New Zealand Drought Index and Drought Monitor Framework

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Executive summary

Droughts (defined here in the agricultural sense as a prolonged deficit of moisture adversely impacting agricultural production) are reasonably common in New Zealand, usually occurring every summer somewhere in the country. Pastoral farmers in New Zealand employ farming systems and practices that are sufficient for them to cope with most droughts, however droughts of longer-than-normal duration (e.g. several months) and/or affecting large areas (e.g. two or three regional council regions) at the same time, can and do lead to significant impacts on farmers. It is therefore important to continually monitor drought conditions nationally, and be able to compare current conditions with those from historical periods.

NIWA have developed the New Zealand Drought Index (NZDI). This is a combined index based on four commonly-used drought indicators, namely the Standardised Precipitation Index (SPI), Soil Moisture Deficit (SMD), Soil Moisture Deficit Anomaly (SMDA), and Potential Evapotranspiration Deficit (PED). These four indicators are combined to give a value of the NZDI for any location on any day. Maps and time series plots (aggregated by Territorial Local Authority) are available on the New Zealand Drought Monitor webpage and updated on a daily basis.

1 Introduction

This report describes the framework for an updated New Zealand Drought Monitor webpage, and the development of the New Zealand Drought Index (NZDI). This work is the result of studies into currently available drought data and an inventory of existing drought monitors in other countries. From this information essential components have been identified. The final product is based on these components using data currently available in New Zealand.

In addition to descriptions of the NZDI and its components, a brief overview over the water balance model is given, since some of the variables that are discussed depend on it. Finally, several possibilities for extensions on the NZDI and proposed Drought Monitor framework are discussed.

2 Elements of International Drought Monitors

When looking at drought monitors from different countries, there are certain components that are always present which we have considered here. These are: input data, a categorisation scheme, and visualisation.

Input data normally come in the form of a choice of drought indices. There is a vast number of indices available that try to quantify drought from different perspectives and for different purposes. Since there is no universal standard to define a drought, the usefulness of these indices will depend on the application and the information that is available.

A categorisation scheme is some set of calculations and rules that translates the values of the chosen indices into a number of drought categories representing different levels and possibly even different types of drought. Such a scheme can be made very simple or very complex, but the outcome should always be something that is easily understandable to the user.

Visualisation is the third essential part of a drought monitor. Maps and/or graphs are created to make insightful to the user the level, spatial extent and possibly also the duration of a drought.

3 The water balance model

To understand some of the concepts in this document, the reader should be familiar with the basics of the water balance model that is currently in use at NIWA.

The main properties of the water balance model are illustrated in Figure 1. Precipitation (typically rain, but possibly also snow or dew etc.) is the main source of water into the system. The soil has a certain capacity for holding water, which depends mainly on the soil composition and layering. Water is lost via plant transpiration and via evaporation from the soil. These two processes together are generally termed evapotranspiration. The amount of water lost via evapotranspiration depends on many factors, including temperature, wind, humidity and solar radiation. If more water comes into the system than the soil can hold, the excess water is designated as runoff and is considered to be lost.

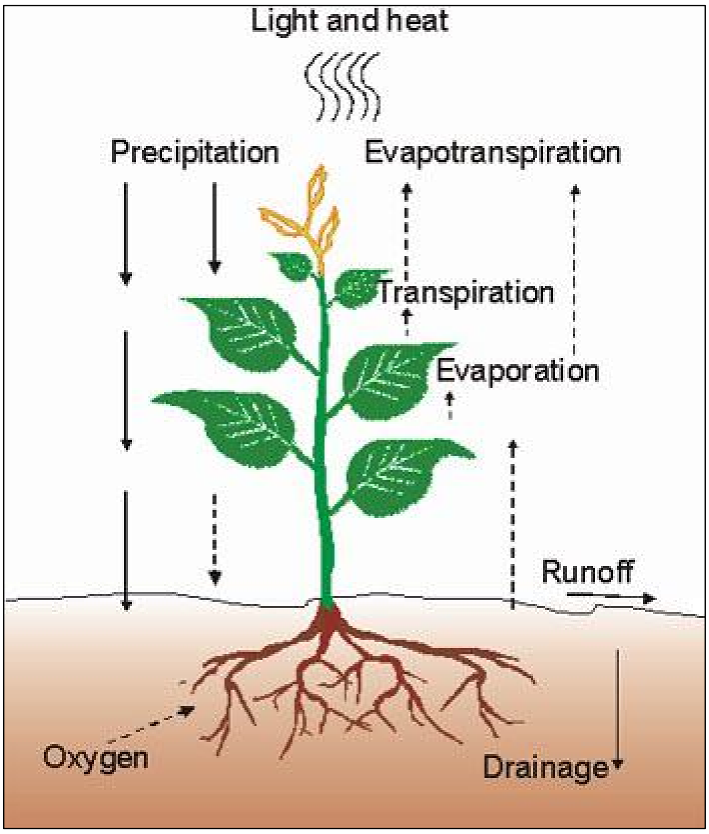

Figure 1: Water balance processes.

3.1 Potential evapotranspiration and deficit

Soil Moisture Deficit (SMD) is the term used to indicate the amount of water that the system is short of full capacity. Therefore the value of the deficit can range from 0 (when the soil holds water to full capacity) to total capacity (when the soil is completely dry).

Potential evapotranspiration, commonly abbreviated to PET, is the expected amount of water that would be evaporated and transpired if all that water is available. The water balance model assumes that, as long as more than half of the total capacity is available, the full amount of PET will be lost to evapotranspiration. When less than half of the total capacity is available, the actual evapotranspiration (AET) will be less than the potential. The difference between actual and potential evapotranspiration will grow larger as less water is available. In the extreme case when all water has been used up, the actual evapotranspiration is considered to be 0. The difference between potential evapotranspiration (PET) and actual evapotranspiration is called the Potential Evapotranspiration Deficit, commonly abbreviated as PED.

4 Drought indicators

Drought is not a well-defined concept. The meaning of the word can change depending on the context in which it is used, the climate and so on. As a consequence there are many different indicators that aim to quantify drought. Drought is defined here in the agricultural sense, as a prolonged deficit of moisture adversely impacting agricultural production. For the New Zealand Drought Monitor, four commonly-used indices are suggested as drought indicators:

- the Standardised Precipitation Index (SPI), which relates to precipitation;
- the Soil Moisture Deficit (SMD), plus its anomaly (SMDA), which relate to available water in the soil; and
- the Potential Evapotranspiration Deficit (PED), which relates to loss via evapotranspiration.

The inclusion of both absolute SMD and its anomaly (or difference from normal) was seen as useful, as these two indices provide different but complementary information on the state of the soil moisture (see section 4.2). It should be noted that by including both these indices there is greater weight given to the state of the soil moisture, compared with the meteorological indices associated with rainfall (SPI) and evapotranspiration (PED). This is desirable however, as agricultural production (in particular pasture growth) is directly related to soil moisture.

4.1 SPI

The Standardised Precipitation Index (SPI) was developed in the 1990s with the primary aim to define and monitor drought. It uses only precipitation as an input. In a nutshell, it indicates how extreme a recent period of precipitation has been when compared to historical data for that location. Typically periods are calculated over 30 or 60 days and the historical data used goes back 30 years.

SPI can indicate both dry and wet conditions. The index has been constructed in such a way that positive values indicate conditions that are wetter than normal and negative values indicate conditions drier than normal. Figure 2 is an example map of the 60-day SPI.

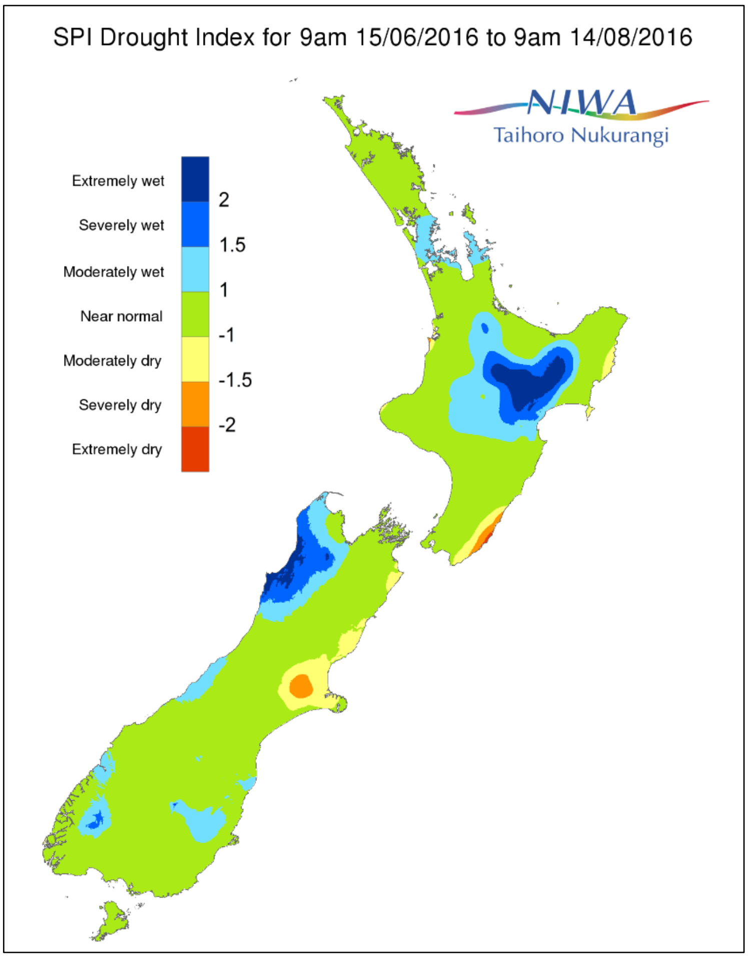

Figure 2: Example 60-day Standardised Precipitation Index (SPI) map for New Zealand.

4.2 SMD

Soil Moisture Deficit (SMD) has been defined in section 3.1. It is the amount of water the soil is short of full capacity. The current NIWA water balance model uses a fixed soil moisture capacity of 150 mm of water, based on a typical loam soil. The possible benefit of using a model where the soil capacity varies spatially, based on available soil data, is currently being investigated. Note that the value of SMD on any day depends on the recent history. Basically, the SMD today is the SMD yesterday, increased by the amount of water lost to evapotranspiration and diminished by the amount of precipitation that has fallen. As a consequence, a high SMD value can be the result of either a short spell of very dry conditions or of a longer spell of moderately dry conditions. SMD only indicates "dryness". In wet conditions the deficit will go down to 0, which means full capacity is reached and any extra precipitation will be lost as runoff. Figure 3 is an example SMD map.

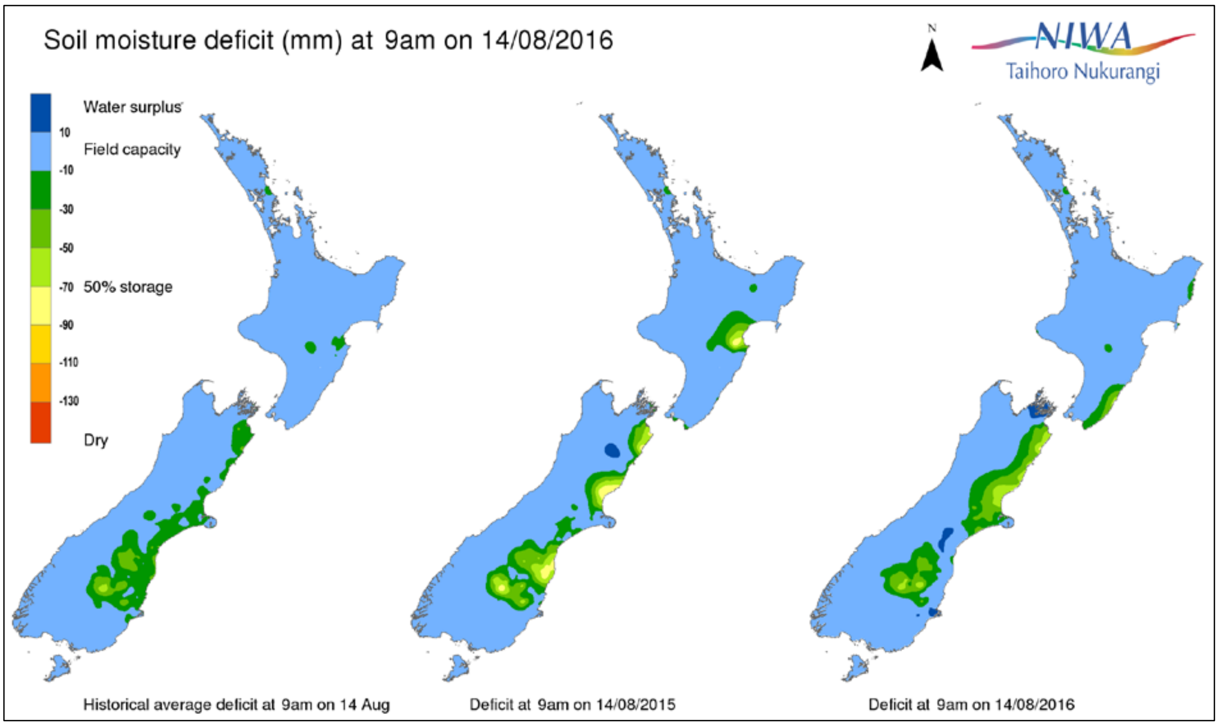

Figure 3: Example Soil Moisture Deficit (SMD) map for New Zealand, showing the historical mean (left map), the SMD one year ago (middle map), and the current SMD (right map).

The SMD anomaly (or difference from normal) is also used here as a drought indicator. The benefit of adding the anomaly is that, similar to the SPI, it emphasises soil moisture conditions that are particularly different from normal (in this case, much drier than normal). As a result, drier-than-normal soils on the West Coast of the South Island (a particularly wet region) may still indicate drought there, even though the actual SMD values would be considered ‘normal’ (or even wetter-than-normal) on the East Coast of the South Island (a much drier location, on average). Figure 4 is an example SMD anomaly map.

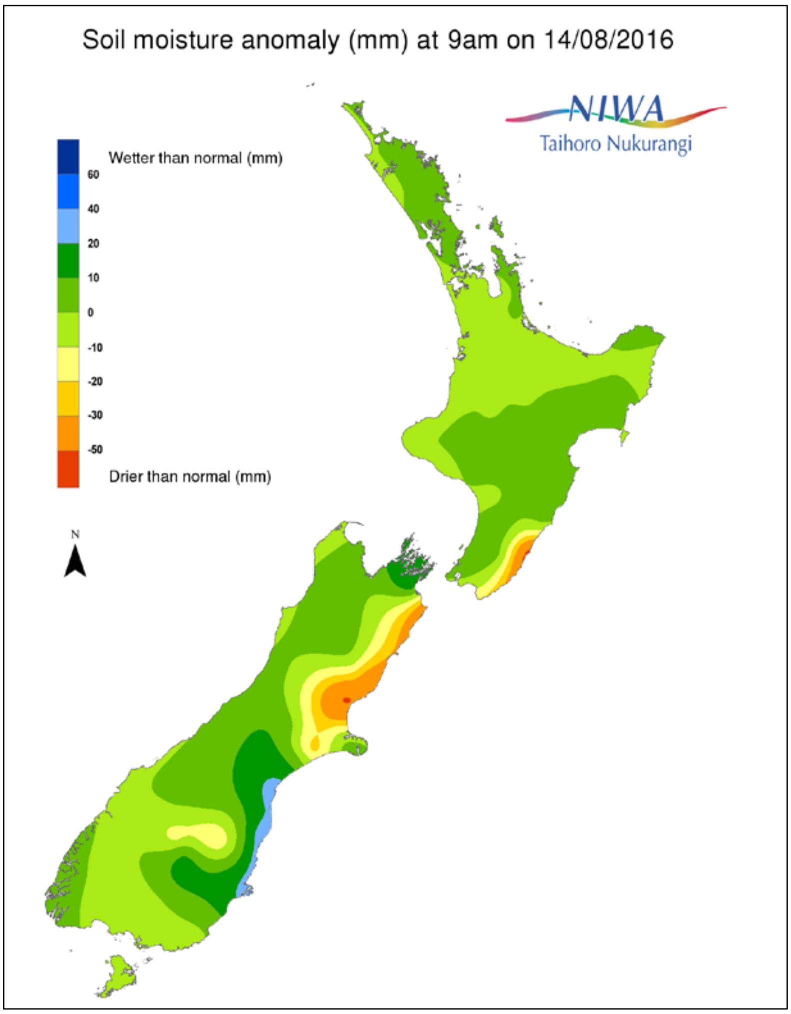

Figure 4: Example Soil Moisture Deficit Anomaly (SMDA; or 'difference from normal') map for New Zealand.

4.3 PED

Potential evapotranspiration deficit (PED) has been explained at the end of section 3.1. As conditions get drier, there will be a difference between the amount of water that is actually evaporated and transpired (i.e. the AET) compared to the amount of water that would be evaporated and transpired if all the water is available (i.e. the PET). PED is a measure of this difference. Because of this, PED is somewhat related to SMD. When SMD is small, enough water is available and the PED is 0. Only when the SMD starts to increase will the PED show non-zero values. As a consequence, similarly to SMD, PED only indicates dryness. Wet conditions will always give a PED of 0. Figure 5 shows a time series of annual accumulated PED for all of New Zealand.

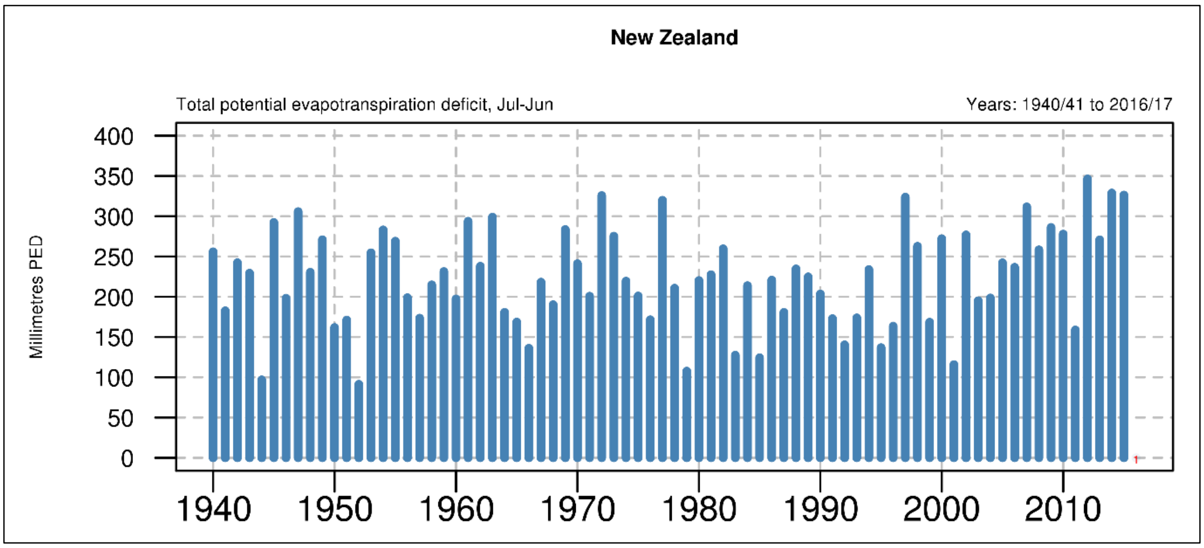

Figure 5: Annual accumulated Potential Evapotranspiration Deficit (PED) for all of New Zealand.

5 Categorising droughts

To determine whether or not a drought is occurring and what the severity is, we propose that the four nominated indices are processed in some way to give a single categorised outcome. There are many ways of doing this. The Canadian drought monitor[1] is based on human interpretation and requires a consensus to be reached by federal, provincial and academic scientists. More commonly, automatic processes are used. This generally comprises two steps, combining the multiple variables into a single one and the application of certain thresholds to translate the value of a continuous variable to one of several levels.

The order in which these two steps are taken can differ. The US drought monitor[2] uses threshold values for each of their indices before combining to an overall drought level. The China drought monitor[3] combines the individual indices into one overall index before applying thresholds to come to an overall drought level. We favour the latter approach because it postpones the coarsening of the scale to the last moment and it delivers one clear outcome. If thresholds are applied before combining, a problematic situation might arise when the different indices do not agree very well. In the US case, the final outcome is then decided by analysts based on the majority outcome, expert knowledge and local conditions.

5.1 Combining indices

The idea behind combining drought indices is that together they can create a more reliable picture than by themselves. As mentioned earlier, many different techniques exist and there is no particular right or wrong way to do this.

To combine the indices mathematically, they should all be on a comparable scale. To achieve this, only the ‘dry’ part of the SPI and SMD Anomaly will be used, while the PED and SMD only indicate dry conditions and not wet conditions. Furthermore we transform the SMD, SMDA and PED to a non-

[1] http://www.agr.gc.ca/eng/?id=1433796848570
[2] http://droughtmonitor.unl.edu/
[3] http://www.wamis.org/agm/meetings/etdret09/WOS5-Zhai.pdf

linear scale, similar to the SPI scale, so that 1 mm of water during very dry conditions has a lot more impact than 1 mm of water during less-dry conditions. The mathematical formula for the transformation of indices is given by:

$$x' = -\log_2\left(1 - \frac{x}{x_{max}}\right)$$

In the case of SMD the maximum value is the soil water capacity (currently a fixed value of 150 mm). In the case of SMDA and PED, the maximum value is determined per location based on the available data.

With all indices on a similar scale, combining them into a single value can be easily done. The simplest way is to either add or multiply the indices. Multiplication has the advantage of being less sensitive to situations where there is a large discrepancy between indices, but addition has the advantages of better limited error propagation and the possibility of adding weighting factors that increase the relative importance to the summation of one index compared to another. For these reasons we have used addition, with the sum divided by four to yield values of a similar scale to the input data.

5.2 Choosing thresholds

Once an overall drought index has been created, historical data can be used to set suitable thresholds. This can be done by examining how often certain values have occurred historically and what typical values have occurred during known periods of drought in the past. We have nominally selected four thresholds (0.75, 1.00, 1.25, 1.50, and 1.75) to depict the following categories of drought:

- dry;
- very dry;
- extremely dry;
- drought; and
- severe drought.

This has been done based on visual analysis of the NZDI maps (see section 6.1 below) and follows the convention used on some international drought monitors.

6 The New Zealand Drought Monitor

The New Zealand Drought Monitor webpage (https://www.niwa.co.nz/climate/information-and-resources/drought) has been updated such that the NZDI products (described below) are displayed on the main page.

6.1 Maps

To make the NZDI numbers more insightful, an interpolated map of these values has been made for the whole country so that it will be clear which areas are experiencing a drought and at which level of severity (see Figure 6). The maps are updated daily, and are an important tool to communicate the current drought conditions to the end user. They have been carefully constructed in order for the end user to be able to easily and intuitively make sense of the NZDI output data.

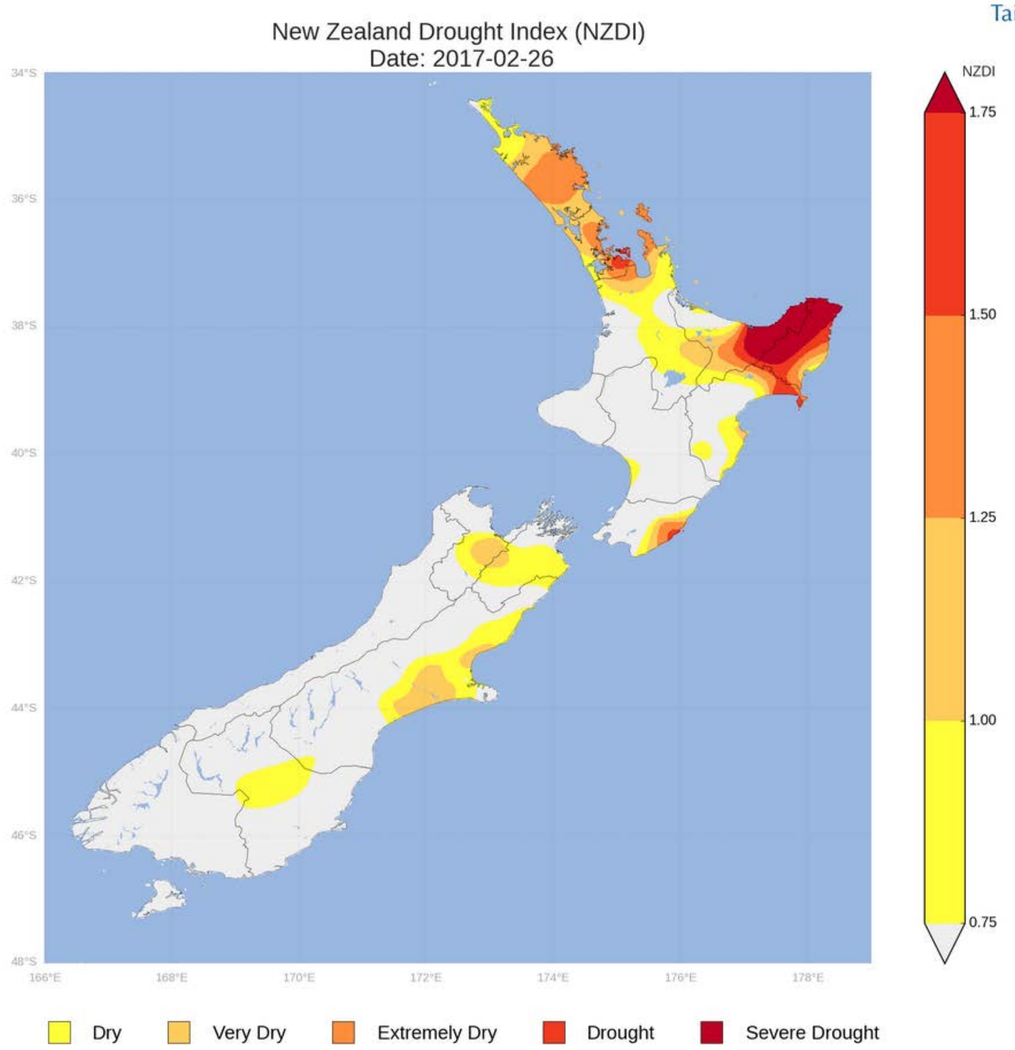

Figure 6: Map of the NZDI for 26 February 2017.

6.2 Time series plots

The NZDI maps give a good overview of which parts of the country are experiencing droughts. Complementing these maps, we have produced a web-based "application" to view daily-updated time series plots of the NZDI (plus the four individual components) averaged over every Territorial Local Authority[4] (TLA) in New Zealand. The drought categories are also indicated on the plots, and the time series data can be downloaded. Figure 7 shows an example plot for Far North District (Northland Region).

[4] https://en.wikipedia.org/wiki/Territorial_authorities_of_New_Zealand

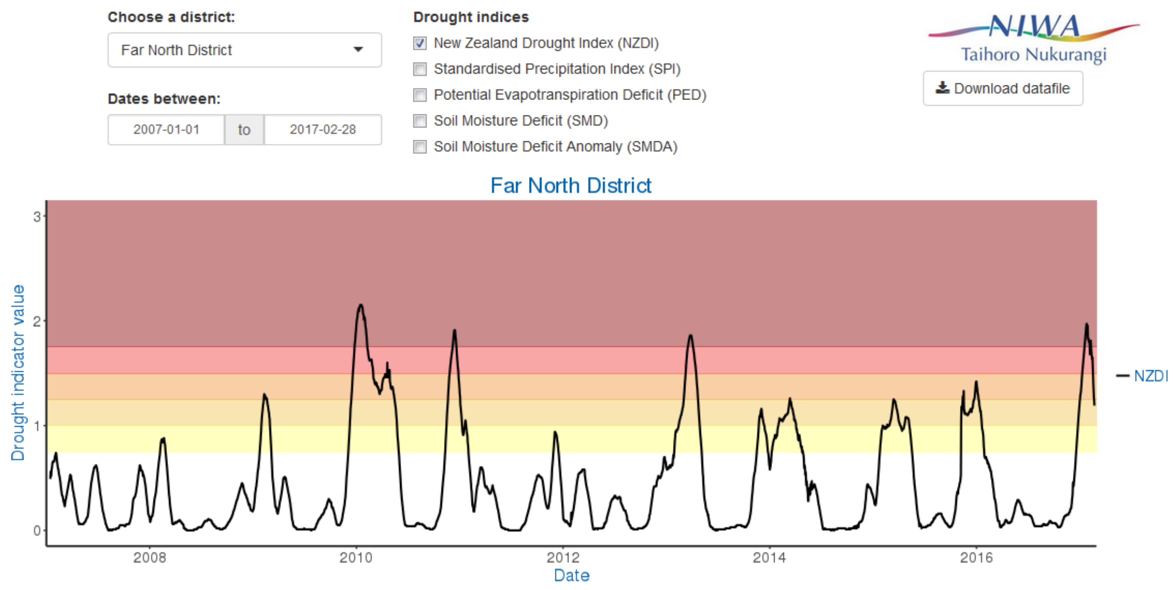

Figure 7: Daily time series plot of the NZDI for Far North District (Northland Region), from 2006 to 2017.

7 Possible extensions

This document describes the framework for an updated New Zealand Drought Monitor. In this section we will briefly describe some of the possible ways the framework could be extended.

7.1 Adding new indices

The proposed way of combining indices makes it relatively easy to add new indices or to change their relative contributions by changing the weighting factors. This way the monitor can be fine-tuned based on user feedback.

7.2 Drought sub-classification

The maps and TLA-aggregated time series plots, which are the main products of the monitor, can be augmented by making use of the spatial information (to determine localised or country-wide droughts) and the temporal information (to determine long and short droughts). Furthermore, the particular combination of values of the different indices might be used to distinguish between e.g. drought mainly caused by lack of rainfall and droughts mainly caused by higher than normal temperatures (and hence evapotranspiration) and so on.

7.3 Variable soil capacity

As mentioned before, currently the water balance model uses a fixed value of 150 mm water capacity throughout New Zealand, even though it is known that soil types vary across the country. At the moment investigations are ongoing into whether the water balance model can be improved by using a varied water capacity which is estimated based on available geospatial data. If this proves to be successful, the drought monitor will also benefit from using a variable water capacity, rather than a fixed one.

8 Glossary of abbreviations and terms

PET	Potential Evapotranspiration (units = mm)
AET	Actual Evapotranspiration (units = mm)
PED	Potential Evapotranspiration Deficit (units = mm)
SMD	Soil Moisture Deficit (units = mm)
SPI	Standardised Precipitation Index (dimensionless)
NZDI	New Zealand Drought Index (dimensionless)
TLA	Territorial Local Authority