Stable isotope values of precipitation in the Horizons Region

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Stable isotope values of precipitation in the Horizons Region

Current estimates and suggested methods for local maps

Prepared for Horizons Regional Council

May 2019

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Executive summary

The isotopic values of rainfall provide a source of information with a range of hydrological uses. These uses include identification of groundwater pathways, assessment of connectivity of rivers and groundwater, and calculation of catchment residence times. Horizons Regional Council (Horizons) contracted NIWA to prepare maps of the stable isotope composition of rainfall for the Horizons (Manawatu-Wanganui) region and provide advice on data collection for the development of higher-resolution maps suitable for catchment-scale hydrological studies.

For the development of high-resolution δ^2H and $\delta^{18}O$ precipitation isoscape maps for the Horizons region we recommend the following:

1. Collection of gridded climate predictor variable data across the Horizons region, as well as digital elevation model (DEM) layers. We suggest NIWA's 500 m resolution Virtual Climate Station Network (VCSN) data as suitable climate data for this task.

2. Collection of precipitation isotope samples from sites throughout the region. Sites should be selected to obtain a full range of the major predictors of variability in precipitation δ^2H and $\delta^{18}O$ values described in section 3.3.1 of this report. We suggest that monthly accumulated samples from ≥ 10 collection sites for a period of at least three years would be appropriate. Collection methods should follow the recommendations for International Atomic Energy Association (IAEA) Global Network of Isotopes in Precipitation (GNIP) sites.

3. Collection of daily predictor variable data from the sites of collection for the periods between and including all precipitation collection events. Data collected onsite are preferable for this, but interpolated VCSN data would also be suitable if onsite data is not available.

4. The methods of Salamalikis, Argiriou (2011) provide a suitable example for data analysis required for preparing precipitation isotope maps using multivariate regression and interpolation. These methods should be modified to include latitude, elevation and the full list of VCSN parameters as predictors of precipitation isotope values.

1 Introduction

Isotopic data from rainfall, surface water and groundwater offer a wealth of information of use to hydrology, ecology and food sciences. Uses include identification of groundwater pathways, calculation of connectivity of rivers and groundwater, identification of natal origins of diadromous fish, and tracing the geographical origins of organic products (Mook and Rozanski 2000; Barbieri, Boschetti et al. 2005; West, Bowen et al. 2006; Walther, Thorrold et al. 2008). Of primary interest to Horizons Regional Council (HRC) are sources and flows of water within catchments. Information on groundwater recharge, groundwater-surface water interactions, and nutrient flux and flow pathways can help when setting limits on the quality and quantity of freshwater under the National Policy Statement for Freshwater Management 2014 (New Zealand Government 2014). Understanding of sources and flows of water within catchments can be greatly aided by knowledge of spatial patterns of isotopes in precipitation.

Two of the most commonly used isotopes for tracing sources and flows of water are stable isotopes of hydrogen (^{2}H) and oxygen (^{18}O). A nationwide precipitation isoscape layer has recently been developed for New Zealand, expressing the predicted distribution of ^{2}H and ^{18}O isotopes in rainfall across the country (Baisden, Keller et al. 2016). This layer is based on relationships between isotope values from rainfall collections at 58 sites nationally and data from NIWA's virtual climate station network (VCSN). Because VCSN data extend out across the entirety of New Zealand, this method allows the extrapolation of precipitation isotope data across the country. This report includes maps of stable isotope values in precipitation across the Horizons (Manawatu-Wanganui) region based on coefficients developed by Baisden, Keller et al. (2016), using VCSN data updated to October 2018. Shapefiles of this data for oxygen and hydrogen stable isotopes are included with this report. These national precipitation isotope layers have so far not been extensively validated or refined for the Horizons region. An opportunity exists to make the layer more relevant to the catchment scale at which it will likely be used in the Horizons region by collecting further precipitation samples. Regionalized multivariate regression and interpolation mapping approaches can provide greatly improved prediction of isotopes in precipitation (Terzer, Wassenaar et al. 2013). In the second part of this short report we therefore provide recommended methods for data collection in the Horizons region, including where additional precipitation samples should be collected, collection methodology, sample storage, and processing. We also provide brief information on statistical methods to process the resulting data, including requirements for accompanying site physical and meteorological data, statistical analysis, and interpolation procedures to prepare refined regional maps.

In this report we refer to the concentrations of the heavier stable isotopes (i.e., the less common isotopes ^{18}O and ^{2}H) relative to the more common lighter isotopes (^{16}O and ^{1}H) using delta notation:

$$\delta^{H}X = \left[\left(\frac{R_{SAMPLE}}{R_{STANDARD}} - 1\right)\right]*1000$$

where the delta notation is specified for a given element *X* (e.g., hydrogen (H) or oxygen (O)), the superscript H gives the heavy isotope mass of that element (e.g., 2 or 18 for hydrogen or oxygen, respectively), and *R* is the ratio of the heavy isotope to the light isotope for that element (e.g., $^{2}H/^{1}H$ or $^{18}O/^{16}O$). The standards to which both hydrogen and oxygen stable isotope standards are compared internationally is Standard Mean Ocean Water (SMOW) for which the heavy to light isotope ratios are 0.00015576, and 0.00020052 for $^{2}H/^{1}H$ and $^{18}O/^{16}O$, respectively.

2 Current maps of precipitation isotopes for the Horizons region

Figure 2-1 and Figure 2-2 give annual weighted δ^2H and $\delta^{18}O$ values of precipitation for the Horizons region. These maps are developed from coefficients of linear models developed by Baisden, Keller et al. (2016). Predictor variables in these models are VCSN climate parameters, and response variables are δ^2H and $\delta^{18}O$ values of precipitation collected at 58 sites around New Zealand between 2007 and 2010. Further details on the methods used to develop these coefficients can be found in Baisden, Keller et al. (2016). We used VCSN data spanning the years 1997 – 2018 to prepare these maps, and data presented are annual weighted averages. The weighting step places a multiplier on the isotope value of rainfall on each day proportional to the amount of rainfall on that day, so that data presented in these figures is a spatial representation of estimated isotope values of total annual rainfall.

Two of the 58 sites used to develop the models of Baisden, Keller et al. (2016) fall within the Horizons region. Raw stable isotope data is available for these sites for the period of that study, and the location of those sites are marked in Figures 2-1 and 2-2. Shape files of the data used to prepare these figures are provided alongside this report.

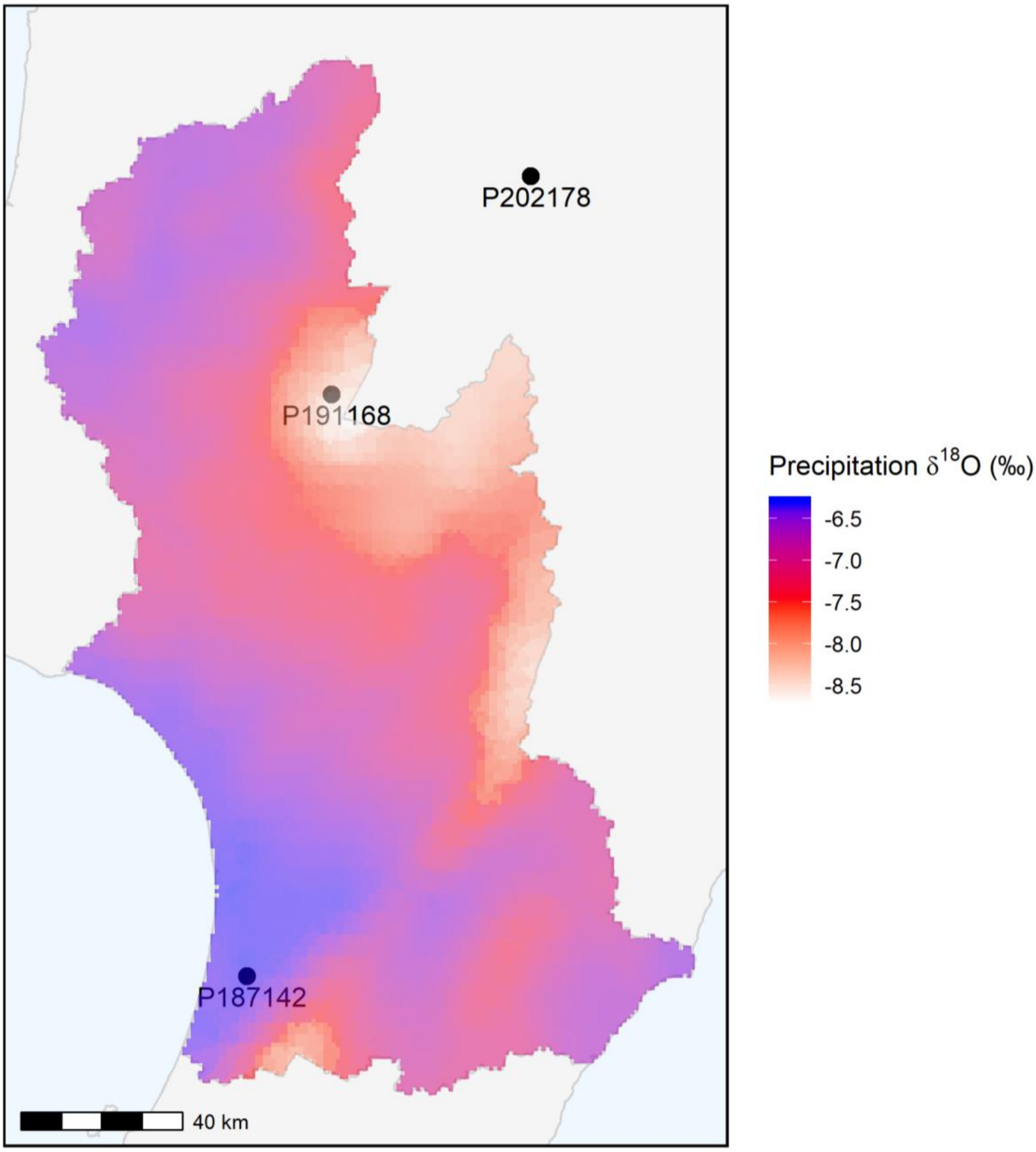

Figure 2-1: Predicted annual averages for $\delta^{18}O$ values of precipitation in the Horizons region based on coefficients from the national model of Baisden et al. (2016). Points marked are precipitation sample collection stations used in that study.

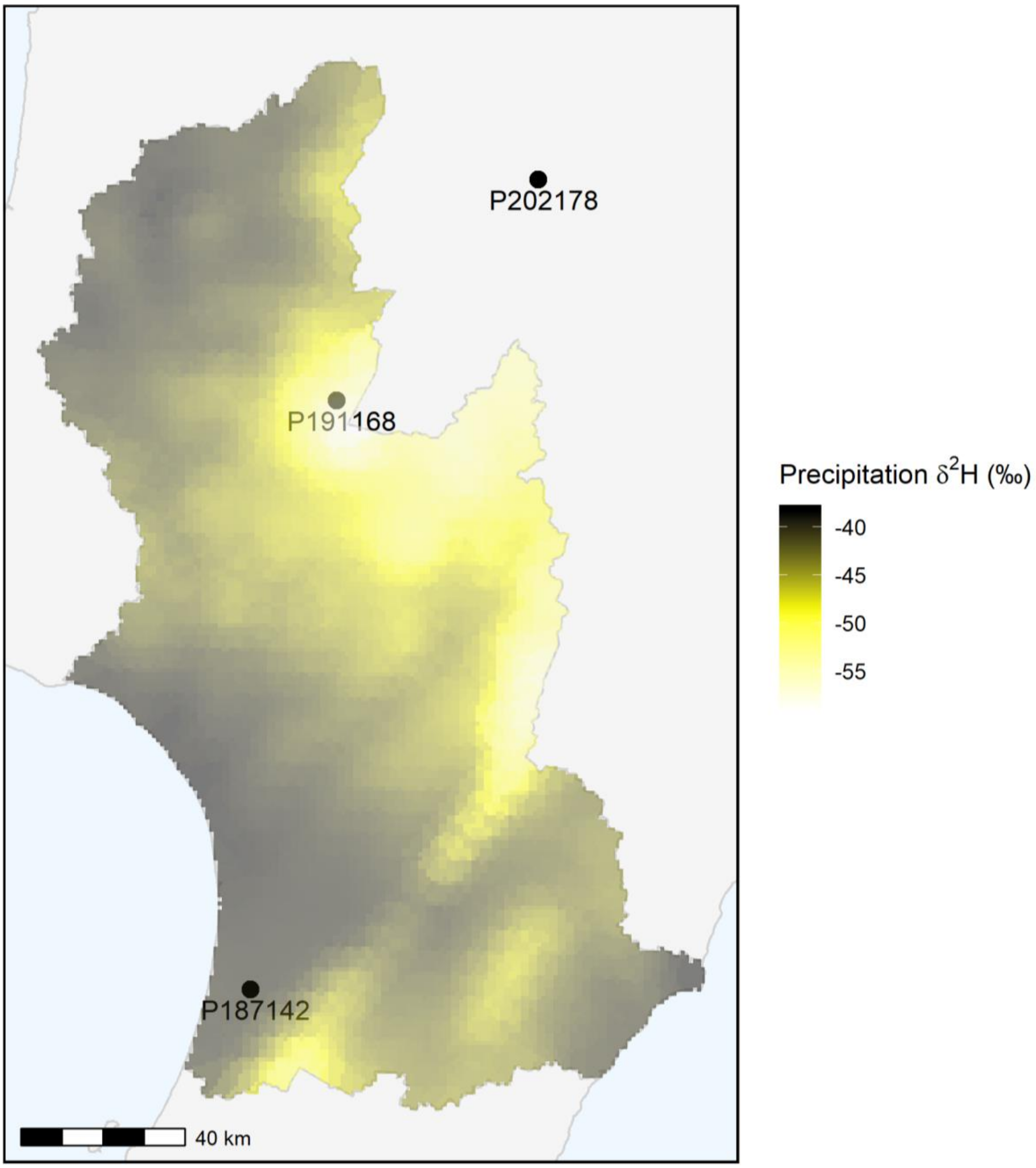

Figure 2-2: Predicted annual averages for δ^2H values of precipitation in the Horizons region based on coefficients from the national model of Baisden et al. (2016).

3 Suggested methods for development of local precipitation isotope layers

3.1 Data requirements

Salamalikis, Argiriou (2011) give basic data requirements for the development of precipitation isotope maps using multivariate regression and interpolation. They suggest that two input datasets are developed. The first dataset should include gridded predictor variable data across the region of interest. In the second, precipitation isotope data from collection sites throughout the region should be accompanied by predictor variable data from the site of collection, averaged over the period between precipitation collection events. These authors provide examples of the required file structure in their report.

3.2 Predictor data

Salamalikis, Argiriou (2011) note that the predictor variables that give the best predictive power of precipitation isotopes globally are latitude and elevation, followed by temperature and vapour pressure. Therefore, we suggest that at a minimum these variables are obtained at the sites of isotope collection over the duration that isotope data are collected, either from measured data on-site (preferable) or from NIWA's Virtual Climate Station Network (VCSN) layers. However, better predictions may be obtained by increasing the number of predictor variables at collection sites if these are available as gridded data across the region of interest. Baisden, Keller et al. (2016) used 5 km resolution gridded VCSN data to develop their national precipitation isotope layers. Their multivariate regression models included the coefficients latitude, elevation, mean sea level pressure (MSLP), potential evapotranspiration (PET), solar radiation, mean minimum daily temperature, and mean wind speed. In addition, the model for $\delta^{18}O$ included vapour pressure and the model for $\delta^{2}H$ included soil temperature at 10 cm below ground level. We suggest that data on these VCSN parameters are obtained for precipitation collection sites, and across the region for the generation of local precipitation isoscapes. For calculation of regional layers relevant to individual catchments in the Horizons region we suggest that 500 m VCSN data may be more appropriate than the 5 km data used for the national isotope layers of Baisden, Keller et al. (2016). This 500 m VCSN data is now available through NIWA.

3.3 Collection of precipitation isotope data

3.3.1 Selection of sites

Because precipitation isotope data should be accompanied by rainfall data and ideally other supporting meteorological data we recommend that precipitation collectors are installed at existing meteorological stations. Installing collectors at existing stations that collect meteorological data may also reduce total monitoring time, if collections can be timed to coincide with regular scheduled site visits. The locations of all operational rainfall sites in the Horizons region are shown in Figure 3-1. Based on the site locations shown, neither of the sites within the region that form part of the national precipitation network of Baisden et al. are current Horizons rainfall collection sites. We therefore suggest selecting sites for precipitation collection from current sites, with site selection based first on elevation, then latitude, mean minimum daily temperature (the VCSN parameter tmin), and mean daily vapour pressure (the VCSN parameter vp). To aid this selection process, sites in Table 3-1 are sorted by elevation, but we recommend that the range of latitudes present in the site list is also considered in the selection process. While it is likely that temperature within the region co-varies strongly with elevation and latitude, we suggest that consideration also be given to including sites across the ranges of vapour pressure that may be present across the region. This reflects the recommendation of Salamalikis, Argiriou (2011) to consider temperature and vapour pressure as 'secondary' predictors of rainfall isotope values.

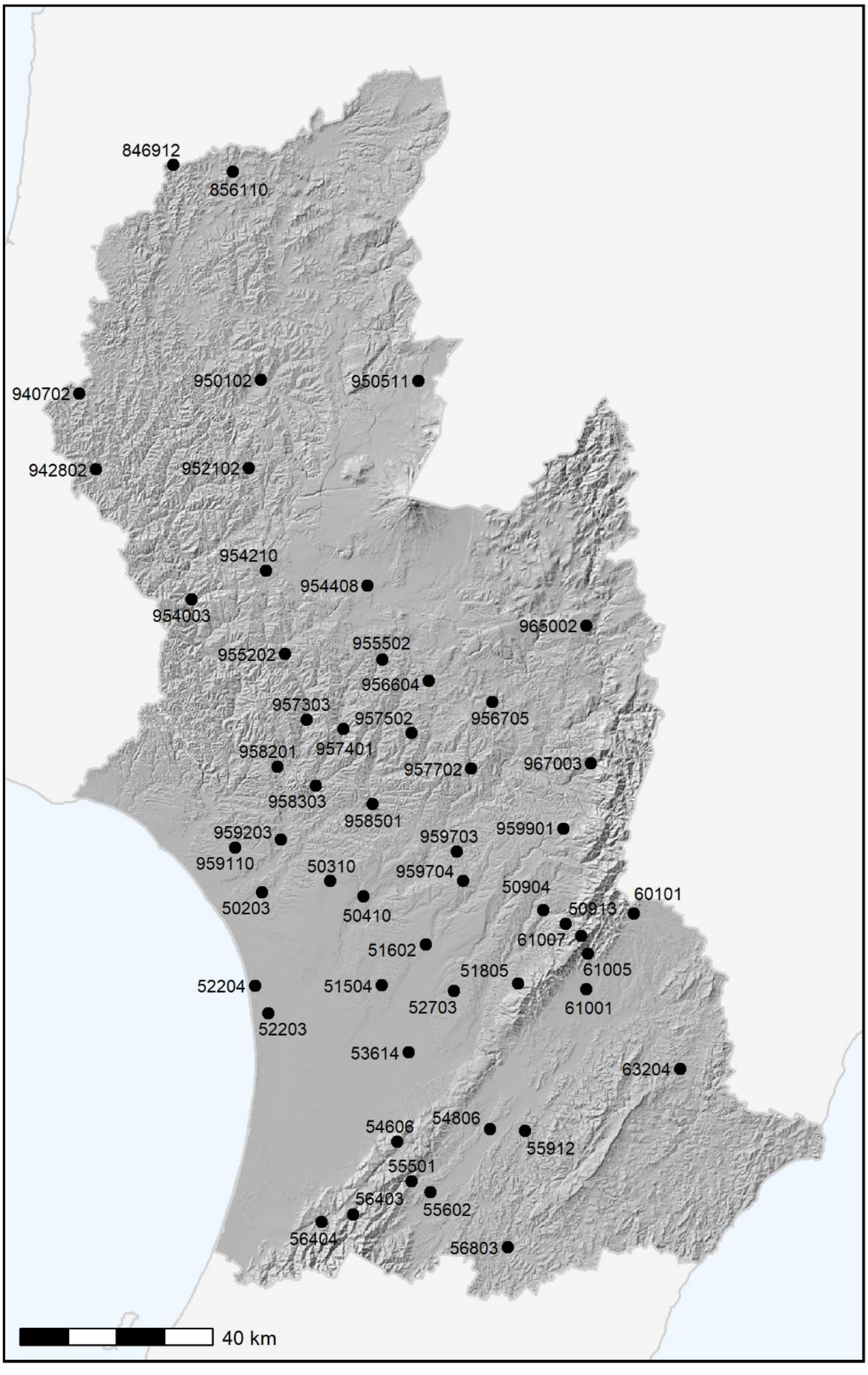

Figure 3-1: Rainfall collections sites in the Horizons region. Site names are short form codes for each site. Corresponding site names can be found in table 3.1.

Table 3-1: Rainfall collection sites in the Horizons region with accompanying geographical data. Elevation and latitude are the two primary recommended predictors variables for modelling precipitation isotope values based on global collection datasets (Salamalikis and Argiriou 2011).

Site No	Hilltop Site Name	Elevation	Lat	Long
52203	Forest Rd Drain at Drop Structure	17	-40.2523	175.2561
52204	Raumai Climate Station	18	-40.2013	175.2222
50203	Turakina at ONeills Bridge	20	-40.0257	175.2333
954003	Whanganui at Pipiriki	26	-39.4796	175.0445
53614	Mangaone at Milson Line	37	-40.3189	175.6021
959203	Whangaehu at Kauangaroa	44	-39.9258	175.2757
959110	Matarawa at Matarawa Valley	60	-39.9432	175.1651
958303	Whangaehu at Kowhai St Mangamahu	89	-39.8233	175.358
958201	Mangawhero at Aberfeldy	94	-39.79	175.263
942802	Whangamomona at Bridge to Somewhere	98	-39.2397	174.807
958501	Turakina at Otairi	109	-39.8545	175.4966
51504	Makino at Halcombe Road	120	-40.1943	175.5315
54806	Mangatainoka at Pahiatua Dairy Factory	122	-40.458	175.8073
957303	Mangawhero at Raupiu Road	132	-39.7003	175.3311
56803	Tiraumea at Alfredton	152	-40.6786	175.861
52703	Mangaone at Valley Road	152	-40.2011	175.7092
957401	Whangaehu at Aranui	156	-39.7155	175.4203
50410	Porewa Catchment at Tututotara	159	-40.0287	175.4807
940702	Whangamomona at Marco Road	179	-39.098	174.7629
55501	Mangahao at Kakariki	180	-40.56	175.6185
950102	Lower Retaruke	223	-39.0652	175.2002
51602	Makino at Cheltenham	225	-40.1154	175.6365
55602	Mangatainoka at Hillwood Hukanui	235	-40.5796	175.6665
50310	Tutaenui at Ribby Farm	240	-40.0011	175.3986
61001	Kumeti at Rua Roa	261	-40.1894	176.033
55912	Tiraumea at Ohehua Repeater	265	-40.4588	175.8941
56404	Ohau at Makahika	282	-40.6414	175.4007
959703	Pakihikura at Pakihikura Airstrip	289	-39.9399	175.7058
63204	Akitio at Toi Flat	293	-40.3326	176.269
955202	Mangawhero at Bangonie	303	-39.578	175.2746
846912	Ohura at Waitewhena Airstrip	319	-38.6656	174.9771
952102	Ruatiti at Ruatiti Station	340	-39.2304	175.1756
856110	Ohura at Waikaka	342	-38.6761	175.1203
54606	Kahuterawa at Scotts Road	384	-40.487	175.5814
61005	Tamaki at Tamaki Reserve	384	-40.1227	176.0335
56403	Upper Mangahao at No.1 Dam	390	-40.6253	175.478

Site No	Hilltop Site Name	Elevation	Lat	Long
50904	Pohangina at Range View Farm	397	-40.0436	175.921
51805	Pohangina at Alphabet Hut	400	-40.1829	175.8647
957702	Makohine at Zohs Road	420	-39.7824	175.7346
956705	Hautapu at Alabasters	445	-39.6569	175.7809
954210	Mangaetoroa at Scarrows	458	-39.4222	175.2229
955502	Whangaehu at Titoki	495	-39.5837	175.5115
60101	Manawatu at Apiti Track	504	-40.045	176.1426
956604	Turakina at Ruanui	579	-39.6209	175.6244
959704	Tapuae at Waituna West	585	-39.9944	175.723
957502	Turakina at Koeke Airstrip	598	-39.7196	175.5875
967003	Kawhatau Catchment at Upper Kawhatau	628	-39.7661	176.0247
959901	Oroua at Rangiwahia	642	-39.8902	175.9635
954408	Waiharuru at S.H.49	660	-39.4457	175.4693
950511	Whanganui at Te Porere	723	-39.0587	175.5787
965002	Rangitikei at Erewhon Station	920	-39.508	176.0029
50913	Pohangina at Delaware Ridge	945	-40.0683	175.9772
61007	Pohangina at Makawakawa Divide	1140	-40.0898	176.0156

3.3.2 Number of sites

Examples of precipitation collection for stable isotope analysis are available for many regions globally that can provide some guidance on the number of sites required to produce suitable precipitation isotope datasets for model development. Examples of larger studies include the continental U.S.A (3,119,885 km^2, 73 sites (Vachon, Welker et al. 2010)), Spain (505,990 km^2, 16 sites (Araguas-Araguas and Diaz Teijeiro 2005)), and New Zealand (268,021 km^2, 58 collection sites (Baisden, Keller et al. 2016)). Examples of smaller collection areas are Central Japan (roughly 40,000 km^2, 16 collection sites (Yamanaka, Makino et al. 2015)), Switzerland (41,285 km^2, 11 stations, (Schürch, Kozel et al. 2003)), and central USA (approximately 45,000 km^2, 8 precipitation stations plus winter snow collections (Benjamin, Knobel et al. 2005)). Given the area of the Horizons region (22,215 km^2), the availability of relevant, existing data from 2-3 stations within the region or nearby, and the requirement for data relevant at the catchment scale we would recommend around 10 long-term stations are established.

3.3.3 Collection protocols

We recommend that sampling stations are set up according to the guidelines of the IAEA/GNIP precipitation sampling guide, available at: http://www-naweb.iaea.org/napc/ih/documents/other/gnip_manual_v2.02_en_hq.pdf

For the purposes of regional mapping, monthly sample collection is likely to be sufficient. For the purposes of weighting the isotope values of each sample in subsequent data analysis, it is important that the date of sampling is recorded as well as the amount of rainfall that the sample represents. We also recommend that, for a given site, sampling is kept as close as possible to a given day of the month. This aids other potential data analysis for precipitation isotope data, such as transit time and young water fraction calculations for streams and groundwater.

While climatic and geographical drivers of precipitation stable isotope values can to some extent be captured by the regression approaches discussed in Salamalikis, Argiriou (2011) and (Baisden, Keller et al. 2016), additional variation can also be expected due to New Zealand's variable exposure to sources of moisture from a wide geographical region. Moisture sources include alternating sub-Antarctic and subtropical air masses (Baisden, Keller et al. 2016). Because the relative contribution of these moisture sources is likely to vary between years and these moisture sources differ in their water isotope values, we would recommend at least three years of monthly samples collections at each site to represent 'average' conditions across the Horizons region. Evidence for inter-annual variation in isotope values nationally can also be seen in the raw data file that accompanies this report.

3.4 Modelling methods

The methods of Salamalikis, Argiriou (2011) provide a suitable example for data analysis required for preparing precipitation isotope maps using multivariate regression and interpolation. We note that that report provides code examples using the software package 'R' (R Core Team 2017), and that this code could be simply adapted to include the full list of VCSN parameters as predictors of precipitation isotope values.

4 Summary

Data provided alongside this report include precipitation isotope GIS shape files for long-term average δ^2H and $\delta^{18}O$ precipitation values calculated from the coefficients of Baisden, Keller et al. (2016), and raw precipitation δ^2H and $\delta^{18}O$ data collected from three sites within or near the Horizons region from 2007-2010, courtesy of Professor Russell Frew of Otago University. For the development of high-resolution δ^2H and $\delta^{18}O$ precipitation isoscape layers for the Horizons region we recommend the following:

1. Collection of gridded predictor variable data across the Horizons region, as well as accurate DEM layers. We suggest NIWA's 500 m resolution Virtual Climate Station Network (VCSN) data as suitable for this task.

2. Collection of precipitation isotope samples from sites throughout the region. Sites should be selected to obtain a full range of the major predictors of variability in precipitation δ^2H and $\delta^{18}O$ values described in section 3.3.1. We suggest that monthly accumulated samples from ≥ 10 collection sites for a period of at least three years would be appropriate. Collection methods should follow the recommendations for IAEA Global Network of Isotopes in Precipitation (GNIP) sites.

3. Collection of daily predictor variable data from the sites of collection for the periods between and including all precipitation collection events. Data collected onsite is preferable for this, but interpolated VCSN data would also be suitable.

4. The methods of Salamalikis, Argiriou (2011) provide a suitable example for data analysis required for preparing precipitation isotope maps using multivariate regression and interpolation. These methods should be modified to include latitude, elevation and the full list of VCSN parameters as predictors of precipitation isotope values.

5 Acknowledgements

The raw precipitation δ^2H and $\delta^{18}O$ data accompanying this report was kindly provided by Professor Russell Frew of Otago University. The source of this data should be referenced as Baisden, Keller et al. (2016) in any subsequent use.

6 References

Araguas-Araguas, L., Diaz Teijeiro, M. (2005) Isotope composition of precipitation and water vapour in the Iberian Peninsula: first results of the Spanish network of isotopes in precipitation. *International Atomic Energy Agency Technical Report*, 1453: 173-190.

Baisden, W.T., Keller, E.D., Van Hale, R., Frew, R.D., Wassenaar, L.I. (2016) Precipitation isoscapes for New Zealand: enhanced temporal detail using precipitation-weighted daily climatology. *Isotopes in Environmental and Health Studies*, 52(4-5): 343-352. 10.1080/10256016.2016.1153472

Barbieri, M., Boschetti, T., Petitta, M., Tallini, M. (2005) Stable isotope (2H, 18O and 87Sr/86Sr) and hydrochemistry monitoring for groundwater hydrodynamics analysis in a karst aquifer (Gran Sasso, Central Italy). *Applied Geochemistry*, 20(11): 2063-2081.

Benjamin, L., Knobel, L.L., Hall, L., Cecil, L., Green, J.R. (2005) Development of a local meteoric water line for southeastern Idaho, western Wyoming, and south-central Montana.

Mook, W., Rozanski, K. (2000) *Environmental isotopes in the hydrological cycle*. IAEA Publishing, Vienna.

New Zealand Government (2014) National Policy Statement for Freshwater Management 2014. http://www.mfe.govt.nz/publications/fresh-water/national-policy-statement-freshwatermanagement-2014

R Core Team (2017) R: A language and environment for statistical computing R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Salamalikis, V., Argiriou, A.A. (2011) ISOGRIDS (Isotopic Gridded Rainfall Data Software) Tutorial. http://www-naweb.iaea.org/napc/ih/IHS_resources_sampling.html#isogrids

Schürch, M., Kozel, R., Schotterer, U., Tripet, J.-P. (2003) Observation of isotopes in the water cycle—the Swiss National Network (NISOT). *Environmental Geology*, 45(1): 1-11.

Terzer, S., Wassenaar, L., Araguás-Araguás, L., Aggarwal, P. (2013) Global isoscapes for δ 18 O and δ 2 H in precipitation: improved prediction using regionalized climatic regression models. *Hydrology and Earth System Sciences*, 17(11): 4713-4728.

Vachon, R., Welker, J., White, J., Vaughn, B. (2010) Monthly precipitation isoscapes (δ18O) of the United States: Connections with surface temperatures, moisture source conditions, and air mass trajectories. *Journal of Geophysical Research: Atmospheres*, 115(D21).

Walther, B.D., Thorrold, S.R., Olney, J.E. (2008) Geochemical signatures in otoliths record natal origins of American shad. *Transactions of the American Fisheries Society*, 137(1): 57-69.

West, J.B., Bowen, G.J., Cerling, T.E., Ehleringer, J.R. (2006) Stable isotopes as one of nature's ecological recorders. *Trends in Ecology & Evolution*, 21(7): 408-414. 10.1016/j.tree.2006.04.002

Yamanaka, T., Makino, Y., Wakiyama, Y., Kishi, K., Maruyama, K., Kano, M., Ma, W., Suzuki, K. (2015) How reliable are modeled precipitation isoscapes over a high-relief mountainous region? *Hydrological Research Letters*, 9(4): 118-124.

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