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Landcare Research

Considering a future spatial framework for wetland mapping and monitoring in New Zealand

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Considering a future spatial framework for wetland mapping and monitoring in New Zealand

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Summary

Currently, New Zealand is unable to report on wetland extent and change with any confidence. State of environment reports seeking to compare pre-human wetland extent with contemporary extent rely on published work by Ausseil et al. (2008) based on provisional data from 2003 and earlier. There is a need for an enduring solution to ongoing wetland monitoring and reporting, utilising the strengths of existing databases, and existing and planned monitoring processes.

Wetlands have not yet been comprehensively, reliably, and accurately mapped at the national level, but the elements necessary to achieve this exist in two national databases (WONI and LCDB) and in sub-national datasets maintained by some regional councils. This report examines the two national layers (WONI and LCDB v4) and regional council layers, and proposes a national spatial framework that would serve New Zealand's monitoring and reporting needs.

The conclusion reached is that, in respect of reporting wetland extent and change at the national level, New Zealand does not have a data deficit problem. Instead, New Zealand has a data fragmentation problem and no present mechanism to interconnect databases to leverage the data we have.

LCDB has the ability to represent, in outline, any wetland. Its attribute structure is skeletal but can accommodate wetlands either explicitly (by class name) or by its WETContext flag and, if necessary, an additional ID could be added to establish parity between databases without distorting LCDB's data structure. LCDB has the great advantage of its established time series for monitoring and reporting, its recognition as a key environmental database and resourcing for ongoing updates.

WONI has a descriptive richness that LCDB lacks, with an attribute table that embodies all the evidential information that combined in its various classifications. It links the present expression of wetlands to its former extent and considers each wetland's place and value in the landscape. It is a key component of the FENZ and a point of reference nationally for researchers, policy-makers and managers. It is a natural junction between locally focussed and verified wetland data and national layers of wetland extent.

Regional (and district) council wetland databases are the tools necessary for implementing resource management and biodiversity conservation outside crown conservation land. They are tuned to local needs and priorities, management strategies and plans, and the resources available to implement them. Associated with spatial layers there are commonly aspatial information and plans.

There is little justification in contemplating creation of a new mapping and monitoring framework when one can be formed from these existing components. A three-tier spatial framework is proposed, whereby WONI remains the repository for wetland information and both LCDB and Regional Council database are the mechanism for maintaining currency in WONI.

We recommend that WONI, LCDB, and the regional databases, are maintained, rules/processes are set up to connect the databases with each other, and decisions are

made around ongoing governance and responsibilities for these databases. This would enable MfE, DOC, RCs, and the wider community ongoing access to information about contemporary changes to wetland extent. Specifically, we recommend that:

1 WONI, which has been in a state of suspension for over a decade, receive a limited upgrade to: clean up polygon artefacts, incorporate unpublished edits held by Landcare Research, and incorporate information from a recent review of wetland loss

2 stakeholder agreement with the spatial framework be secured, and protocols and rules around its final form developed

3 the spatial framework be connected by reconciling differences between WONI, LCDB, and regional council databases, updating each so that parity is achieved, and creating the links to enable bi-directional data flows between them

4 governance and ongoing management of the framework be formalised and resourced.

1 Background

This report focusses on a deficiency in the delivery of information on the contemporary changes in national wetland extent and a critical need to remedy this deficiency in order to improve New Zealand's ability to report on wetlands and changes in their extent.

The Environmental Reporting Act 2015 has put in place:

- independent reporting by the Government Statistician and the Secretary for the Environment
- a requirement to fairly and accurately represent the state of New Zealand's environment
- best practice and robust statistics and measures.
- regular reporting – every 6 months MfE must publish a report on one of the five environmental domains (air, freshwater, land, marine, atmosphere and climate). The topics cover environmental issues that are most significant to New Zealanders. A synthesis report, with analysis of cross-domain trends and interactions, must be published every 3 years.

New Zealand is currently unable to report with any confidence on contemporary change in wetland extent due to a shortfall in data and limitations in data quality. State of environment reports seeking to compare pre-human wetland extent to contemporary extent rely on published work by Ausseil (2008) based on provisional data from 2003 and earlier. There is a need for an enduring solution for ongoing wetland monitoring and reporting, utilising the strengths of existing databases, and existing and planned monitoring processes.

Wetlands have not yet been comprehensively, reliably and accurately mapped at the national level, although elements of this exist in two national databases (WONI and LCDB) and in sub-national datasets maintained by some Regional Councils.

This report examines more closely the two national layers (WONI and LCDB v4) and attempts a synthesis of their qualities and their potential to form a national spatial framework alongside Regional layers maintained by Councils.

Material contributing to this synthesis informed a workshop of invited stakeholders from among regional councils, MfE and DoC, the aim of which was to consider a future where New Zealand has a functioning spatial framework for wetlands.

The workshop considered current and evolving remote sensing technologies as they could apply to detection and mapping of wetlands, recognising that advances are continually being made in spectral and spatial resolutions, revisit frequencies and cost. Sentinel 2, for example, provides better spatial resolution (10 m and 20 m), more spectral bands (including red edges) that could assist differentiation of vegetation, better revisit capability (10 days reducing soon to 5 days), and imagery free to download. However, as improvements in imagery are incremental and operational utilisation in the realm of wetland mapping is still experimental, this topic is not discussed in this report.

Also not discussed are world examples because none were found that were a significant advance over the combination of databases we presently have, and there seems no present willingness in Government to fund any new national wetland mapping programme.

2 New Zealand's wetland framework

New Zealand does not have a planned and organised structure for mapping and monitoring wetlands. The New Zealand Land Resource Inventory, dating from the 1970s recognised some forms of wetland as part of its vegetation inventory. Dating from the same period were inventories of wetlands collected as part of wildlife surveys, which were later compiled into the 3000-record WERI (Wetlands of Ecological and Representative Importance) database. However, neither is comprehensive nor systematically updated. Since 2000, databases representing wetlands can be characterised as either:

- national and updated, but with shortcomings in wetland delineation, detection and thematic detail (notably, the LCDB), or
- national and thematically-detailed, but not updated, and with similar (but different) shortcomings in wetland delineation and detection (notably, WONI), or
- local and variable in terms of geographic extent, updating, comprehensiveness, polygon fidelity and thematic detail (notably, regional council datasets).

This is disappointing but unsurprising, since the mandate to monitor and conserve wetlands does not exist at a national level and, aside from superficial reports in national statistics and state of environment reports, the obligation to manage and report on extant wetlands has devolved to regional councils. Hence, the components of the matrix have developed systems sufficient to their need at the time, without regard to cooperation and coordination. This discussion will concentrate on the two datasets most commonly used to analyse and report wetland extent at a national level –WONI and the LCDB.

2.1 Wetlands of National Importance (WONI)

WONI is now a component of the wider FENZ (Freshwater Environments of New Zealand) database (Leathwick et al. 2010), a set of spatial data layers that describes and interprets environmental and biological patterns in New Zealand's lakes, rivers and wetlands and provides DOC with a systematic conservation, planning and reporting tool. Since incorporation into FENZ, WONI has been improved but still retains its original character as described in the following passages. WONI describes the environmental attributes, biodiversity values, pressures and rankings of palustrine (inland, non-flowing, freshwater) wetlands. It comprises three interrelated layers (Fig 1):

1 Historic Typology – the delineation and classification of pre-human wetlands.

2 Current sites – the delineation and naming of current wetlands and accessory information relating to biodiversity values, conservation and threat status.

3 Current Typology – the delineation and classification of contemporary wetlands, plus the evidential information that underpins wetland recognition and classification.

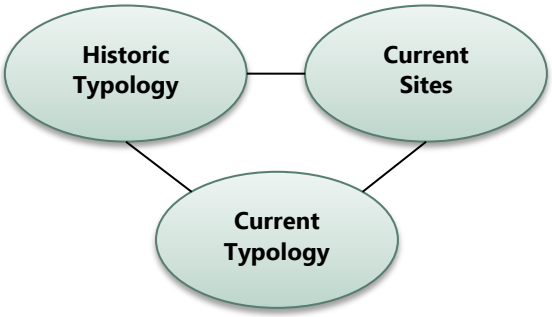

Figure 1: WONI comprises three layers, among which this analysis concentrates on Current Typology.

Current Typology is the layer most consistently used for reporting and analysing contemporary wetlands. It is the most up-to-date and information-rich of the two 'current' layers. It is much more than a simple delineation and classification of wetland types. It also contains the underpinning data that contributed to the classification logic (Table 1). Current wetlands recognised by WONI have seldom originated as 'green-fields' or new mapping by compilers. Instead, WONI polygons were 'seeded' from evidential data with various origins, including:

- Authoritative wetland polygons from other (e.g. regional council) layers.
- Authoritative localities from other (e.g. regional council) sources, which then underwent a raster-based 'region-growing' process until it occupies the assumed wetland area visible on imagery.
- Probability polygons resulting from the combination of evidential data such as soil, substrate, vegetation, slope, and hydrology.

Table 1: WONI has an attribute table rich in evidential data, indicated by multiple columns in the facsimile of the attribute table below.
These data determine the classification of wetland type in the final column

IDUNIQUE	Type probabilities	Indicator vegetations	Substrate qualities	Slope factors	Hydro indicators	Soil indicators	Wetland type
							Bog
							Fen
							Swamp
							Marsh
							Seepage
							Gumland
							Inland saline
							Pakihi

Polygons in WONI are resolved to a minimum map unit size of 0.5 ha. WONI polygon boundaries inherit qualities from their original data and from the process employed to create them. Sometimes the result is both visually-appealing and cartographically-

meaningful and sometimes it is neither (particularly where the region-growing process has been used).

This dependence on underlying data is remarked upon by Rutledge & Ausseil (2006), who also identify the opportunity for WONI to coordinate with the soil modelling programme, S-map, to improve key data such as soil drainage, required for robust wetland classification.

The ecological scope of WONI was intended to be just palustrine & inland saline hydrosystems as defined by Johnson and Gerbeaux (2004). This excluded estuarine, marine, riverine, lacustrine, plutonic, geothermal, and nival hydrosystems. However, visual inspection of Current Typology, suggests the inclusion of at least some riverine, estuarine, and lacustrine (and some ephemeral) hydrosystems, so its mapping appears to have exceeded its intended scope and indeed, some errors at the Hydrosystem level and the need to refine definitions and rule sets in WONI were noted during uncompleted efforts to update the FENZ wetland layer in 2014 (Ausseil & Sutherland 2014). All wetlands in WONI are classified to the level of Wetland Class, as defined by Johnson and Gerbeaux (2004).

2.2 New Zealand Land Cover Database (LCDB)

The New Zealand Land Cover Database (LCDB) is a multi-temporal, classification of New Zealand's land cover. Landcare Research is the current compiler and custodian of the database and has been responsible for publication of its last two major revisions. Land cover is delineated by polygon boundaries and described by a land cover code, and a land cover name at each of four nominal time steps: summer 1996/97, summer 2001/02, summer 2008/09, and summer 2012/13. LCDB can therefore be considered as a virtual stack of four land cover maps embodied in one polygon layer (Fig. 2). As the name implies, the LCDB covers all New Zealand (including the Chatham Islands, but neither the Kermadec nor the sub-antarctic islands) and all terrestrial (and some intertidal) ecosystems.

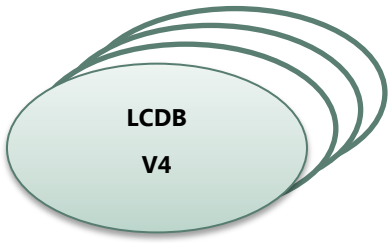

Figure 2: Although sometimes imagined to be separate layers, LCDB comprises just one layer with attributes to distinguish the different time steps.

The data set is designed to complement Topo50, New Zealand's 1:50,000 topographic database, in both theme, scale and accuracy. LCDB has adopted some elements of Topo50 to better harmonise the two databases, for instance, the coastline, lakes and rivers are common between the two. The minimum map unit size (of nominally, 1 ha) is similar to both Topo50 and WONI.

When first created, LCDB was new mapping, either classified directly from SPOT and LandSat satellite imagery, or interpreted visually and digitised manually by image analysts. Since then, the mapping of each new version of LCDB has embodied processes to improve polygon delineation mapping resolution, and classification accuracy, not just for the new mapping date but also including all earlier dates. A particularly fruitful relationship exists between LCDB and MfE's LUCAS-Land Use Map, the database that underpins New Zealand's international greenhouse gas reporting under the United Nations Framework Convention on Climate Change and the Kyoto Protocol (and other conventions). LCDB and LUM share imagery, change-detection and mapping processes, quality control, and checking techniques, and they both adopt each other's polygons and use them to cross-check their validity.

LCDB, at versions 2 and 3, was reported as being inappropriate for reporting on wetlands at national scale due to underestimations noted in the Wellington region (Davies et al. 2013). Since then, however, noticeable improvements have been made at versions 3.1 and 4. LCDB currently maps to a classification of 33 land cover classes on mainland New Zealand (2 further classes cater for particular vegetation communities on the Chatham Islands). In respect of wetlands, four classes apply: Herbaceous freshwater vegetation, Herbaceous saline vegetation, Flaxland, and Mangrove (Table 2).

Table 2: LCDB has four land cover classes that indicate wetlands, plus a binary 'flag', WETContext, identifying less obvious wetlands
(e.g. a kahikatea swamp forest would be recorded as Indigenous Forest with the WETContext field set to 'y')

WETContext (y/null)	1996 land cover		2001 land cover		2008 land cover		2012 land cover	Onshore (y/n)	QA/AC Records			LCDB_ UID
							Herbaceous freshwater vegetation					
							Herbaceous saline vegetation					
							Flaxland					
							Mangrove					
y							...					

In addition, LCDB has a 'WETContext' flag that can identify sites that are edaphically 'wetlands' despite having a land cover that does not explicitly identify with wetlands. In this way environments such as swamp-forests and wet heathlands can be recognised as wetlands while retaining their literal land cover class. In addition to a general improvement in mapping quality from version to version, LCDB has favoured wetlands particularly and, in five Regions (Bay of Plenty, Taranaki, Manawatū-Whanganui, Wellington, and Otago) and one District (Far North), has incorporated higher-quality wetland information from regional and district councils.

2.3 Regional Council Wetland Databases

Virtually all regional councils have some system of wetland mapping and monitoring in relation to the preparation and delivery of regional plans, and maintain a degree of similarity by sharing ideas in such fora as the Regional Council Biodiversity Working Group.

However, their capacity to support wetland mapping and monitoring, and the priority accorded to wetlands varies from region to region. Most regions have attempted at one time or other to comprehensively map wetlands (above certain area, or other threshold) but few invest heavily in ongoing mapping programmes to quantify change. Instead, a number of regions prioritise a representative set of wetlands for detailed monitoring based on assessed rarity, current extent, wetland class, vegetation type, ecological significance rankings and other criteria.

Such monitoring programmes are often in significant detail, employing 2 × 2 m or 10 × 10 m plots recording such information as; species present, species cover, fauna, weeds, pests, fences, plantings, condition score, water chemistry and hydrology, threats and trends.

Ten of the sixteen regional/unitary councils currently follow Clarkson et al.'s (2004) handbook for monitoring wetland condition. The Working Group recommends that regional councils follow components of the handbook for monitoring wetland condition, in combination with the WETMAK (WETland Monitoring and Assessment Kit) system of Denyer and Peters (2012) for semi-quantification of the assessment.

Each regional council's current wetland monitoring method has been summarised in Table 3 below (adapted from material prepared in 2016 by MfE for the Regional Council Biodiversity Working Group):

Table 3: Local authorities have developed wetland mapping and monitoring systems to suit their needs and resources

Regional/Unitary Council	*Wetlands monitored?*	*Wetlands mapped?*	*Wetlands classified?*	*Wetland condition assessed?*
Northland	Y		Y	Y (Landcare WCI)
Auckland	Y	Y	Y	Y (modified – Clarkson et al. 2004)
Waikato	Y	N	N	Y (Clarkson et al. 2004 –some sites)
Bay of Plenty	Y	Y	Y	Y (Clarkson et al. 2004)
Gisborne	Developing	Y (FENZ & aerial photos)	Y	Y (Clarkson et al. 2004)
Taranaki	Y	Y	Y (Johnson & Gerbeaux)	Y (modified condition score – Clarkson et al. 2004)
Hawke's Bay	Developing	Y	N	Y (Clarkson et al. 2004 & 2013)
Horizons	Y	Y	Y (Johnson & Gerbeaux)	Y (WETMAK & Singers)
Greater Wellington	Developing	Y		Y (Clarkson et al. 2004)
Nelson	N	N	N	N
Tasman	N	Y		N
Marlborough	Y	N	N	Y
West Coast	N	N	N	N
Canterbury	Y	Y	Y (Johnson & Gerbeaux)	Y (Clarkson et al. 2004)
Otago	Y	Y	Y	N
Southland	Y	Y	N	N

Collectively, a wealth of detailed local information accumulates at the regional level that, while not aggregating to a coherent national picture, could certainly inform a national expression of wetland extent.

3 Comparing WONI and LCDB

It is clear that assembling a nationally consistent and comprehensive database of wetland extent from regional databases would be a formidable but not impossible task, but with a probable outstanding need to infill gaps and reconcile differences. It is equally clear that either WONI or LCDB (or both) should already be fulfilling the need for a national database for monitoring and reporting wetland extent at the national level – both are national (although one professes not to map all wetland environments), and both resolve wetlands to a useful minimum map unit size of 1 ha or less. The fact that neither is completely satisfactory in this role is due, in part, not only to their differences in origin, compilation, and resourcing, but also to their historic un-connectedness when one considers that both have useful information that could enhance the other, as the following passages show.

Figure 3 presents a high-level view of wetlands as represented by each database, the areas they have in common, and those that are not. Even though wetlands are still being lost at the national scale (a study in Southland by Evans (2016) revealed loss of 1.3% per year between 2007 and 2014), the comparison made here is between WONI (c <2003) and LCDB at its 2001 time-step to get the time period as equivalent as possible.

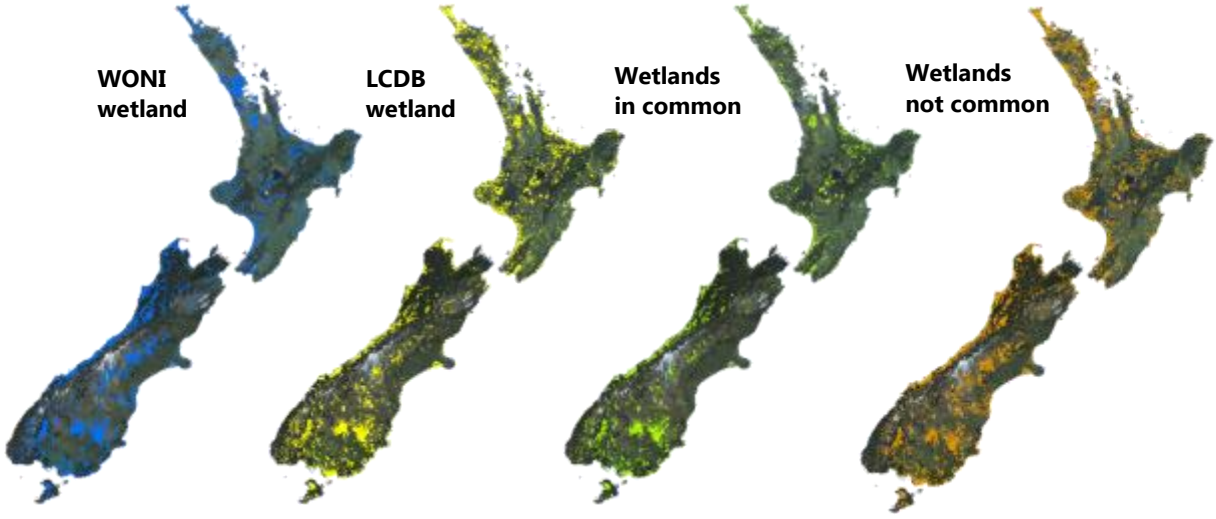

Figure 3: While outwardly similar, WONI and LCDB exhibit more differences than commonalities.
The coloured areas in all the maps above exaggerate their true area when reproduced at such small scale but this exaggeration serves to illustrate not only the similarity in distribution of wetlands mapped by each database, but also the distribution of areas of disagreement.

The first two maps in Figure 3 give the illusion of close similarity – which, unfortunately, is false. A spatial join of WONI and LCDB reveals 130,000 hectares of agreement shown in the third map of Figure 3. But there exists an even greater area of disagreement (Table 4) illustrated by the fourth map of Figure 3.

Table 4: Differences outweigh areas in common in WONI and LCDB

		LCDB	
		Wetland	**Not Wetland**
WONI	**Wetland**	129,772 ha	111,896 ha
	Not wetland	64,361 ha	

The proportions of disagreement are similar whether analysed by area or by number of polygons. This result is not just 'noise' – it follows removal of polygon artefacts and slivers resulting from the merge of the two layers and also removal of disjunct mapping, for example, LCDB maps mangrove communities whereas WONI does not, so these LCDB polygons were removed from the comparison.

3.1 Agreements and Differences Illustrated

While considering possible explanations for this disagreement, a working distinction was made between differences in delineation (where the two databases agree on the presence of a wetland, but differ in how it is drawn) and differences in detection (where one database identifies wetlands that the other does not). For this purpose, disagreement-polygons that were in contact with an area of agreement (also called a polygon-in-common) were considered to be differences in delineation. Conversely, disagreement-polygons not in contact with a polygon-in-common were considered to be differences in detection.

Figure 4 shows a locality in Taranaki that illustrates real examples of each condition. In this figure (and in all subsequent figures unless stated otherwise), WONI polygons are drawn in cool colours (blue and teal) and LCDB polygons are drawn in warm colours (red and orange). Polygons-in-common (representing areas of agreement) are coloured green.

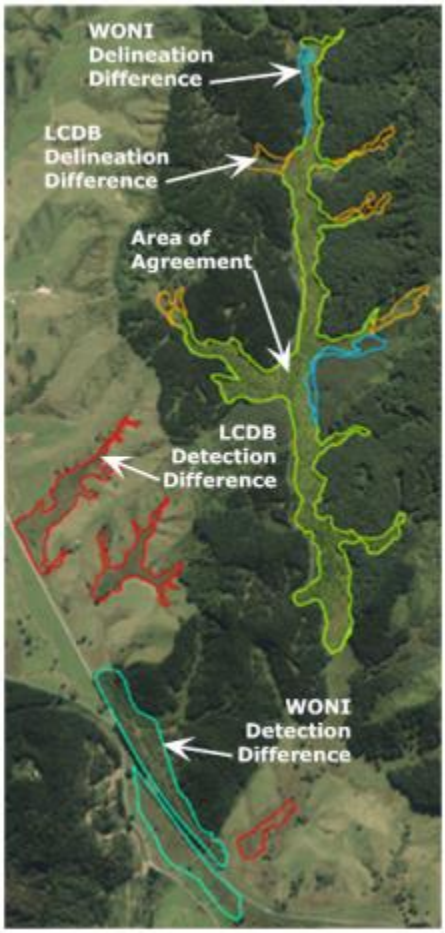

Figure 4: A locality in Taranaki showing an area of agreement (green), with 'differences in delineation'
(WONI polygons in blue and LCDB polygons in orange) and 'differences in detection' (WONI polygons in teal and LCDB polygons in red).

To better appreciate the scope of both agreement and difference between WONI and LCDB, and importantly the value of each, it is useful to view their treatment of wetland areas across various geographies from north to south of New Zealand. The following section shows seven further views of wetland localities, and makes some comment on aspects of each illustration. In all cases we have maintained the distinction between differences in delineation (i.e. in contact with an area of agreement) vs differences in detection (i.e. detached from an area of agreement), although some of the former are seen to be very far from minor disagreements in line placement and some of the latter can sometimes be viewed as extensions of an area of agreement.

Unless otherwise specified the colours are as described earlier vis.:

- Polygons-in-common (areas of agreement) are coloured Green
- Disagreement-polygons present in WONI are in cool colours
  - Delineation differences in blue
  - Detection differences in teal
- Disagreement-polygons present in LCDB are in warm colours
  - Delineation differences in orange
  - Detection differences in red

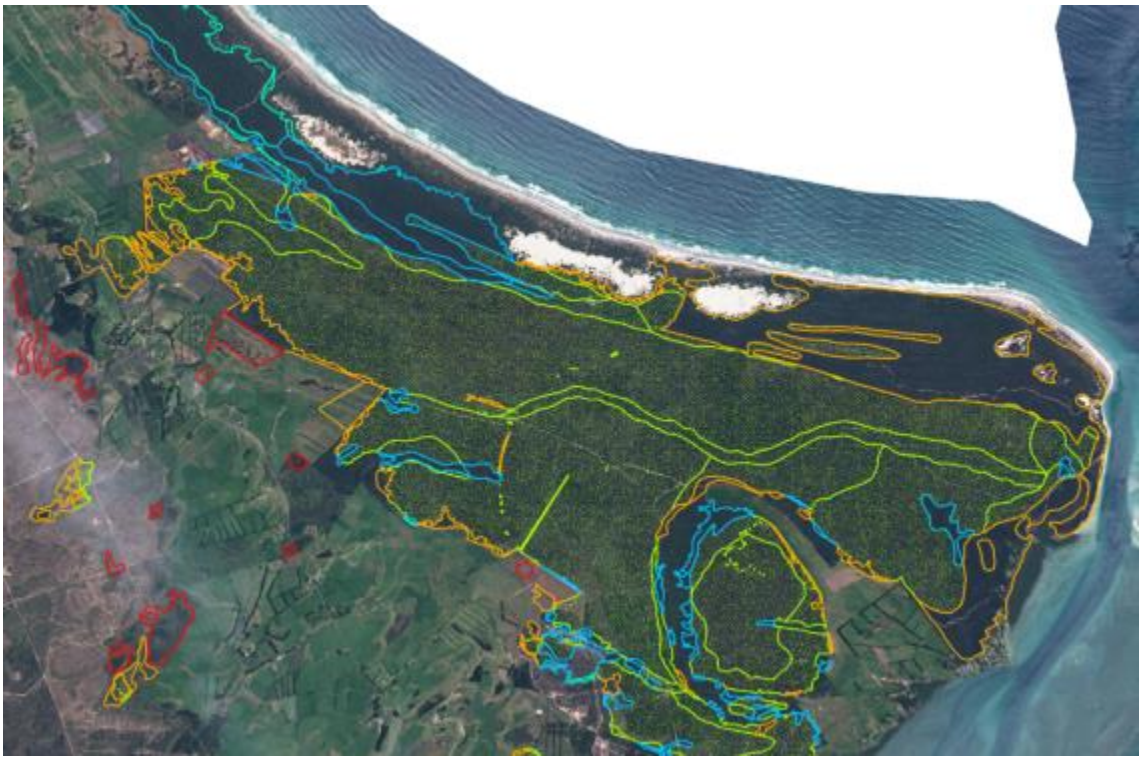

Figure 5: This is an extensive concentration of wetlands in Rangaunu Bay, Northland. There is a large core of agreement between WONI and LCDB but significant adjoining areas to seaward and smaller outliers inland are mapped by only one database.

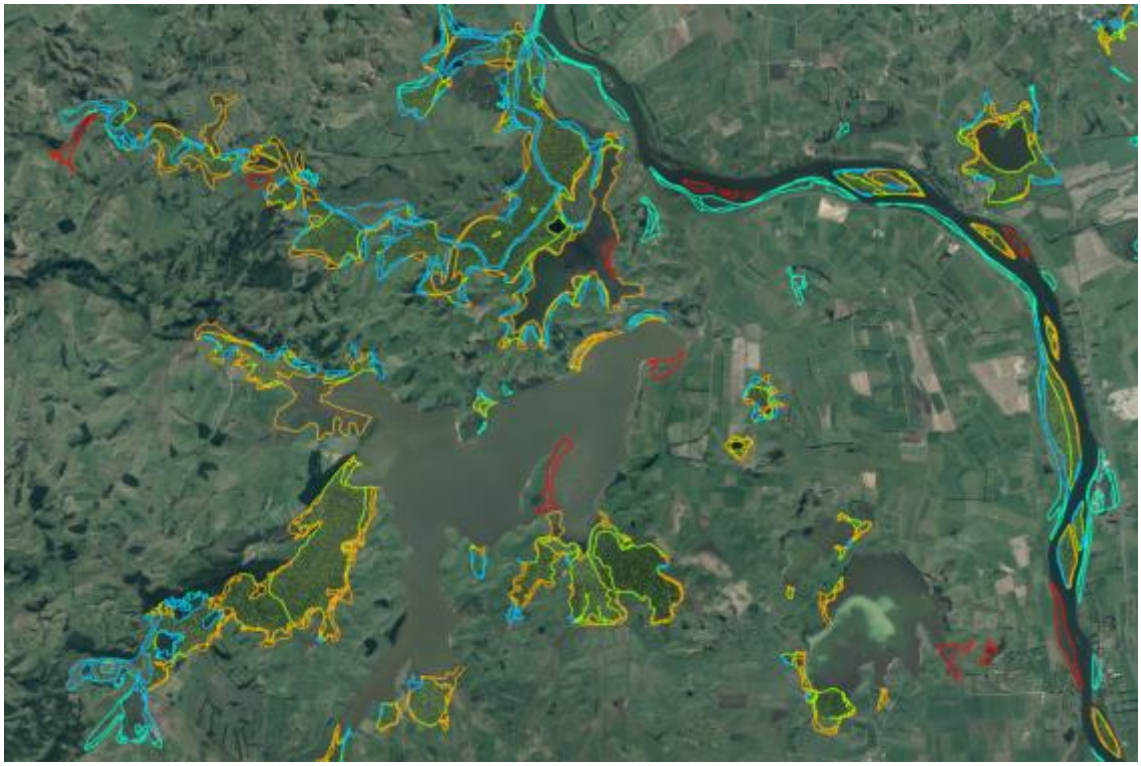

Figure 6: A disbursed area of wetlands in the vicinity of Lake Whangape, Waikato. The areas of agreement are more extensive than a first glance conveys but there are numerous 'differences in delineation' threading around and away from these (and a few new outliers in one layer or the other). This may illustrate both 'green-fields' discovery by LCDB and enhanced detail in WONI from local mapping.

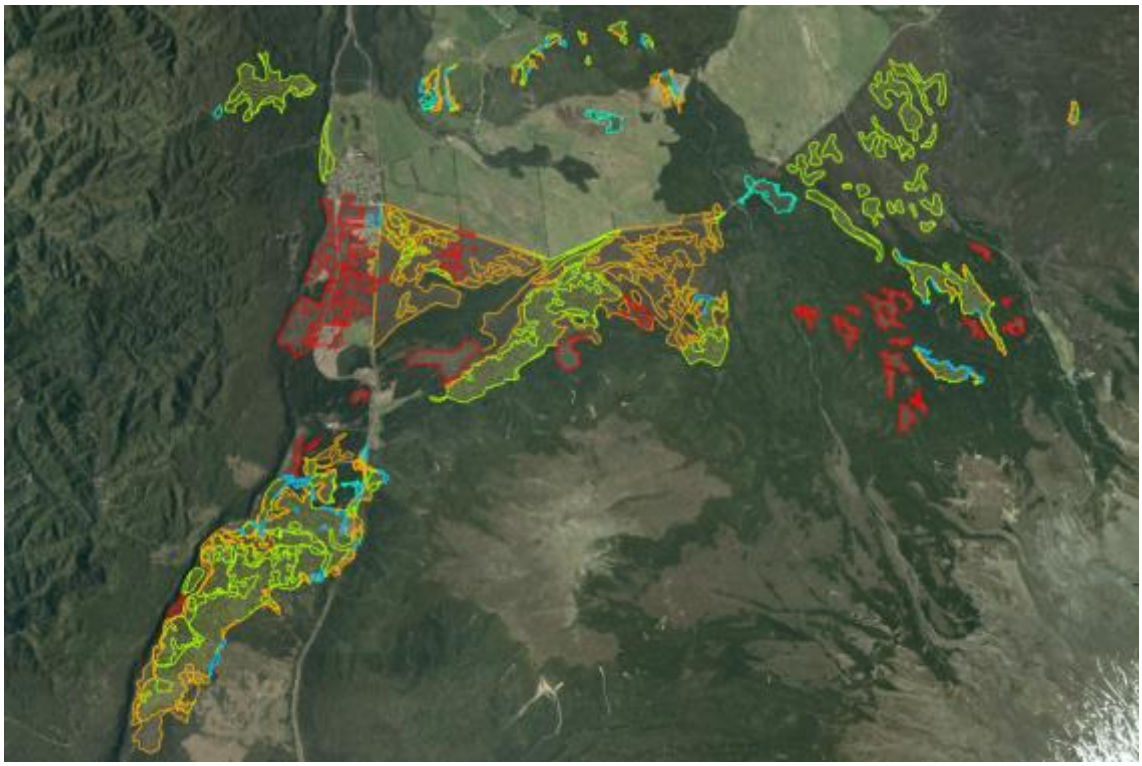

Figure 7: Extensive wetlands South and East of National Park village, Central North Island. There is good agreement in wetlands disbursed over the footslopes of Mt Ruapehu (upper right of image) and along the Waimarino Stream (lower left), but very poor agreement South and East of the village where LCDB has discovered and mapped large additional areas of putative wetland.

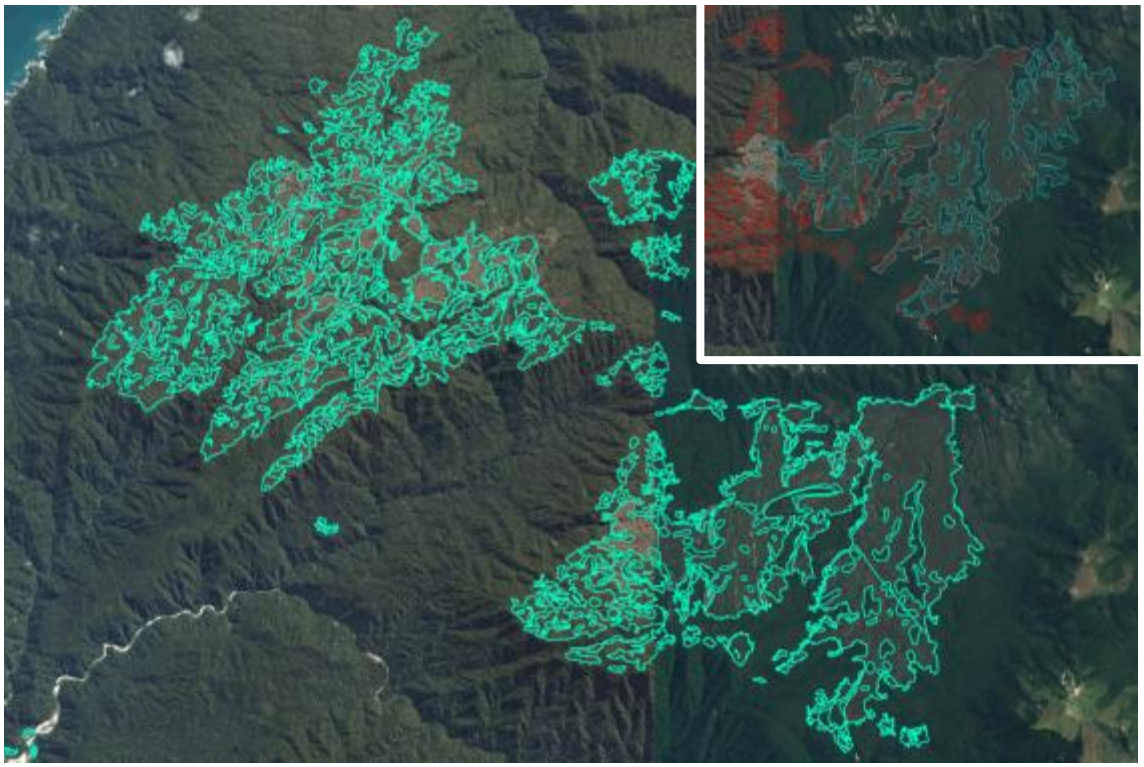

Figure 8: Two very large areas of montane wet downlands (the Mackay and Gouland Downs, NW Nelson) mapped by WONI but not recognised as wetlands by LCDB.
Ironically, LCDB has delineated some very good polygons that could have WETContext switched to 'yes' in order to recognise these areas as wetland. Refer to the inset image where one such polygon is shown in blue superimposed on the underlying WONI areas in red.

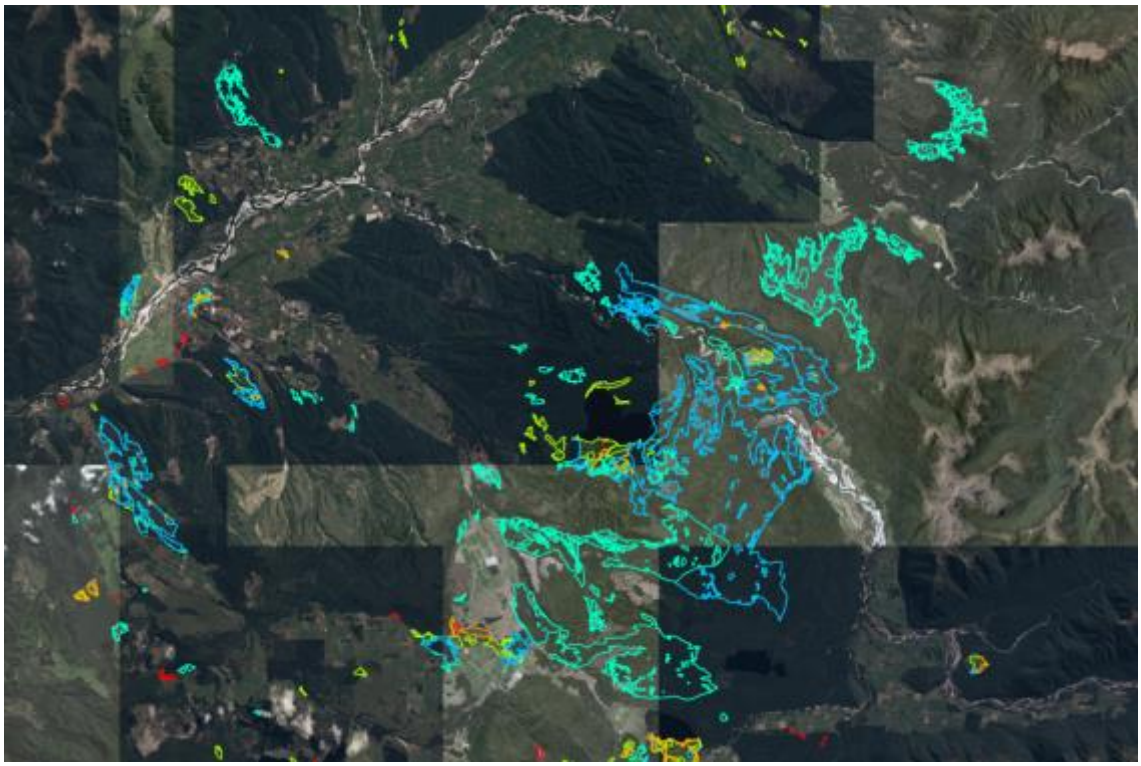

Figure 9: A disbursed series of mainly pakihi wetlands in the Grey Valley, Westland, that are substantially unrecognised by LCDB.
As in Figure 8 above, these areas of mainly shrubland and fernland could easily be recognised as wetlands by LCDB using WETContext. This also illustrates some unnecessarily complex polygons generated by the 'region-growing' process used by WONI.

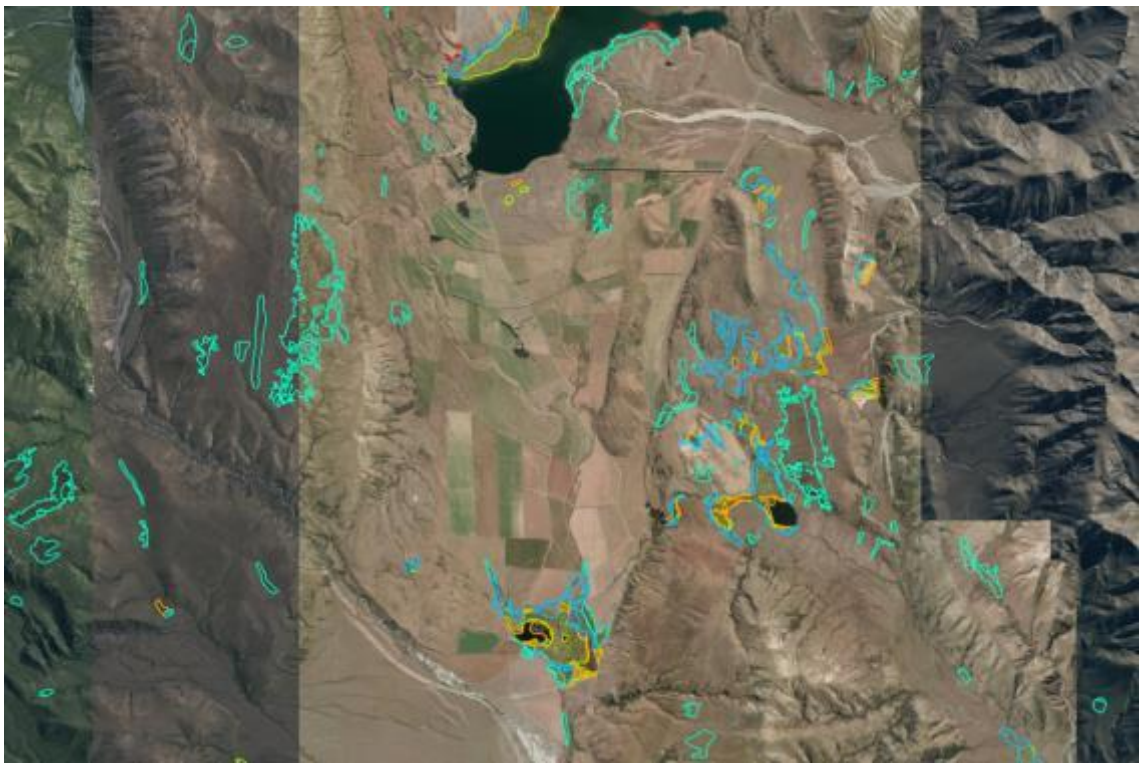

Figure 10: An extensive array of small tussock marshes in the vicinity of Lake Heron, central Canterbury high-country, that are substantially unrecognised by LCDB.
A difficult target for image classification, difficult even for visual interpretation, but could readily be recognised as wetlands by LCDB using WETContext.

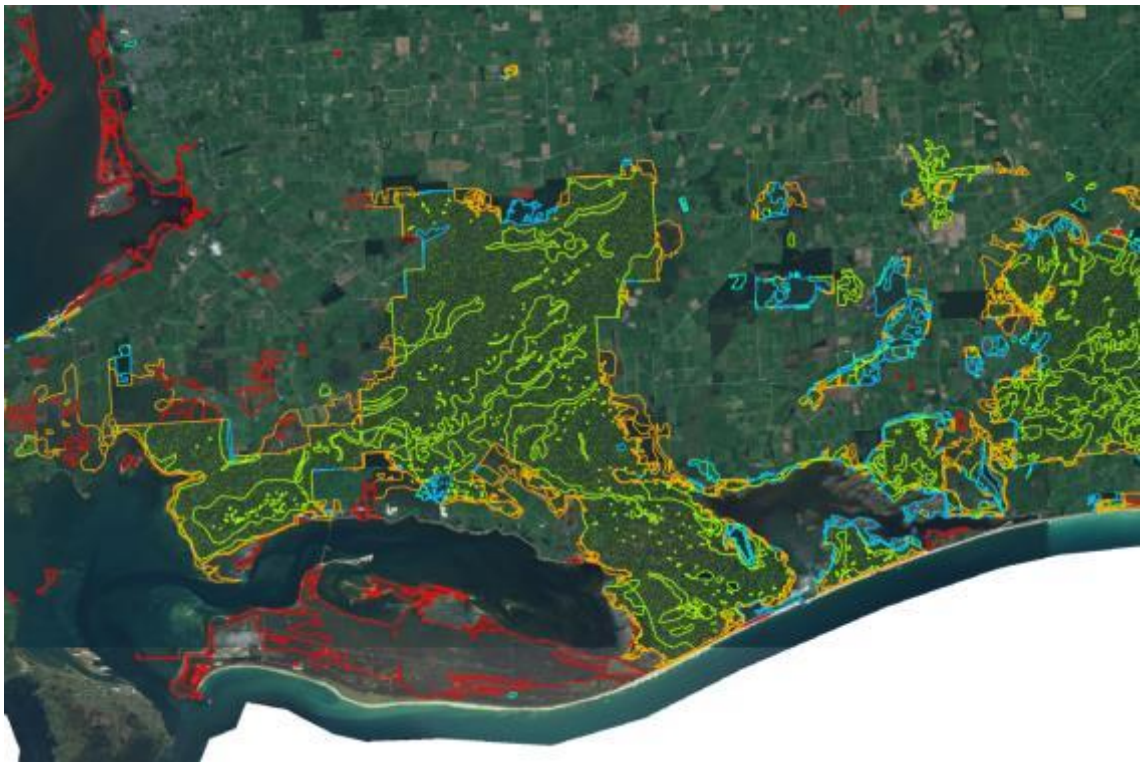

Figure 11: The nationally significant Awarua-Waituna wetlands in Southland (showing Tiwai Point in the lower left of the image).
There are numerous differences in delineation around the margins of the main wetlands with both databases contributing additional area. LCDB proposes further large areas of wetlands undetected by WONI (though some of these may be estuarine and therefore generally outside the scope of WONI). Mapping by Environment Southland, that post-dates both WONI and LCDB, could clarify these areas of disagreement.

3.2 Differences between WONI and LCDB

When analysed, Differences in Delineation explain about half of the disagreement between WONI and LCDB (Table 5).

Table 5: Postulated 'differences in delineation'

		LCDB	
		Wetland	**Not Wetland**
WONI	**Wetland**		54,959 ha
	Not wetland	35,843 ha	

This suggests that a review and rationalisation of polygon-in-common delineations in the two databases would benefit both layers and bring them much closer together without perturbing their individual mapping rationales.

The converse analysis, Differences in Detection, presented in Table 6, suggests something more fundamental is going on in each dataset.

Table 6: Postulated 'differences in detection'

		LCDB	
		Wetland	**Not Wetland**
WONI	**Wetland**		56,937 ha
	Not wetland	28,518 ha	

The areas affected are approximately equivalent in aggregate to the differences in delineation. Also similar is that the additional wetlands mapped by WONI are approaching twice the area of additional wetlands mapped by LCDB. This implies WONI and LCDB are different in either:

- Their threshold for resolving features that both would agree to be wetland
- Their process for discriminating wetlands from surrounding ecosystems or land covers
- Their definition of what constitutes a wetland, or
- Their scope for inclusion of wetlands of various types

The following is a brief discussion of these possible explanations.

Threshold differences

The most obvious threshold to consider is that of spatial resolution, and in this respect WONI and LCDB are very similar. WONI claims a minimum map unit area of 0.5 ha (although some polygons are smaller than that). WONI makes no mention of any test of linearity but one presumes that slivers of less than about 10 m would not be countenanced. LCDB claims a minimum map unit area of 1 ha but recent mapping by Landcare Research in LCDB versions 3 and 4 has extend mapping of wetlands to sub-hectare level. LCDB does not cite a width threshold either, but current mapping practice would place this in the region 10–30 m.

So, while WONI claims a slightly lower area threshold, this explanation is unlikely to account for a large proportion of the differences discovered.

Process differences

There is a fundamental point of difference in the process for creating of a WONI polygon and that for creating an LCDB polygon.

WONI polygons, for the most part, originate from evidential data that establish the location (and in some cases, the extent) of a probable wetland. In some cases, evidential data are highly reliable, for example, where they originate from high-resolution mapping by local authorities. In other cases data are locationally accurate (in the sense of knowing that a wetland is present) but the areal extent of the wetland has been established by an image-processing process called 'region-growing', which inflates a polygon from the

known locality until it approximates the visible edge of the putative wetland. Few, if any, WONI polygons were created by 'green-fields' discovery or undirected observation.

LCDB, in contrast, has mapped most of its wetlands de novo through image classification and visual interpretation (and delineation) of (satellite and photographic) imagery. Topographic mapping has sometimes provided a cue to resolving wetlands, as have other evidential layers (such as peat soils) but their use has not been widespread. High-resolution mapping by some local authorities has been used in recent years in the compilation of versions 3 and 4 of LCDB.

This independence of origin of the two datasets will likely explain a significant proportion of the differences discovered. It also suggests that each dataset will likely contain valuable polygons that could enhance the other.

Definition differences

WONI and LCDB have different, but convergent, approaches to defining and classifying wetlands.

WONI follows the six-level wetland classification of Johnson and Gerbeaux (2004). This first classifies land into hydrosystems (broad hydrological and landform settings, with aspects of salinity and temperature). The classification then provides for this high-level breakdown to be successively sub-classified into subsystems, classes, forms, structures and, ultimately, vegetations. Under WONI, the classification breakdown reaches the third level, Wetland Class, with eight categories used: bog, fen, swamp, marsh, seepage, gumland, inland saline, and pakihi. An attempt was made to classify the structural vegetation class using LCDB2 but this was unsatisfactory and not retained in the FENZ database. The hydrosystem approach to mapping wetlands is good, in that it enables recognition of wetlands in all its variable forms, some of which are not instantly recognisable as wetlands.

At one end of the hydrological spectrum, WONI recognises shallow open water as wetlands but, without a mechanism for thresholding 'shallow', has simply included all open water less than 500 m long (in any dimension). This is something that LCDB would find equally difficult to classify.

LCDB, founded heavily on satellite imagery and aerial photography, recognises most of its wetlands by visual observation. LCDB has four land cover classes that typically align with wetlands: herbaceous freshwater vegetation, herbaceous saline vegetation, flaxland, and mangroves. All are visually identifiable and separable on imagery – a necessary attribute for the LCDB mapping process as discussed above. LCDB does, however, provide a mechanism for identifying less visually identifiable wetlands through use of a binary attribute called 'WETContext'. Through this mechanism, a swamp forest, for example, can remain classified as forest, with WETContext set to 'y' to convey the signal that it is a wetland.

Considering the foregoing, it is evident that while each database has the ability to recognise and classify all wetland conditions, their approaches are different. WONI begins from the standpoint of available databases or local knowledge from regional councils of variable accuracy. From there, WONI classifies in a hierarchy from hydrosystem to the

visible form of the wetland. LCDB focusses primarily on the visible form of the wetland, classifying it into one of four cover classes. Beyond this, LCDB has an (underutilised) mechanism for any not-obviously-wetland cover class to be flagged as wetlands by switching on the WETContext flag. But, to switch on the WETContext flag, external information typically must come into play to inform the LCDB compiler that (not obviously visible) substrate conditions exist that qualify the site as a wetland. Bringing such disparate external information into play has often been difficult for LCDB mapping agencies.

Clearly there exists, between these different approaches, quite wide scope for differences in mapping wetlands.

Recent work by Clarkson (2013) addresses the problem of a standardised wetland delineation system by considering three environmental criteria – vegetation, soils and hydrology and advocates incorporating all three criteria in delineating wetlands. While this fits the WONI philosophy well, and could equally be accommodated in the structure of both databases, it provides challenges for national mapping based primarily on observable features.

Scope differences

Unlike LCDB, WONI is not ecologically comprehensive of terrestrial New Zealand and nor does it address inter-tidal areas (even though its database structure and classification has the ability to do both). In contrast, LCDB has attempted (not always successfully) to map all wetlands. WONI's ecological selectivity (on palustrine and inland saline hydrosystems) may not be absolute – a visual inspection suggests inclusion of areas of riverine, lacustrine, and even estuarine hydrosystems.

So, differences in scope may exist in the two databases in their treatment of palustrine, inland saline, riverine and lacustrine hydrosystems. Differences certainly exist in their treatment of estuarine and geothermal – WONI considers neither, and LCDB attempts both (with arguable success). LCDB also maps the frozen waters of the nival zone, classifying it as 'perennial snow and ice' but declines to use WETContext to tag these areas as wetlands. Neither database addresses marine and plutonic hydrosystems as defined by Johnson and Gerbeaux (2004).

4 Configuring existing databases into a future spatial framework

The foregoing narrative asserts that, in respect of reporting wetland extent and change at the national level, New Zealand does not have a data-deficit problem. Instead, New Zealand has a data fragmentation problem and no present mechanism to interconnect databases to leverage the data we have.

Characterising the databases discussed in earlier sections, we have:

- WONI, a national database that is key to understanding wetlands and their place at the interface of land and water. It was compiled under constraints of time, resources, and evidential data and is described in its documentation as a 'work in progress' (Ausseil et. al. 2008). Further, while polygons have been improved since inclusion in FENZ, it has not been comprehensively updated in the decade since its creation.
- LCDB, a national database with capacity to identify wetlands among numerous other land cover classes. It has a capacity similar to WONI in resolving wetland outlines, a capacity that is presently under-utilised, but improving, and is regularly updated to underpin national reporting.
- Regional council databases, which are highly variable in coverage and nature and essential to underpin resource management and biodiversity conservation at the local level.

Each of the databases above have their place and cannot sensibly be deposed – LCDB as a record of all land covers nationally, RC databases as references for implementing resource management and biodiversity conservation locally, and WONI as an intrinsic part of the Freshwater Environments of New Zealand databank and the prime reference for pre-historic and present wetlands, their classification, and conservation value.

It seems achievable to arrive at a spatial framework that harnesses the essential character of each database to deliver national outcomes. The key processes required are those of reconciliation and interconnection.

LCDB has the ability to represent, in outline, any wetland resolvable by WONI. Its attribute structure is skeletal but can recognise wetlands either explicitly (by land cover class) or by its WETContext flag. If necessary, an additional linking field (or fields) could be added to establish parity between databases – for example, to segregate polygons that fall inside and outside the ecological scope of WONI and LCDB. LCDB has the great advantage of its established time series for monitoring and reporting, its recognition as a key environmental database, and resourcing for ongoing updates.

WONI has a descriptive richness that LCDB lacks. WONI's attribute table embodies all the evidential information that contributes to its various classifications. It links the present expression of wetlands to its former extent and considers each wetland's place and value in the landscape. It is a key component of the FENZ and a point of reference nationally for researchers, policy-makers and managers. It is a natural junction between locally-focussed and verified wetland data, and national layers of wetland extent.

Regional (and District) Council wetland databases are the tools necessary for implementing resource management and biodiversity conservation outside crown conservation land. They are tuned to local needs and priorities, management strategies and plans and the resources available to implement them. Associated with spatial layers there are commonly aspatial information and plans.

Considering this, a three-tier spatial framework similar to that illustrated in Figure 12 is proposed. This framework should be the subject of considered architectural design, but this need not entail significant restructuring of existing databases. The main investment required is a staged series of reconciliation and interconnection processes. Under this framework, all databases retain their present roles and functions. While regional councils undertake a considerable volume of wetland monitoring, their diversity and sometimes targeted focus make this a useful, but not comprehensive mechanism for 'across-the-board' wetland updates. Instead, that role would be primarily performed by LCDB as part of its regular remapping cycle, and any changes detected would be propagated to WONI/FENZ (and thence to RC databases as appropriate).

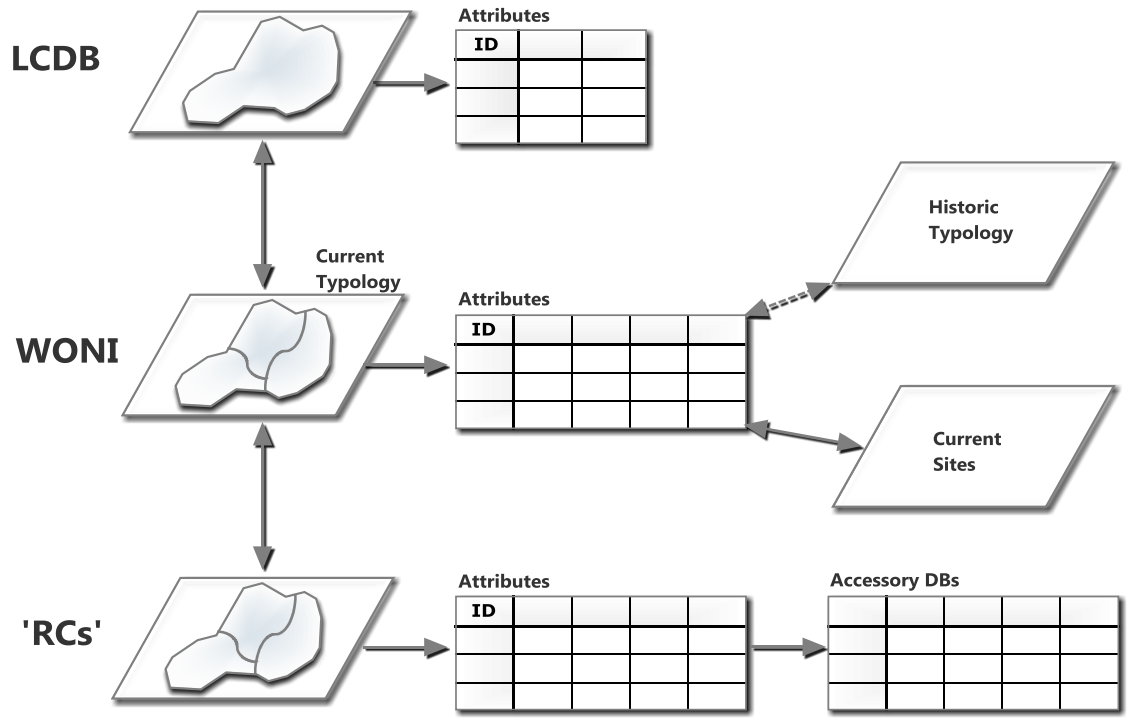

Figure 12: The proposed three-tier spatial framework for wetland mapping and monitoring.

4.1 Building the spatial framework

A possible six-stage workflow is listed below:

1 WONI Preliminary Review

2 Framework design

3 Reconcile WONI and LCDB, updating LCDB in the process

4 Update WONI

5 Reconcile RC databases and WONI, updating WONI in the process

6 Update LCDB

These steps are elaborated below. Steps 2–6 relate directly to building of the framework but first we propose Step 1, a review of the integrity of the WONI component of FENZ, to get it in the best condition possible for integrating into a national spatial framework…

WONI Preliminary Review

First, we advocate a clean-up of polygon artefacts in WONI/FENZ to remove slivers and holes, and to smooth erroneous straight lines and spurious angular line segments (usually resulting from the 'region-growing' process remarked on in an earlier section). The LCDB programme has developed workflows to do these tasks with negligible negative effect on boundary placement and polygon area.

Second, we advocate uplift of a polygon review of WONI undertaken by Belliss et al. (2017). The purpose of this review was to gauge wetland loss between the time of WONI's creation (referencing imagery up to 2003) and 2016. The review made several records of interest:

- wetlands completely lost
- wetlands partially lost
- wetlands poorly delineated
- wetlands possibly detected in error

The last two categories should be addressed and edits made to WONI to avoid these artefacts complicating the spatial framework. The first two categories relating to wetland loss should be used to flag WONI change polygons for later attention in the WONI/LCDB reconciliation stage.

Finally, there exists an unpublished partial upgrade of WONI based primarily on improved (and probably more recent) regional council datasets (Ausseil & Sutherland 2014). This should be examined and compared with the published dataset and a process developed to either incorporate this improved knowledge or to use it as a more sensible start-point of the framework. The question of date-stamping the two versions becomes pertinent, and establishing parity (however approximate) with LCDB time-steps. Useful temporal insights should be captured and used in the WONI/LCDB reconciliation stage below.

Framework Design

Designing the architecture of the three-tier framework is a specialised task that should be undertaken by a database architect. The result need not be radically different from that which currently exists within each database but if linking identifiers are indicated, they should be added and the mechanism for creating and establishing relationships between databases determined. Consideration needs also to be given to the scope, content, and descriptors of wetlands in each tier – perhaps to the point of creating a data dictionary, at

least for the national tiers. If the scope of WONI is to remain a subset of hydrosystems then consideration should be given to whether LCDB alone maintains the other hydrosystems or whether other databases need to be included. Other issues to resolve include:

- The treatment of shallow water bodies as wetlands
- Complementarity of wetland classifications
- Whether multiple time steps are built into WONI (and/or RC databases) or whether LCDB alone contains the temporal dimension

The desired outcome would be an architecture that accommodates existing functions alongside the new functions of national monitoring and reporting in as simple a structure as possible. WONI would ideally remain the national reference set of wetlands, with interrelationships established so that LCDB and RC databases can contribute updates and exchange records as occasion demands.

Reconcile WONI and LCDB

Of foremost importance is to examine and reconcile the very large differences between WONI and LCDB. The present state supports divergent representations of wetland locations and causes considerable confusion in the different analyses possible from the two sources. LCDB would struggle to maintain the complexity of classification of WONI, and nor could LCDB manage the internal subdivision of wetlands arising from the various evidential layers, but reconciliation of outer boundaries is an achievable and desirable objective. Reconciliation is a bi-directional process but for efficiency we suggest a focus on LCDB in the first instance.

All wetlands in both databases could have their veracity reviewed but, pragmatically, one could provisionally accept the polygons-in-common and focus attention solely on difference polygons. Developing an 'order of trust' is one mechanism that can be used, drawing on confidence measures in WONI and records of source and era mapping in LCDB. Alternatively (or as well), a manual visual review of difference polygons is not an impossible task, to rank features for inclusion in the final layer(s). The objective of the review would be to produce a set of reconciliation polygons. Polygons in-scope in either layer, not in the reconciliation set, and not in-common, would be marked for deletion or more careful scrutiny. Polygons in-scope in the reconciliation set and not already in one or other of the layers would be marked for inclusion. The WONI change polygons detected by the Belliss et al. (2017) wetland loss review should be incorporated into the reconciliation layer as a change set for the period 2001/3–2016.

The process for inclusion would start with LCDB because a) it is a simpler structure for which semi-automated processes already exist, and b) it is imminently due for mapping of a further (2016) time-step and it would be convenient to have this process completed before then. LCDB already has processes for artefact removal and feature smoothing so that only 'clean' polygons are presented as targets for inclusion. Inclusion can variously be by automated means or manual methods depending on complexity. The polygon set for inclusion in WONI, and removal from WONI, would be held over for the following step (and implemented as resources become available).

Update WONI

Updating WONI/FENZ is a more complex task involving a more detailed attribute set and related layer dependencies. It is also something in which custodians and stakeholders need to be centrally engaged. Potentially a process similar to that used for LCDB could be implemented. Alternatively a completely hands-on manual edit would be required. Collateral tasks like attempting to populate evidential fields and generating wetland classifications could be done as part of the boundary update or left until later.

Once completed, for those wetlands within their common scope, WONI and LCDB should be in agreement (at LCDB's 2001 time-step).

Reconcile RC databases and WONI

Regional (and District) council databases are a fertile source of detailed information supported by local insight. They are, however, a more diffuse subject on which to work and will likely require individual workflows to be developed for each region.

Most local databases will have either have begun with the WONI polygon set or have donated their polygons to WONI during its creation. It is likely therefore that instances where WONI has records not represented in RC datasets, will be few. Nonetheless, there may be regional target sets arising from this process that regional councils may want to uplift to fill their record of wetlands in their region. It is more likely that RC datasets will have new records that could be donated to WONI (and thence to LCDB under the next process) and these can be accumulated into a target set for incorporation in an adaptation of the workflow created for the previous process.

Update LCDB

Propagating, into LCDB, those records gleaned from regional and district council databases, should be a semi-automated step using an adaptation of workflows already in use for LCDB updating. As will all LCDB updates, there is a consequential process to back-cast and fore-cast the new records so they are true for all previous and following time-steps (i.e. if a wetland has been created or removed, then the interval during which that change occurred is recorded in the attribute table).

4.2 The cost of building the Framework

Building the framework would be a multi-agency exercise, engaging at least the custodians of WONI/FENZ and LCDB, and as many regional councils as are prepared to participate. However, many of the processes for streamlining workflows created for LCDB mapping could be used to advantage in making the build as efficient as possible.

Detailing and budgeting the six-step process described above should therefore be a collaborative exercise for the future. In the interim, we estimate that each step will likely cost in the region of $50–80k, amounting to a total build cost around $450,000.

4.3 Maintaining the Framework

Onward maintenance of the spatial framework should not require new infrastructure. LCDB, being a key database for monitoring and reporting in several subject domains, is expected to have ongoing funding to support future updates. WONI, in the opinion of the author, is overdue for an upgrade and, as a key component of FENZ, requires continuing financial support in the custody of DOC. And regional councils, while interpreting their responsibilities to map, monitor and report on wetland extent and condition in different ways, will continue to discharge these responsibilities.

Almost all change mapping will originate from either the LCDB or RC databases, so the data flows to maintain harmony between layers will be directed inward, as indicated in Figure 13. Additional richness is likely to accumulate in the RC databases from wetland condition surveys according to the method described by Clarkson et.al. (2004), and this could also be shared with WONI.

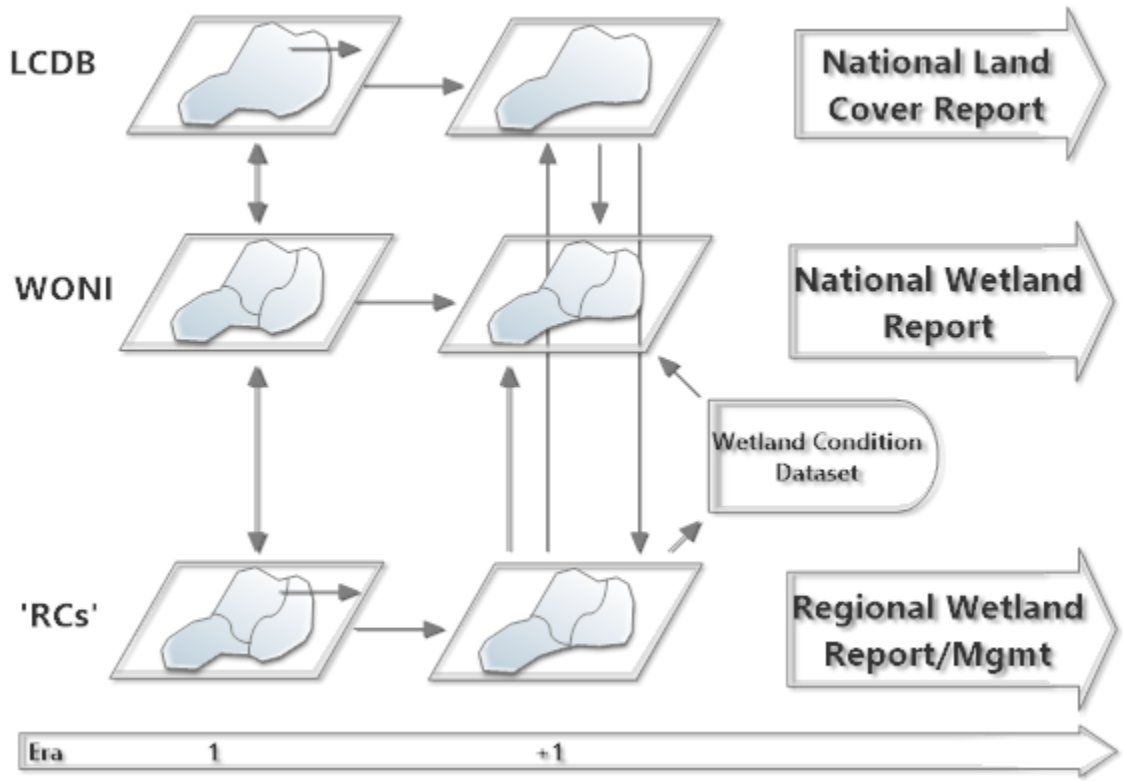

Figure 13: Data and information flows over time from the proposed spatial framework.

There will be costs associated with maintaining harmony within the framework which will need Other measures that need to be factored into its implementation include:

- LCDB must install a specific sensitivity to wetland change and not rely on this necessarily being detected as part of a general land use change algorithm
- Custodians of all databases must be resourced to manage the operational transactions involved in data sharing

- Custodians of all databases must be resourced to implement the considerable data editing and management operations involved in a coordinated and responsive data structure that underpins reporting at multiple levels.

5 Conclusion & Recommendations

New Zealand has a stable and appropriate structure of spatial (and aspatial) databases with the capacity to contribute meaningfully to wetland mapping and monitoring. That these databases are subject to fluctuating (and sometimes zero) funding that results in uncertain maintenance, periods of neglect, and their occasional inability to answer key questions related to environmental state and change, is no reflection on their intrinsic design and value. In this environment, there is little justification in contemplating creation of a new mapping and monitoring framework when one can readily be formed from existing components. The factors inhibiting New Zealand's ability to report on wetland extent and change are those of unintended neglect (of wetlands and the databases describing them), independent development (of databases), and disconnection (between databases). These shortfalls could be remedied by fine-tuning, reconciliation, and interconnection of the three tiers of database discussed here to form a useful spatial framework.

6 Recommendations

Overall recommendation

We recommend that the existing national databases, WONI, LCDB, and the regional databases, are maintained, rules/processes are set up to connect the databases with each other, and decisions are made on ongoing governance and responsibilities for these databases. This would allow MfE, DOC, RCs, and the wider community ongoing access to information about contemporary changes to wetland extent.

Recommendation 1

Update the current WONI database, which has not been reviewed for a decade, building on the uncompleted update of the database from 2014 (Ausseil & Sutherland, 2014) and recent edit lists from Belliss et al. (2017).

WONI has been in a state of suspension for over a decade. Before the comprehensive update that will come from reconciliation with LCDB and RC databases, a limited upgrade involving three processes is recommended:

a A clean-up of polygon artefacts in WONI to remove slivers and holes, and a further process to smooth erroneous straight lines, and spurious angular line segments. The LCDB programme has developed scripted workflows that could be adapted and used to effect these improvements

b Implement appropriate edits arising from the Belliss et.al. (2017) review of wetland loss between 2003 and 2016

c Examine, compare, and incorporate the improved knowledge arising from the (Ausseil, pers. comm.) unpublished partial upgrade of WONI based on improved (and probably more recent) regional council datasets.

Recommendation 2

Secure stakeholder agreement with the spatial framework, and develop protocols and rules around its final form:

a Socialise the spatial framework in Figure 13 with data custodians, key stakeholders and a database architect

b Get consensus and rules

Recommendation 3

Connect the current spatial layers as per the agreed framework:

a Reconcile WONI and LCDB, and update LCDB before its programmed 2016 remapping, if possible

b Update WONI content (and data structure if necessary) with reconciliation data and any legacy upgrade data from the unpublished improvements and wetland loss review activities

c Reconcile WONI and RC databases, and update WONI as appropriate to current date

d Update LCDB with reconciliation data from the RC review and back-cast and fore-cast all wetlands accurately to reflect change at multiple time-steps

Recommendation 4

Set up governance and ongoing ownership/expectations around the datasets:

a Going forward, we recommend participants in the spatial framework be resourced and supported to update and exchange data to maintain harmony between tiers and underpin accurate reporting of wetlands at regional and national levels and of land cover nationally for myriad purposes.

b Setting and formalising expectations about maintenance, funding, and database access for various stakeholders.

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