Manaaki Whenua
Landcare Research

Wetland delineation using desktop methods: a guide

Guidance for regional councils to meet mapping requirements under the NPS-FM 2020

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Wetland delineation using desktop methods: a guide

Guidance for regional councils to meet mapping requirements under the NPS-FM 2020

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Executive summary

The National Policy Statement for Freshwater Management (NPS-FM) came into force on 3 September 2020 and sets requirements for the mapping and monitoring of wetlands.[1] A nationally consistent method of mapping wetlands to 0.05 ha is required for implementing the NPS-FM. After consultation between the Ministry for the Environment, regional council wetland representatives, and Manaaki Whenua – Landcare Research, it was agreed that guidance would focus on manual desktop mapping of wetlands and assignment of wetland type, both using aerial imagery. This report sets out guidance on using aerial imagery to map wetlands and classify them to wetland type. It also discusses the use of other data that can assist with the desktop mapping of wetlands.

This guidance is intended to be consistent with, and complementary to, the field-focused protocols for the delineation of wetland extent (Clarkson 2014; Fraser et al. 2018; MfE 2021, 2022a), as well as Johnson and Gerbeaux's book on wetland types in New Zealand (Johnson & Gerbeaux 2004). The guidance should be read alongside these documents.

In this report we make the following recommendations.

- Aerial imagery (ideally 0.3 m resolution or better) should be used for mapping wetlands.
- Photoblique imagery should be used to assist with classifying wetland type.
- The mapping should be undertaken by operators with botanical skills and knowledge of the landscape processes that indicate wetlands.
- Councils should use the accompanying template to record wetland extent and wetland type data.
- LiDAR-derived data, such as the Topographic Wetness Index and Topographic Position Index, should be used with due regard to their limitations, and considerations such as spatial scale and appropriate flow algorithm. The same applies to radiometric data, which requires assessment within each base rock type.
- Wetlands in pasture areas that may be subject to the pasture exclusion methodology should be mapped as wetlands, but field verification is required. We emphasise that the pasture exclusion methodology is not capable of being implemented in the desktop setting and requires an in-field assessment.
- Constructed wetlands, which may or may not qualify as inland natural wetlands, should be mapped. Although it may be possible to identify 'constructed' wetlands, whether or not a constructed wetland is intended for restoration will affect whether it meets the 'natural' wetland definition, and this will not be possible to assess at the desktop stage.
- Where national wetland mapping is used as a starting point, operators should be aware that although smaller wetlands are almost certain to have been missed (e.g. < 1 ha), large wetlands may have been missed and may also be detected during regional council mapping. Most recent national wetland mapping does not have wetland types classified.
- In-field verification will be guided by the priorities set out in the NPS.

[1] https://www.mfe.govt.nz/publications/fresh-water/national-policy-statement-freshwatermanagement-2020.

1 Background

The National Policy Statement on Freshwater Management (NPS-FM) came into force on 3 September 2020 and sets requirements for mapping and monitoring wetlands.[2] A nationally consistent method of mapping wetlands to 0.05 ha is required to implement the NPS-FM. After consultation between the Ministry for the Environment, regional council wetland representatives, and Manaaki Whenua – Landcare Research (MWLR), it was agreed that guidance would focus on manual desktop mapping of wetlands and assignment of wetland type, both using aerial imagery. This report sets out guidance for using aerial imagery to map wetlands and classify them to wetland type. It also discusses the use of other data that can assist with desktop mapping of wetlands.

This guidance is intended to be consistent with, and complementary to, the field-focused protocols for delineating wetland extent (Clarkson 2014; Fraser et al. 2018; MfE 2021, 2022a), as well as Johnson and Gerbeaux's book on wetland types in New Zealand (Johnson & Gerbeaux 2004). This guidance should be read alongside these documents.

2 Preparing to delineate wetlands

An overview of the processes at the council level, and at the individual operator level, for delineating wetlands is provided in Appendix 1.

2.1 Set-up of regional geospatial databases

Although many ecologists will be familiar with shapefiles (and their associated files), geospatial file databases (or 'geodatabases') are more suited to the rich information that might be stored alongside information on wetland extent. For those unfamiliar with geodatabases, geodata can include feature datasets, which are the equivalent of different 'themes' of information. Under feature datasets sit feature classes, which can be thought of as conceptually similar to shapefiles in that they are a set of features (such as polygons, lines or points) with the same fields.

In the context of wetlands, a complex geodatabase might include a feature dataset of 'Administrative Boundaries', under which a feature class of 'Freshwater Management Units' might sit. This allows the classified and organised storage of groups of related data. We recommend working with geospatial experts from within each council to determine the best location and structure that will work for the information each council is collecting. This will allow inter-relationships between other council datasets, such as mapping of significant habitats or significant natural areas, to be appropriately linked and documented.

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[2] https://www.mfe.govt.nz/publications/fresh-water/national-policy-statement-freshwatermanagement-2020.

While recognising the need for systems that are tailored to individual councils, MWLR (and regional councils) recognise that nationally consistent reporting will be advantageous for national-scale syntheses and assessment of state and trends across New Zealand (except for public conservation land, which is currently excluded from the NPS-FM mapping requirements). Therefore we propose some data standards that will assist with the synthesis of national data, but will also encourage a consistent set of standards to allow, for example, neighbouring councils to easily share information on trans-boundary wetlands.

These standards were developed by a working group led by Roger Uys (Greater Wellington Regional Council) and Hugo Geddes (Auckland Council), and we thank them for sharing this work. A copy of the standards, current at the date of this report, has been archived in MWLR's datastore (https://doi.org/10.7931/eydz-8665; see Appendix 2). Note that this geodatabase with its restricted-options fields has been designed for ArcGIS and will not function as designed in alternative programmes, such as QGIS. However, below, we discuss the key features of the attribute fields, such that a new interface could be built within QGIS with the same functionality, if desired.

We suggest that councils follow these data standards for the wetland extent/typology feature class, and then incorporate other information as appropriate within their own geodatabases.

2.2 Data standards for geospatial databases

This section sets out the attribute fields that are part of the geospatial template, and explains each field and how it should be interpreted and recorded. Some form of access restriction may be required to access the geodatabase or feature classes within it, depending on any agreements made with landowners.

During 2022/23 council discussions were held to discuss the required elements of the data standards, and while these data standards are intended as a 'minimum' set of data, some commonly recorded variables are included. These include 'ecosystem code' and 'structural class' (see below).

In preparing this report we have suggested some changes to the template. Specifically, we suggest that wetland type be listed with the nine major wetland types from Johnson & Gerbeaux (2004), allowing the operator to record the relative percentages of the major types (e.g. 40% swamp, 30% fen, 30% bog). We suggest the same for structural class (e.g. 30% rushland, 70% forest). This will allow a wetland-level summary of the wetland type and vegetation composition, while more detailed layers can be used to delineate structural classes, wetland types, and vegetation composition in a spatially explicit manner, where required. In the review stage it was also suggested that a 'confidence' field for wetland type be added.

By now it may be apparent that this template is designed for recording *wetland-level* information. As discussed above, we suggest that a separate layer record *within-wetland* data, such as vegetation composition data or wetland type, where that data is needed to be spatially explicit. This more detailed data will be useful to quantify, for example, the spatial extent of a willow invasion over time, which may inform management.

Table 1. Description of fields within the example wetlands feature class

Field name	Type	Status	Description	Options
GlobalID	Global id	Necessary	Automatically assigned by ArcGIS to *each row of the attribute table*.	
Identifier	Free text	Optional	Allows for an ID for each individual wetland. This can be left blank and the globalID (above) used.	
Wetland name	Free text	Optional	Allows for the name of each wetland to be recorded. As some names are repeated nationally, and even regionally, this field should not be relied upon for identifying unique wetlands.	
Territory	Multi-choice	Optional (can be achieved via intersection with TLA boundaries)		Territorial districts of New Zealand
Region	Multi-choice	Recommended, but can be achieved via spatial intersection.		Regional districts of New Zealand
Wetland type (columns staring with "WT_")	Numeric integer	Necessary	Wetland types as per Johnson & Gerbeaux (2004)	Wetland types as per Johnson & Gerbeaux (2004) (e.g. bog, fen, swamp, marsh, seepage) are listed as separate columns. The relative percentage of each type for the wetland is recorded.
Hydrosystem	Multi-choice	Optional	Hydrosystem types as per Johnson & Gerbeaux (2004)	Hydrosystem types as per Johnson & Gerbeaux (2004) (e.g. palustrine, lacustrine).
Structural classes present	Multichoice	Optional	Structural classes as per Johnson & Gerbeaux (2004)	Structural classes as per Johnson & Gerbeaux (2004) (e.g. forest, rushland, treeland) are listed as different options. Alternatively, councils may wish to record he relative percentage of each type (new columns would be required for this)

Field name	Type	Status	Description	Options
Ecosystem code	Multi-choice	Optional	Optional – for councils who want to record Singers & Rogers (2014) attributes. We note that in the current form, only the dominant structural class can be recorded for each wetland.	Singers & Rogers (2014) attribute codes (e.g. W1, W7, PL).
Natural wetland	Multi-choice	Necessary	Allows differentiation of natural and non-natural wetlands to determine inclusion within NPS criteria.	Yes/No
Inland wetland	Multi-choice	Necessary outcome, but might be achieved by other methods	Allows differentiation of inland and non-inland wetlands. Together with the 'natural wetland' field, natural inland wetlands can be selected for reporting. The alternative is to use a spatial layer to delineate inland from coastal wetlands, but noting that this will split some polygons, and these polygons will be assumed to have a uniform spatial distribution of wetland types across the coastal/inland boundary, which may not be the case.	Yes/No
Threatened species present	Multi-choice	Necessary in some circumstances	Allows a description of whether threatened flora, fauna or other threatened ecosystem components are present within the wetland.	All combinations of flora, fauna, and other
Reference	Free text	Recommended, recording of information in some form is mandatory (see Description)	Allows a description of a relevant report, etc. The NPS requires that a wetland inventory record any existing monitoring information about each wetland. Given this is likely to be primarily for internal use, councils should work with their GIS experts to ensure this field (or an alternative method) meets their needs and compliance with the NPS.	
Naturalness confidence	Numeric	Necessary for field delineation prioritisation	Allows a description of how sure the operator is that the polygon represents a *natural* wetland (i.e. a qualifying wetland).	Low, medium, high.
Boundary confidence	Numeric	Necessary for field delineation prioritisation	Allows a description of how confident the operator is that the polygon extent accurately reflects the wetland extent spatially.	Low, medium, high..
Type confidence	Numeric	Necessary for field delineation prioritisation	Allows a description of how confident the operator is that the wetland type is accurately described.	Low, medium, high..
CreatedBy	Free text	Recommended	Allows a description of which operator created and described the polygon.	

Field name	Type	Status	Description	Options
CreatedByCouncil	Multiple choice	Recommended	Allows description of which Regional Council created the polygon, in cases where councils reach agreement as to mapping of cross-boundary polygon that involves mapping some portions of polygons outside the region.	Regional districts of New Zealand
SiteNotes	Free text	Optional	Basic notes field	
NZTM_X	Numeric	Optional	Nominated NZTM easting location of wetland centre. Note that automatically calculating the 'centroids' of wetlands may lead to the centroid falling outside the boundary of the wetland, depending on its shape, and so councils may wish to nominate a wetland centre point themselves.	
NZTM_Y	Numeric	Optional	Nominated NZTM northing location of wetland centre. Note that automatically calculating the 'centroids' of wetlands may lead to the centroid falling outside the boundary of the wetland, depending on its shape, and so councils may wish to nominate a wetland centre point themselves.	
Date of evidence	Date	Recommended	Allows a description of when the wetland as mapped existed. This may vary depending on the latest determinative imagery date for that wetland. This is important because a wetland may exist at the time of delineation by the initial operator, but by the time of peer review subsequently available imagery reveals the wetland has been lost (or changed extent, or even type). In this case, the wetland is not a 'false positive' just because it is mapped but no longer exists.	
Source geometry	Free text (or multi-choice)	Recommended	The default assumption is that councils will digitise the majority of their mapped wetlands. However, some wetlands may be sourced from pre-existing datasets, such as LCDB, or a deep-learning model. Regardless of how the source is described in this field, we recommend each council keep a 'look up table' that links the short names in this field to longer metadata about each source.	

Notes: NZTM = New Zealand Transverse Mercator; LCDB = New Zealand Land Cover Database.

2.3 Data and aerial imagery requirements

There are three key factors when considering either the suitability of existing aerial imagery for mapping or when considering acquiring new aerial imagery for mapping:

- resolution (affecting how clear the image is)
- seasonal timing (affecting whether wetlands can be delineated from drylands)
- overall timing (affecting whether recent changes will be seen).

Resolution: To complete wetland extent mapping with an acceptable level of certainty, aerial imagery with a minimum resolution of 0.5 m can be used. Imagery with a resolution of 0.3 m (Figure 1), or better, will further increase the certainty of this mapping. Oblique images can help to identify the vegetation component of wetland areas and so are particularly useful for classifying wetland type. In some cases, oblique images can also assist with the provisional delineation of wetland extent. However, obliques cannot be used directly to map the extent of the identified wetland polygons, because the angle of the imagery precludes this: the operator will need to orientate themselves with the oblique, compare to the base layer imagery, and then map on the base layer imagery.

Seasonal timing: Delineating wetlands should always be done during the growing season and when 'normal conditions' (MfE 2022a) prevail. Field visits should be planned to take this into consideration, as should the timing of imagery used to form the base layer of any desktop mapping of wetlands. In practice the late summer period often provides the most useful time of year.

Overall timing: Obviously, less recent imagery will not show any changes in wetland extent that post-date the imagery. Such imagery is also likely to be of lower resolution. Operators should be aware that where imagery sources are mixed across a region, this may lead to confusion: we suggest, at minimum, using a coherent set of imagery for each catchment, and keeping metadata of which imagery was used for which catchment, particularly when there are differences in the timing (or other relevant details) between catchments.

Figure 1. An example of a wetland apparent using 0.3 m imagery (LINZ 2016/17) on the West Coast of the South Island of New Zealand.

2.3.1 Using national wetland layers as a base layer

The most up-to-date wetland mapping at the national scale is the New Zealand Land Cover Database version 5 (LCDB) (MWLR 2020). The LCDB provides wetland polygons at the national scale for each coverage date (e.g. 2012, 2018). We understand that the LCDB is considered to be a reasonable 'starting point' for councils who have completed very little wetland mapping. However, there are a number of considerations to keep in mind.

Minimum polygon size: LCDB has a nominal minimum polygon size of 1 ha. Regional councils will therefore need to prioritise their effort to wetlands that are less than 1 ha, which are expected to be entirely missed by national-scale mapping.

Lack of typology: LCDB does not provide a wetland typology, unlike other older, national-scale layers, such as the 'Current wetlands layer' within the Ausseil et al. dataset (Ausseil et al. 2008, 2011), otherwise collectively referred to as WONI (Waters of National Importance).

Not primary purpose: LCDB is not collated with the primary purpose of mapping wetlands, so operators should be aware that some large wetlands may also be lacking from the layer. An example is provided in Figure 2 below, which is a c. 300 ha wetland located near Moana, West Coast.

Figure 2. Large wetland near Moana on the West Coast of the South Island. The yellow polygon indicates wetland found on aerial imagery that was not mapped by LCDB 2018. (Imagery and mapping: Yuliya Wills, West Coast Regional Council)

2.4 Other data useful for mapping

Although this report focuses on aerial imagery-based mapping, we include a discussion below of other potential data sources that may be useful to map wetlands, including an overview of their advantages and disadvantages. Further investigation on their suitability for a particular region should be undertaken before adopting a specific data source.

2.4.1 LiDAR-derived data products

LiDAR (**Li**ght **D**etection **A**nd **R**anging) data is a form of precise elevational data that can be used to create high-resolution digital elevation models (DEMs) and, less relevantly for our situation, digital surface models (DSMs), which are used to model the height of vegetation. While a DEM derived from LiDAR might be a 1 m or 5 m DEM (for example), traditional DEMs were in the order of 20 m. The number refers to the cell size of the DEM, and therefore smaller numbers allow for much smaller changes in elevation to be captured.

Although DEMs by themselves can be useful for identifying potential wetlands, data products derived from DEMs have recently proven useful for mapping wetlands. Two of the most common data products derived from LiDAR-based DEMs are the Topographic Wetness Index (TWI) and the Topographic Position Index (TPI). Like DEMs, TPI and TWI are data products in the form of rasters (grid cells covering the area of interest).

A TWI layer is generated by spatial algorithms that model how water is expected to flow in a catchment, and consists of a value for each raster cell. High-precision TWI layers have been recommended for mapping wetlands (Higginbottom et al. 2018; Bian et al. 2021), and have been used in combination with soils data to map historical wetlands in Hawaii (Van Rees & Reed 2014).

In generating a TWI layer the user is required to prepare the DEM, including deciding on an appropriate cell size and selecting which algorithm should be used to model water flow. Recent work indicates that a class of algorithms using multiple flow direction methods is more suited to modelling wetlands (Lang & McCarty 2009; Lang et al. 2013). In the context of mapping forested palustrine wetlands, multiple flow direction methods have been described as better capturing shifts in soil moisture that represent wetlands, compared to abrupt riverine channels, which are better characterised by other flow direction methods (Lang & McCarty 2009).

There are two key considerations relevant to wetland mapping: first, by definition TWI is most suited to wetlands that receive water via surface water flow, as the process by which TWI is created only considers surface water flow. We would therefore expect bogs to be particularly poorly signalled by TWI because they are rainfed. The second consideration is that all current algorithms require that 'depressions' in the landscape from which no water flows (e.g. kettlehole wetlands, small lakes and tarns) must be 'filled in' for processing requirements. This means depressional wetlands are unlikely to be identified using TWI. Although the use of TWI for desktop mapping of wetlands is promising, we are not aware of any work that has ground-truthed using TWI for New Zealand wetlands.

A TPI layer is generated by comparing each cell in a raster to every other cell within a user-specified distance, effectively indicating whether that cell is in a depression, plateau, ridge, etc. The user-specified distance is critical to determining the outcome: consider a raster cell that sits within a tarn on a hilltop, but the hilltop is one of many and is the smallest. At the near scale the cell might be considered to be in a depression (lower than other cells) around it, because the tarn cell is compared to slightly higher elevation cells a few metres away. At the moderate scale, the cell might be considered to be on a peak, as most of the cells within the user-specified distance are downslope. Finally, at the large scale, the result is likely to be more equivocal, given that the cell is higher than those downslope, but the hill itself is surrounded by higher peaks. As a result, smaller wetlands may need a relatively small user-specified distance, while large flood plain swamps and marshes may only be distinguishable with a distance that is large enough to compare each cell to the dryland areas around it, rather than other cells within the wetland.

Furthermore, cell size combines with the user-specified distance to affect the results. Where a large raster cell size is used (e.g. 20 m × 20 m; not to be taken as a recommendation), small wetlands are likely to be obscured because they only contribute to a small portion of the 400 m^2 area of the cell. Rapinel et al. (2023) used a multi-scale TPI approach to map wetlands in mainland France, with a minimum mapping unit of 250 m^2 (under the NPS-FM, wetlands not containing threatened species are required to be mapped to 0.05 ha, or 500 m^2). TPI (all three TPI scales used) was found to be a useful contributor, alongside more important variables such as vertical distance to the channel network (effectively vertical height above nearest drainage, such as a river) and TWI. Rapinel et al. (2023) noted that soils information was needed to supplement other numerical data in the case of flat wetlands, which were otherwise hard to distinguish on certain soil types.

When TPI has been used, wetlands are typically associated with values that represent areas that are lower in the landscape. Thus domed bogs (which may be slightly higher than the surrounding area) will not be indicated by TPI due to their relatively higher position in the landscape.

Finally, data from TWI and TPI do not directly map wetlands. In the case of TWI, very high values indicate large, water-carrying bodies, such as lakes and rivers, while very low values indicate dryland. A 'sweet spot' of values that represent wetlands needs to be identified. An example of this process can be found in Van Rees & Reed (2014), where Hawaiian current wetlands were used to estimate the ranges of TWI values that represented historical wetlands. Note that if some types of wetland with extreme TWI values were preferentially drained with human settlement (as has occurred over much of the world, see Davidson (2014)) then the TWI range identified will probably only identify wetlands with a similar TWI profile as extant wetlands, and therefore will under-identify historical wetlands. MWLR have recently conducted trials using the Mahalanobis distance to identify the region of combined TWI and TPI values that indicate wetlands. This work is currently ongoing, so we refer the reader to Etherington (2021) for a discussion of the technique.

Height above nearest drainage (HAND) takes elevation data that represent vertical height above sea level (such as that derived from LiDAR) and converts them to elevation data, which represent vertical height above the nearest river, or other relevant item of the drainage network (Nobre et al. 2011). Note that some of the steps that are described with caution above, including dealing with depressions and algorithm selection to describe water (in this case drainage) flow, will have important implications for wetland detection. The advantages of HAND include incorporating an element of groundwater levels, which is missing from TWI, although, again, raised bogs are likely to be missed by this approach. HAND does require a mapped stream network and is less well studied in the context of mapping wetlands, but this is likely to be a developing area.

All topographic indices derived from elevational information will fail to account for rainfall, which will mediate the effect of topography on the likelihood of wetland development. Slopes that might seem inconceivably inhospitable to wetlands in low-rainfall areas may house many wetlands in high-rainfall areas, such as the west coast of the South Island. Thus, where strong rainfall gradients exist within a region it may be useful to include a representation of rainfall. The climate-topographic index incorporates rainfall as well as TWI. It was first described by Merot et al. (2003), and was recently improved by Hu et al. (2017) to become a precipitation-topographic index. Their 2017 layer was used to develop an estimate of global historical wetland extent, and they considered that the precipitation-topographic index outperforms its predecessor in wetland mapping.

Finally, recent work has shown that drains near wetlands in New Zealand can be detected using a random forest model and terrain indices. High concentrations of drains are likely to indicate wet soils, and potentially wetlands, and therefore a LiDAR-based model of drain extent may be another useful indicator of likely wetlands. We refer to the case study of Burge et al. (2023) in this regard.

2.4.2 Radiometrics

Radiometric data is another form of remote sensed data but differs from the data products discussed above as it is derived from measurements of radioactivity rather than measurements of elevation. Soil bulk density and soil water content (or depth of standing water) affect returned gamma ray values. However, this effect, termed attenuation, also differs according to base rock, including where base rock is covered by a peat layer. Therefore, any analysis of radiometric data to infer peatlands or wetlands via proxies of bulk density and soil water content should account for the geological base layer (Beamish 2014).

Radiometric data have been used in New Zealand to delineate hydric soils and peatlands in the Northland region, where Rissman et al. (2019) first classified the geology and assessed the gamma ray total count values by geological classification. The attenuation for each raster pixel was then calculated by dividing the total count value by the median total count value for the relevant geological class and multiplying by 100. While some improvements were needed (e.g. to account for weathering), radiometric data were found to be strongly correlated with wetland occurrence, and even able to detect historical wetlands.

Rissman et al. (2019) note that the timing of radiometric imagery (which is generally held by New Zealand Petroleum and Minerals, as the data are primarily acquired for mineral exploration) is critical to achieving good results: for example, they considered that the timing of radiometrics flown in their study (during a drought year) could have led to some wetlands, such as ephemeral wetlands, being missed.

Radiometric data may therefore be utilised when it happens to be available, but the degree of interpretation of soil and geological data requires relevant expertise if it is to be used for accurate wetland mapping.

2.5 Skill requirements for desktop mapping

The key skill requirements to map wetlands effectively can be broken down into the following areas.

1. Recognising the existence of a wetland on aerial imagery requires:
    - botanical skills, to recognise wetlands from vegetative cover – unlike field observations, plant identification needs to be based on aerial imagery, and therefore a different thought process is required, along with an ability to deal with uncertainty
    - geographical skills, to recognise where wetlands are likely to be positioned in the landscape
    - observational skills (combined with the above), to recognise wetlands that remain in lush vegetation at dry periods of the year when other vegetation appears dry, or where non-vegetated wetlands exist.

2 Where applicable, recognising the existence of a wetland on other data sources requires:

- an understanding of how signals from the data source might be interpreted to indicate wetlands (e.g. the skills and knowledge to pick out soil that is saturated during the growing season for two weeks of the year from a time series of soil moisture values)
- an understanding of the strengths and limitations of the data source (e.g. soil moisture data from a wet winter is far less conclusive than the similar data from mid-summer).

3 Delineating the extent of the wetland requires:

- an ability to identify transitional vegetation (e.g. wetland-dryland ecotones)
- good GIS skills and hand-eye coordination to delineate the extent of the wetland once the extent is recognised.

4 Assigning wetland type requires:

- knowledge of wetland types and the ecological processes that underlie wetland types in New Zealand
- an ability to translate how these might appear on aerial imagery.

Individuals tasked with mapping wetlands will produce data of a higher quality if they have familiarity with wetland plant species (Johnson & Gerbeaux 2004; Clarkson 2014; MfE 2022a) and how those plants will appear on aerial imagery throughout the year (e.g. flowering, with fresh growth or denudate). In most cases it will be useful for staff who are familiar with botanical field identification to use aerial imagery of sites where they are very familiar with the vegetation composition (preferably a time series of aerial imagery, as above) in order to become familiar with how species appear on aerial imagery.

An awareness, gained through training or field experience, of general ecological processes, seasonal land use, and other anthropogenic changes will also be useful in interpreting observations (e.g. post-inundation sediment deposition, pugging from excessive stock densities, frost damage, plantation logging practices and restoration plantings).

Staff with these ecological skills may well need assistance from skilled GIS operators to set up the project geodatabase (see below), with its associated data entry forms, base data, linked obliques, and the like. Ongoing support to resolve minor issues would also be an advantage. GIS assistance may be required to conclude the mapping process, extract data into report-compatible formats, and archive the completed project.

3 Delineating wetlands using aerial imagery

3.1 Methodology for delineation

Different approaches may be taken to delineating wetlands, most of which involve splitting an area into manageable subsets: councils may progress catchment-by-catchment, sub-catchment by sub-catchment, or in a grid-based fashion. A grid-based approach used currently by one council uses the LINZ Topo50 grid layer[3] to work systematically through their case study areas, scanning systematically through each cell at a 1:1,000 scale for wetland identification, and then zooming into 1:500 scale for wetland delineation. A grid-based approach can also be used in combination with sub-catchments or catchments to divide these areas into smaller, more manageable subsets. Attribute data (e.g. wetland type) should be filled in at time of delineation.

Once the overall approach for wetland delineation is decided, the initial search for wetlands in the landscape of interest will be guided by an interpretation of the geomorphology. The operator will search for localised depressions and flat areas (such flat areas may not always be level) that may have poor apparent drainage visible and will often be close to existing drains, streams, rivers or other water bodies. Remaining aware of the likely flow of water in the landscape being searched is essential. We refer to the wetlands delineation protocols (MfE 2022a), and specifically the hydric soils field identification guide (Fraser et al. 2018), for further details on this, as well as Johnson and Gerbeaux (2004) for background reading.

Once potential wetland areas are identified, certainty may be increased by confirming the extent with sequences of images under varying light and shade conditions or from different directions. However, for consistency, care needs to be taken to map the wetlands using the characteristics visible on the base image only.

Potential wetland areas can be seen at the base of slopes and often on larger flat areas: see Figure 3 below, from the hydric soils field identification guide (Fraser et al. 2018).

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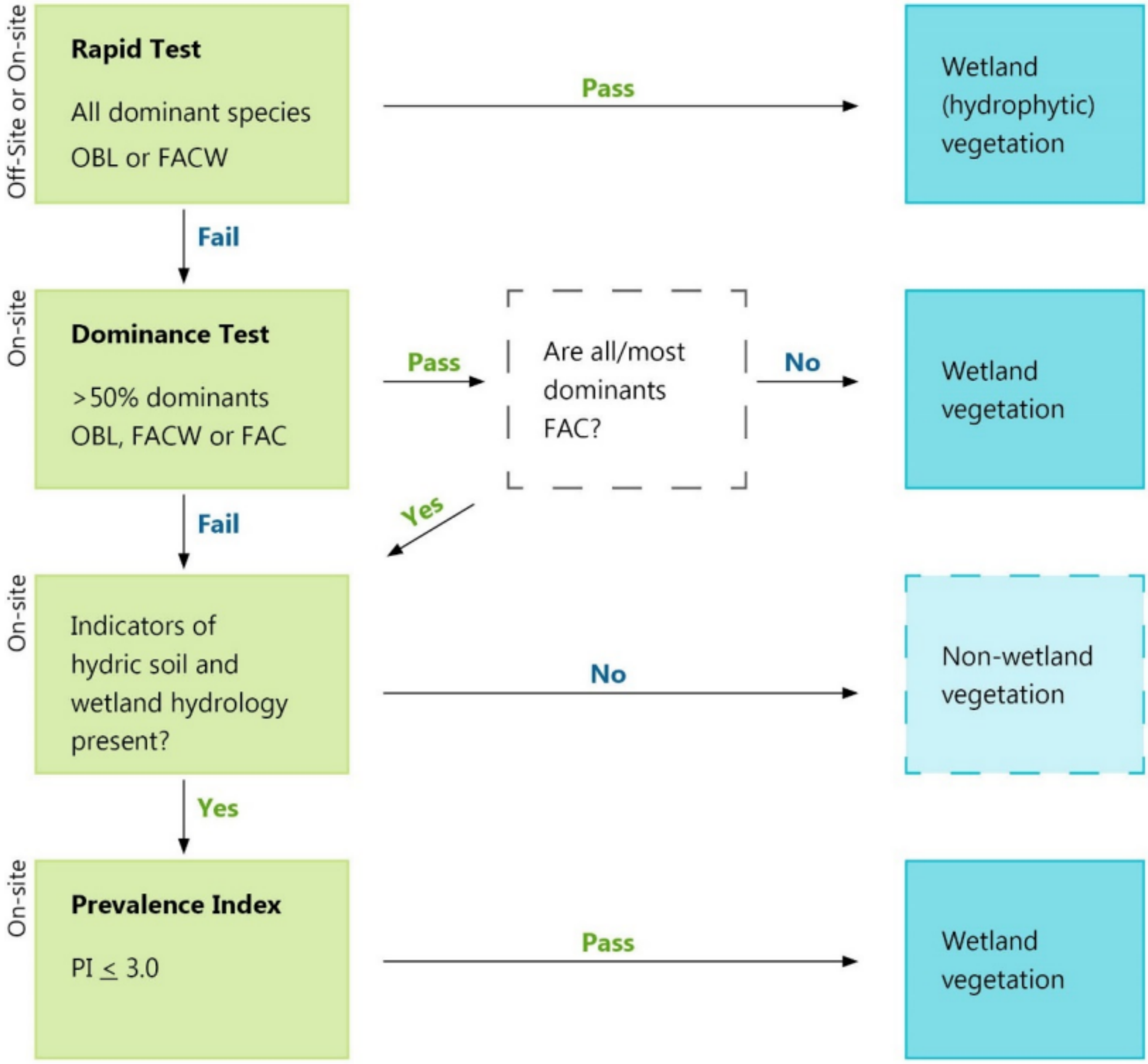
[3] For example, https://www.linz.govt.nz/products-services/maps/new-zealand-topographic-maps/topo50-map-chooser/topo50-sheet-index)

Figure 3. Examples of wetlands found at the base of slopes and on flatter areas. Images reproduced from the hydric soils field identification guide (Fraser et al. 2018).

Some existing tools created to facilitate wetland delineation and presence determination can be applied to mapping wetlands using aerial imagery. The 'rapid test' from the vegetation tool (Clarkson 2014; MfE 2022a) is applicable to aerial imagery that is of sufficient quality to distinguish plants to species level (see Figure 4).



Notes: OBL = obligate wetland species; FACW = facultative wetland species; FAC = facultative species; PI = prevalence index.

Figure 4. Flowchart of steps for wetland delineation. Reproduced from MFE (2022a)

Areas that are mosaics of small (<0.05 ha) wet and dry patches can be excluded if the percentage of natural inland wetland is obviously <50% of the overall area (see section below on mapping mosaics).

These situations are commonly seen in wet pasture landscapes with areas of rushes intermixed with dryland pasture grasses or dry and bare soil/rock. This approach should be applied with pasture exclusion methodology (MfE 2022b) in mind, where 'rapid assessments' can be used to determine areas that are clearly natural inland wetlands or clearly dry pasture. However, the rapid assessment of the pasture exclusion methodology cannot be applied to areas of uncertainty, where an in-field assessment is required. In such cases, we recommend mapping the uncertain areas as 'qualifying' wetlands, but recording the uncertainty as maximal, such that these areas are prioritised for in-field assessment.

Also, some small wetlands (e.g. small seeps) may be less than 0.05 ha in area. Where these are contiguous with other wetland types (e.g. marsh), they be mapped as one 'wetland' given the likely hydraulic connection between the two types, with the distinct types recorded as a proportion of the whole (see data standards, above).

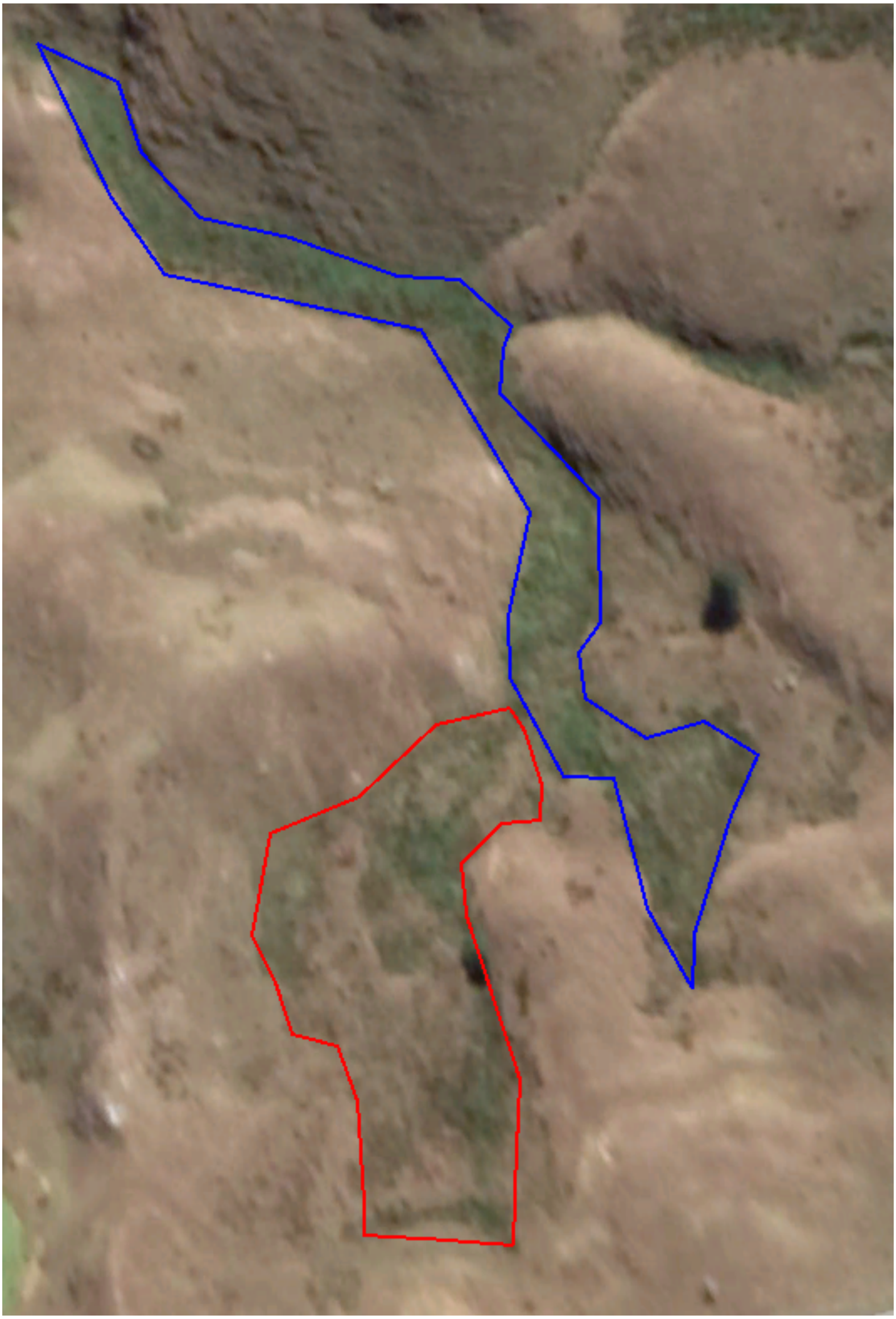


Figure 5. Example of wet–dry mosaics. The blue-bordered polygon contains a wetland, whereas the red-bordered polygon, containing a wet and dry matrix, does not. Photo taken from the Whangape catchment using WRAPS 2017-2019 imagery.

3.2 Data quality and timing considerations

Utilising recent aerial imagery taken late in a summer but when 'normal circumstances' are present (i.e. typical climatic/hydrologic conditions, and with no recent disturbances or modifications; refer MfE 2022a) will greatly help the process of identifying and mapping wetland extent and type. Soil moisture levels create obvious vegetation differences during the late summer. Imagery (Figure 6) from this time often shows this as a clear colour change between the dryland areas and the wet soils. This can be especially useful in farming landscapes where the original wetland vegetation may have been replaced with wetland-tolerant exotic grasses (e.g. *Holcus lanatus*, *Paspalum dilatatum*, *Agrostis stolonifera*).

Figure 6. Late summer imagery clearly shows the extent of the wetland area during the growing season and would be ideal for mapping. Note, imagery from an exceptionally dry year that does not represent normal circumstances should be avoided.

Imagery (Figure 7) captured during the middle and late winter season can also be useful for identifying wetland locations. 'Obligate wetland' and 'facultative wetland' plants (MfE 2022a) that die back in winter, for example *Typha orientalis* (raupō; see Figure 9(b)) or *Salix cinerea* (grey willow) and *Bolboschoenus fluviatilis* (kukuraho), are often easily discernible and can assist in locating wetland areas. These winter images, while useful for locating wetlands, should not be the sole source for mapping wetland extent, however, because this is determined during the growing season (MfE 2021).

Figure 7. Example of winter imagery that shows inundation but is poor at revealing wetland extent.

If there is concern that the aerial imagery does not accurately reflect the true hydrology of the potential wetland, this can be checked by studying a time series of images of the area in question. Imagery is available through Land Information New Zealand[4] (LINZ) to visualise these temporal changes. Other sources, such as Google Earth products, may also be useful, but care should be used to determine the imagery date and source when doing so. Additional information may be discerned from these images, which could be valuable; for example, in determining plant species (if the image captured flowering, for instance). However, as mentioned earlier, the mapping should be done on characteristics visible on the base image.

Obliques, when taken at high resolution and under ideal light conditions, can help to determine the vegetation present and the hydrological conditions at the time the images were collected. It should be noted that in landscapes containing a high density of wetlands, care should be taken when using oblique images to confirm whether the wetland pictured and the base image wetland to be characterised are the same wetland. See Figure 8 – Figure 10 for examples of the additional information visible from oblique imagery.

Councils may already have pre-existing spatial data relating to wetlands. It is also possible that national-scale mapping needs to be used in places where more detailed mapping has

[4] https://www.linz.govt.nz/products-services/data/types-linz-data/aerial-imagery

yet to be undertaken, such as where aerial imagery for an area is still being sourced. In this case the most recent Land Cover Database (LCDB) wetland layer (MWLR 2020) can be used as a starting point for an area within a region for which no previous mapping has been completed, or to supplement initial efforts at mapping.

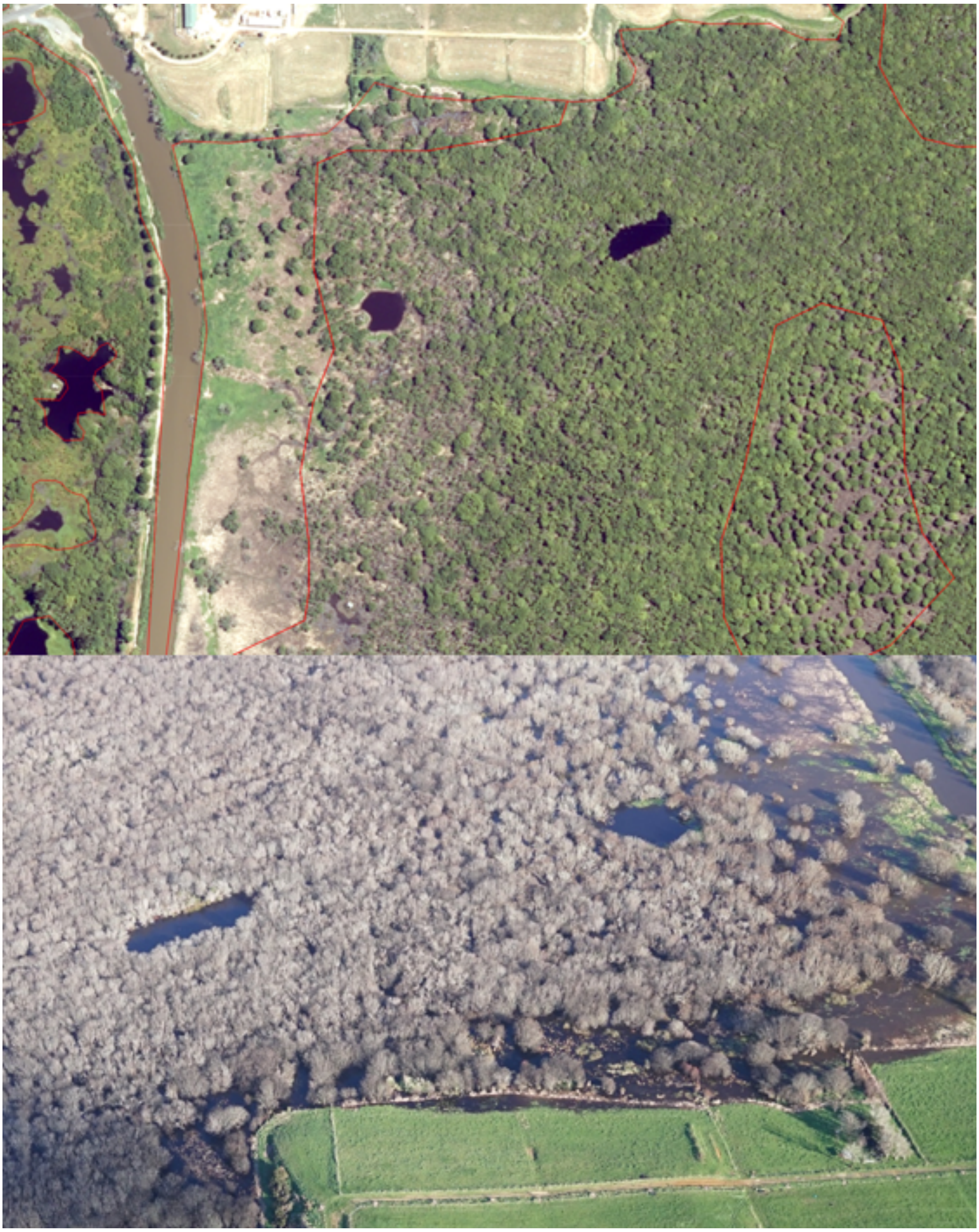


Figure 8. The 0.3 m resolution base layer image (top) indicates a possible wetland, but it is not clear what species of trees are present. At the time privet, wattle, and mahoe were considered. Contrast this with the oblique image (below) from late winter, where the timing, angle, and extra detail of the image help to clarify that the trees are mostly *Salix* species.

Figure 9. Another example of the importance of imagery timing, type, and resolution, from the Whangape catchment. (a) Google Earth image (N at top)) from March resolves vegetation composition poorly. (b) Google earth image (N at top) from August suggests raupō. (c) August oblique image (S at top) confirms raupō presence.

Figure 10. An example of how high-resolution oblique images can provide useful information to delineate wetland extent, in addition to ascertaining vegetation cover and therefore wetland type. Here an image from the Whangape catchment clearly shows the edge of a raupō-dominated wetland, with a cabbage tree in the middle. The other vegetation ('rank' grass and sprayed gorse) is considered to be indicative of dryland environments, and therefore the extent of the wetland will be limited to the raupō area.

3.3 Worked case study example

In the following section, we present a sequence of images that begin with scanning a base image for any indications of wetlands and what to look for, checking the size of an apparent wetland, and assessing wetland type. In this case, the "base imagery" is a LINZ-sourced 0.3 m imagery, but additional imagery is incorporated to provide more information.

Figure 11. Base image is scanned for wetlands, in this case, indicated by pale green colouration. Contour shadows indicate this pale green area is at the lowest point in this sub-catchment.

Figure 12. If there is concern that a wetland may not meet the minimum 0.05 ha mapping threshold, then the area of interest can quickly be measured to check (upper image). Where oblique images are available, these can be checked to confirm identification of wetland before delineating on the base image. In the lower image the resulting delineated wetland is shown as a blue polygon.

Figure 13. Upper image: When an oblique image is viewed, take care to reorientate yourself and confirm correct area of interest has been found. In this example the oblique is looking south, and the lake is now on the right side of the image. This can be compared to the opposite orientation (of the same wetland) in Figure 12, above. The Lake, rock outcrop and row of trees have been used to confirm target wetland. Lower image: Oblique image shows rush, herbs and grasses in the wetland area. Note the perimeter is difficult to discern on the oblique image, compared to 0.3 m LINZ image.

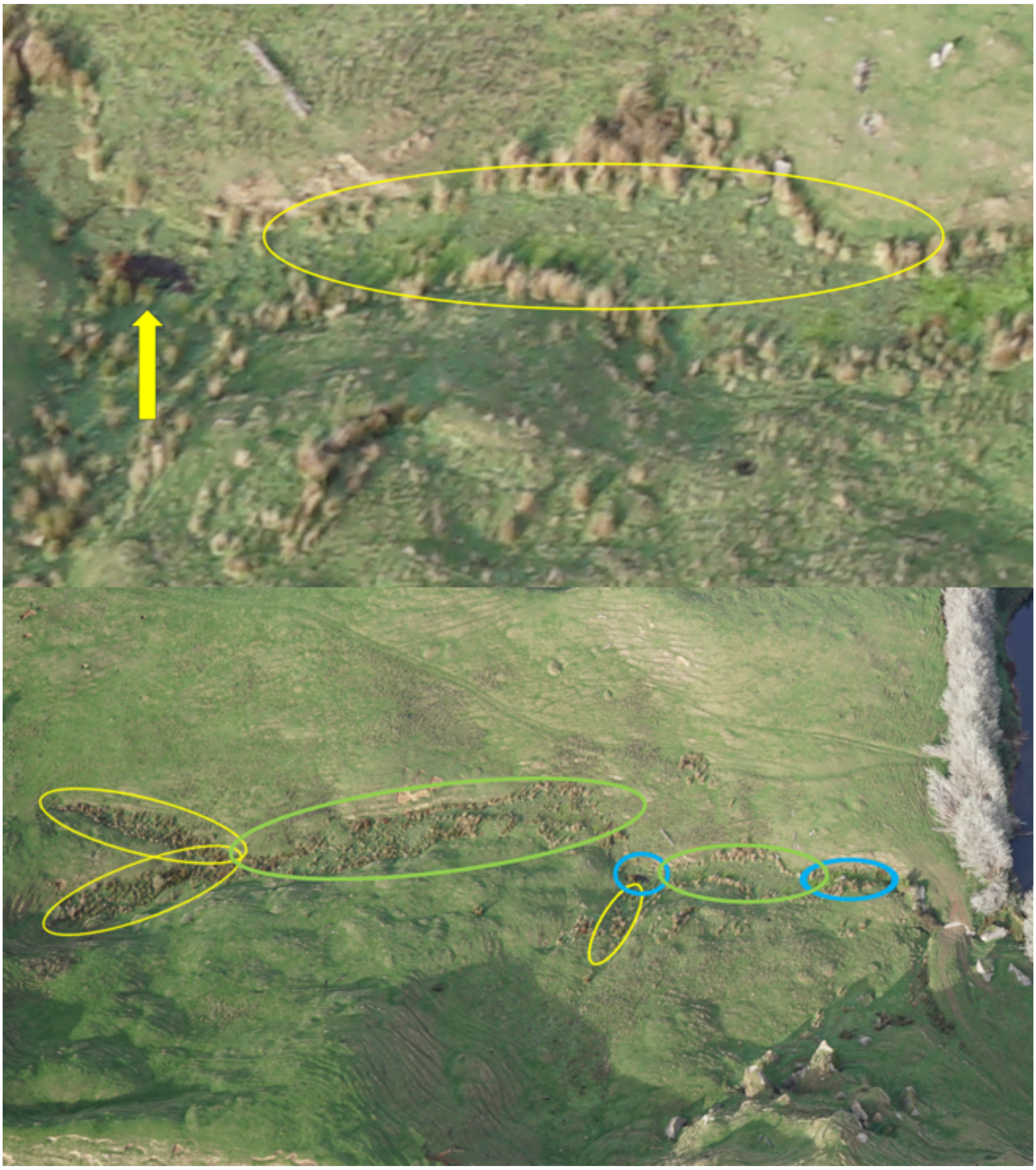


Figure 14. Case study, oblique images (continued). Upper image: orthophoto is magnified to show flat wetland area (circled) with small open water present (arrow). Lower image: the orthophoto is useful for wetland type – seeps (yellow) and possibly small swamp (blue) areas present, but on average this wetland should be considered a marsh.

The combination of low-stature vegetation of rush, grass and herbs, combined with a low water table and the geomorphic position, all indicate this is a marsh system.

4 Desktop assessment of wetland type using aerial imagery

The main types of wetlands found in New Zealand (bog, fen, swamp and marshes, and less common variants) can be differentiated based on characteristics defined by Johnson and Gerbeaux (2004). To supplement Johnson and Gerbeaux (2004), the most useful characteristics of each type that can be observed in aerial imagery are summarised here. These should be read in conjunction with guides to field-based type classification, such as Johnson and Gerbeaux (2004) and the field guide to wetland type and associated Lucid key (Burge & Bartlam 2024; Burge 2024). Note that 'shallow water' is one class of wetland, as defined in Johnson and Gerbeaux (2004), which includes lakes and rivers (primarily the margin thereof).

- **Bogs** are characterised by flat to gently sloping terrain, with the water table close to the soil surface, and they do not normally adjoin flowing water channels. Bogs are often bordered by fens, and are normally dominated by low-stature native vegetation, possibly with identifiable restiads.
- **Fens** are characterised by flat to slightly sloping terrain, with the water table close to the soil surface, and can be found between swamp and bog-type wetlands. Sedges, ferns, scattered flax and some scrub are often present, but fens are also prone to being invaded by exotics such as grey willow.
- **Swamps** are usually seen with open water and/or channels of flowing water. The vegetation present can often tolerate deep water and near-permanent saturated soil (e.g. flax, grey willow, raupō, *Carex secta*, reeds). Swamps can be invaded by exotic vegetation (e.g. grey willow, alder, mercer grass, *Glyceria maxima*).
- **Marshes** are characterised by flat to moderately sloping terrain, most often seen with little to no surface water but with periods of inundation. Seeps, which Johnson and Gerbeaux (2004) include as a subset of marshes, are frequently found adjoining marshes where the contour steepens abruptly. Most marshes are found on valley floors surrounded by farmland, and they are frequently prone to obvious drainage attempts from landowners. The vegetation is most often low-stature sedges, herbs, grasses, and rushes, often with a high proportion of exotic species that can tolerate saturated soil. Plant species can be difficult to distinguish from aerial imagery, but late summer imagery often significantly helps delimit the edge of the marsh system. Marshes may show visible signs of heavy stock grazing pressure and may also be a matrix of wet and dry areas (see Figure 15).

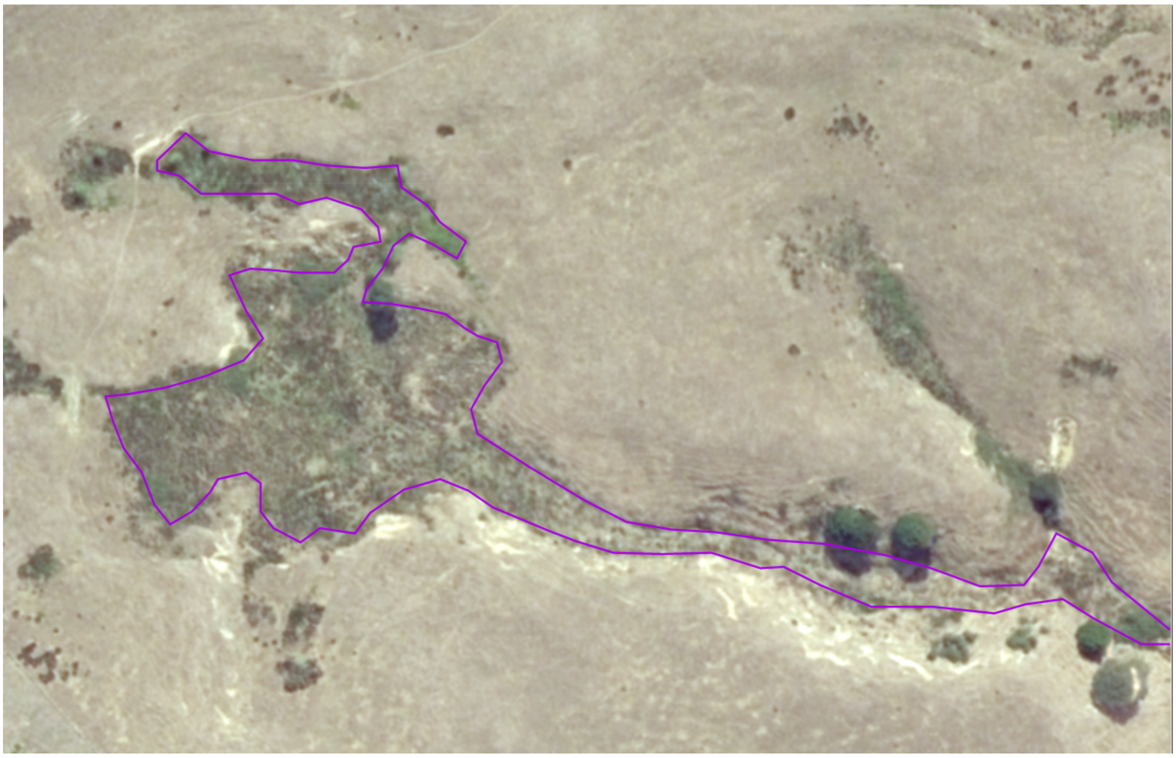


Figure 15. Example image from the Whangape catchment showing a wetland (purple polygon) that contains a matrix of wetland and dryland areas but that is, overall, a marsh.

A polygon/wetland attribute database can be used to assist with this determination, and for the ongoing monitoring of changes between assessments: see sections on geospatial databases below.

The process of characterising wetland type using a desktop process means that many of the useful indicators that can be determined from a field visit will be missing. For example, water parameters such as depth, pH, flow rate or conductivity can assist with characterising wetland type, but are unlikely to be available for most wetlands, unless a previous field visit has been undertaken. The same thing applies for soil characteristics such as Von Post, bulk density or colour. Also, not all plant species can be resolved from even the best aerial imagery, but all of these indicators are useful to indicate wetland type (Johnson & Gerbeaux 2004).

The limits of these desktop-type determinations should be understood: field validations will always provide the most authoritative answer to the question of wetland type. Utilising staff with extensive field experience of working in various wetlands will greatly increase the accuracy of type determinations.

5 Complex mapping

5.1 Wetland mosaics of wet and dry areas and the pasture exclusion methodology

The NPS-FM (as at 21 December 2023) requires that regional councils identify and map every inland natural wetland that is greater than 0.05 ha in extent, along with wetlands that are smaller than 0.05 ha but contain threatened species (excluding public conservation land). Mosaics of wetlands that contain both wet and dry areas will need to have all small qualifying wetlands mapped individually. This requirement notwithstanding, councils may choose to use other layers (see database guidance above) to create 'management polygons', or similar, that cover multiple small wetlands.

We noted earlier that it is advisable to map features that *appear* to be wetlands or qualifying wetlands, but note they are in fact not qualifying wetlands to save repeatedly reviewing and rejecting non-wetlands or non-qualifying wetlands. However, in large, complex mosaics we recommend a grid-based approach, where each section is searched once, and each grid-polygon is marked as 'complete' after searching. Afterwards, the entire mosaic might be marked as 'completed'.

Areas of 'wet pasture' can be very difficult to assess using aerial imagery, particularly in wetland mosaics, where there are multiple intergrading wet and dry areas. We suggest that where such areas are uncertain, these potentially qualifying wetlands should be mapped with polygons around the potential full extent, but noted as being highly uncertain and prioritised for field verification. Note that the pasture exclusion methodology (MfE 2022b) relies on species-level identifications and typically requires detailed in-field observations, so it is not possible to adequately complete the pasture exclusion methodology using aerial imagery. We recommend mapping all areas of 'wet pasture' (i.e. wetlands) and then note that the naturalness is highly uncertain; these areas can then be prioritised for in-field verification.

5.2 Mixed wetland types

Earlier we discussed the need to delineate each wetland individually when it falls within an area of mixed wetland–dryland. We suggested mapping each wetland individually for the wetland feature layer (required for NPS compliance), but having a separate feature layer for management units or ecosystem units. This effectively allows a multi-scale treatment of wetlands. Here we discuss a different scale problem: where wetlands have a mix of wetland *types*. Again, we suggest a multi-scale approach as the solution for where one wetland encompasses more than one wetland type, and each wetland type is non-trivial and needs to be mapped.

Because the focus for the NPS is on mapping wetland extent and assigning wetland class, we suggest that, at the individual wetland level, councils record the proportion of wetland types within the wetland polygon attribute table. Then, another feature layer can be created to map wetland typologies explicitly. For example, within Whangamarino wetland there might be multiple adjacent polygons mapping fen, bog, and swamp as the major types. We suggest for this process that the operator take the extent polygon and 'split' it, as appropriate, to create smaller polygons with the exact same overall spatial extent as the wetland itself. Some parts of the wetland may be classified as 'unassigned type' in this process where information does not allow explicit mapping of small areas; such areas might also be folded into larger adjacent areas. Note that when wetland extent changes (such as a portion is drained), the wetland typology layer will also need to be changed. The alternative – which we do not recommend – would be to have one feature layer with wetlands broken into separate polygons (multi-polygons would not be appropriate because some of the attributes, such as wetland type, differ). While this approach is workable, it will lead to duplication of all the wetland-level information in the attribute table for each wetland type, and therefore we prefer the more parsimonious multi-level solution.

We emphasise that creating additional feature layers is at the discretion of regional councils, and that a layer with the extent and overall wetland type (along with other required data) is the requirement under the NPS-FM. However, providing guidance on recording additional spatial information at coarser (management unit) and finer (vegetation structure) scales allows for regional councils to be consistent with each other where that information is collected.

5.3 Locating and identifying constructed wetlands so they can be excluded from further analysis

The NPS-FM requires that every 'inland natural wetland' in the region be mapped (excluding wetlands on public conservation land). Every inland natural wetland that is mapped (including those mapped on public conservation land by the regional council) is subject to the monitoring plan required by clause 3.23(6) of the NPS-FM. We suggest that non-natural wetlands be mapped but a note added to exclude them from monitoring, as this will avoid duplication of effort where operators repeatedly check a non-qualifying wetland to ensure it is in fact non-qualifying.

The data standards provide several variables relating to 'naturalness'. First, there is a variable that allows the recording of whether or not a wetland is a 'natural' wetland, and secondly, there is a variable to record how certain the operator is that the wetland is in fact natural or not.

However, those familiar with wetland restoration practices will be aware that constructed wetlands are often on ex-wetlands (i.e. are targeted to naturally wet areas in the landscape, see Uuemaa et al. (2018) for a New Zealand approach). It is important to note that while 'deliberately constructed wetlands' are excluded from the definition of 'inland natural wetlands' under the NPS-FM, wetlands that were "constructed to offset impacts on, or to restore, an existing or former natural inland wetland" are specifically included under 'inland natural wetlands'.

We provide some guidance below on the characteristics of constructed wetlands using aerial imagery, but note that a constructed wetland for *restoration purposes* (which still qualifies as an inland natural wetland) may be indistinguishable from a constructed wetland for *nutrient attenuation (non-restoration) purposes* (which does not qualify as an inland natural wetland). So being classified as a constructed wetland does not necessarily mean it fails to qualify as an inland natural wetland under the NPS-FM. We suggest applying the precautionary principle approach, such that unless the purpose for which the wetland was constructed is known, it should be considered to be a qualifying inland natural wetland until demonstrated otherwise.

Finally, the exclusions for 'restored wetlands' and the like under the NPS-FM leave an unclear position for wetlands that were not constructed for offsetting or restoration purposes, but were constructed in areas that would have qualified as inland natural wetland just prior to construction (e.g. a wet pasture area with a mix of native and exotic pasture species that has been converted to a constructed open-water treatment wetland). This may occur in areas of wet pasture that would not meet the pasture exclusion methodology test, for example. Such activities in wetlands might no longer be permitted under regional plans but may have occurred historically.

Figure 16. Image showing a constructed (floating rectangle) wetland in a wider area of natural wetland featuring restoration plantings around margins of fenced-off area in the Mangawara catchment. Distinctive artificial characteristics of the floating wetland are apparent: in this case, 90^0 corners and straight edges. From this image it is unclear whether this is a restoration project or an artificial wetland, which means its qualifying status as 'inland natural' might be unclear.

Figure 17. The images show a constructed wetland with distinctive straight edges, 90^0 corners, and rows of planted vegetation. This constructed wetland was created on what was most likely a wetland area from 2002 to 2019 (2002 and 2019 images). In some areas earthworks appear to have been done to lower the soil level and hence elevate the relative water table to be more suitable for planted wetland species (2020 image) and additional plantings done. By 2023 this wetland area has become much less obviously constructed and would most likely be mapped as 'natural' based on the 2023 image alone.

6 Principles and methods for field verification and/or updating of desktop mapping

The NPS-FM requires that field verification of a wetland occur in the case of *uncertainty* or *dispute* about the existence *or* extent of a natural wetland (clause 3.23(3)), and that regional councils must develop and undertake a monitoring plan that enables the council to assess whether its policies, rules, and methods are ensuring no net loss of wetlands. We address field verification first.

The NPS-FM requirement for field verification can be triggered in two difference circumstances. First there is the situation where a dispute about the existence or extent of a natural wetland arises. This may occur where it is disputed that a mapped wetland is a qualifying 'natural wetland' (see definitions in the NPS-FM), or where it is agreed a natural wetland exists but the extent is questioned. The NPS-FM refers to the wetland delineation protocols (MfE 2022a) as being appropriate to use in these cases, and we refer the reader to these for guidance on their implementation. We suggest that in the case of dispute over the existence of a qualifying wetland, this issue should be resolved before any field verification of extent takes place, because this may prove unnecessary if the wetland is found not to fit the definition of a qualifying wetland. This may happen when, for example, the pasture exclusion applies.

The existence or extent of wetlands will most likely be challenged where new restrictions on activities that may be undertaken in wetlands apply; for example, where an area is currently used for grazing and it is not immediately apparent whether the pasture exclusion conditions will be met. It may be useful to identify any areas that are agreed to be qualifying or non-qualifying, and then proceed to apply the field verification protocols to areas that are in dispute. Note that the field verification protocols are to be applied by vegetation type.

The second situation triggering the need for field verification is where the extent or existence of a wetland is 'uncertain'. In this case no third party dispute is required to trigger the requirement for field verification. There is no explicit guidance on how much uncertainty is required before the condition is met; we suggest that regional councils use the uncertainty recorded in the geospatial database (see above) to prioritise the most uncertain wetlands for early field verification. We recommend maximising the quality of imaging or obliques prior to mapping in order to reduce the number of areas that will need field verification due to uncertainty because of low-quality imagery.

We suggest that councils also maintain consistency in terms of the order in which wetlands are required to be mapped (clause 3.23(4) NPS-FM) when assessing which wetlands to field verify. However, where multiple wetlands have a similar degree of uncertainty, any of those wetlands that are at risk of loss of extent or values might be prioritised for field verification.

Where updating is required, 'change detection' is a rapidly progressing field of modelling that has been applied more successfully to wetland features that have *already been identified*, in contrast to the task of mapping wetlands where many features have yet to be mapped (B Martin MWLR, pers. comm., 2023). So although initial mapping is often best done by skilled operators manually, updated maps might be made by modelling generating a layer of suggested changes to wetlands, which are then rejected or accepted by a skilled operator, with some manual verification performed for quality control purposes.

We suggest that where manual updating is undertaken, a similar time period and hydrological setting be used when comparing old and new imagery. The wetland delineation hydrology tool (MfE 2021) sets out useful detail on this:

> *Wetland delineation using the hydrology tool should be undertaken during periods of 'normal rainfall'. Normal rainfall is monthly rainfall two-to-three months before the field assessment time, which is sufficiently similar to historical monthly rainfall.*

7 Acknowledgements

Manaaki Whenua acknowledges the images provided by Waikato Regional Council and West Coast Regional Council that are among those used as examples in this report.

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Appendix 1 – Process flowcharts

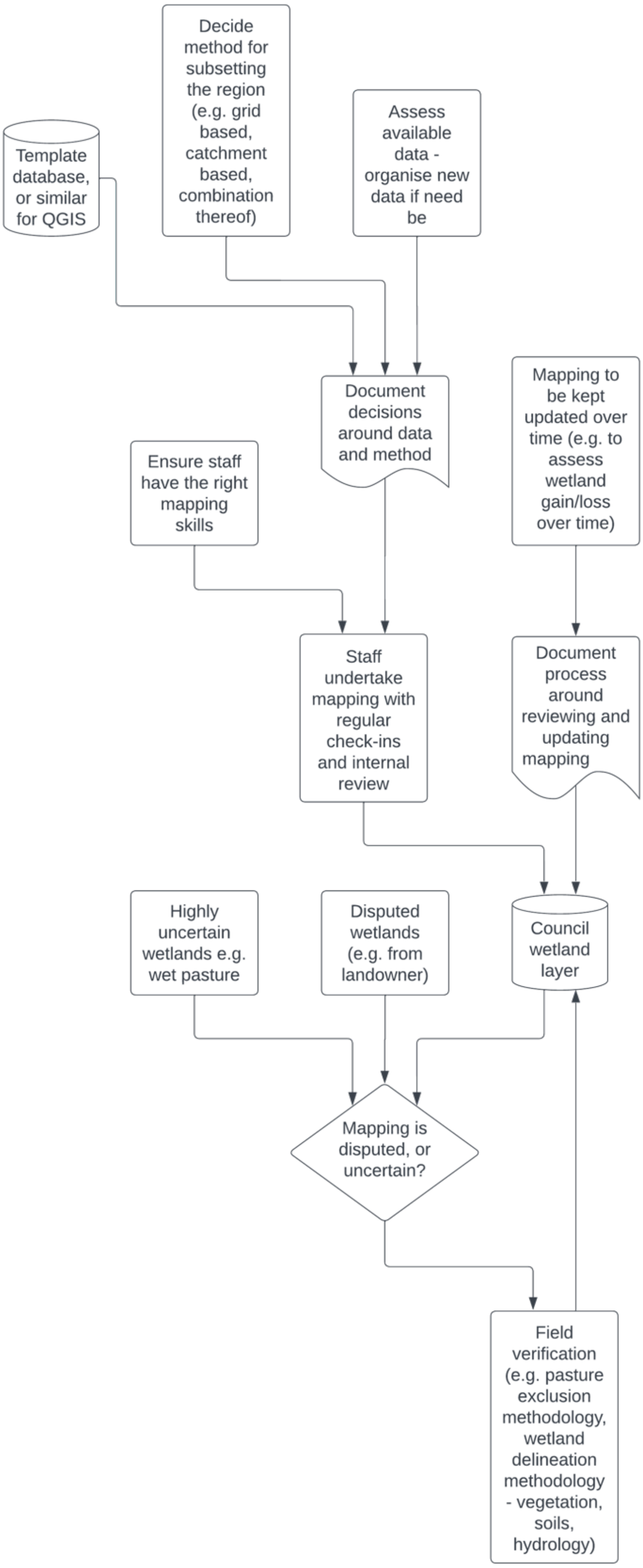


Figure 18. Process flowchart of mapping from the regional council perspective. For further details, please see main text.

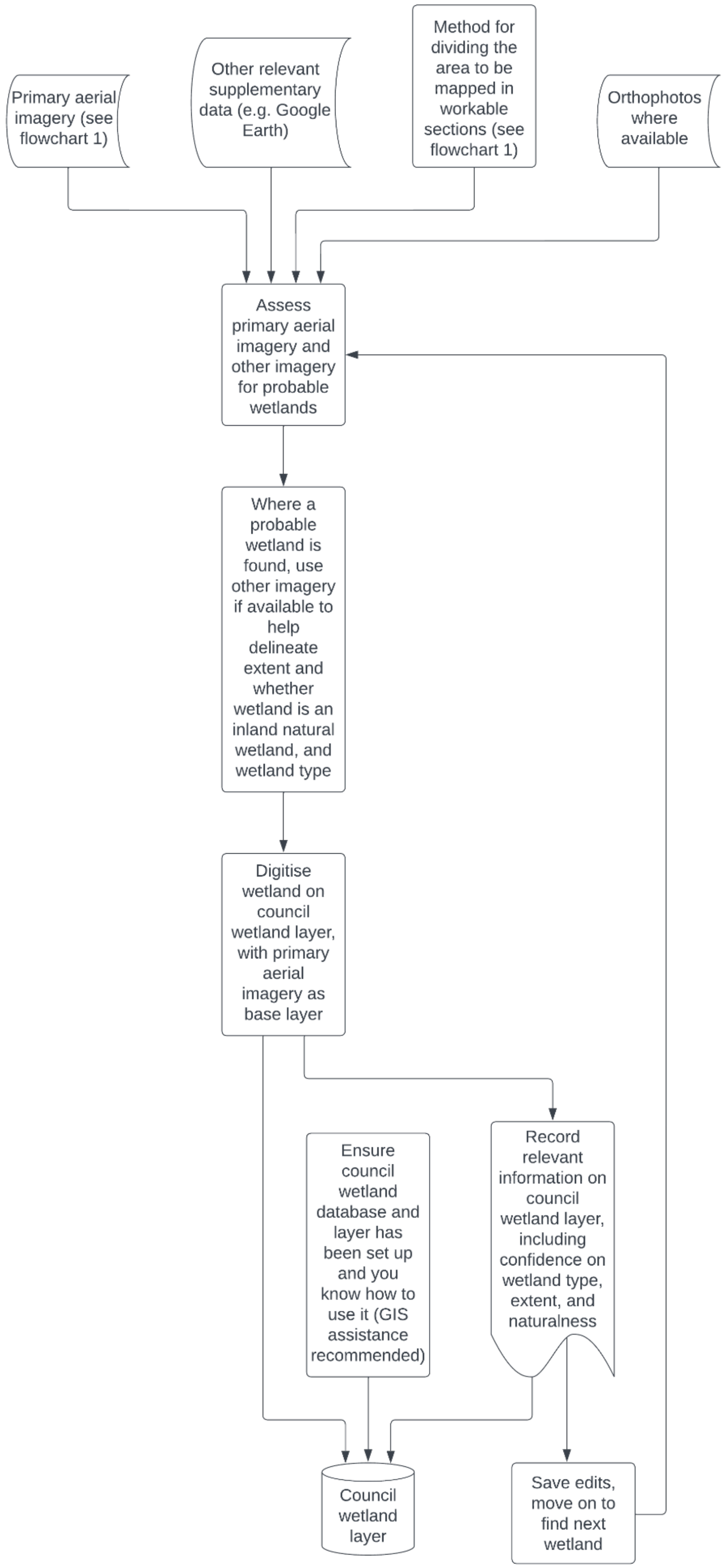
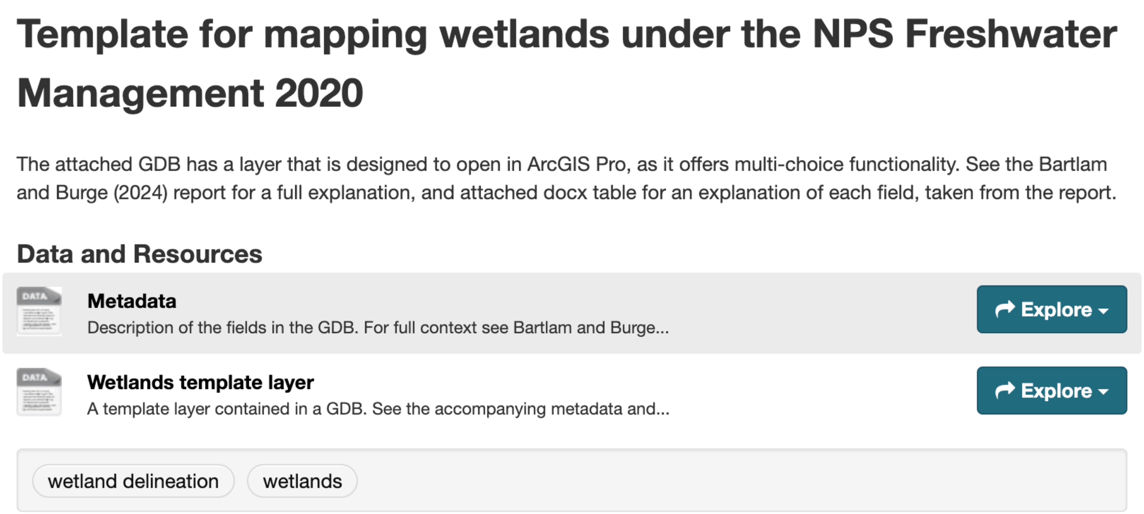


Figure 19. Process flowchart of mapping from the individual operator perspective. For further details, please see main text.

Appendix 2 – Data template

See https://doi.org/10.7931/eydz-8665 which will take you to a page like that pictured below:



Template for mapping wetlands under the NPS Freshwater Management 2020

The attached GDB has a layer that is designed to open in ArcGIS Pro, as it offers multi-choice functionality. See the Bartlam and Burge (2024) report for a full explanation, and attached docx table for an explanation of each field, taken from the report.

Data and Resources

Metadata
Description of the fields in the GDB. For full context see Bartlam and Burge...
Explore

Wetlands template layer
A template layer contained in a GDB. See the accompanying metadata and...
Explore

wetland delineation
wetlands