgh EWS	2317005	5475563	10	NIWA
Queenstown	2168420	5565818	322	Other
Queenstown Aero Aws	2174345	5568034	357	MetService
Cromwell Sub Stn	2209902	5564839	213	Other
Northburn	2213088	5571008	210	Other
Lauder EWS	2248801	5568999	375	NIWA
Clyde EWS	2220517	5549165	171	NIWA
Roxburgh Power Stn	2221812	5518770	110	Other
Ettrick No.2	2225164	5503123	91	Other
Beaumont N.z.f.s.	2236897	5476822	46	Other

Site name	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Recording authority
Mahinerangi Dam	2275070	5476213	396	Other
Tapanui	2219690	5467167	180	Other
Rankleburn Forest	2233936	5464347	255	Other
Taieri Mouth	2292707	5455253	15	Other
Balclutha, Finegand	2258464	5432204	6	Other
Owaka 2	2253331	5412087	5	Other
Nugget Point Aws	2264841	5413020	131	MetService
Tautuku	2237176	5397601	25	Other

Table A-3: List of sites used to derive 1981-2010 sunshine hour normals in the Otago region.

Total number of sites, 5.

Site name	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Recording authority
Dunedin, Musselburgh EWS	2317005	5475563	10	NIWA
Invermay, Taieri 2	2306807	5479621	30	Other
Dunedin Aero	2292387	5471702	1	Other
Queenstown	2168420	5565818	322	Other
Balclutha, Finegand	2258464	5432204	6	Other

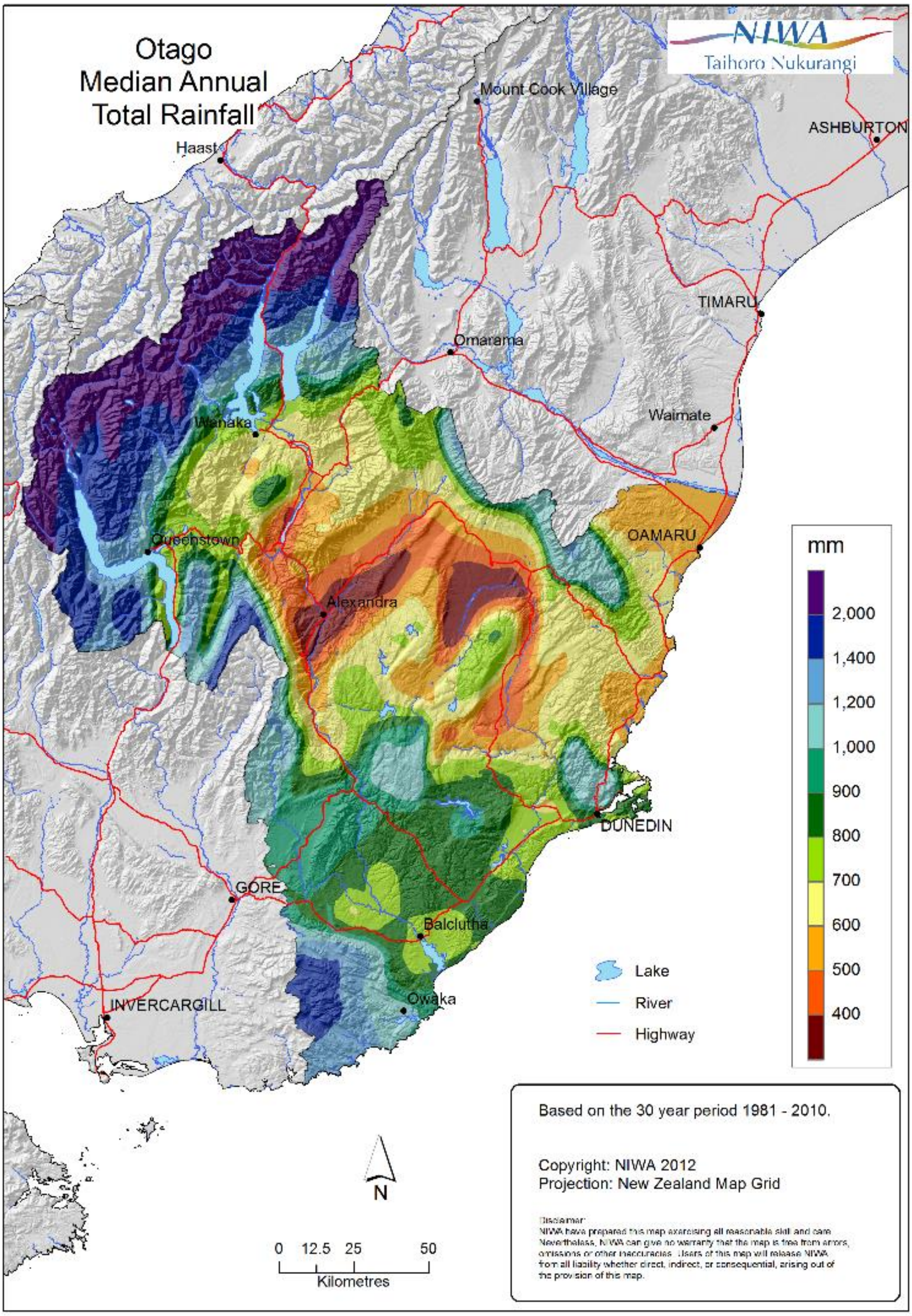

Figure A-1: Long term rainfall normals derived based on data from 1981 to 2010.

Data source: NIWA

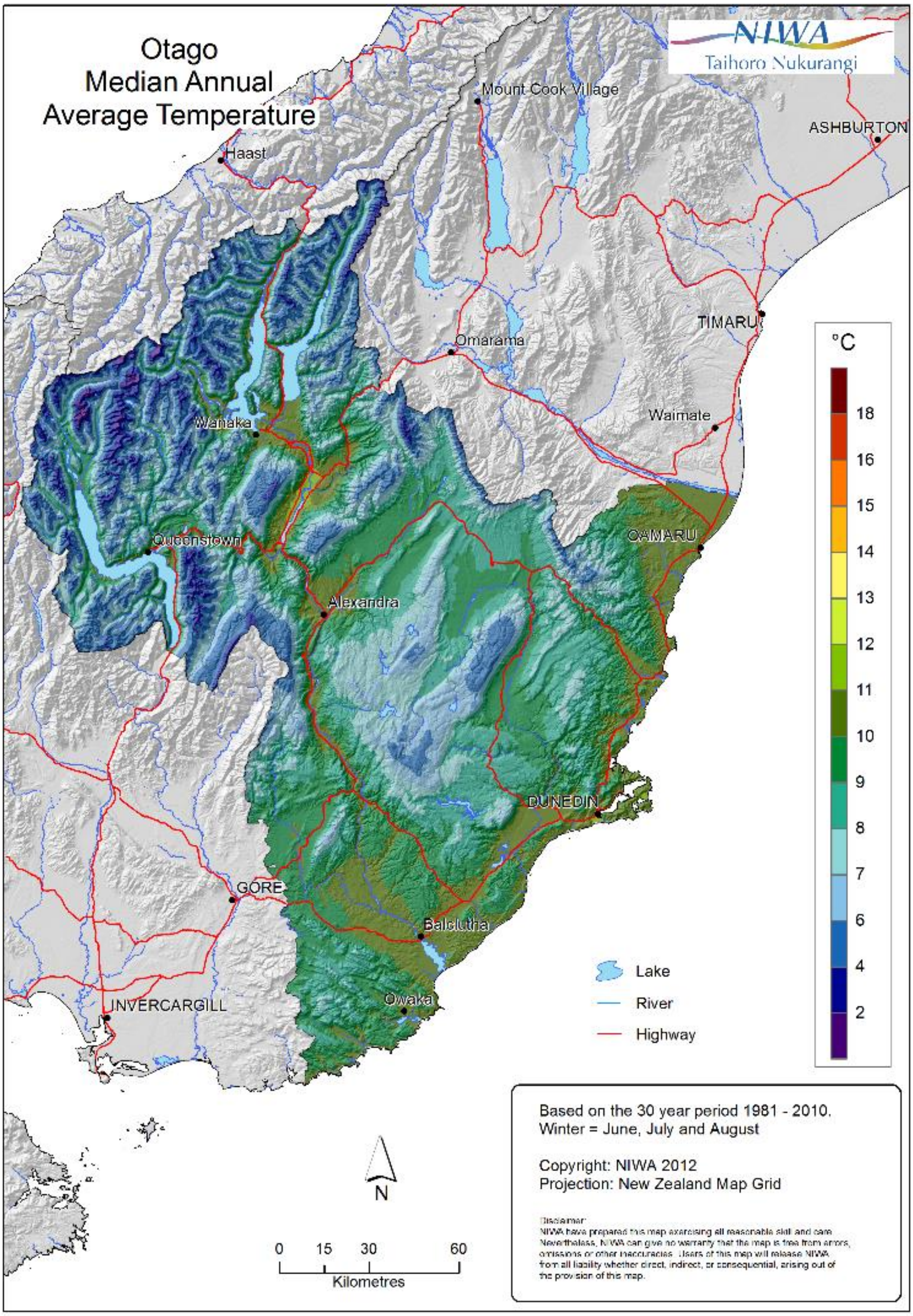

Figure A-2: Long term air temperature normals derived based on data from 1981 to 2010.
Data source: NIWA

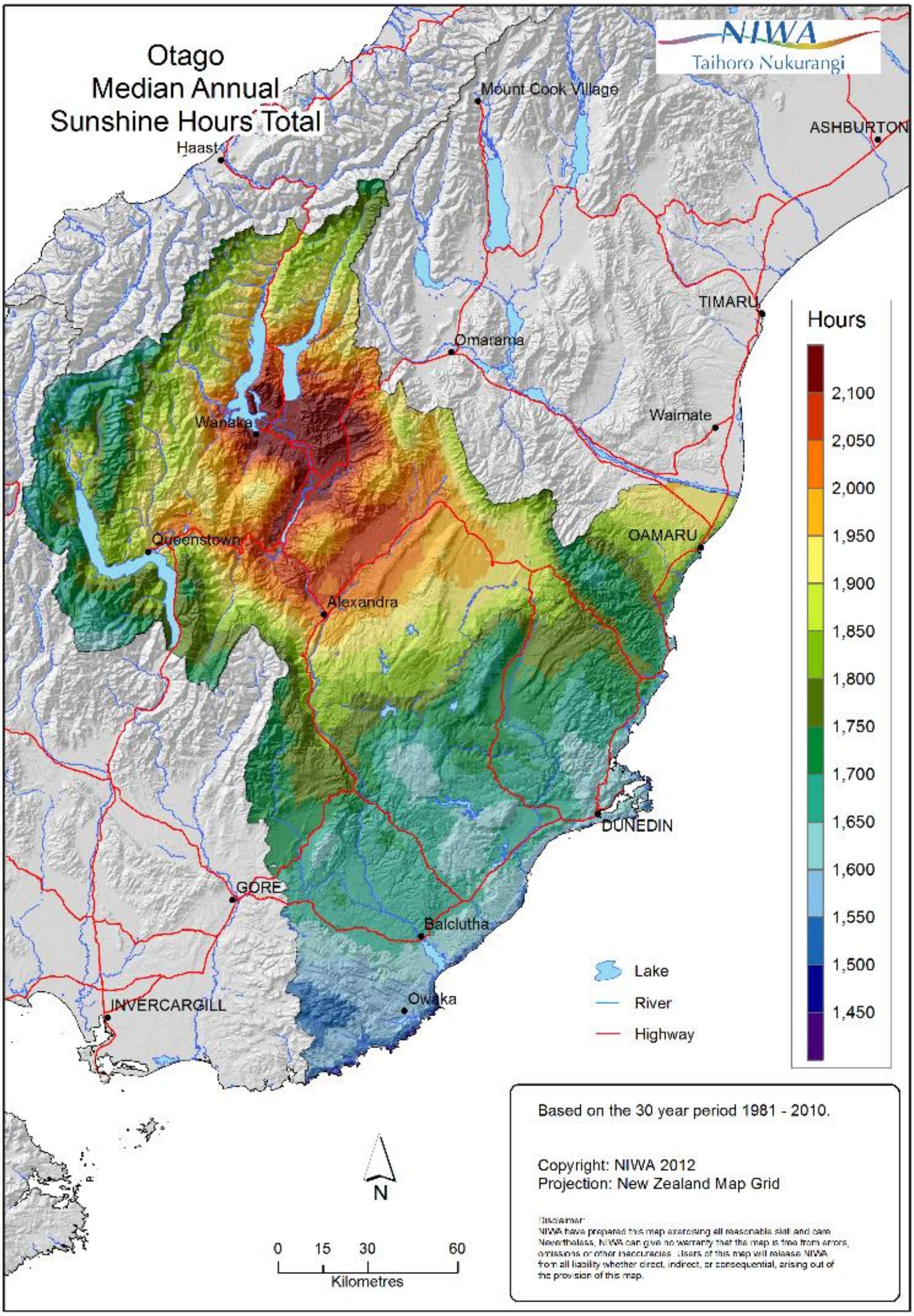

Figure A-3: Long term sunshine hours normals derived based on data from 1981 to 2010.

Data source: NIWA

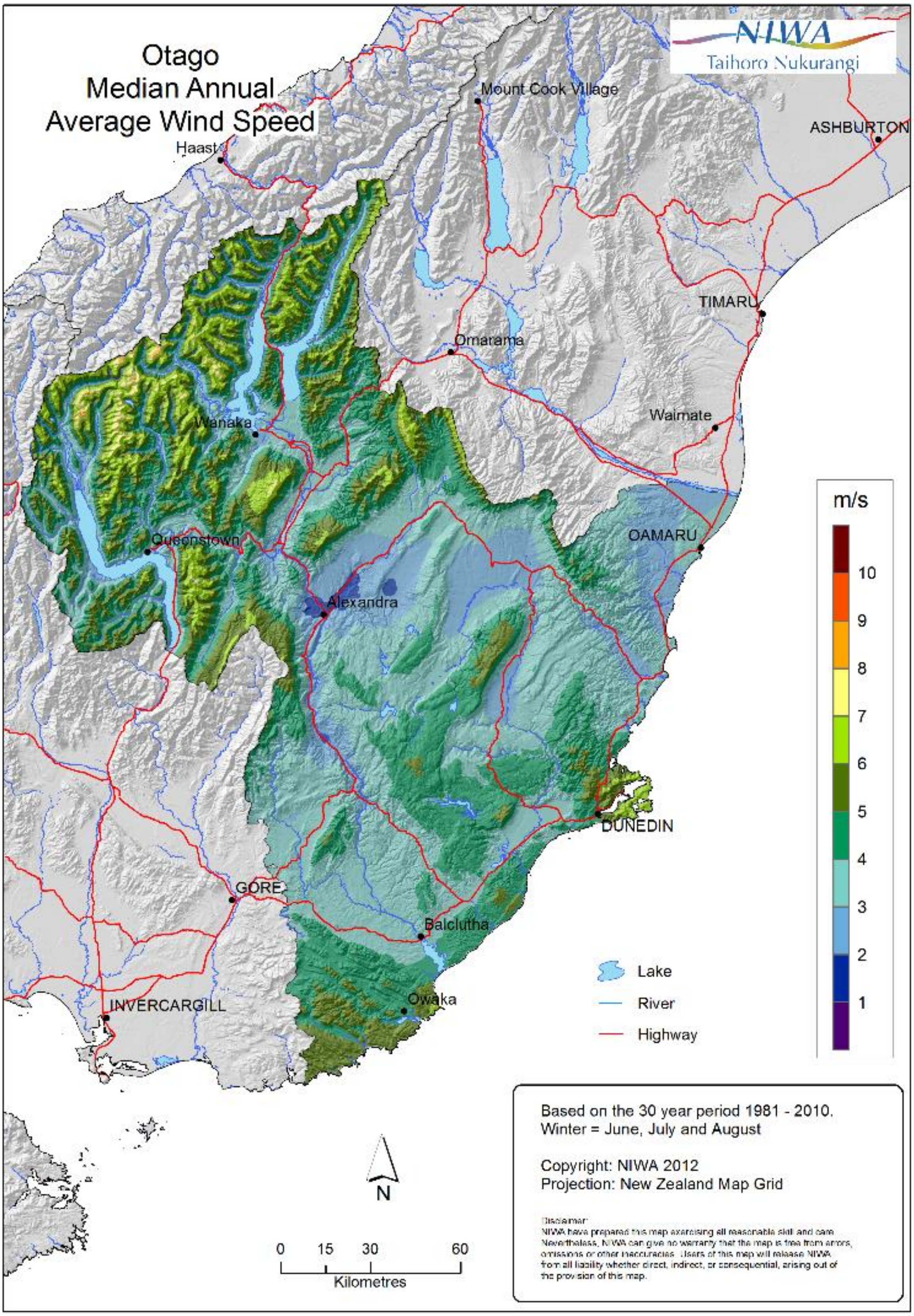

Figure A-4: Long term average of wind speed based on data from 1991-2020.
Data source: NIWA

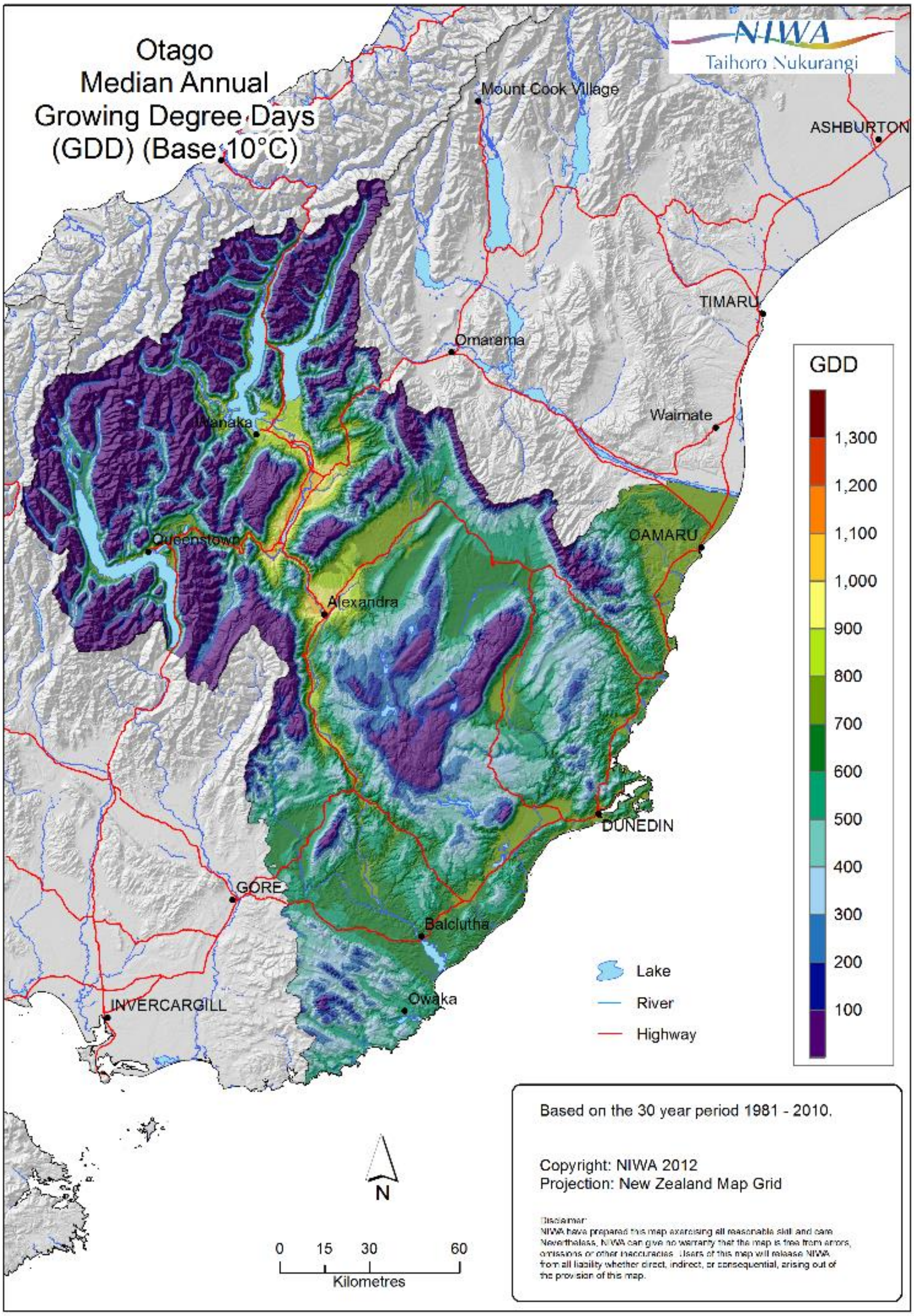

Figure A-5: Long term average of growing degree days based on data from 1981-2010.
Data source: NIWA

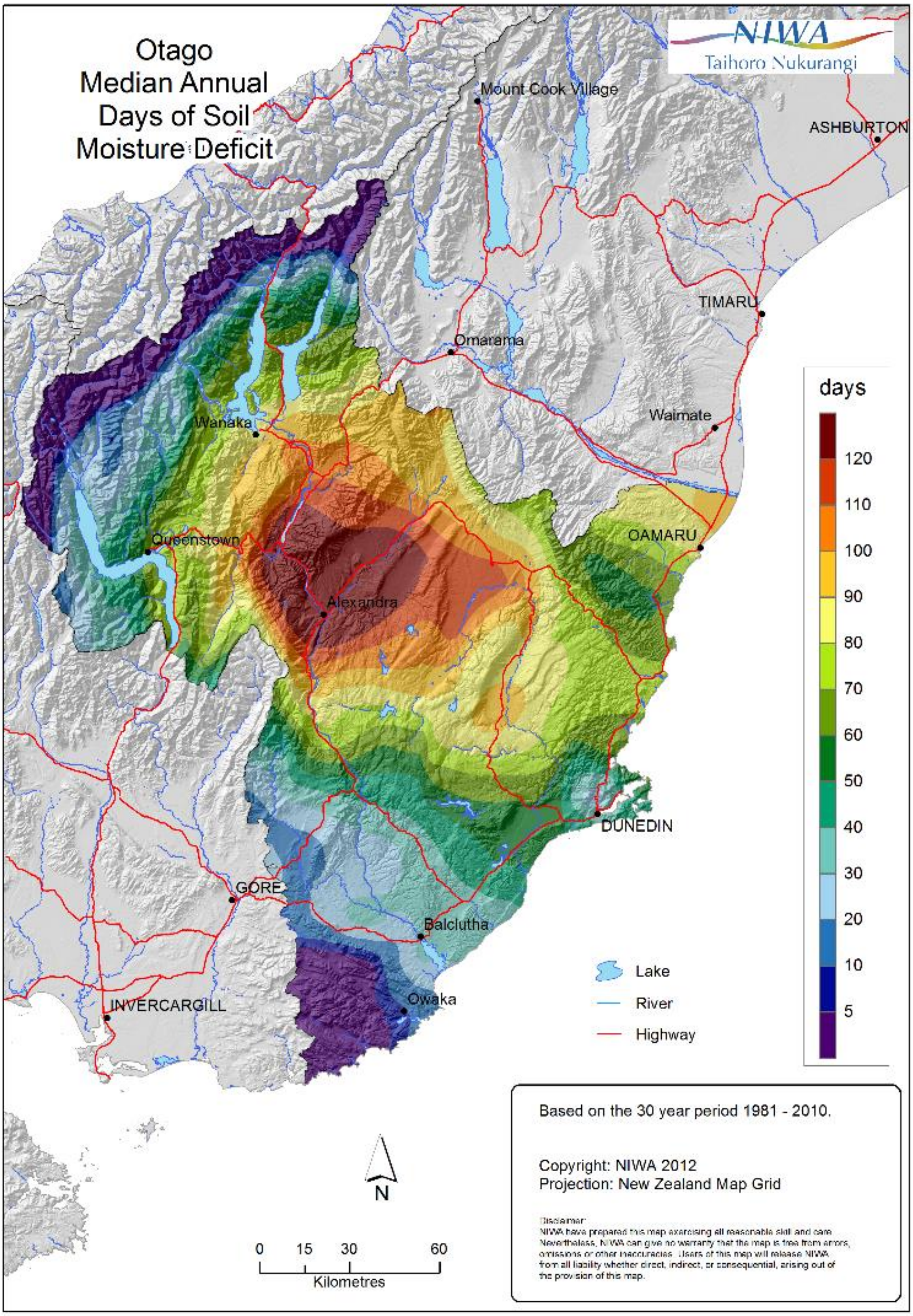

Figure A6: Long term average of soil moisture deficit based on data from 1981-2010.
Data source: NIWA

Appendix B Assessing climate and rainfall networks based on WMO guidelines

The assessment of rainfall and climate network based on guidance extracted from WMO (2003) as used by the UK Met Office is presented as an appendix. While no analysis or recommendation is provided based on the assessment, the gaps in the network as identified by using this statement of guidance match those presented in the main document. Generally, the Otago region well served by the current network.

The guidance refers to: N for NCIC; B for business; I for international, M for climate monitoring and R for research.

The exact meaning of these is not clear especially 'business' but our interpretation of these are: NCIC is the National Climate Information Centre; Business is specifically mentioned in the Urban requirements; International refers to stations required for global monitoring; Climate monitoring is the long term climate network; and Research for short term projects.

The GCOS principles referred to are:

GCOS CLIMATE MONITORING PRINCIPLES

Effective monitoring systems for climate should adhere to the following principles:*

1. The impact of new systems or changes to existing systems should be assessed prior to implementation.
2. A suitable period of overlap for new and old observing systems is required.
3. The details and history of local conditions, instruments, operating procedures, data processing algorithms and other factors pertinent to interpreting data (i.e., metadata) should be documented and treated with the same care as the data themselves.
4. The quality and homogeneity of data should be regularly assessed as a part of routine operations.
5. Consideration of the needs for environmental and climate-monitoring products and assessments, such as IPCC assessments, should be integrated into national, regional and global observing priorities.
6. Operation of historically-uninterrupted stations and observing systems should be maintained.
7. High priority for additional observations should be focused on data-poor regions, poorly observed parameters, regions sensitive to change, and key measurements with inadequate temporal resolution.
8. Long-term requirements, including appropriate sampling frequencies, should be specified to network designers, operators and instrument engineers at the outset of system design and implementation.
9. The conversion of research observing systems to long-term operations in a carefully-planned manner should be promoted.
10. Data management systems that facilitate access, use and interpretation of data and products should be included as essential elements of climate monitoring systems.

** The ten basic principles (in paraphrased form) were adopted by the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) through decision 5/CP.5 at COP-5 in November 1999.*

Below is a section of guidance for climate observations as presented (WMO, 2003, Appendix 2).

Statement of Guidance for Surface Climate Observations over Land Areas of the UK

Introduction

This document covers meteorological observations made over surface land areas of the UK that may be used for climatological purposes. It does not cover the climatological requirement for observations over the oceans or in the upper air.

The methodology used for addressing requirements for observations is an internal Rolling Requirement Review (RRR). Two documents have already been produced in stages 1 and 2 of the RRR process for Climate Observations, the User Requirement and the Critical Review. This Statement of Guidance draws on these two documents to address the deficiencies identified and provides a strategy for meeting user needs.

Issues are considered under 7 broad headings. The source of the identified requirements is indicated by a letter: N for NCIC; B for business; I for international, M for climate monitoring and R for research. The GCOS principles are designated by the letter G (G1 refers to principle 1, etc).

1. Stations and Networks
(a) WMO recommended categorisation of stations should be maintained (I).
(b) Stations should be representative, with respect to **topography and land use**, of an area in accordance with its application. Typically this might be a 15 km radius for temperature. Different environments should be reflected within the network – urban, coastal and upland (N,G5,B,I,R).
(c) There should be stations in each large (100-150,000) urban conurbation (B).
(d) The environment of stations used for climate monitoring should be remote from the influence of man (M).
(e) Stations should provide a record of at least 10 years, preferably 30 years or more (N,G6,G9,B,I,R).
(f) Existing long period stations should be preserved including around 20 Reference Climatological Stations used for climate monitoring purposes including the 3 CET stations (M,N,G6,B,I,R).
(g) High priority should be given to filling gaps in the network (G7).
(h) There should be a 12 month overlap where new stations are established to replace existing long period stations (G2,B,R).

2. Elements, Distribution, Frequency, Resolution and Accuracy
Note: Numbers separated by a slash / denote the minimum and maximum requirement specifications.

2.1 General
(a) Observing processes should deliver data of adequate accuracy and with biases sufficiently small to resolve climate variations (N,G8,I,R).
(b) Different elements should be collocated (N,M).
(c) High resolution data should be available to document extreme weather events (G4). Data at 1 minute resolution for limited periods should be available on request (R).

2.2 Air Temperature
(a) Spatial resolution of 60/30 km (N); about 150 km (M,I); 50 km (B).
(b) Temporal resolution of hourly with 12-hourly max and min (N,M,B,I)
(c) Resolution of 0.2/0.05 deg C and accuracy of 0.5/0.1 deg C (N,M,B,I).

2.3 Surface and Soil Temperatures
(a) Spatial resolution of 60/30 km (N); about 150 km (M); 50 km (B).
(b) Daily temporal resolution (N,M,B); hourly at 10 cm (N).
(c) Resolution of 0.2/0.05 deg C Accuracy of 0.5/0.1 deg C for soil temperature Accuracy of 0.75/0.3 deg C for surface temperature (N,M,B).
(d) Soil temperatures at 30 cm required for historical continuity (N).

2.4 Wind speed and direction
(a) Spatial resolution of 70/20 km. Wind observations are required from every major area of high ground in the UK(N,R).
(b) Wind in urban areas should be made at the highest location outside the urban canopy (N).
(c) Temporal resolution of hourly (N) with a subset of at least 10 stations providing sub hourly data (N)
(d) Direction resolution of 10/5 deg and accuracy of 15/5 deg (N). Speed resolution of 1.0/0.5 km and an accuracy of 1.0/0.5 km or 10/5% (N). Accurate resolution of low wind speeds is essential (N,R).

Wind measurements should be made at a site having an exposure meeting WMO recommendations (N).

2.5 Relative humidity and vapour pressure
(a) Spatial resolution of 60/30 km (N, B); about 150 km (M).
(b) Hourly temporal resolution (N,M,B); daily min (N).
(c) Resolution (RH) of 2/0.5 % and accuracy of 5/1 % for RH < 75% and 2/0.5 % for RH > 75% (N,M,B). (The figures of percent refer to the error in the measured value, not the percent error of the measured value)

2.6 Rainfall
(a) Spatial/temporal resolution of Daily (0900) 50/5 km (M,N,B) Hourly 30/5 km (N,B,R)
(b) A selection of stations producing data with a time resolution of 5 min or better for hydrological purposes (B)
(c) Resolution of 0.5/0.05 mm and accuracy of 0.3/0.1 mm (<4mm) and 7.5%/2.5% (>4mm) – (M,N,B,R)

2.7 Sunshine
Spatial resolution of 120/60 km (N,B).
Daily temporal resolution (N,B)
Resolution of 0.2/0.1 hr and accuracy of 0.4/0.2 hr (N,B). Meet exposure standards.
Parallel deployment of Campbell-Stokes recorders at a few stations for continuity purposes (M,N,R).

2.8 Radiation
Spatial resolution of 80/50 km (N,B).
Hourly temporal resolution plus daily max (N,B)
Resolution of 20/10 kjm-2 and accuracy of 7/4% (N,B).
At least one station should provide solar and terrestrial data of high quality and high time resolution.

2.9 Snow Depth
Spatial resolution of 50/20 km (N).
Hourly temporal resolution plus daily max (N)
Resolution of 1/0.5 cm and accuracy of 2/0.5 cm (N).

The above WMO (2003) spatial resolutions were applied to the current rainfall and climate network of ORC and the resulting maps are presented in the following pages.

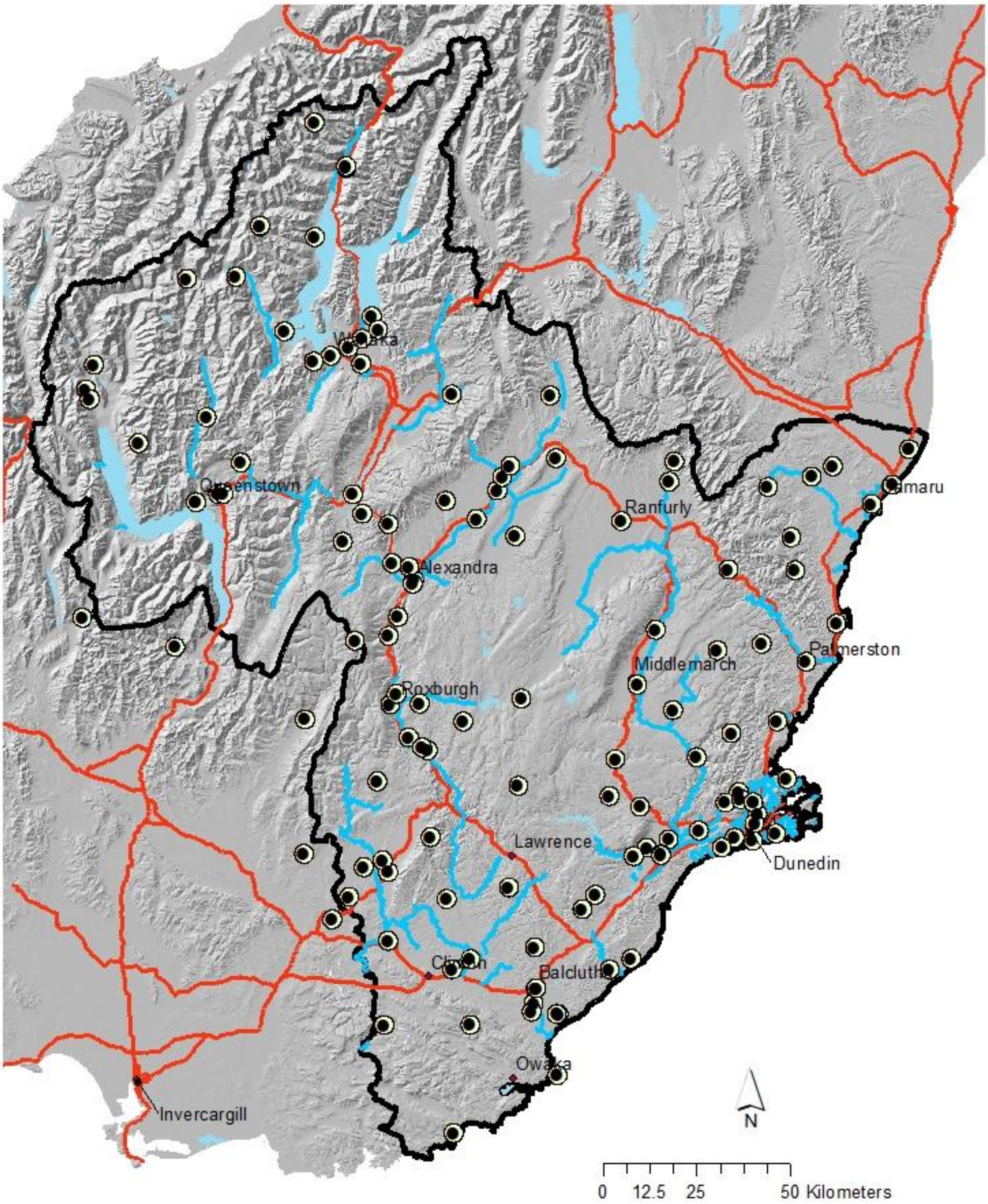

Figure B-1: Assessment of Otago region's rainfall network based on WMO (2003) guidelines. Each circle represents a spatial resolution of 5 km.

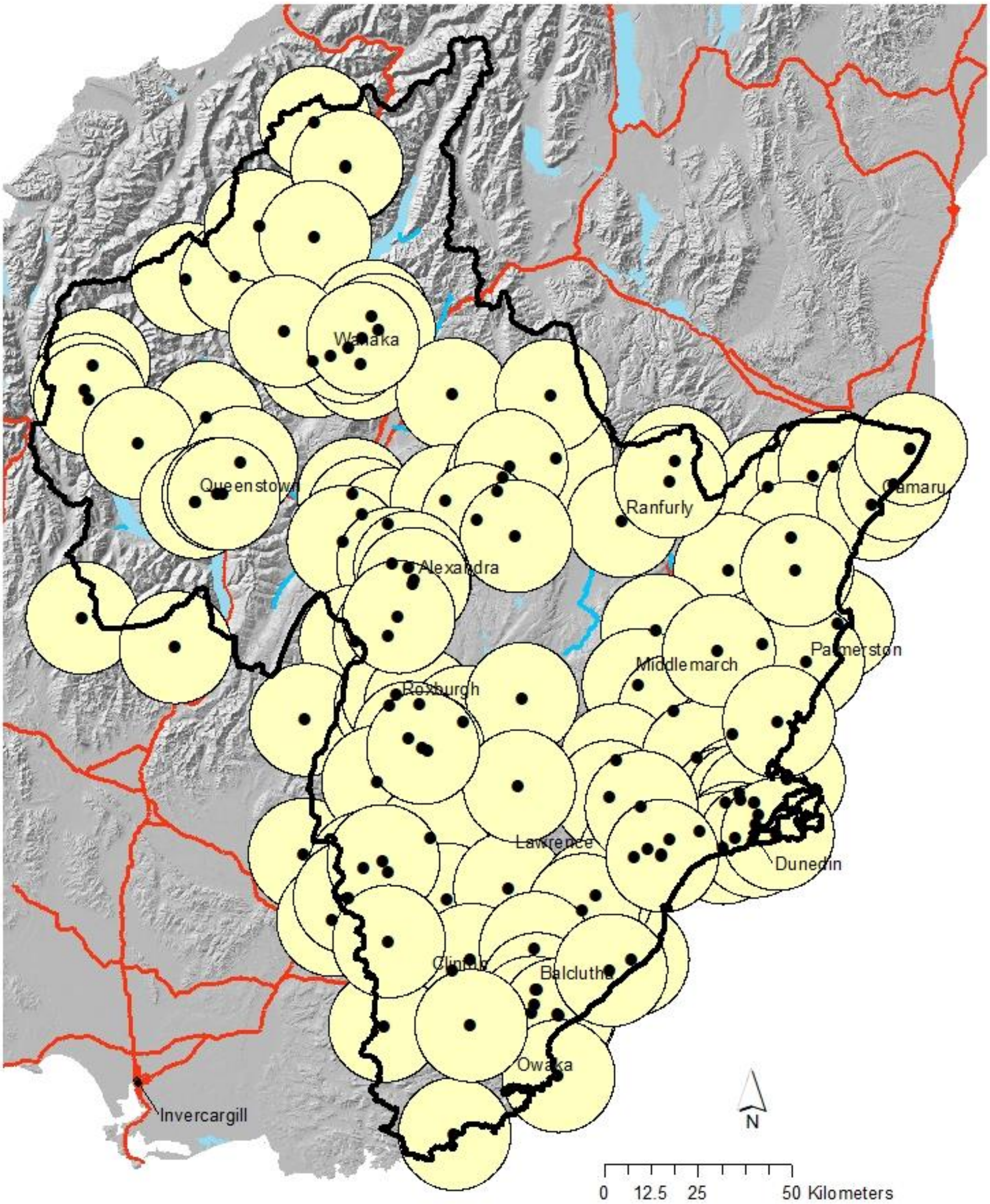

Figure B-2: Assessment of Otago region's rainfall network based on WMO (2003) guidelines. Each circle represents a spatial resolution of 30 km.

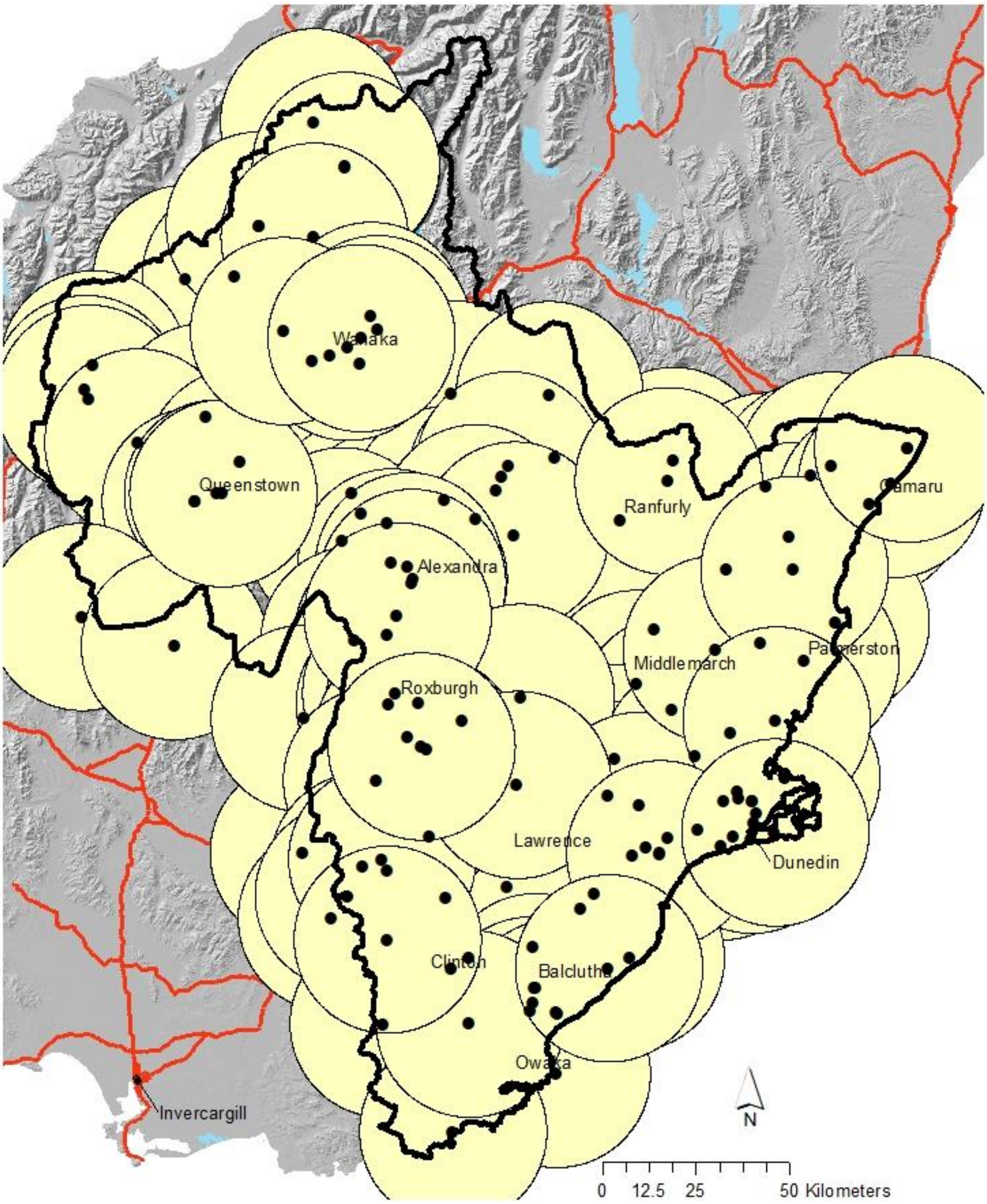

Figure B-3: Assessment of Otago region's rainfall network based on WMO (2003) guidelines. Each circle represents a spatial resolution of 50 km.

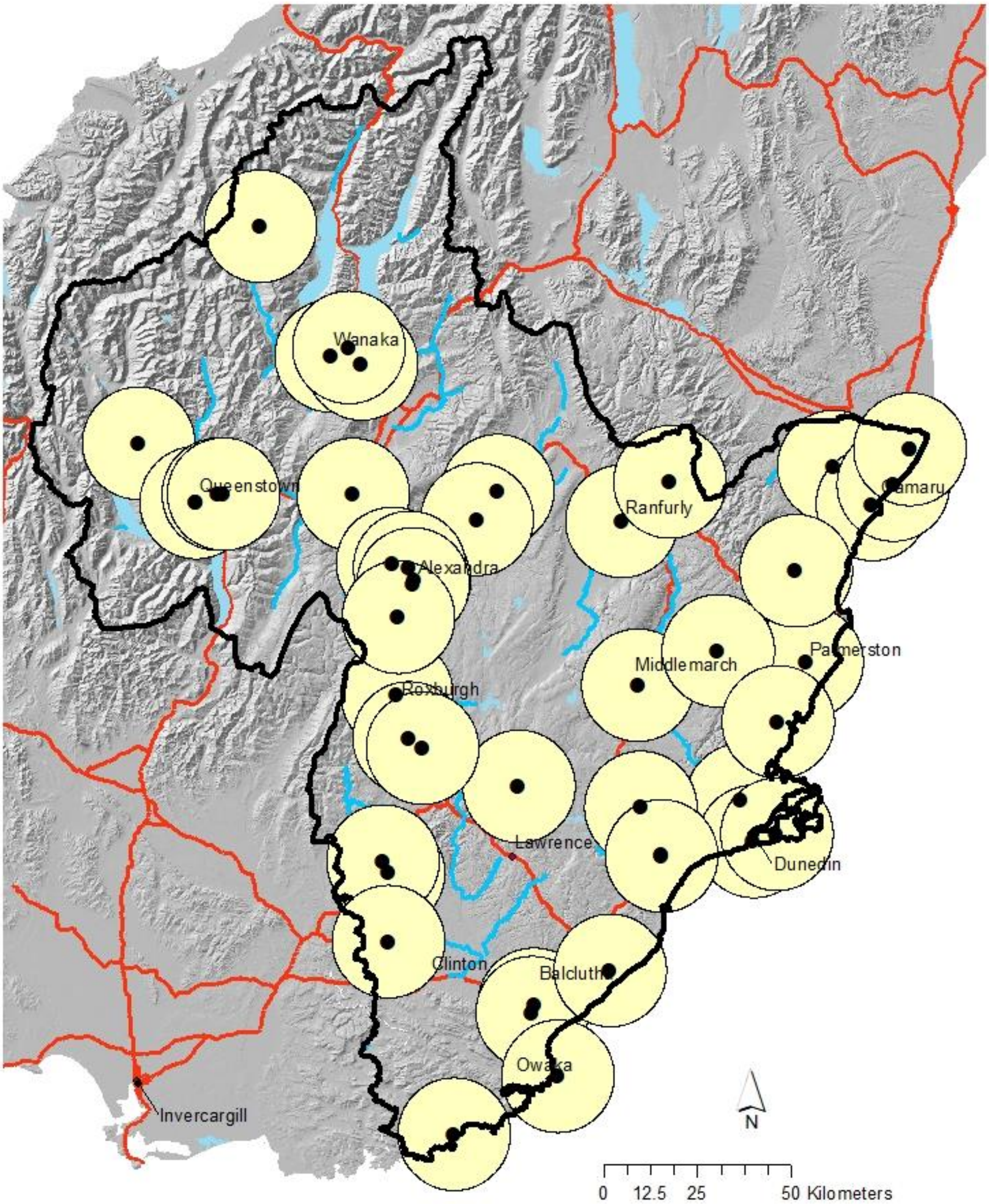

Figure B-4: Assessment of Otago region's air temperature monitoring network based on WMO (2003) guidelines. Each circle represents a spatial resolution of 30 km.

Each circle represents a spatial resolution of 30 km.

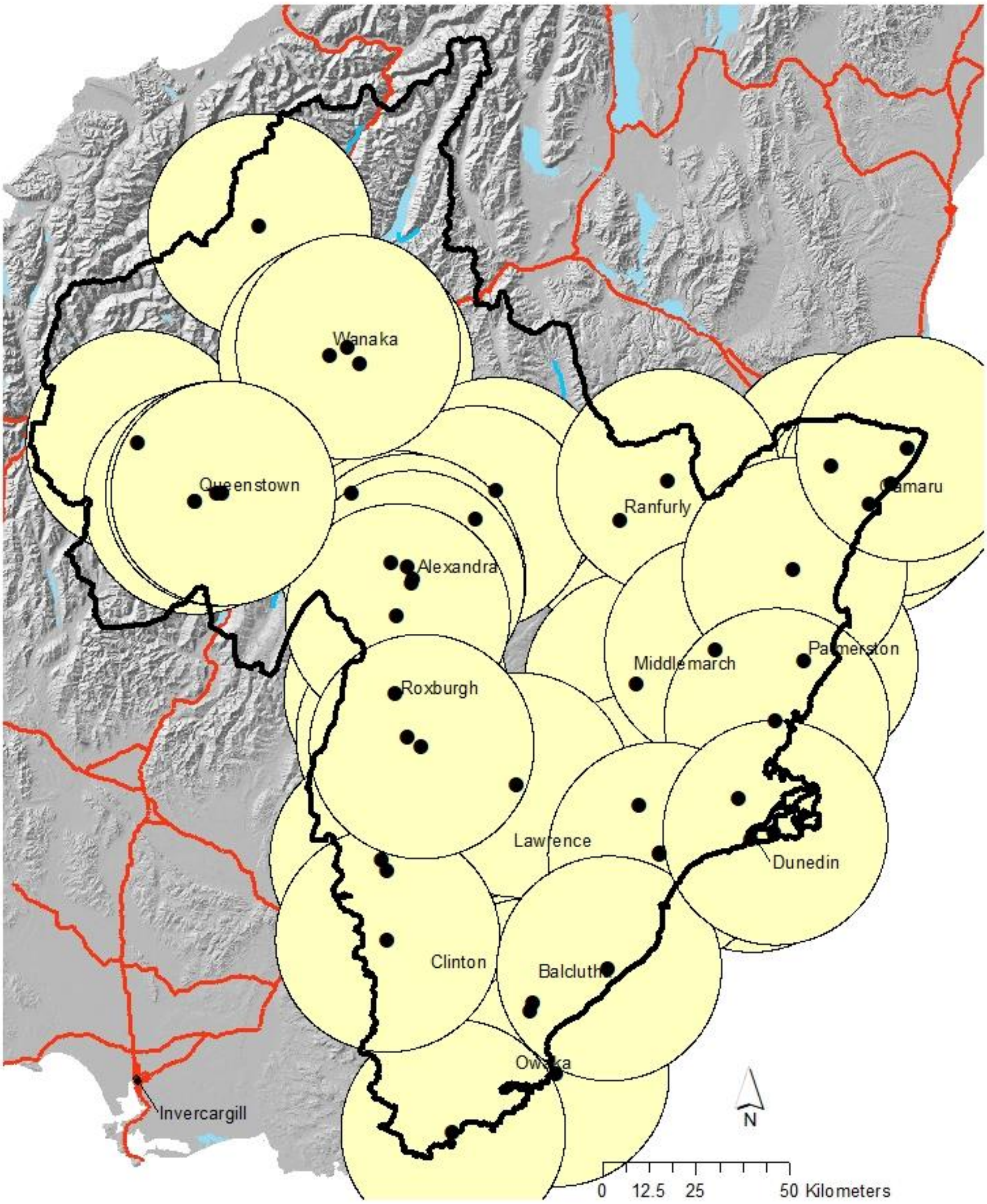

Figure B-5: Assessment of Otago region's air temperature monitoring network based on WMO (2003) guidelines. Each circle represents a spatial resolution of 60 km.

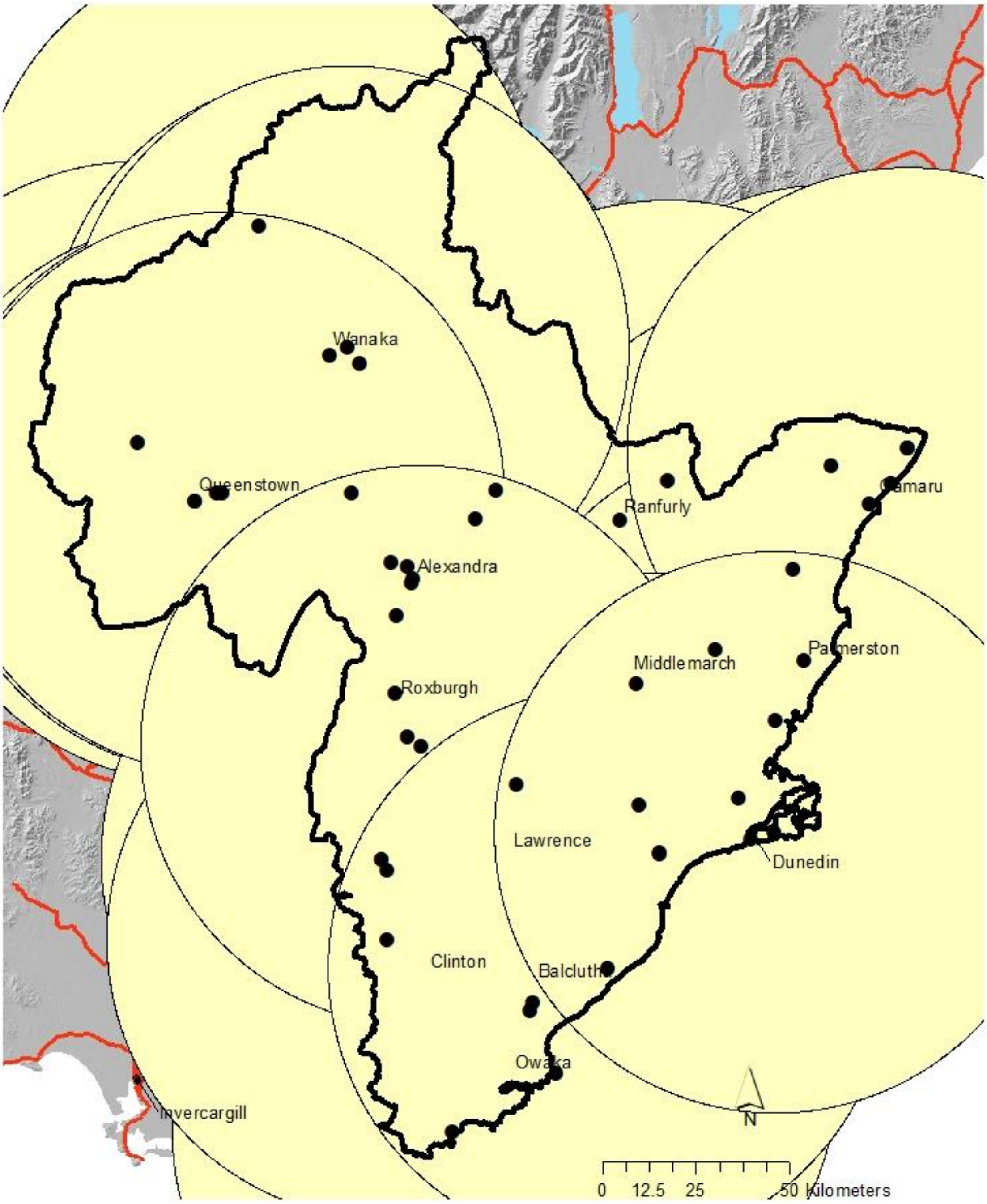

Figure B-6: Assessment of Otago region's air temperature monitoring network, based on based on WMO (2003) guidelines. Each circle represents a spatial resolution of 150 km.

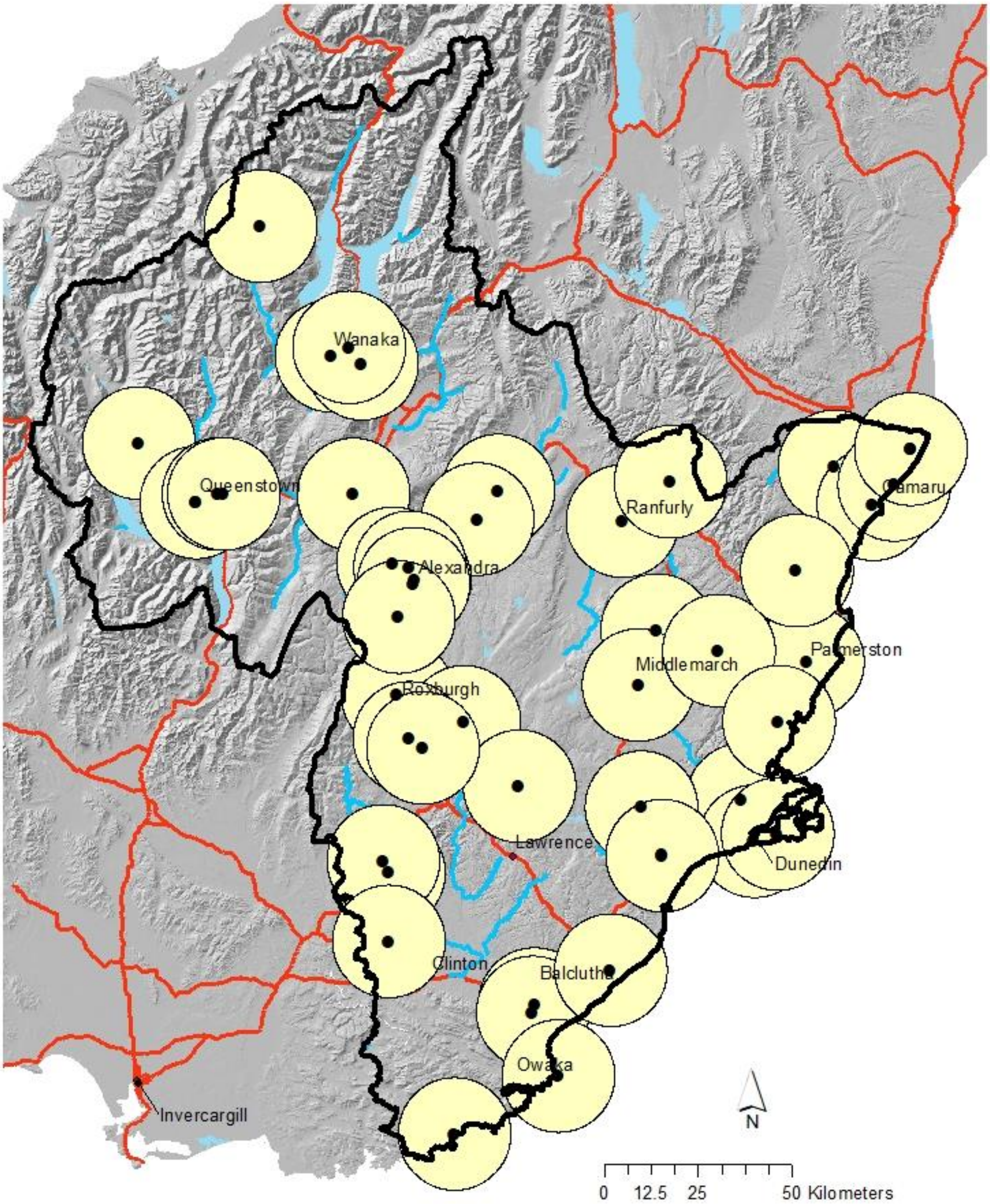

Figure B-7: Assessment of Otago region's relative humidity monitoring network based on WMO (2003) guidelines. Each circle represents a spatial resolution of 30 km.

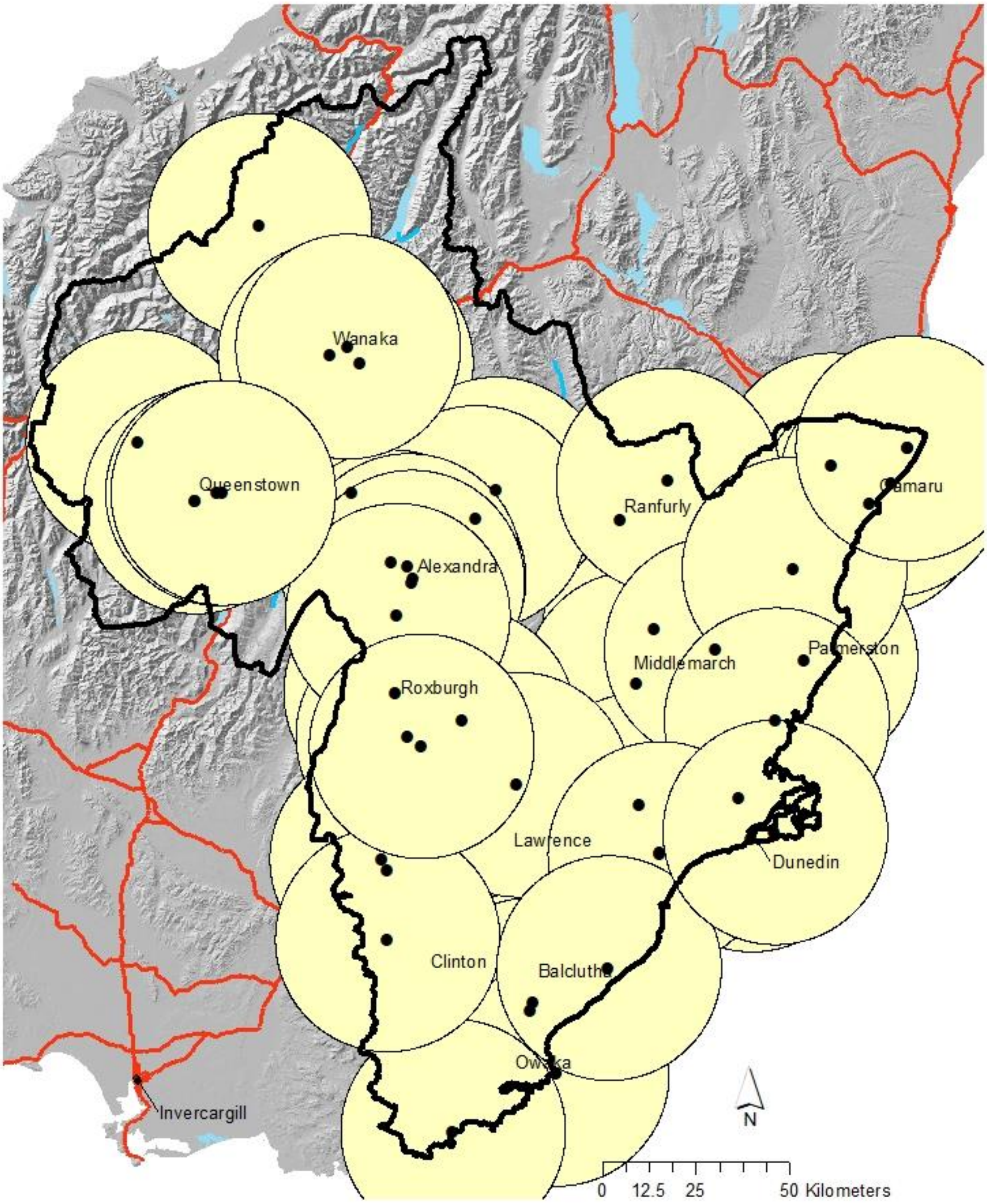

Figure B-8: Assessment of Otago region's relative humidity monitoring network based on WMO (2003) guidelines. Each circle represents a spatial resolution of 60 km.

Figure B-9: Assessment of Otago region's relative humidity monitoring network based on WMO (2003) guidelines. Each circle represents a spatial resolution of 150 km.

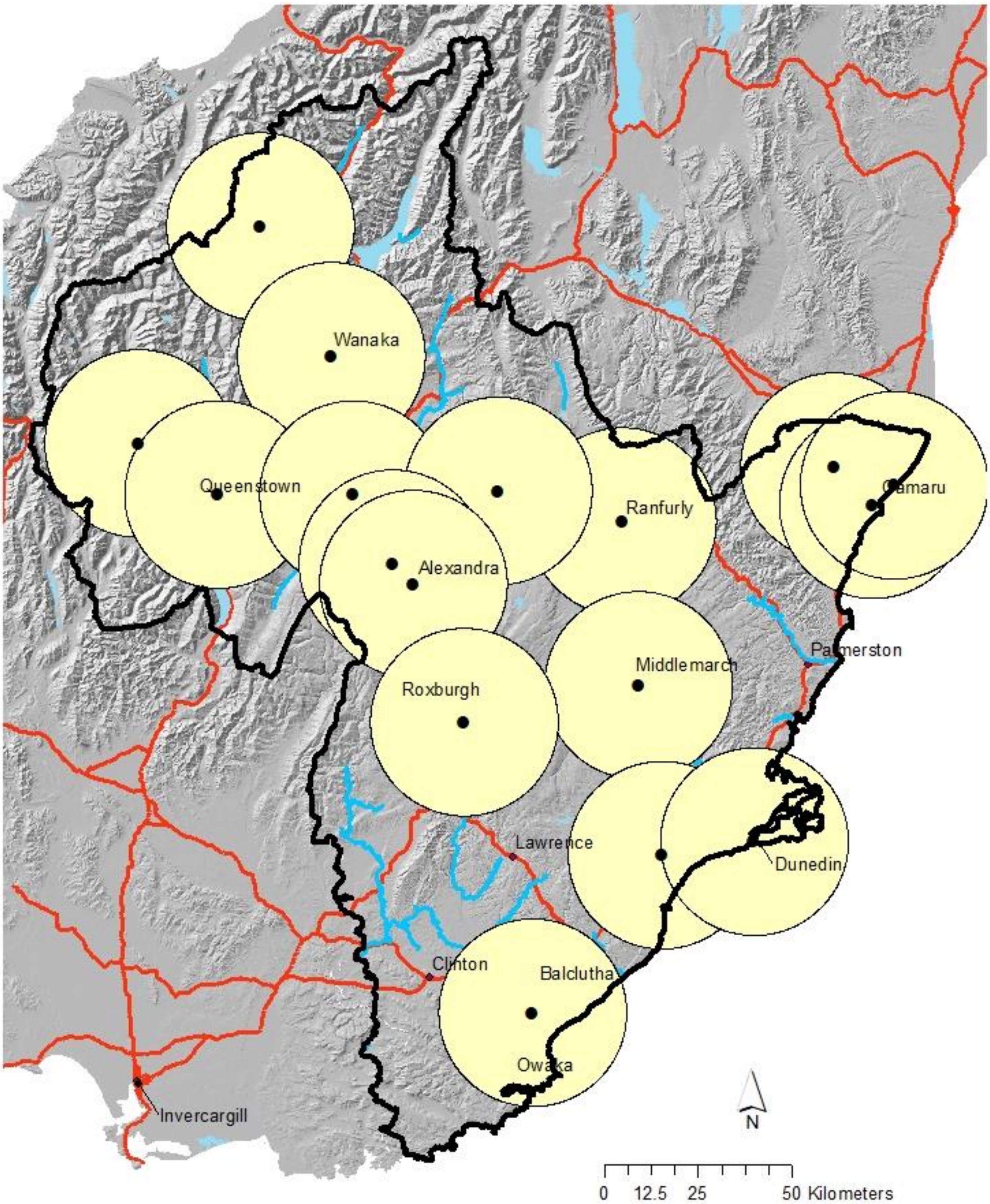

Figure B-10: Assessment of Otago region's solar radiation monitoring network based on WMO (2003) guidelines. Each circle represents a spatial resolution of 50 km.

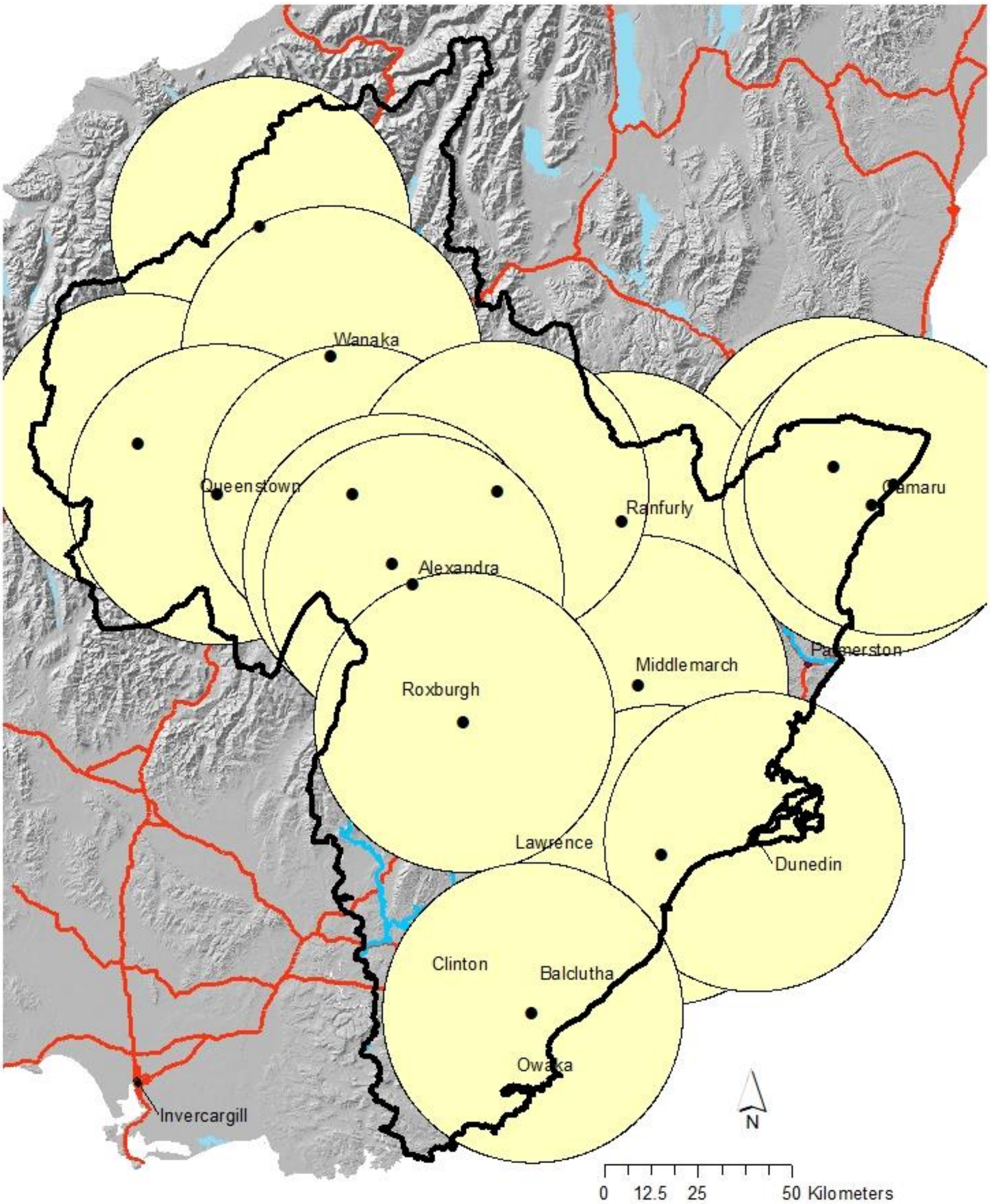

Figure B-11: Assessment of Otago region's solar radiation monitoring network based on WMO (2003) guidelines. Each circle represents a spatial resolution of 80 km.

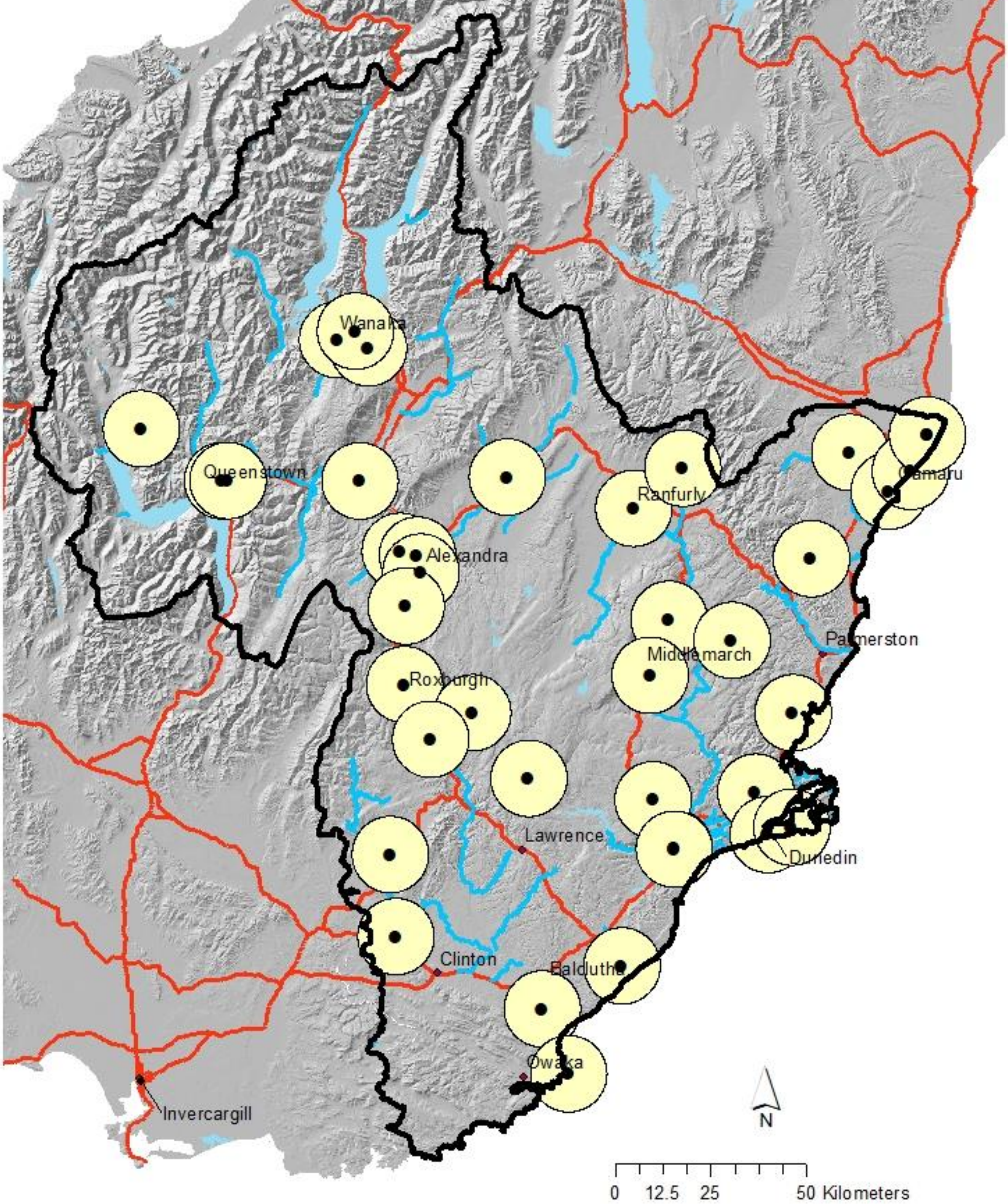

Figure B-12: Assessment of Otago region's wind direction and speed monitoring network based on WMO (2003) guidelines. Each circle represents a spatial resolution of 20 km.

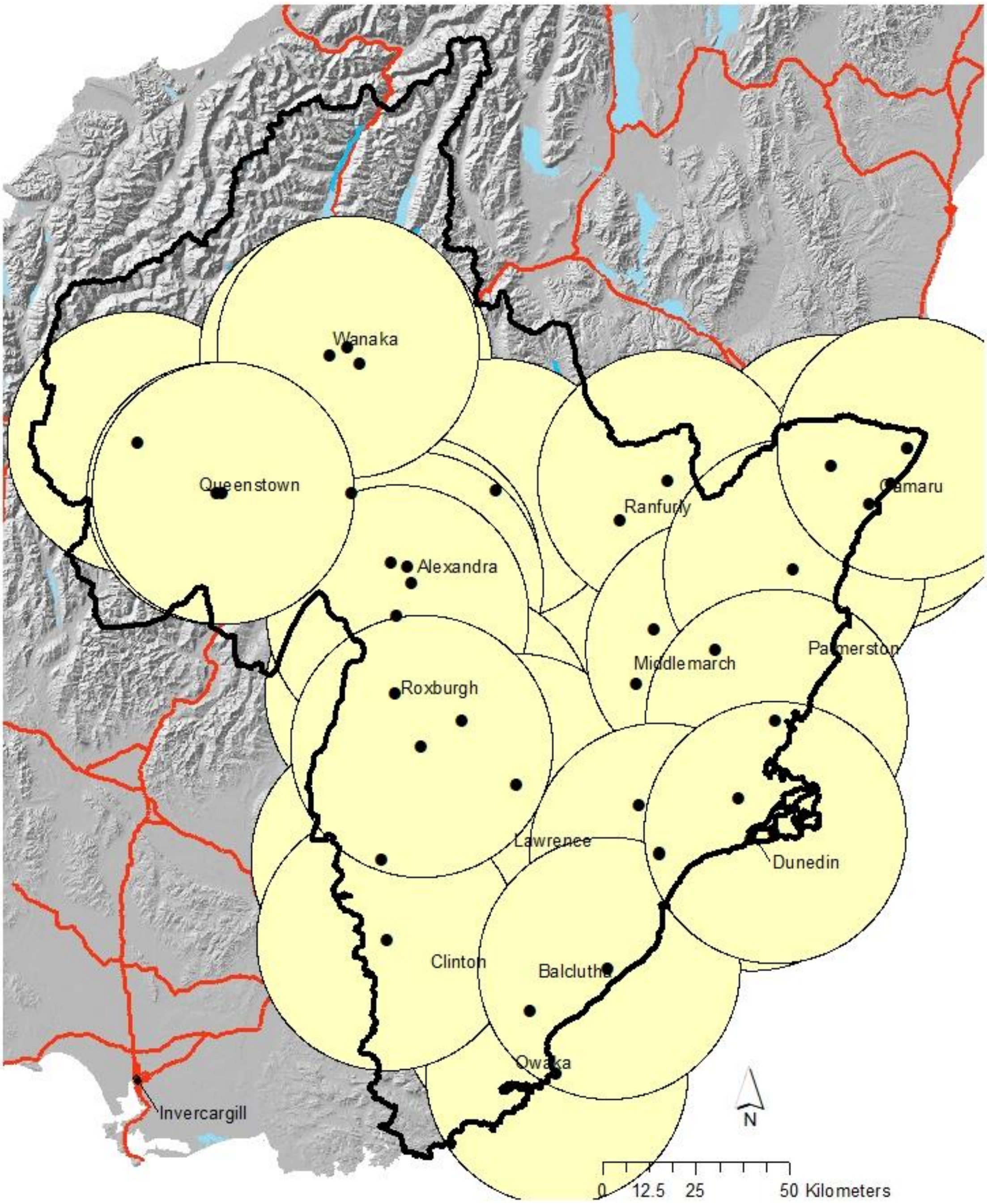

Figure B-13: Assessment of Otago region's wind direction and speed monitoring network based on WMO (2003) guidelines. Each circle represents a spatial resolution of 70 km.

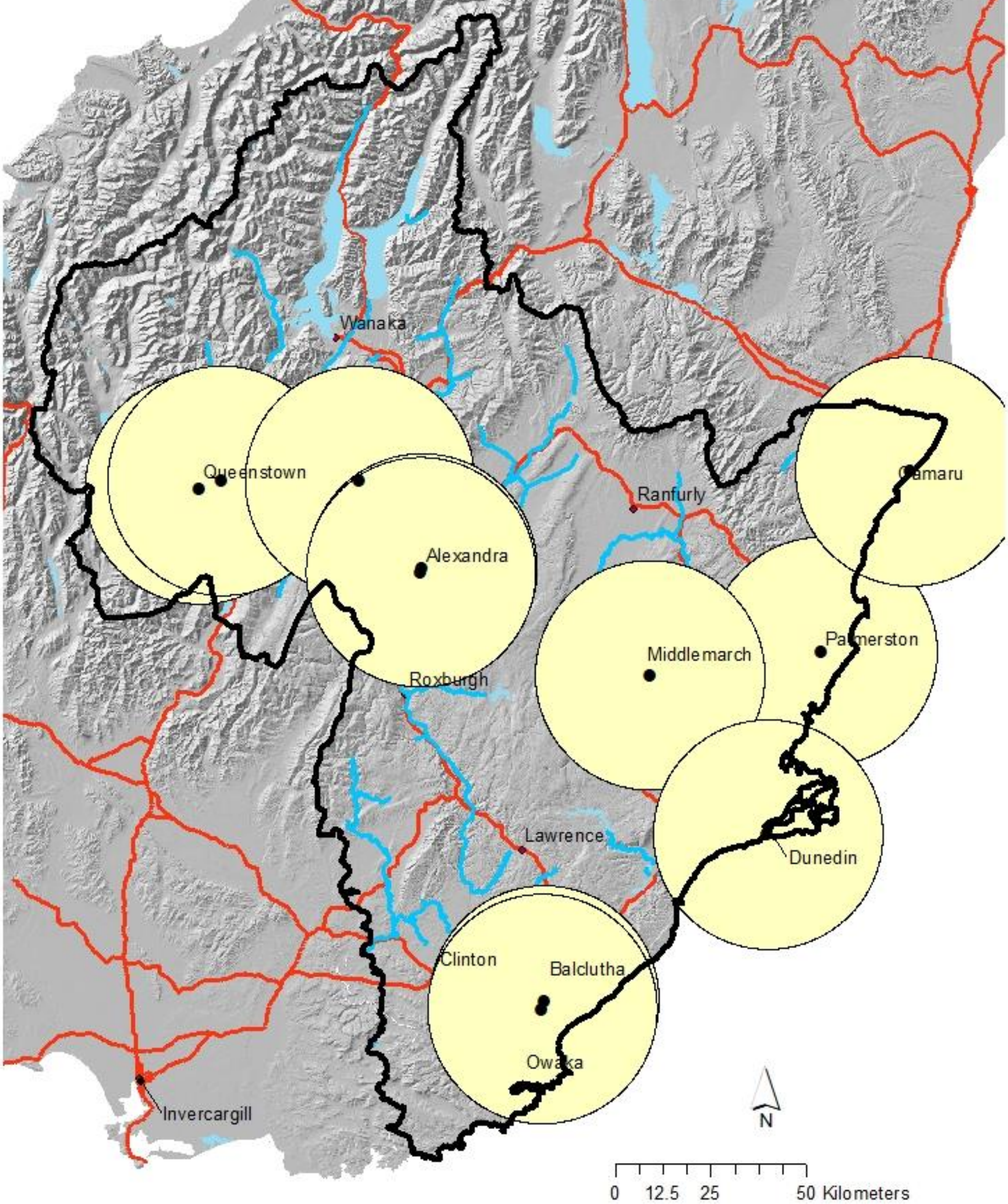

Figure B-14: Assessment of Otago region's sunshine monitoring network based on WMO (2003) guidelines. Each circle represents a spatial resolution of 60 km.

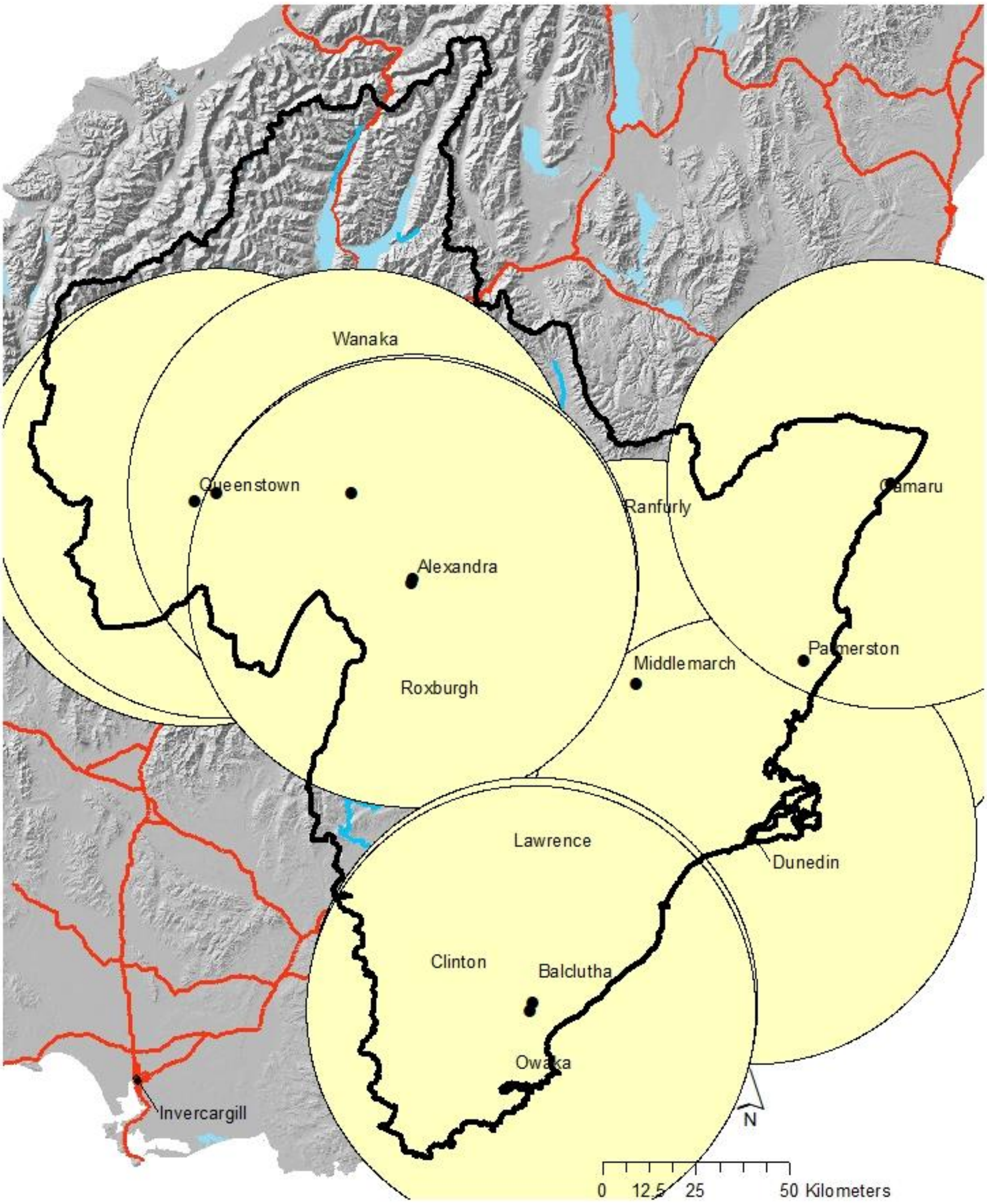

Figure B-15: Assessment of Otago region's sunshine monitoring network based on WMO (2003) guidelines. Each circle represents a spatial resolution of 120 km.

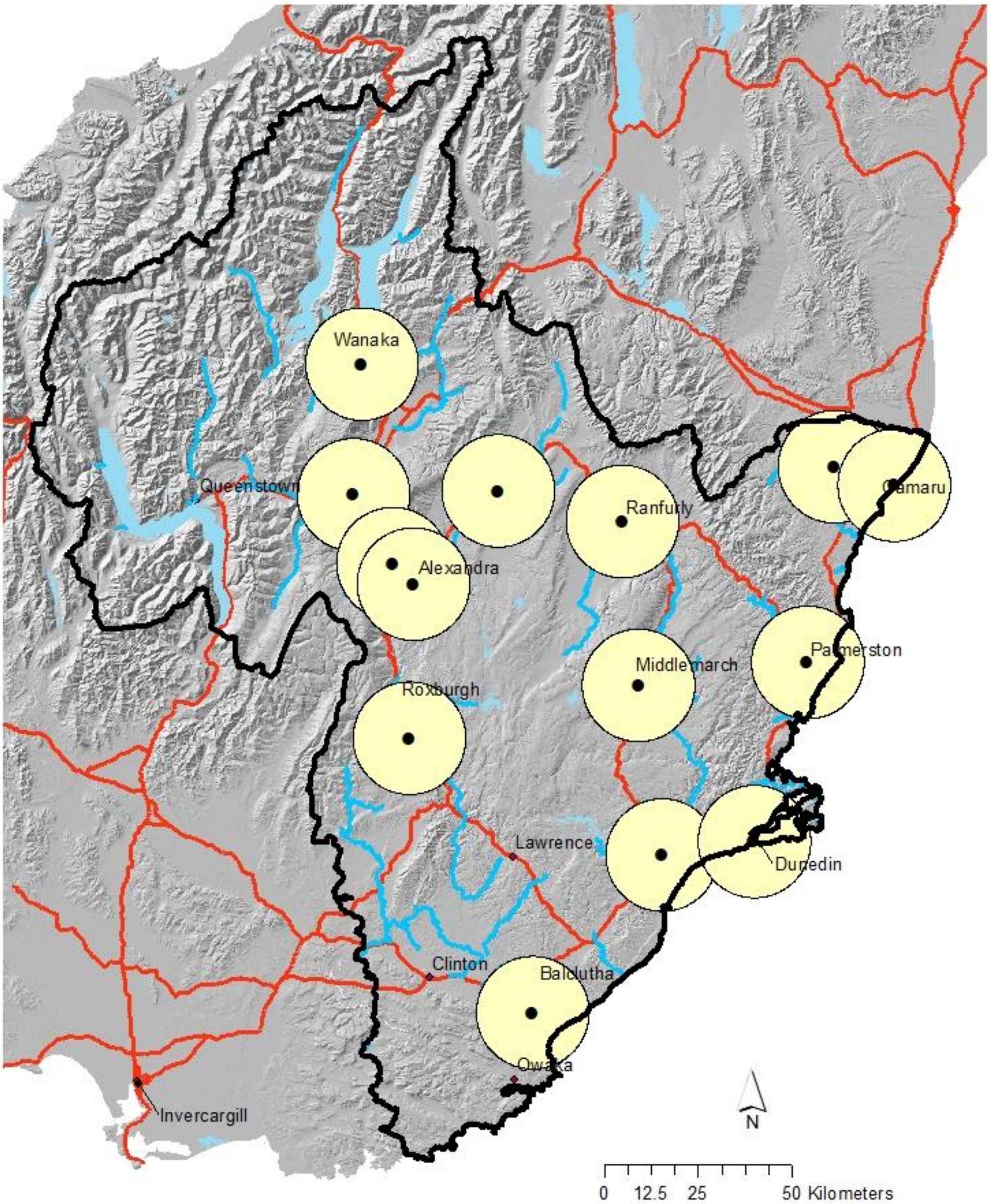

Figure B-16: Assessment of Otago region's soil temperature @ 10 cm monitoring network based on WMO (2003) guidelines. Each circle represents a spatial resolution of 30 km.

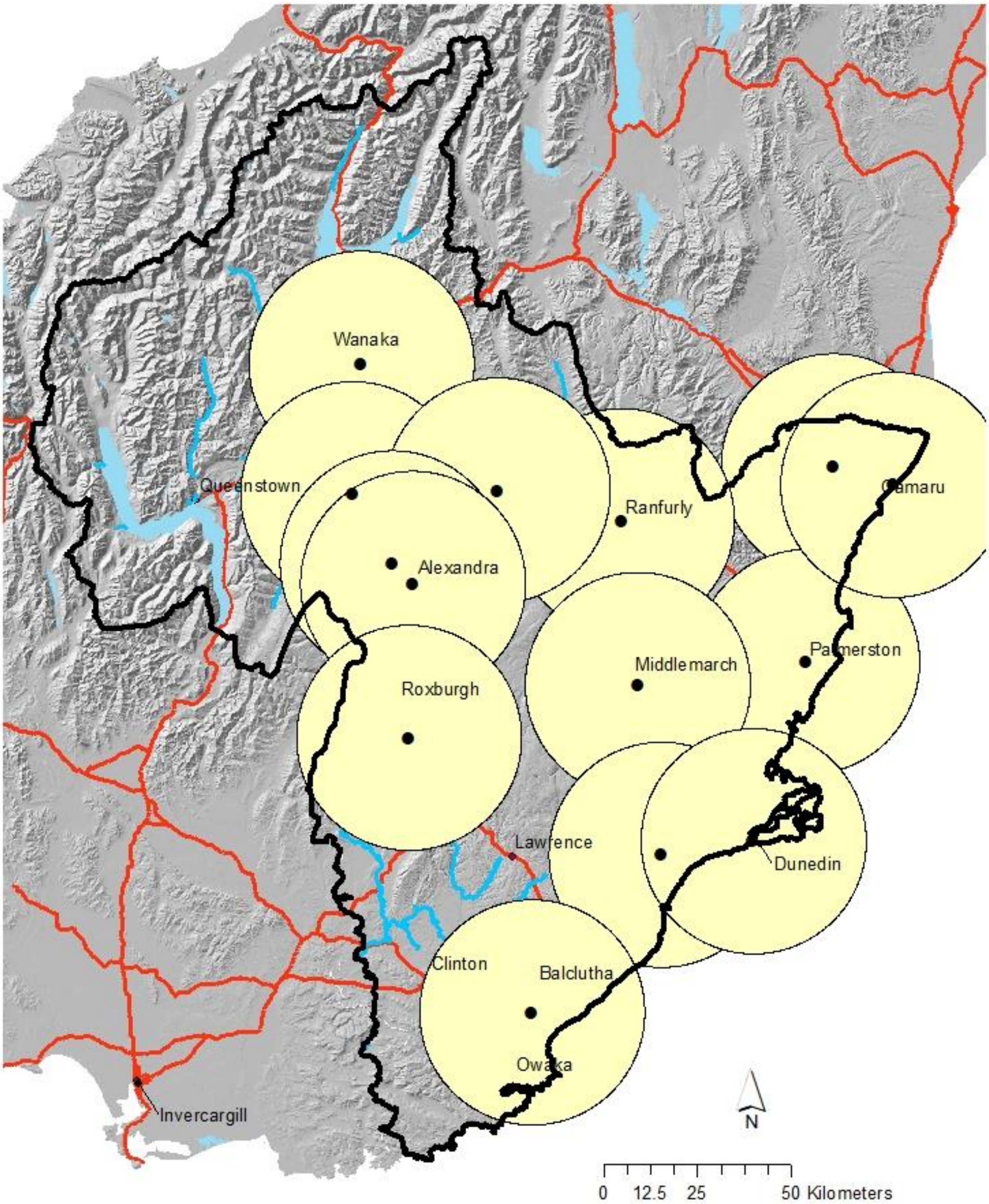

Figure B-17: Assessment of Otago region's soil temperature @ 10 cm monitoring network based on WMO (2003) guidelines. Each circle represents a spatial resolution of 60 km.

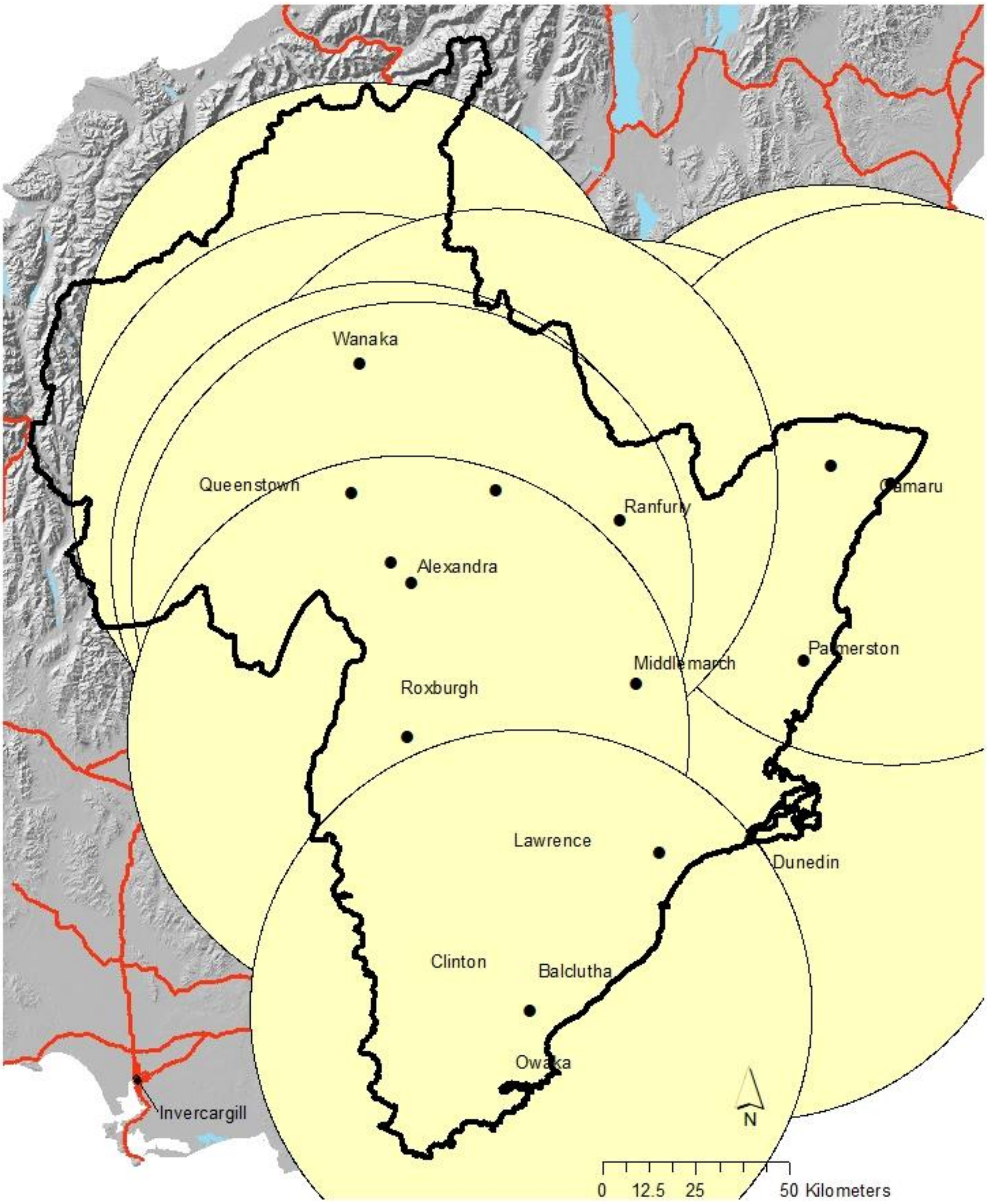

Figure B-18: Assessment of Otago region's soil temperature @ 10 cm monitoring network based on WMO (2003) guidelines. Each circle represents a spatial resolution of 150 km.

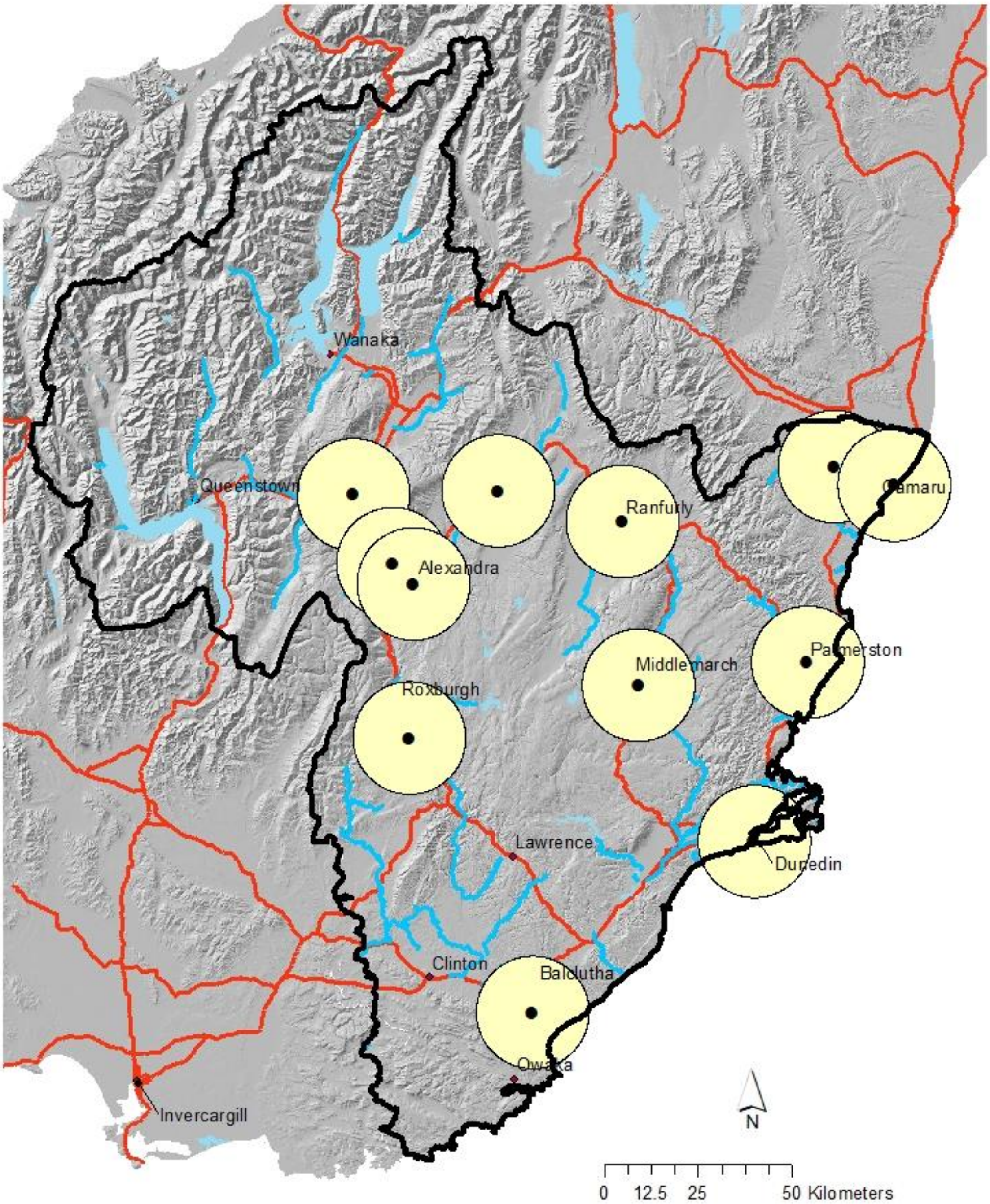

Figure B-19: Assessment of Otago region's soil temperature @ 20 cm monitoring network based on WMO (2003) guidelines. Each circle represents a spatial resolution of 30 km.

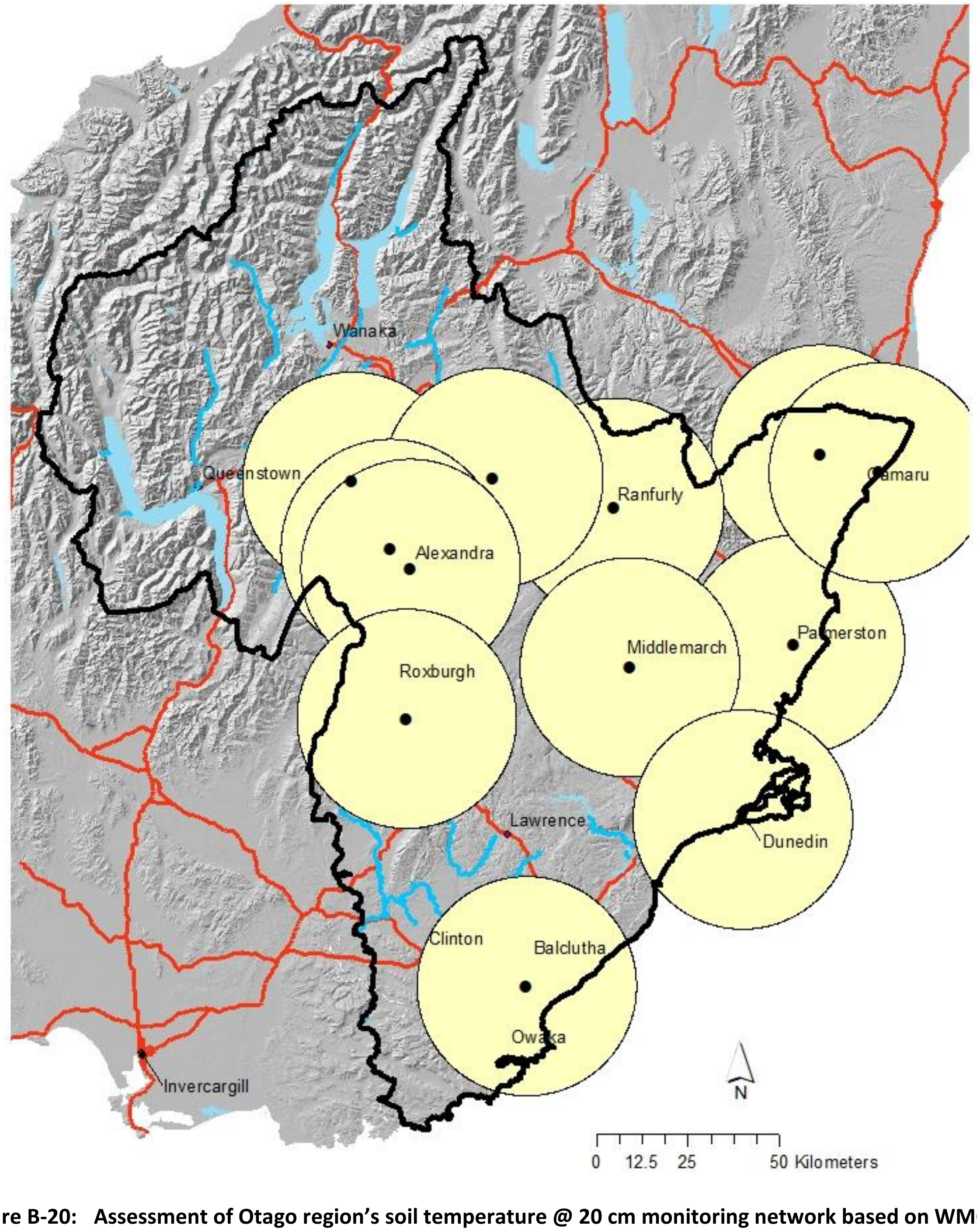

Figure B-20: Assessment of Otago region's soil temperature @ 20 cm monitoring network based on WMO (2003) guidelines. Each circle represents a spatial resolution of 60 km.

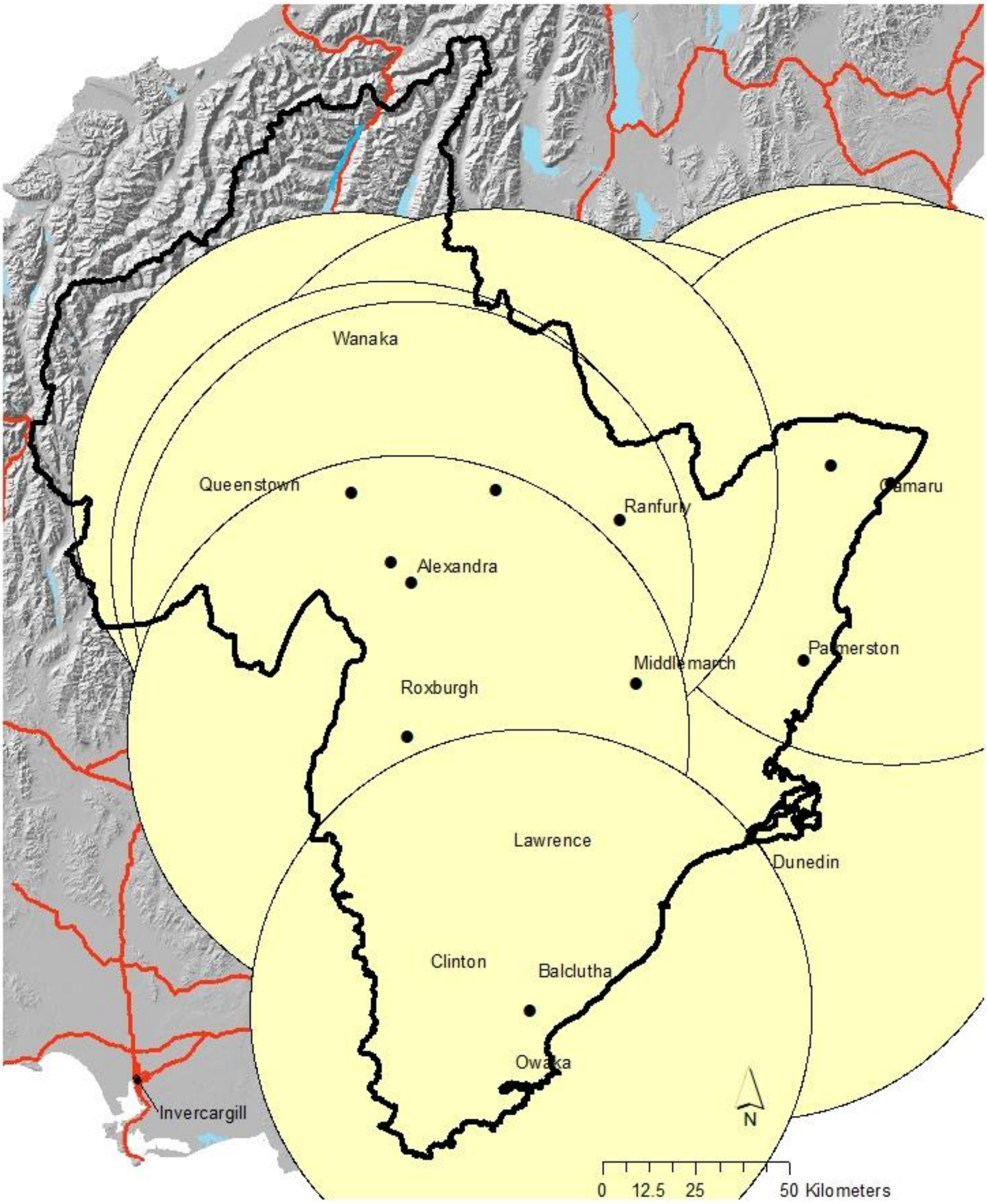

Figure B-21: Assessment of Otago region's soil temperature @ 20 cm monitoring network based on WMO (2003) guidelines. Each circle represents a spatial resolution of 150 km.

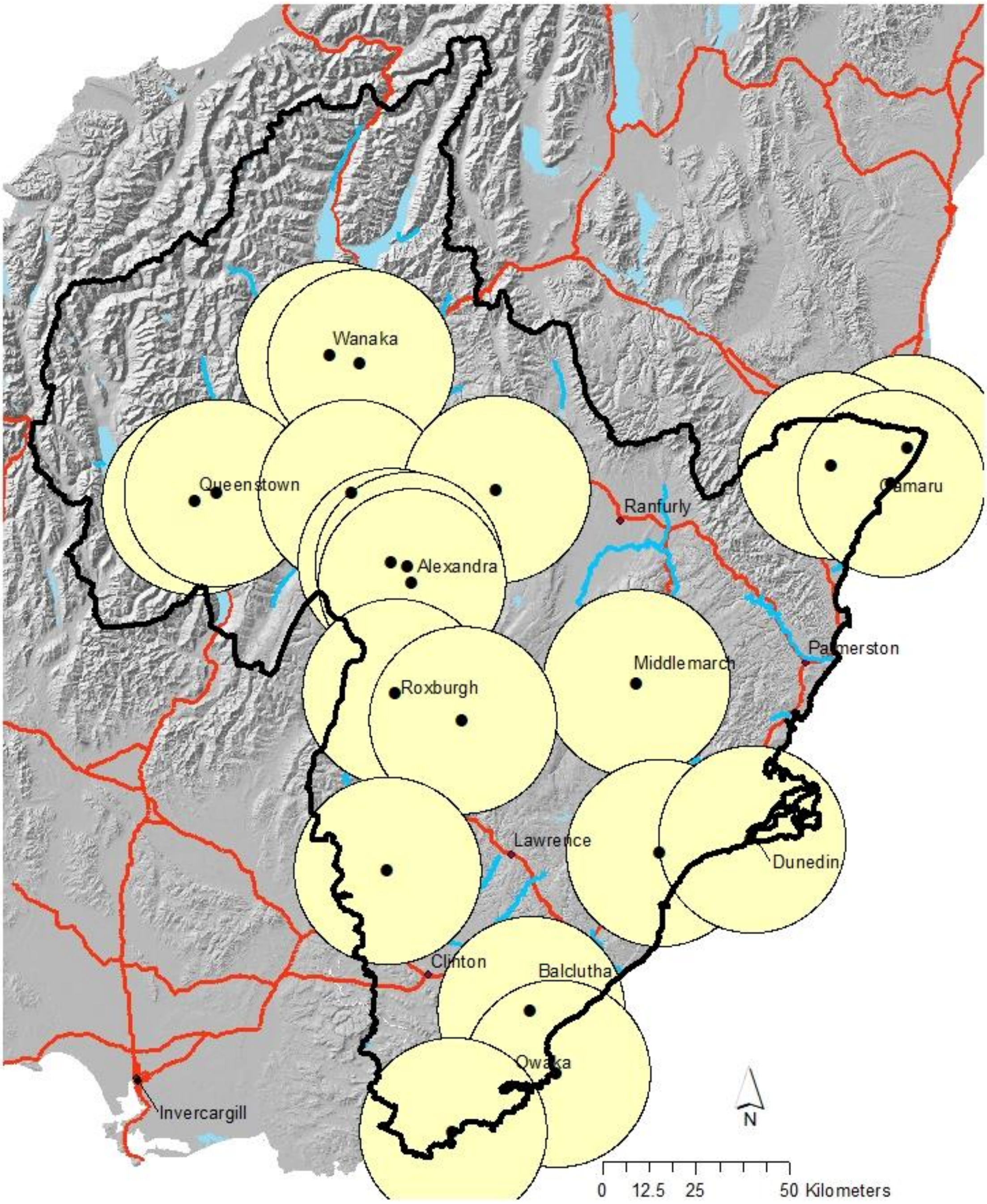

Figure B-22: Assessment of Otago region's barometric pressure monitoring network based on WMO (2003) guidelines . Each circle represents a spatial resolution of 50 km.

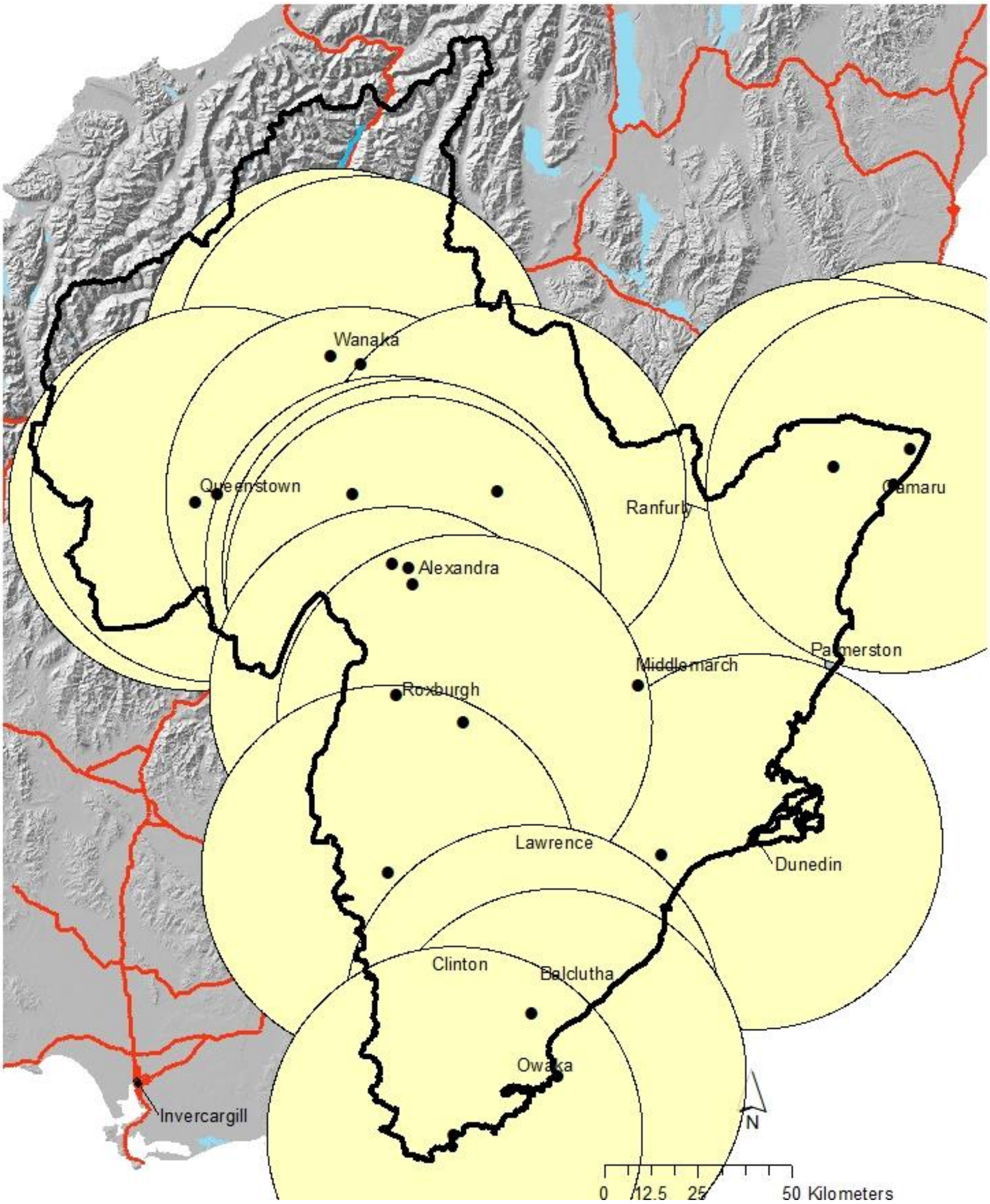

Figure B-23: Assessment of Otago region's barometric pressure monitoring network based on WMO (2003) guidelines. Each circle represents a spatial resolution of 100 km.

Appendix C Open rainfall sites in the ORC region

Table C-1: List of all open rainfall sites in the Otago and bordering regions.

Total number of sites, 130

Site name	Start date	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Telemetered	Recording authority
Kyeburn Rainfall at Danseys Pass	30-May-96	2296053	5576689	1100	Yes	ECAN
McKellars Flat at Gorge Burn	27-Oct-74	2138080	5535042	0	Yes	ES
Fairlight at Cainard Station	9-Sep-77	2162866	5527248	0	Yes	ES
Wendon Valley at Waikaka	26-Jul-88	2197265	5472059	0	Yes	ES
Upper Waikaia at Hyde Rock	17-Oct-05	2210823	5528897	1652	Yes	ES
Waikaia River at Piano Flat	28-Aug-77	2197508	5507912	215	Yes	ES
Chatton Aquifer at Cunningham Road	26-Jun-07	2204743	5454552	158	Yes	ES
Rock And Pillar Raws	12-Jul-96	2291091	5531815	270	Yes	FENZ
Butchers Dam Raws	15-Dec-09	2222331	5535265	383	Yes	FENZ
Traquair Raws	31-Dec-72	2286906	5484627	425	Yes	FENZ
Dansey Pass Raws	31-Dec-92	2294691	5571315	495	Yes	FENZ
Tapanui Raws	6-Jul-96	2218205	5470326	200	Yes	FENZ
Glendhu Raws	31-Dec-90	2254447	5490223	660	Yes	FENZ
Mcraes Raws	23-Nov-97	2307562	5526325	633	Yes	FENZ
Herbert Raws	31-Dec-94	2328300	5547657	572	Yes	FENZ
Bucklands Raws	31-Dec-95	2323551	5507397	75	Yes	FENZ
Waipahi Raws	15-Dec-14	2219674	5448888	115	Yes	FENZ
Hawera Flats Raws	1-Apr-17	2209092	5607157	307	Yes	FENZ
Queenstown Aero Raws	1-Apr-17	2175748	5568075	346	Yes	FENZ
Oamaru Raws	1-Jun-17	2358658	5579998	41	Yes	FENZ
Dunedin Raws	1-Jan-18	2292461	5471699	1	Yes	FENZ
Millers Flat Raws	1-Jul-18	2228737	5500452	93	Yes	FENZ
Toko Mouth Raws	29-May-19	2278792	5441218	127	Yes	FENZ
Highcliff Rdnz	30-Oct-19	2323185	5477483	351	Yes	FENZ
Oamaru Airport Aws	1-Apr-77	2358595	5579964	30	Yes	MetService
Wanaka Aero Aws	1-May-92	2212511	5602778	352	Yes	MetService
Oamaru Aws	13-Sep-05	2348651	5565348	40	Yes	MetService
Swampy Summit Aws	29-Jan-08	2313752	5486642	716	Yes	MetService
Dunedin Aero Aws	31-Oct-91	2292444	5471955	2	Yes	MetService
Queenstown Aero Aws	1-Aug-77	2174345	5568034	357	Yes	MetService
Alexandra Aws	30-Sep-12	2225317	5548567	231	Yes	MetService
Roxburgh Wxt Aws	27-Apr-10	2221926	5514752	160	Yes	MetService
Nugget Point Aws	1-Jul-83	2264841	5413020	131	Yes	MetService
Mt Larkins Ews	13-Jun-13	2153094	5581629	1900	Yes	NIWA
Wanaka Cws	27-Oct-15	2204381	5604889	331	Yes	NIWA

Site name	Start date	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Telemetered	Recording authority
Lake Hawea At Gladstone Gap	1-Aug-08	2215310	5615429	353	Yes	NIWA
Windsor Ews	21-Nov-00	2338333	5575447	81	Yes	NIWA
Ranfurly Ews	20-Nov-00	2281864	5560831	450	Yes	NIWA
Middlemarch Ews	30-Aug-00	2286136	5517182	213	Yes	NIWA
Dunedin, Musselburgh Ews	1-Aug-97	2317005	5475563	10	Yes	NIWA
Oamaru Ews	11-Sep-15	2354201	5570499	20	Yes	NIWA
Queenstown Ews	23-Feb-16	2168420	5565818	322	Yes	NIWA
Cromwell Ews	5-Apr-06	2210270	5567979	213	Yes	NIWA
Cairnmuir Slide at Lower Slip	1-Aug-89	2212801	5562799	425	Yes	NIWA
Dunlays Slide at Windy Point	29-Aug-89	2219801	5559999	410	Yes	NIWA
Lauder Ews	1-Jul-85	2248801	5568999	375	Yes	NIWA
Clyde 2 Ews	1-Mar-99	2220767	5549601	170	Yes	NIWA
Alexandra Ews	18-Apr-19	2226217	5544151	132	Yes	NIWA
Lake Roxburgh at Gorge Creek	15-Nov-07	2219800	5530200	320	Yes	NIWA
Tapanui Ews	22-Dec-20	2219690	5467167	180	Yes	NIWA
Balclutha, Telford Ews	14-Dec-05	2257972	5429980	11	Yes	NIWA
Tautuku Ews	2-Jun-21	2237176	5397601	25	Yes	NIWA
Matukituki at West Wanaka	21-Aug-79	2192001	5611399	280	Yes	NIWA
Albert Burn	23-Jan-08	2185504	5639415	1280	Yes	NIWA
Mosgiel Town	1-Jun-47	2302577	5478264	8	No	ORC
Young North Branch at Dam	20-Aug-08	2200000	5667099	300	Yes	ORC
Matutukituki at Cascade Hut	18-Jun-03	2166001	5625399	439	Yes	ORC
Dart at Paradise	5-May-03	2141201	5602499	400	Yes	ORC
Dart at The Hillocks, Glenorchy	21-Aug-97	2140101	5593299	310	Yes	ORC
Albert Burn at Dragonfly	21-Apr-04	2185500	5639599	1300	Yes	ORC
Shotover at Peat's Hut	19-Dec-96	2171201	5588499	460	Yes	ORC
Makarora at Makarora	4-Oct-97	2208501	5655499	280	Yes	ORC
Clutha at Stoney Creek	2-May-18	2199864	5603363	0	Yes	ORC
Cluden Stream at Stock Yards	21-Nov-12	2236652	5594581		Yes	ORC
Ida Burn at Hills Ck	1-Jan-88	2264501	5577599	580	Yes	ORC
Manuherikia at Tunnel Hill	18-Mar-08	2262901	5594299	810	Yes	ORC
Kakanui at Mole Hill	20-Jun-17	2321023	5569905	0	Yes	ORC
Kakanui at Clifton Falls	2-Jul-87	2332701	5572699	95	Yes	ORC
Kauru at The Dasher	29-May-95	2327201	5556499	540	Yes	ORC
Shag at Stoneburn	1-Jan-85	2319301	5528099	400	Yes	ORC
Nenthorn at Mt Stoker	30-Aug-93	2295701	5510399	300	Yes	ORC
Deep Stm at Glengarry	26-Aug-93	2280301	5497299	360	Yes	ORC
Waikouaiti at Mt Misery	3-Sep-07	2311254	5504267	500	Yes	ORC
Leith at Pinehill	25-Apr-79	2318201	5482699	270	Yes	ORC

Site name	Start date	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Telemetered	Recording authority
Silverstream at Swampy Spur	15-May-07	2313242	5488523	638	Yes	ORC
Leith at Sullivans Dam	2-Feb-00	2317101	5485799	290	Yes	ORC
Leith at Sullivans Dam No.2	19-Dec-16	2317100	5485799	0	Yes	ORC
Poolburn at Merino Ridges	21-Apr-09	2253601	5556799	455	Yes	ORC
Clutha at Teviot Valley	10-Oct-18	2220240	5511872	440	Yes	ORC
Mt Teviot Ews	9-Nov-21	2239756	5507383	960	Yes	ORC
Pomahaka at Moa Flat	1-Jan-88	2216801	5491399	580	Yes	ORC
Heriot Burn at Blue Mountains	9-May-13	2231031	5476550	800	Yes	ORC
Pomahaka at Kelso	1-Nov-07	2213200	5468499	0	Yes	ORC
Washpool at Lone Hill	25-Mar-04	2235300	5459999	0	Yes	ORC
Waitahuna at Clarks Flat	1-Jan-85	2251901	5463099	340	Yes	ORC
Tokomairiro at Table Hill Rd	4-Aug-11	2271501	5457299	225	Yes	ORC
Clutha at Balclutha	1-Jan-88	2259201	5436199	10	Yes	ORC
Waipahi at Slopedown	10-Apr-17	2218601	5426399	170	Yes	ORC
Inchclutha Soils	19-Aug-08	2264656	5429380	0	Yes	ORC
Puerua at Lochindorb	2-Jun-09	2241606	5426436	640	Yes	ORC
Hawea at Camphill Farm	2-Feb-12	2212700	5609499		Yes	ORC
3 OClock Stream at Lambhill	24-Aug-10	2302001	5497799	160		ORC
Glenfinnan	1-Jan-69	2179134	5625982	341	No	Other
Routeburn Stn	1-Mar-71	2139110	5595899	381	No	Other
Arrowtown No2	1-Apr-04	2180375	5576424	409	No	Other
Makarora Station	1-Aug-24	2208537	5654985	320	No	Other
Minaret Bay	1-Aug-52	2200131	5636575	313	No	Other
Hawea Flat	1-Jul-21	2217021	5611880	335	No	Other
Islay Downs	1-Apr-69	2310479	5547899	360	No	Other
Trotters Creek	1-Mar-08	2339283	5533480	30	No	Other
Palmerston	1-Feb-69	2331212	5523309	21	No	Other
Lee Flat	1-Mar-54	2278707	5487466	354	No	Other
Long Beach	31-Dec-84	2326112	5492094	10	No	Other
Balmoral, Outram	1-Jan-48	2294499	5475888	3	No	Other
Powder Creek, Pump House	1-Apr-93	2309650	5485715	100	No	Other
Dunedin, Btl Gardens	1-Feb-13	2317435	5480167	73	No	Other
Maungatua	1-Nov-70	2288672	5473690	25	No	Other
Southern Reservoir	1-Jun-54	2312113	5476338	110	No	Other
Green Island, Kaikorai Estuary	25-Nov-93	2308697	5473786	27	No	Other
Queenstown	01 Sep 1871	2168420	5565818	322	No	Other
Matakanui	1-May-47	2235042	5566191	357	No	Other
Lauder Flat	1-Jan-36	2250105	5572574	366	No	Other
Lauder 2	31-Dec-99	2252275	5575551	406	No	Other
Bannockburn	1-Jul-71	2207589	5555276	427	No	Other

Site name	Start date	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Telemetered	Recording authority
Ophir 2	1-Apr-24	2243270	5561387	305	No	Other
Alexandra	1-Feb-29	2226574	5545121	150	No	Other
Roxburgh, Hilltop	1-Jan-33	2228127	5512152	518	No	Other
Ettrick No.2	31-Dec-84	2225164	5503123	91	No	Other
Tima	1-Apr-90	2230231	5499674	90	No	Other
Glenledi Rd	28-Aug-84	2284583	5444074	61	No	Other
Rosebank	1-Jan-71	2209269	5460586	168	No	Other
Kintore	28-Jan-04	2274930	5461125	275	No	Other
Taumata	31-Oct-01	2236769	5441265	80	No	Other
Baverstock Waiwera	1-Oct-54	2241665	5443988	91	No	Other
Hillend	1-Jan-47	2258786	5447120	261	No	Other
Balclutha	1-Jul-49	2259082	5436122	12	No	Other
Balclutha, Finegand	1-Jun-64	2258464	5432204	6	No	Other
Inchclutha, T'graph rd	1-Mar-66	2265134	5429236	8	No	Other
West Taieri	16-Mar-06	2285178	5471456	100	Yes	Other
Taieri at Canadian Flat	26-Jan-89	2255201	5513499	640	Yes	Other

Appendix D Open climate sites in the ORC region

Table D-1: List of all open climate sites in the Otago region.

Total number of sites, 49

Site name	Start date	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Telemetered	Recording authority	A*	B	C	D	E	F	G	H	I	J	K	L	M	N
Rock And Pillar RAWS	12-Jul-96	2291091	5531815	270	Yes	FENZ	X	X	X	X	X									
Butchers Dam RAWS	15-Dec-09	2222331	5535265	383	Yes	FENZ	X	X	X	X	X									
Traquair RAWS	31-Dec-72	2286906	5484627	425	Yes	FENZ	X	X	X	X	X									
Dansey Pass RAWS	31-Dec-92	2294691	5571315	495	Yes	FENZ	X	X	X	X	X								X	
Tapanui RAWS	6-Jul-96	2218205	5470326	200	Yes	FENZ	X	X	X	X	X									
Glendhu RAWS	31-Dec-90	2254447	5490223	660	Yes	FENZ	X	X	X	X	X									
Mcraes RAWS	23-Nov-97	2307562	5526325	633	Yes	FENZ	X	X	X	X	X									
Herbert RAWS	31-Dec-94	2328300	5547657	572	Yes	FENZ	X	X	X	X	X									
Bucklands RAWS	31-Dec-95	2323551	5507397	75	Yes	FENZ	X	X	X	X	X								X	
Waipahi RAWS	15-Dec-14	2219674	5448888	115	Yes	FENZ	X	X	X	X	X									
Hawera Flats RAWS	1-Apr-17	2209092	5607157	307	Yes	FENZ	X	X	X	X	X									
Queenstown Aero RAWS	1-Apr-17	2175748	5568075	346	Yes	FENZ	X	X	X	X	X									
Oamaru RAWS	1-Jun-17	2358658	5579998	41	Yes	FENZ	X	X	X	X	X									
Dunedin RAWS	1-Jan-18	2292461	5471699	1	Yes	FENZ	X	X	X	X	X									
Millers Flat RAWS	1-Jul-18	2228737	5500452	93	Yes	FENZ	X	X	X	X	X								X	
Toko Mouth RAWS	29-May-19	2278792	5441218	127	Yes	FENZ	X	X	X	X	X									
Highcliff Rdnz	30-Oct-19	2323185	5477483	351	Yes	FENZ	X	X	X	X	X								X	
Oamaru Airport Aws	1-Apr-77	2358595	5579964	30	Yes	MetService	X	X	X	X	X					X		X		X
Wanaka Aero Aws	1-May-92	2212511	5602778	352	Yes	MetService	X	X	X	X	X	X				X				

Site name	Start date	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Telemetered	Recording authority	A*	B	C	D	E	F	G	H	I	J	K	L	M	N
Oamaru Aws	13-Sep-05	2348651	5565348	40	Yes	MetService	X	X	X	X	X									
Swampy Summit Aws	29-Jan-08	2313752	5486642	716	Yes	MetService	X	X	X	X	X									
Dunedin Aero Aws	31-Oct-91	2292444	5471955	2	Yes	MetService	X	X	X	X	X	X				X		X		X
Queenstown Aero Aws	1-Aug-77	2174345	5568034	357	Yes	MetService	X	X	X	X	X						X	X		X
Alexandra Aws	30-Sep-12	2225317	5548567	231	Yes	MetService	X	X	X	X	X					X				
Roxburgh Wxt Aws	27-Apr-10	2221926	5514752	160	Yes	MetService	X	X	X	X	X					X				
Nugget Point Aws	1-Jul-83	2264841	5413020	131	Yes	MetService	X	X	X	X	X					X				
Mt Larkins EWS	13-Jun-13	2153094	5581629	1900	Yes	NIWA	X	X	X	X	X							X		
Wanaka Cws	27-Oct-15	2204381	5604889	331	Yes	NIWA	X	X	X	X	X					X		X	X	X
Windsor EWS	21-Nov-00	2338333	5575447	81	Yes	NIWA	X	X	X	X	X	X	X	X	X	X		X	X	X
Ranfurly EWS	20-Nov-00	2281864	5560831	450	Yes	NIWA	X	X	X	X	X	X	X	X	X	X		X	X	X
Middlemarch EWS	30-Aug-00	2286136	5517182	213	Yes	NIWA	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Dunedin, Musselburgh EWS	1-Aug-97	2317005	5475563	10	Yes	NIWA	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Oamaru EWS	11-Sep-15	2354201	5570499	20	Yes	NIWA	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Queenstown EWS	23-Feb-16	2168420	5565818	322	Yes	NIWA			X	X	X					X				
Cromwell EWS	5-Apr-06	2210270	5567979	213	Yes	NIWA	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Lauder EWS	1-Jul-85	2248801	5568999	375	Yes	NIWA	X	X	X	X	X	X	X	X	X	X		X	X	X
Clyde 2 EWS	1-Mar-99	2220767	5549601	170	Yes	NIWA	X	X	X	X	X	X	X	X	X	X		X	X	X
Alexandra EWS	18-Apr-19	2226217	5544151	132	Yes	NIWA	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Tapanui EWS	22-Dec-20	2219690	5467167	180	Yes	NIWA			X	X	X					X				
Balclutha, Telford EWS	14-Dec-05	2257972	5429980	11	Yes	NIWA	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Tautuku EWS	2-Jun-21	2237176	5397601	25	Yes	NIWA			X	X	X					X				
Albert Burn	23-Jan-08	2185504	5639415	1280	Yes	NIWA			X	X	X							X		
Mt Teviot EWS	9-Nov-21	2239756	5507383	960	Yes	NIWA	X	X	X	X	X					X		X		

Site name	Start date	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Telemetered	Recording authority	A*	B	C	D	E	F	G	H	I	J	K	L	M	N
Palmerston	1-Feb-69	2331212	5523309	21	No	Other			X	X	X	X	X	X	X		X			X
Queenstown	01 Sep 1871	2168420	5565818	322	No	Other			X	X	X						X			X
Ophir 2	1-Apr-24	2243270	5561387	305	No	Other			X	X	X									
Alexandra	1-Feb-29	2226574	5545121	150	No	Other			X	X	X						X			X
Ettrick No.2	31-Dec-84	2225164	5503123	91	No	Other			X	X	X	X	X	X	X					
Balclutha, Finegand	1-Jun-64	2258464	5432204	6	No	Other			X	X	X						X			

* A. Wind direction and speed; B. Gust speed and direction; C. Rainfall; D. Air temperature; E. Relative humidity; F-I. Soil temperature @ 10, 20, 50 and 100 cm respectively; J. Barometric pressure; K. Sunshine; L. Solar radiation; M. Soil moisture (varying depth); N. Potential evapotranspiration (estimated).

Appendix E Open soil moisture monitoring sites in the ORC region

Table E-1: List of all open soil moisture monitoring sites in the Otago region.

All 14 sites are telemetered.

						Soil moisture sensor type			
Site name	**Recording authority**	**Start date**	**Easting (NZMG)**	**Northing (NZMG)**	**Altitude (m above mean sea level)**	**Aquaflex**	**Acclima**	**EnviroPro**	**Other**
Wanaka CWS	NIWA	27-Oct-15	2204381	5604889	331		X		
Windsor EWS	NIWA	21-Nov-00	2338333	5575447	81	X			
Ranfurly EWS	NIWA	20-Nov-00	2281864	5560831	450	X			
Middlemarch EWS	NIWA	30-Aug-00	2286136	5517182	213	X			
Dunedin, Musselburgh EWS	NIWA	1-Aug-97	2317005	5475563	10	X			
Oamaru EWS	NIWA	11-Sep-15	2354201	5570499	20			X	
Cromwell EWS	NIWA	5-Apr-06	2210270	5567979	213	X			
Lauder EWS	NIWA	1-Jul-85	2248801	5568999	375	X			
Clyde 2 EWS	NIWA	1-Mar-99	2220767	5549601	170	X			
Alexandra EWS	NIWA	18-Apr-19	2226217	5544151	132			X	
Balclutha, Telford EWS	NIWA	14-Dec-05	2257972	5429980	11	X			
Pomahaka at Kelso	ORC	1-Nov-07	2213199	5468498	0				X
Washpool at Lone Hill	ORC	25-Mar-04	2235300	5459999	0				X
Inchclutha Soils	ORC	19-Aug-08	2264656	5429380	0				X

Aquaflex is a TDR (Time Domain Reflectometry) based sensor. Acclima is a TDT (Time Domain Transmissometry) based sensor. Enviropro is a capacitance based sensor.

More information on these soil moisture sensors can be accessed from the websites listed below:
https://www.aquaflex.co.nz/
https://acclima.com/acclima-sdi-tdt-data-sheet/
https://enviroprosoilprobes.com/

Appendix F Open rainfall sites bordering ORC region

Table F-1: List of open rainfall sites in the regions that border Otago.

Total number of sites, 7.

Site name	Start date	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Telemetered	Recording authority
Kyeburn Rainfall at Danseys Pass	30-May-96	2296053	5576689	1100	Yes	Environment Canterbury
McKellars Flat at Gorge Burn	27-Oct-74	2138079	5535041	0	Yes	Environment Southland
Fairlight at Cainard Station	9-Sep-77	2162865	5527247	0	Yes	Environment Southland
Wendon Valley at Waikaka	26-Jul-88	2197265	5472059	0	Yes	Environment Southland
Upper Waikaia at Hyde Rock	17-Oct-05	2210822	5528897	1652	Yes	Environment Southland
Waikaia River at Piano Flat	28-Aug-77	2197507	5507912	215	Yes	Environment Southland
Chatton Aquifer at Cunningham Road	26-Jun-07	2204742	5454551	158	Yes	Environment Southland

Appendix G Closed rainfall sites in the ORC region

Table G-1: List of all closed rainfall sites in the Otago region.

Total number of sites, 490. The list below does not include sites temporarily installed during the growOTAGO campaign launched in 2000.

Name	Start date	End date	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Recording authority
Omarama at Dunstan Peaks	4-Dec-07	19-Jan-11	2260258	5619699	580	ECAN
Mokoreta at Slopedown	4-Jan-67	31-Dec-81	2216901	5423999	168	ES
Glenledi RAWS	31-Dec-94	17-May-19	2283205	5443716	100	FENZ
Deep Stream RAWS	31-Dec-94	3-Feb-14	2264743	5492476	862	FENZ
Waitati AWS	30-Sep-10	20-Jul-16	2319943	5490988	35	MetService
Shotover at 16 Mile rainfall	4-Feb-77	23-Apr-86	2165101	5606499	610	NIWA
Shotover Branches	1-May-73	30-Apr-13	2172210	5598258	503	NIWA
Glenorchy School	1-May-53	1-Jun-78	2145188	5585113	311	NIWA
Glenorchy	1-Mar-29	30-Nov-44	2146636	5583303		NIWA
Manuherikia at Forks	10-Dec-98	11-Mar-04	2265001	5600599	700	NIWA
Big Stm at Mt Allan rainfall	18-Oct-95	2-Sep-98	2305601	5490399	80	NIWA
Sutton Stream at Old Road	10-Mar-88	22-Dec-93	2283200	5508436	210	NIWA
Clutha at Mt Horn	15-Aug-89	15-Jun-94	2216902	5565332	1100	NIWA
Clutha at Brewery Ck	17-Aug-89	15-Jun-94	2214811	5564655	777	NIWA
Clutha at Tunnel	4-Aug-89	14-Jun-94	2214653	5563281	305	NIWA
Clutha at Ridge Top	18-Aug-89	14-Jun-94	2212287	5562691	580	NIWA
Clutha at K2	1-Sep-89	16-Jun-94	2220362	5560914	735	NIWA
Clutha at Dam Site	21-Jul-89	13-Jun-94	2218901	5552399	380	NIWA
Clutha at Sonara Ck	28-Nov-91	6-May-94	2220373	5565484	1432	NIWA
Clutha at Fairfax Spur	28-Nov-91	6-May-94	2220373	5565484	1432	NIWA
Kawarau at Above Sargoods Weir	22-Dec-92	24-Dec-96	2205077	5567226	430	NIWA
Gimmerburn at Garabaldi	26-Mar-69	12-Jan-94	2263394	5557191	792	NIWA

Name	Start date	End date	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Recording authority
Gimmerburn at Dougherty's Gorge	10-Aug-71	12-Jan-94	2266838	5558897	480	NIWA
Fraser at Dam	22-Oct-71	21-Jan-94	2212301	5547299	560	NIWA
Clyde EWS	31-Dec-95	12-Oct-12	2220517	5549165	171	NIWA
Alexandra CWS	16-Nov-08	23-Feb-21	2226806	5544279	140	NIWA
Manorburn at Manorburn	6-Aug-69	23-Dec-74	2230801	5545599	106	NIWA
Fraser at Old Workings	11-May-72	29-Sep-87	2207492	5539024	1255	NIWA
Small Burn at Manorburn No 4	25-Feb-74	27-Jan-76	2246001	5532399	786	NIWA
Small Burn at Manorburn No 10	15-Jan-74	27-Jan-76	2246401	5532899	848	NIWA
Sentinal Ck at Speargrass	20-Mar-80	17-Jan-86	2266774	5510256	869	NIWA
Taieri at Elliots Auto	1-Oct-68	15-Aug-72	2262508	5518959	616	NIWA
Loganburn at Loganburn Reservoir	13-Mar-87	29-Nov-90	2269684	5516432	820	NIWA
Elbow Ck at Plateau Tipping Bucket	14-May-86	27-Oct-89	2255851	5496900	1042	NIWA
Deep Stream at Longstone	10-Oct-68	4-Feb-97	2263701	5504299	981	NIWA
Deep Stm at Trig H	16-Jan-69	26-Apr-74	2256174	5494072	549	NIWA
Tussockburn at Old Dam	27-Mar-80	28-Jan-86	2257696	5485321	725	NIWA
Deep Ck at Gulch	20-Jan-81	13-Jan-94	2258957	5497046	1061	NIWA
Deep Ck at Gulch Tipping Bucket	14-May-86	27-Oct-89	2258957	5497046	1061	NIWA
Anonymous Ck at Mahinerangi rainfall	10-Feb-82	28-Jan-86	2276801	5484599	390	NIWA
Nobles Stm at Easons	31-Dec-70	6-Feb-94	2282349	5444780	150	NIWA
Kintore CK at Kintore Ck Weir	6-Jan-82	11-Jan-94	2276200	5460620	245	NIWA
Waikoura at Marchwood	30-Oct-84	28-Jun-94	2339301	5582899	205	ORC
Matukituki at Raspberry Flat	21-Jan-15	26-May-17	2173202	5624763	370	ORC
Lindis at Tarras - The Point	2-Mar-97	1-Jan-98	2230400	5590298	280	ORC

Name	Start date	End date	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Recording authority
Lauder Station	1-Jan-87	29-Feb-00	2251100	5581099	480	ORC
Manuherikia at Waldrons	25-Jun-92	10-Aug-92	2260001	5578999	0	ORC
Kye Burn at Glenshee Station	2-Nov-90	31-Jul-93	2291700	5570598	515	ORC
Crestlo, Fushia Creek	1-Feb-53	18-Mar-02	2328300	5566399	268	ORC
Mt Dasher	8-Aug-87	1-Aug-92	2324801	5570499	382	ORC
Shag at Glendale Station	2-Jan-92	1-Sep-97	2312146	5535371	550	ORC
Deepdell Ck at Deepdell Ck	19-Mar-90	25-Sep-01	2307801	5536299	360	ORC
Taieri at Kilmory, Lug Creek	2-Jul-87	1-Jan-92	2290375	5476528	350	ORC
Taieri at Depot Mosgiel	1-Jun-62		2302001	5478299	15	ORC
Horne Creek at Skyline	2-Aug-87	1-Apr-94	2167341	5566653	735	ORC
Rastusburn at Remarkables Ski Area	2-Jan-88	1-Oct-90	2176924	5567369	790	ORC
Manuherikia at Tiger Hill	2-Mar-00	1-Feb-02	2239571	5563884	0	ORC
Manuherikia at Larkhill	5-Nov-11	17-Mar-16	2244954	5563513	0	ORC
Taieri at Puketoi	2-Feb-91	1-Jan-96	2272901	5544599	460	ORC
Pomahaka Rainomatic at Moa Flat	2-Mar-00	2-Jun-04	2216514	5492015	580	ORC
Waiwera at Kuriwao	2-Oct-87	1-May-90	2235742	5439583	330	ORC
Frasers Creek at Remote	2-Sep-87	1-Dec-93	2267300	5441599	100	ORC
Waipahi at The Cairn	10-Apr-90	15-Jan-20	2219401	5428599	230	ORC
Glenomaru at Bushy Park	28-Jul-05	28-Mar-06	2253020	5418951	0	ORC
Silverstream at Taieri Depot	22-Jan-70	11-Jun-13	2302074	5478314		ORC
Wilkin Valley	1-Aug-71	1-Jun-73	2185497	5650330	488	Other
The Divide	1-Oct-34	28-Feb-35	2125348	5585860	530	Other
Haast Pass Road	1-Feb-37	31-Aug-44	2215125	5673968		Other
Kiwi Camerons Flat	1-Feb-38	31-May-44	2214098	5666470	341	Other
Dansey Pass Hotel	1-Aug-72	30-Nov-87	2295888	5576234	625	Other
Dansey Pass	1-Dec-61	1-Nov-86	2302210	5580885	935	Other

Name	Start date	End date	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Recording authority
Livingstone Sub Stn	1-Aug-72	1-Oct-78	2323383	5583077	305	Other
Oamaru Airport	1-Dec-42	8-Nov-12	2358757	5579536	30	Other
Mt Aspiring Hut	1-Jul-55	1-Aug-90	2165216	5627155	457	Other
Mt Aspiring	1-Jun-49	1-Aug-90	2176100	5629277	335	Other
Treble Cone Ski Anem	1-May-81	31-Jan-87	2184395	5609892	1750	Other
Routeburn Falls Hut	1-Mar-71	1-Aug-90	2129804	5597699	914	Other
Earnslaw	1-Dec-47	30-Jun-15	2146098	5595737	335	Other
Skippers, Mt aurum stn	1-Jul-49	1-Jan-76	2168674	5587058	564	Other
Branches Cabin	1-Jan-56	23-Nov-91	2171551	5586540	501	Other
Coronet Peak Ski Anem	1-Jul-83	31-Jan-87	2173600	5579080	1645	Other
Macetown	01 Jan 1894	31-Jan-03	2180894	5583348		Other
Cardrona Ski Area	1-Jun-82	31-Dec-93	2189722	5585569	1798	Other
Arthurs Point	1-Jan-66	1-Nov-11	2168434	5570577	607	Other
Arrowtown, Douglas	1-May-66	31-Dec-70	2176717	5573789	375	Other
Coronet Peak Skifield	1-May-83	31-Dec-93	2173820	5577868	1220	Other
Arrowtown, Zelkova	9-Apr-92	1-May-00	2178433	5575768	413	Other
Shotover at Middletons	21-May-85	1-Nov-95	2172199	5571035	355	Other
Arrowtown	1-Jul-27	1-Jan-91	2180189	5576970	360	Other
Craigroy Arrowtown	1-Jan-16	1-Sep-16	2181085	5579575		Other
Makarora No 2	1-Jan-56	31-Dec-60	2206704	5653121	290	Other
Upper Makarora	1-Jul-53	1-Mar-58	2209164	5657016	317	Other
Makarora No 1	1-Aug-24	31-May-30	2209164	5657016	305	Other
Mt Albert Stn	1-Jun-72	1-Jul-73	2207637	5657168	320	Other
Makarora South	1-Sep-30	1-Jan-56	2206872	5649458	296	Other
Hunter Valley	1-Nov-47	1-Dec-58	2224330	5646568	331	Other
Bendigo	1-Mar-53	1-Apr-55	2216779	5636894	341	Other
Hunter Valley 2	1-Nov-47	31-Aug-19	2216077	5634750	360	Other
Glendhu Station	1-Aug-52	1-Apr-66	2192907	5607974	290	Other

Name	Start date	End date	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Recording authority
Wanaka Station	1-Jan-11	31-Dec-35	2200911	5606578		Other
Albert Town	1-Dec-70	31-Aug-72	2208038	5606911	293	Other
Lake Hawea	1-Mar-55	1-Sep-09	2211718	5614977	350	Other
Maungawera	1-Oct-15	30-Apr-44	2217932	5611031		Other
Morven Hills	1-Apr-52	1-Sep-96	2232727	5612230	442	Other
Wanaka	1-Feb-30	1-Sep-90	2204668	5604307	314	Other
Mt Barker	1-Jun-47	1-Feb-11	2207679	5602667	305	Other
Luggate	1-Jun-13	28-Feb-06	2214634	5601428	295	Other
Wanaka Aero	1-Aug-83	31-Mar-86	2212616	5602227	360	Other
Wanaka Airport	14-Jul-04	31-Oct-20	2212447	5602441	348	Other
Lagoon Valley	1-Jan-49	1-Sep-64	2216834	5605420	335	Other
Willowbank	1-Nov-53	1-Jul-63	2218591	5596267	305	Other
Lindis Pass	1-Nov-47	31-Aug-48	2231323	5606053	305	Other
Merrivale	1-May-53	1-Jun-63	2234169	5602504	335	Other
Cardrona	1-Jun-27	31-Dec-14	2195579	5585520	518	Other
Lochar	1-Apr-47	1-Apr-56	2216402	5585046		Other
Queensbury EWS	31-Oct-78	1-Jul-08	2217701	5586199	277	Other
Queensbury Nzms	31-Jan-83	31-May-92	2219880	5586870	213	Other
Tarras	1-Jan-02	1-Aug-86	2227532	5590987	290	Other
St Bathans	01 Jun 1892	1-Nov-31	2257141	5588530		Other
St Bathans 2	1-May-73	1-Nov-80	2257881	5587780	625	Other
St Bathans 3	1-Jul-89	31-May-00	2258991	5587711	640	Other
St Bathans, Post Office	5-May-00	1-Dec-10	2258024	5587856	585	Other
Upper Meg Power Stn	1-May-53	30-Apr-14	2199267	5572904	518	Other
Mt Pisa Station	1-Jun-08	31-May-24	2215310	5581215		Other
Bendigo 1	1-May-55	1-Jul-79	2219017	5583161	202	Other
Bendigo 2	1-May-78	1-Jul-08	2218293	5579512	200	Other
Bendigo Stn	1-Oct-75	31-Jul-90	2222831	5575544	874	Other

Name	Start date	End date	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Recording authority
Mount Moka	1-Jan-75	31-Mar-75	2228904	5575698	1215	Other
Thomsons Saddle A	1-Jan-74	31-Dec-74	2232106	5576503	810	Other
Thomsons Saddle B	1-Oct-75	30-Apr-78	2231679	5577263	890	Other
Cambrian	1-Jan-36	1-May-73	2253336	5584712	549	Other
Manuherikia Dam	1-Mar-32	29-Feb-36	2262641	5583180		Other
Blackstone Hill	1-Dec-15	30-Jun-07	2266287	5580759	637	Other
Oturehua	1-Feb-17	1-Feb-74	2268580	5576396	549	Other
Wedderburn 2	1-Apr-86	1-Jan-88	2273990	5570812	550	Other
Wedderburn	1-Jul-57	1-Dec-83	2273096	5571558	549	Other
Naseby	1-May-08	1-Sep-65	2285412	5571103	600	Other
Naseby Forest 1	1-Jan-23	1-Apr-83	2280684	5571050	610	Other
Naseby Forest 2	1-Oct-83	15-Mar-17	2284764	5571636	607	Other
Kyeburn Diggings	1-Aug-52	1-Feb-77	2294568	5573189	518	Other
Windsor, Arnmore	1-Jun-08	29-Feb-20	2336511	5576321		Other
Oamaru, Elderslea	01 Jan 1893	30-Jun-08	2339207	5572723		Other
Oamaru, Windsor park	01 Jan 1892	30-Apr-08	2343101	5574601		Other
Weston	1-Sep-73	1-Sep-83	2343466	5566384	92	Other
Enfield	1-Jun-77	1-Oct-99	2341373	5571222	107	Other
Windsor M.a.f.	1-Aug-81	1-Dec-85	2337900	5574467	88	Other
Oamaru	01 Jul 1866	1-Feb-66	2351157	5567463	46	Other
Oamaru, Parkside	1-Aug-81	31-Jan-86	2344678	5568304	180	Other
Oamaru, Spey st	28-Feb-82	31-Jan-94	2350937	5566791	5	Other
Ranfurly, Eweburn	01 Jan 1897	1-Jan-23	2280464	5561591	423	Other
Gimmerburn Edl	31-Dec-81	2-Apr-86	2278067	5553722	369	Other
Ranfurly	1-Mar-43	1-Jan-01	2282020	5559866	424	Other
Waipiata	1-Aug-15	30-Jun-93	2286028	5555446	360	Other
Ranfurly Maniototo	1-Mar-75	1-Jan-90	2281678	5560633	427	Other
Kyeburn	1-Sep-68	1-May-75	2293867	5558601	396	Other

Name	Start date	End date	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Recording authority
Kauru, The Dasher	1-Jan-36	31-Jan-13	2327409	5556498	549	Other
Maheno	1-Apr-49	1-Jan-57	2334305	5561477	76	Other
Kauru Hill Maheno	01 Sep 1890	30-Apr-30	2334207	5565143		Other
Kanohi	1-Aug-60	31-Dec-60	2335710	5555955	101	Other
Kuriheka	1-Jan-13	31-Dec-51	2339592	5557836		Other
Totara Stn	1-Apr-08	1-Sep-29	2342168	5561682		Other
Waimotu	1-Feb-61	28-Feb-62	2337046	5555991	46	Other
Kauru Hill, Balruddery	1-Apr-14	31-May-19	2344672	5565414		Other
Oamaru 2	21-Nov-91	23-Nov-91	2349943	5565544		Other
Patearoa 2	1-Jan-27	1-Jul-76	2276929	5550346	381	Other
Puketoi Stn	1-Jan-15	31-Dec-28	2276929	5550346	442	Other
Diamond Hill Station	1-Aug-76	1-Nov-81	2274569	5552596	381	Other
Waipiata 2	1-Jan-25	1-Oct-66	2285805	5548211	472	Other
Waipiata, Station view	1-Jan-14	30-Nov-28	2282251	5548755		Other
Waipiata, The beeches	1-Jan-22	31-Dec-28	2283650	5546913		Other
Kokonga	01 Jan 1893	31-Dec-17	2293901	5552820		Other
Ivybridge	1-Jul-62	1-May-82	2297694	5547385	366	Other
Herbert	1-Dec-58	1-Feb-60	2334092	5551799	107	Other
Herbert Forest	1-Jul-66	1-Jan-90	2335183	5549160	61	Other
Rock And Pillar A	1-Sep-74	31-Dec-76	2280970	5540481	980	Other
Rock And Pillar B	1-Jun-75	30-Apr-77	2281487	5539165	1090	Other
Glendale Station	1-Jan-61	30-Apr-13	2312122	5535162	550	Other
Golden Point Otago	1-Aug-85	1-Jan-89	2309037	5536069	488	Other
Shag Valley	1-Jan-15	31-Dec-60	2317842	5540558		Other
Moeraki Est Hampden	01 Jan 1895	31-Dec-42	2340167	5535615		Other
Rock & Pillar	29-Apr-78	2-Dec-79	2281102	5527809	1350	Other
Robertslee	1-Jul-19	1-Mar-53	2285671	5524743	274	Other
Kilmory Lug Creek	1-Jan-72	1-Mar-94	2286009	5526312	343	Other

Name	Start date	End date	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Recording authority
Nenthorn	1-Apr-69	1-Jul-08	2301180	5524369	360	Other
Stoneburn	1-Apr-69	31-Aug-78	2318275	5525783	396	Other
Stoneburn Cloverdowns	1-May-87	1-May-09	2316385	5526172	260	Other
Appin	1-Aug-45	1-Jan-81	2325491	5530771		Other
Bushey Park	1-Jan-08	1-Jul-79	2336214	5522170	91	Other
Moeraki Lighthouse	1-Oct-35	1-Jun-75	2342669	5532789	43	Other
Middlemarch, Gladbrook 1	01 Jan 1894	1-Jul-19	2282391	5515622	223	Other
Middlemarch, Gladbrook 2	01 Jan 1897	31-Dec-06	2279873	5513865	320	Other
Middlemarch, Garthmyl 2	1-Jan-31	1-Jan-51	2284679	5517258	202	Other
Middlemarch, Garthmyl	01 Jan 1896	28-Feb-15	2286124	5516996	200	Other
Hummock Run	1-May-69	1-Jul-73	2309889	5513411	533	Other
Palmerston, Mt royal	1-Apr-50	1-Jul-71	2328829	5520524	15	Other
Centrewood	1-Jan-12	1-Aug-97	2335058	5518581	90	Other
Waikouaiti	1-Feb-41	1-Sep-58	2327889	5509379	8	Other
Cherry Farm Hospital	1-Jan-61	1-Jan-90	2324488	5508172	6	Other
Hindon Farm	1-Jan-67	1-Oct-81	2291789	5491812	455	Other
Pinewood	1-Jun-61	30-Nov-11	2296401	5493634	351	Other
Hindon	1-Nov-47	1-Jun-73	2303622	5496758	351	Other
Mt Allen	1-Jun-60	31-Aug-60	2302313	5493825	84	Other
Hindon, Ardachy	1-Jun-73	31-Jan-17	2302897	5495067	120	Other
Orokonui Waitati	1-Jul-04	31-Dec-10	2320490	5492712	3	Other
Waitati Upper	1-Nov-70	1-Oct-76	2318863	5489773	117	Other
Evansdale	31-Jan-91	20-Aug-99	2320795	5495612	1	Other
Warrington	1-Jul-67	1-Nov-86	2322559	5496552	15	Other
Mopanui	1-Jul-81	31-Dec-81	2323512	5490463	380	Other
Aramoana Ridge No 2	1-Dec-81	31-May-82	2329527	5489632	200	Other
Aramoana Ridge No 1	1-Apr-81	1-May-82	2329979	5490200	235	Other
Taiaroa Head	1-Apr-35	15-Nov-02	2333179	5489843	72	Other

Name	Start date	End date	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Recording authority
Deep Stream (doc)	10-Jul-03	1-Aug-06	2264586	5492507	700	Other
Eighty Ck at School Rd	13-Feb-79	28-Jan-86	2284101	5488799	455	Other
Invermay, Taieri	1-May-39	1-Sep-79	2304930	5480007	24	Other
Mosgiel	1-May-16	29-Feb-24	2304164	5477203		Other
Salisbury, Tara hills	1-Jun-72	1-Sep-72	2303533	5484856	183	Other
Invermay, Taieri 2	29-Feb-76	1-Jan-86	2306807	5479621	30	Other
Invermay Edr	1-Apr-85	17-Oct-94	2306807	5479621	30	Other
Dunedin	1-Jan-41	22-Nov-91	2314431	5479299	213	Other
Whare Flat	1-Aug-07	31-Mar-93	2310083	5484282	158	Other
Dunedin, Balaclava	31-Dec-75	31-Dec-15	2313273	5476484	140	Other
Dunedin, Princes Street	01 Nov 1852	31 Jul 1864	2315751	5479339	15	Other
Ross Creek	1-Apr-29	1-Jul-10	2315218	5481547	165	Other
Sullivans Dam	1-Jan-50	28-Feb-14	2317426	5485727	300	Other
Dunedin, Opoho	01 Jan 1889	31-Jul-21	2317070	5479378	117	Other
Dunedin, Roslyn	01 Oct 1862	1-Mar-28	2315694	5481227	168	Other
Dunedin, Beta st	1-Apr-38	1-Dec-47	2315751	5479339	210	Other
Dunedin, Leith Valley	01 May 1886	1-Feb-13	2315694	5481227	94	Other
Mt Cargill Bcnz	1-Aug-69	31-Aug-91	2319773	5485240	676	Other
Mt Cargill	1-Jun-75	31-Dec-77	2319693	5485349	666	Other
Mooyman Homestead	1-Aug-71	1-Oct-99	2317794	5481179	60	Other
Signal Hill	1-Jun-75	31-Dec-77	2320204	5481138	386	Other
Dunedin, Irl Uv	31-Dec-08	30-Sep-12	2316784	5479406	10	Other
Dunedin, Irl Uv 2	22-Jun-12	30-Sep-15	2316784	5479406	10	Other
Sawyers Bay	1-Jul-21	1-Jan-81	2323089	5486226	67	Other
Portobello	1-Jan-06	1-Feb-59	2327288	5483453	12	Other
Highcliff	1-May-55	1-Apr-71	2323030	5477439	322	Other
Dunedin, Broad bay	1-Jan-70	1-Nov-01	2325623	5481850	3	Other
Sawyers Bay Sewage Pl	1-Jun-80	1-Dec-00	2323914	5484581	3	Other

Name	Start date	End date	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Recording authority
Sandfly Bay	1-May-75	31-Aug-75	2327630	5476791	66	Other
Sandy Mount	1-Jun-75	31-Mar-77	2328803	5476490	252	Other
Port Otago Wind	9-Sep-02	24-Sep-10	2316796	5478146	15	Other
Harbour Services Superintendent	9-Sep-02	24-Sep-10	2316796	5478146	15	Other
Cape Saunders Light	1-Oct-35	1-May-80	2333494	5478175	52	Other
Cape Saunders	1-Mar-75	31-Mar-80	2333488	5478397	81	Other
Berwick Forest	1-Dec-47	1-Mar-87	2283094	5466712	18	Other
Waipori Falls	1-Jan-30	1-Jun-43	2277078	5474395	213	Other
Taieri at Jura Rd	22-May-78	14-Jul-87	2277429	5465087	215	Other
Henley	1-Jun-61	1-Jun-87	2290486	5465966	5	Other
Dunedin Aero	1-Nov-62		2292387	5471702	1	Other
Kaikorai Estuary	1-Aug-74	31-Mar-76	2308906	5474571	12	Other
Burnside	1-Sep-16	1-Jan-89	2312281	5475898	43	Other
Green Island	1-Aug-68	31-Aug-91	2309590	5475037	18	Other
Dunedin, Musselburgh	1-Jan-18	1-Sep-97	2316882	5475258	2	Other
John Wilson Drive	1-Jul-69	31-Aug-70	2317984	5474734	23	Other
Maori Head	1-Feb-65	31-Jan-66	2321015	5474600	57	Other
Kaikorai at Headquarters	1-Jan-75	29-Dec-86	2311269	5475455	15	Other
Oamaru, Pukeuri	1-Sep-16	31-Aug-23	2354962	5573112		Other
Oamaru, Iona hospital	1-Feb-66	1-Apr-75	2351994	5568706	14	Other
Von River	1-Dec-49	31-Jul-52	2150571	5559483	366	Other
Mt Creighton	1-May-18	31-Oct-22	2150060	5568692		Other
Frankton	1-Nov-20	1-Nov-55	2172516	5568008	338	Other
Frankton Aero	1-Apr-53	1-May-56	2175113	5568143	349	Other
Kawarau Falls	1-Feb-62	1-Mar-82	2173541	5566504	320	Other
Queenstown Aero	1-Sep-68	N/A	2173973	5567305	349	Other
Queenstown Aero New	1-Aug-87	31-Oct-88	2175482	5559483	375	Other

Name	Start date	End date	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Recording authority
Remarkables Ski Area	1-Jun-85	31-Dec-93	2180382	5563851	1645	Other
Remarkables Sugarbowl	21-Nov-91	31-Dec-93	2181303	5564343	1860	Other
Gibbston, Loop rd	1-Sep-52	1-Jan-85	2191139	5566392	533	Other
Gibbston Nevis Bluff	1-Oct-84	1-Jul-87	2193269	5566385	366	Other
Cecil Peak	1-Jun-65	1-Apr-79	2163800	5558313	351	Other
Wye Creek	1-Jan-53	1-Apr-81	2176513	5554752	335	Other
Halfway Bay	1-Feb-67	1-May-69	2170905	5547561	305	Other
Staircase Creek	1-Nov-47	30-Sep-48	2176449	5542286	326	Other
Lower Nevis	1-Jan-48	30-Nov-50	2193368	5545029	442	Other
Kingston	1-Oct-29	31-May-12	2174689	5532292	310	Other
Roaring Lion Hut	1-Jan-55	23-Nov-91	2183702	5527858		Other
Waitiri Stn	1-Jan-61	1-Jan-68	2197566	5565592		Other
Ripponvale	1-Sep-25	1-Apr-61	2206772	5566028	232	Other
Cromwell Sub Stn	1-Apr-76	1-Mar-88	2209902	5564839	213	Other
Cromwell Anem	1-Aug-76	1-Nov-84	2211292	5568907	204	Other
Cromwell M.w.d.	1-Jun-49	1-Feb-89	2210236	5567857	213	Other
Cromwell Gorge	1-Mar-73	1-Mar-77	2215378	5562308	183	Other
Northburn	31-Oct-78	1-Jul-08	2213088	5571008	210	Other
Cromwell 2	1-Jul-84	1-Aug-07	2210236	5567857	213	Other
Lauder	1-Oct-42	1-Mar-65	2248717	5567847		Other
Lauder Pel	1-Aug-81	1-Jun-86	2248913	5568856	370	Other
Lauder D.s.i.r. A	1-Jul-74	1-May-75	2248913	5568856	356	Other
Lauder D.s.i.r. B	1-Jul-75	1-Mar-78	2248593	5568955	371	Other
Becks	1-Jan-36	1-Jun-71	2253772	5573608	390	Other
Becks No 2	1-Jan-72	1-Apr-77	2252433	5573556	390	Other
Craigroy Nevis	1-Jun-52	1-Jan-87	2195378	5550578	671	Other
Clyde, Fraser st	01 Aug 1896	1-Aug-89	2220699	5550757	183	Other
Clyde	1-Jul-73	1-Dec-77	2219608	5554045	183	Other

Name	Start date	End date	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Recording authority
Clyde Dam	31-Dec-77	1-Aug-07	2220135	5551065	160	Other
Moa Creek	1-Jun-13	29-Aug-86	2247072	5551989	427	Other
Ophir 1	1-Nov-14	31-Jan-31	2242490	5560143		Other
Poolburn, Armstrong	1-Jan-59	30-Sep-62	2255584	5561558	424	Other
Poolburn, Flannery	1-Sep-61	30-Apr-71	2251679	5558735	412	Other
Poolburn Edl	1-Apr-84	31-Aug-86	2251679	5558735	412	Other
Nth Rough Ridge	1-Oct-74	31-Jan-78	2262471	5560600	1007	Other
Doughertys	3-Apr-69	31-Jan-81	2268603	5558717	450	Other
Fraser Dam 1	1-Mar-36	30-Nov-37	2212894	5547734		Other
Fraser Dam 2	1-Nov-75	30-Jun-78	2214496	5548808	599	Other
Earnscleugh	1-May-18	31-May-48	2220740	5548089	183	Other
Earnscleugh D.s.i.r.	1-Apr-47	1-Apr-83	2222015	5545921	152	Other
Conroys Gully	1-Apr-51	1-Mar-61	2219654	5542479		Other
Alexandra 1	1-Jan-22	1-Oct-83	2226588	5543787	141	Other
Clyde, Earnscleugh	31-Jan-83	1-Jun-96	2220376	5549185	171	Other
Alexandra Aero	1-Jul-67	1-Jul-96	2224972	5548387	218	Other
Alexandra, Theyers St	1-Oct-83	31-Jan-94	2225941	5544203	141	Other
Alexandra, Bridge Hill	10-Apr-00	1-Jul-09	2226387	5542999	160	Other
Galloway 2	1-Jan-22	1-Jun-83	2232481	5549269	177	Other
Galloway 1	01 May 1898	30-Apr-18	2232509	5548603		Other
Obelisk	1-Feb-79	31-Jul-90	2212488	5536035	1689	Other
Fruitlands	1-Jun-52	1-Jan-62	2219983	5535152	335	Other
Manorburn Dam	1-Mar-13	1-Mar-81	2244082	5532849	746	Other
Patearoa	1-Jan-12	30-Nov-28	2272155	5539053		Other
Stony Creek	1-Jan-82	30-Jun-84	2267313	5540543	408	Other
Roxburgh Power Stn	1-Jan-48	1-Jan-88	2221812	5518770	110	Other
Coal Creek Mt Benger	1-Oct-46	1-Jan-74	2220565	5522163	244	Other
Rocky Peak	1-Mar-75	31-Jul-78	2266205	5528268	728	Other

Name	Start date	End date	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Recording authority
Paerau	1-Aug-08	1-Mar-51	2271231	5527899	594	Other
Roxburgh East	1-Jan-21	1-Oct-84	2222490	5512349	119	Other
Roxburgh	01 May 1892	1-Oct-00	2222119	5511887	97	Other
Roxburgh East Wind	1-May-77	1-Apr-79	2223987	5512081	295	Other
Teviot River	1-Feb-20	31-May-20	2231279	5515181		Other
Lake Onslow	1-Jan-36	31-Dec-61	2240717	5508240		Other
Mount Teviot	1-Feb-76	31-Jul-90	2239598	5506970	967	Other
Lake Onslow 2	1-May-69	22-Nov-91	2243868	5511374	716	Other
Lake Onslow Auto	31-Oct-85	31-Dec-13	2243703	5511590	695	Other
Onslow Wind	21-Dec-05	24-Sep-10	2249311	5516289	890	Other
Great Moss Swamp	1-Oct-09	30-Jun-31	2261255	5516403		Other
Rocklands Trig P	22-Nov-91	22-Nov-91	2265328	5509996	936	Other
Rocklands Site A	1-Sep-74	31-Mar-78	2268268	5508661	813	Other
Rocklands Site B	1-Jul-75	31-Mar-78	2268301	5507772	843	Other
Daws Spur	1-Sep-62	1-Aug-88	2208837	5498375	724	Other
Fruitvale Ettrick	1-Mar-16	30-Nov-16	2226776	5500191		Other
Ettrick No.1	1-May-83	1-Jul-89	2226392	5501842	83	Other
Millers Flat	1-Nov-48	1-May-75	2229428	5498415	82	Other
Tima, Derry Downs	1-Dec-70	1-May-90	2231381	5501949	250	Other
Deep Stream 1	1-Jul-36	1-Jan-62	2273574	5500182	366	Other
Deep Stream 2	1-Sep-59	31-Jul-12	2274729	5498444	366	Other
Deep Stream M.a.f.	1-Oct-81	1-Jul-86	2274500	5498325	396	Other
Rocklands V (ii)	1-Sep-75	31-Jul-90	2272698	5500706	582	Other
Rocklands Trig (iii)	1-Dec-78	31-Jul-90	2272620	5500703	592	Other
Heriot, Hukarere stn	1-Jan-45	31-Dec-60	2209077	5488262	244	Other
Wilden No 1	1-Jan-63	1-May-88	2214632	5489410	427	Other
Moa Flat	1-Jan-36	1-Oct-80	2220712	5487573	410	Other
Shelleys	1-Jan-77	22-Nov-91	2220970	5487028	406	Other

Name	Start date	End date	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Recording authority
Wilden	22-Nov-91	22-Nov-91	2225943	5489029		Other
Edievale 2	31-Jan-89	1-Nov-04	2227667	5483271	270	Other
Sunnyvale Orchard	1-May-16	30-Apr-18	2235037	5489424		Other
Beaumont	1-May-30	28-Feb-34	2250585	5490069		Other
Kelso, The Holt	1-Feb-61	1-Feb-03	2212193	5474834	180	Other
Edievale	1-Nov-20	30-Apr-24	2222305	5483305		Other
Raes Junction	1-May-37	31-Oct-01	2233703	5486030	152	Other
Beaumont N.z.f.s.	1-Dec-39	1-Apr-87	2236897	5476822	46	Other
Caversham	01 Jul 1898	1-Oct-05	2239391	5478485		Other
Waipori Township	1-May-30	31-Jan-41	2267725	5481503		Other
Mahinerangi Dam	1-Jun-43	1-Apr-90	2275070	5476213	396	Other
Tapanui	01 May 1897	31-Dec-20	2219690	5467167	180	Other
Kelso, Toropuke stn	1-May-18	31-May-19	2217608	5471968		Other
Rankleburn Forest	1-Mar-62	1-Dec-80	2233936	5464347	255	Other
Lawrence	1-Dec-17	31-Dec-90	2252730	5471468	122	Other
Waitahuna	1-Aug-55	1-Dec-73	2258051	5464448	101	Other
Waipori Weir	1-Jan-11	31-Dec-29	2275828	5472459	381	Other
Browns Block	1-Jun-75	30-Sep-75	2272486	5468333	518	Other
Milburn	1-Aug-57	31-Dec-63	2279124	5454114	29	Other
Waihola	1-Jan-61	1-Jul-01	2283501	5461721	30	Other
Taieri Mouth	1-Nov-64	1-Apr-87	2292707	5455253	15	Other
Glenledi	1-Apr-57	31-Aug-59	2282580	5443892	122	Other
Nobles Stm at Ruarekau Rd	9-Jun-70	27-Oct-83	2280311	5446300	180	Other
Akatore	1-Feb-57	31-Oct-64	2289786	5445588	24	Other
Bull Creek	1-Sep-65	1-Dec-71	2285895	5444120	171	Other
Toko Mouth	1-Jan-59	1-Jan-60	2280890	5439272		Other
Cook Rock	1-Sep-59	31-Aug-65	2284680	5441297	82	Other
Chrystalls Beach	1-Nov-65	1-Oct-83	2285513	5441771	30	Other

Name	Start date	End date	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Recording authority
Conical Hill	1-Dec-52	31-Dec-80	2218984	5453673	104	Other
Tuapeka Mouth	1-Nov-48	20-Oct-11	2243230	5459067	116	Other
Clydevale	1-Jul-07	1-Jan-71	2243260	5447165	24	Other
Greenfield	1-Jul-07	1-Jul-46	2245657	5450935		Other
Pukekoma	1-Jan-30	31-Mar-44	2257246	5451402		Other
Milton	1-Dec-29	1-Jan-86	2275693	5450542	18	Other
Clinton	1-Nov-29	31-Jul-52	2230692	5439175	122	Other
Clinton P.o.	1-Jul-56	1-Jan-88	2230099	5438593	122	Other
Kuriwao	1-Nov-65	1-Jan-93	2229879	5434800	625	Other
Clinton School	1-Oct-83	1-Dec-94	2230538	5439168	120	Other
Warepa	1-Sep-67	31-Mar-06	2248188	5432572	70	Other
Te Houka	1-Nov-70	1-Dec-11	2252083	5437402	82	Other
Balclutha Post Office	01 Apr 1890	1-May-55	2257827	5436629	6	Other
Telford Farm	1-Dec-75	31-Jul-77	2258179	5429635	11	Other
Kaitangata 2	1-Jan-53	1-Nov-57	2267056	5431423	5	Other
Kaitangata	01 Aug 1894	31 Dec 1899	2266989	5433200		Other
Lovells Flat	1-Oct-59	31-Oct-15	2267372	5441446	91	Other
Lochindorb	1-Feb-57	1-Aug-02	2242424	5424657	198	Other
Romahapa	1-Jul-59	30-Nov-60	2258337	5423633		Other
Inchclutha	1-Oct-58	1-Jul-69	2264424	5429654	6	Other
Mokoreta	2-May-31	1-Jan-18	2206266	5413662	109	Other
Owaka	1-Jul-13	1-Jan-88	2253024	5412075	12	Other
Owaka Valley	1-Dec-54	1-Jun-80	2247595	5415080	37	Other
Ratanui	01 Oct 1895	31-Jan-04	2251244	5408554		Other
Owaka 2	1-Mar-75	1-Jan-90	2253331	5412087	5	Other
Nugget Point	1-Jan-30	1-Apr-89	2264681	5412866	129	Other
Nugget Lighthouse B	1-Mar-75	31-Aug-77	2264605	5412863	112	Other

Name	Start date	End date	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Recording authority
Nugget Lighthouse A	1-Mar-75	31-Aug-77	2264835	5412871	123	Other
Tahakopa, Linklater	1-Jul-71	1-Oct-81	2228982	5406166	58	Other
Tahakopa, Wharuarimu	1-Apr-14	31-Jan-42	2233450	5405916		Other
Papatowai	1-Mar-69	1-Sep-98	2239116	5399149	18	Other
Papatowai, Fleming	1-Jan-71	1-Nov-80	2235075	5396751	26	Other
Tautuku	1-Apr-76	N/A	2237176	5397601	25	Other
Hawea at Camphill Farm	2-Feb-12	5-Aug-16	2212700	5609499	0	
Geordie Hill	2-May-87	1-Jan-95	2235282	5606335	455	
Branch Burn at Cardrona Valley	22-Apr-90	1-Jan-08	2197804	5590095	0	
Shag at Goodwood	2-Jun-89	1-Aug-92	2334100	5518699	70	

Appendix H Closed climate sites in the ORC region

Table H-1: List of all closed climate sites in the Otago region.

Total number of sites, 66. The list below does not include climate sites temporarily installed as a part of Grow Otago campaign launched in early in 2000.

Name	Start date	End date	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Recording authority
Glenledi RAWS	31-Dec-94	17-May-19	2283205	5443716	100	FENZ
Deep Stream RAWS	31-Dec-94	3-Feb-14	2264743	5492476	862	FENZ
Waitati AWS	30-Sep-10	20-Jul-16	2319943	5490988	35	MetService
Glenorchy Ranger Stn	22-Nov-91	31-Jul-90	2145797	5584146	330	NIWA
Clyde EWS	31-Dec-95	12-Oct-12	2220517	5549165	171	NIWA
Alexandra CWS	16-Nov-08	23-Feb-21	2226806	5544279	140	NIWA
Livingstone Sub Stn	1-Aug-72	1-Oct-78	2323383	5583077	305	Other
Treble Cone Skifield	1-May-81	31-Oct-90	2185119	5609705	1280	Other
Routeburn Falls Hut	1-Mar-71	1-Aug-90	2129804	5597699	914	Other
Cardrona Ski Area	1-Jun-82	31-Dec-93	2189722	5585569	1798	Other
Coronet Peak Skifield	1-May-83	31-Dec-93	2173820	5577868	1220	Other
Makarora Ranger Stn	22-Nov-91	31-Jul-90	2209074	5657234	330	Other
Albert Town	1-Dec-70	31-Aug-72	2208038	5606911	293	Other
Wanaka	1-Feb-30	1-Sep-90	2204668	5604307	314	Other
Wanaka Aero	1-Aug-83	31-Mar-86	2212616	5602227	360	Other
Queensbury EWS	31-Oct-78	1-Jul-08	2217701	5586199	277	Other
Bendigo 2	1-May-78	1-Jul-08	2218293	5579512	200	Other
Naseby Forest 1	1-Jan-23	1-Apr-83	2280684	5571050	610	Other
Naseby Forest 2	1-Oct-83	15-Mar-17	2284764	5571636	607	Other
Weston	1-Sep-73	1-Sep-83	2343466	5566384	92	Other
Windsor M.a.f.	1-Aug-81	1-Dec-85	2337900	5574467	88	Other

Name	Start date	End date	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Recording authority
Oamaru, Spey st	28-Feb-82	31-Jan-94	2350937	5566791	5	Other
Ranfurly Maniototo	1-Mar-75	1-Jan-90	2281678	5560633	427	Other
Oamaru 2	21-Nov-91	23-Nov-91	2349943	5565544		Other
Waipiata 2	1-Jan-25	1-Oct-66	2285805	5548211	472	Other
Herbert Forest	1-Jul-66	1-Jan-90	2335183	5549160	61	Other
Cherry Farm Hospital	1-Jan-61	1-Jan-90	2324488	5508172	6	Other
Hindon Farm	1-Jan-67	1-Oct-81	2291789	5491812	455	Other
Taiaroa Head	1-Apr-35	15-Nov-02	2333179	5489843	72	Other
Deep Stream (doc)	10-Jul-03	1-Aug-06	2264586	5492507	700	Other
Invermay, Taieri	1-May-39	1-Sep-79	2304930	5480007	24	Other
Invermay, Taieri 2	29-Feb-76	1-Jan-86	2306807	5479621	30	Other
Dunedin, Princes Street	01 Nov 1852	31 Jul 1864	2315751	5479339	15	Other
Dunedin, Irl Uv	31-Dec-08	30-Sep-12	2316784	5479406	10	Other
Dunedin, Irl Uv 2	22-Jun-12	30-Sep-15	2316784	5479406	10	Other
Berwick Forest	1-Dec-47	1-Mar-87	2283094	5466712	18	Other
Dunedin, Musselburgh	1-Jan-18	1-Sep-97	2316882	5475258	2	Other
Oamaru, Iona hospital	1-Feb-66	1-Apr-75	2351994	5568706	14	Other
Frankton Aero	1-Apr-53	1-May-56	2175113	5568143	349	Other
Remarkables Ski Area	1-Jun-85	31-Dec-93	2180382	5563851	1645	Other
Remarkables Sugarbowl	21-Nov-91	31-Dec-93	2181303	5564343	1860	Other
Gibbston Nevis Bluff	1-Oct-84	1-Jul-87	2193269	5566385	366	Other
Cromwell Sub Stn	1-Apr-76	1-Mar-88	2209902	5564839	213	Other
Cromwell M.w.d.	1-Jun-49	1-Feb-89	2210236	5567857	213	Other
Northburn	31-Oct-78	1-Jul-08	2213088	5571008	210	Other
Cromwell 2	1-Jul-84	1-Aug-07	2210236	5567857	213	Other
Lauder Pel	1-Aug-81	1-Jun-86	2248913	5568856	370	Other

Name	Start date	End date	Easting (NZMG)	Northing (NZMG)	Altitude (m above mean sea level)	Recording authority
Clyde	1-Jul-73	1-Dec-77	2219608	5554045	183	Other
Clyde Dam	31-Dec-77	1-Aug-07	2220135	5551065	160	Other
Moa Creek	1-Jun-13	29-Aug-86	2247072	5551989	427	Other
Earnscleugh D.s.i.r.	1-Apr-47	1-Apr-83	2222015	5545921	152	Other
Alexandra 1	1-Jan-22	1-Oct-83	2226588	5543787	141	Other
Clyde, Earnscleugh	31-Jan-83	1-Jun-96	2220376	5549185	171	Other
Alexandra Aero	1-Jul-67	1-Jul-96	2224972	5548387	218	Other
Alexandra, Theyers St	1-Oct-83	31-Jan-94	2225941	5544203	141	Other
Stony Creek	1-Jan-82	30-Jun-84	2267313	5540543	408	Other
Ettrick No.1	1-May-83	1-Jul-89	2226392	5501842	83	Other
Deep Stream M.a.f.	1-Oct-81	1-Jul-86	2274500	5498325	396	Other
Moa Flat	1-Jan-36	1-Oct-80	2220712	5487573	410	Other
Beaumont N.z.f.s.	1-Dec-39	1-Apr-87	2236897	5476822	46	Other
Mahinerangi Dam	1-Jun-43	1-Apr-90	2275070	5476213	396	Other
Tapanui	01 May 1897	31-Dec-20	2219690	5467167	180	Other
Rankleburn Forest	1-Mar-62	1-Dec-80	2233936	5464347	255	Other
Browns Block	1-Jun-75	30-Sep-75	2272486	5468333	518	Other
Taieri Mouth	1-Nov-64	1-Apr-87	2292707	5455253	15	Other
Milton	1-Dec-29	1-Jan-86	2275693	5450542	18	Other