Wetland suitability modeling in the Styx/ Pūharakekenui catchment

ECOL699 – Research placement

Sara Alves Coutinho

1139357

Table of Contents

Summary

Wetlands provide important ecosystem services. Historically, a large area of the Styx/Pūharakekenui catchment was covered with wetlands, but since European arrival most have been drained for urban and agricultural development. Recent initiatives have been established to restore and enhance the earlier natural values of the area, including a mapping project initiated by the Styx Living Laboratory Trust. One of the objectives of this project is to identify existing and potential wetlands along the Styx river and its tributaries.

We created a wetland suitability model to help identify and prioritise areas for wetland restoration, using as factors hydrology, soils, historical data, land use zones and vegetation cover. The results including only environmental and historical factors indicate that a large area of the catchment is suitable for wetland restoration. Including all factors greatly reduces the suitable areas, but large tracks on the margins of the lower Styx river and Sheppards creek still class as highly suitable for wetland restoration.

We acknowledge the limitations of our model and recommend ground-truthing the results before any application. However, we hope the results can guide wetland restoration efforts in the Styx catchment and contribute to the long-term vision outlined in The Styx: Vision 2000-2040 document.

Introduction

Wetlands provide important ecosystem services; these include water quality maintenance, flood mitigation, shoreline protection, habitat provision and carbon sequestration. In New Zealand, 90% of the original wetland extent has been lost in the last 150 years, following worldwide trends of wetland drainage for urban and agricultural development. The Resource Management Act (1991) identifies the protection and management of wetlands as matters of national importance (B. R. Clarkson et al., 2013). In recent years, wetland restoration initiatives have emerged as tool to reverse and restore lost ecosystem services (Bendor & Kleiss, 2015).

New Zealand has an official, although not yet complete, wetland delineation protocol. This protocol follows the US wetland delineation system (Environmental Laboratory, 1987) and uses three criteria: vegetation, hydric soils, and hydrology (B. Clarkson, 2018). Landcare Research has created tools for the vegetation and hydric soils criteria (B. R. Clarkson, 2013;

Fraser et al., 2018), but the hydrology tool is still in progress (B. Clarkson, 2018). Additionally, the tools used for vegetation and soils may require visiting and sampling sites.

GIS has proved to be a powerful tool for wetland mapping and suitability modeling. Lin et al. (2006) proposed a flexible approach that could be adapted to the specific need of individual projects. This approach was later used to identify and prioritize potential wetlands in the Mississippi Gulf Coast, in a large-scale restoration project aimed at reducing flood risk, following Hurricane Katrina (Lin & Kleiss, 2007). Other projects investigated identifying potential sites for wetlands using diverse factors, including environmental, hydrological, social and ecological data (Darwiche-Criado et al., 2017; Higginbottom et al., 2018; Palmeri & Trepel, 2002; van Lonkhuyzen et al., 2004).

In New Zealand, Ausseil et al. (2007) mapped potential wetlands in the Manawatū-Whanganui region using remote sensing and a diverse set of criteria. More recently, Uuemaa et al. (2018) investigated identifying wetland restoration areas in a catchment near Invercargill, using mostly hydrological factors. Dymond et al. (2021) have recently revised the wetland extent in New Zealand by combining two existing GIS data sets. To our knowledge, no one has attempted wetland suitability modeling in an urban context in New Zealand.

In this study we aim to create a wetland suitability model and apply it to the Styx/Pūharakekenui river catchment, using hydrology, soils, historical data, current land use zones and vegetation cover as factors. This model will help identify and prioritise areas for wetland restoration within the Styx/Pūharakekenui catchment, contributing to the long-term vision outlined in The Styx: Vision 2000-2040 document (Christchurch City Council, 2000).

Methods

Study area

The Styx/Pūharakekenui is a 24.8 km long river that meanders through the northern side of Christchurch city. The river originates in the suburb of Harewood, near the Christchurch airport, and terminates at Brooklands Lagoon and the Waimakariri River. The river has several tributaries and waterways, both natural and man-made (Figure 1). Three tributaries of interest are Kaputone creek, Smacks creek and Sheppards creek (Antony Shadbolt, personal communication, 31 August 2022, Styx Living Laboratory Trust, n.d.).

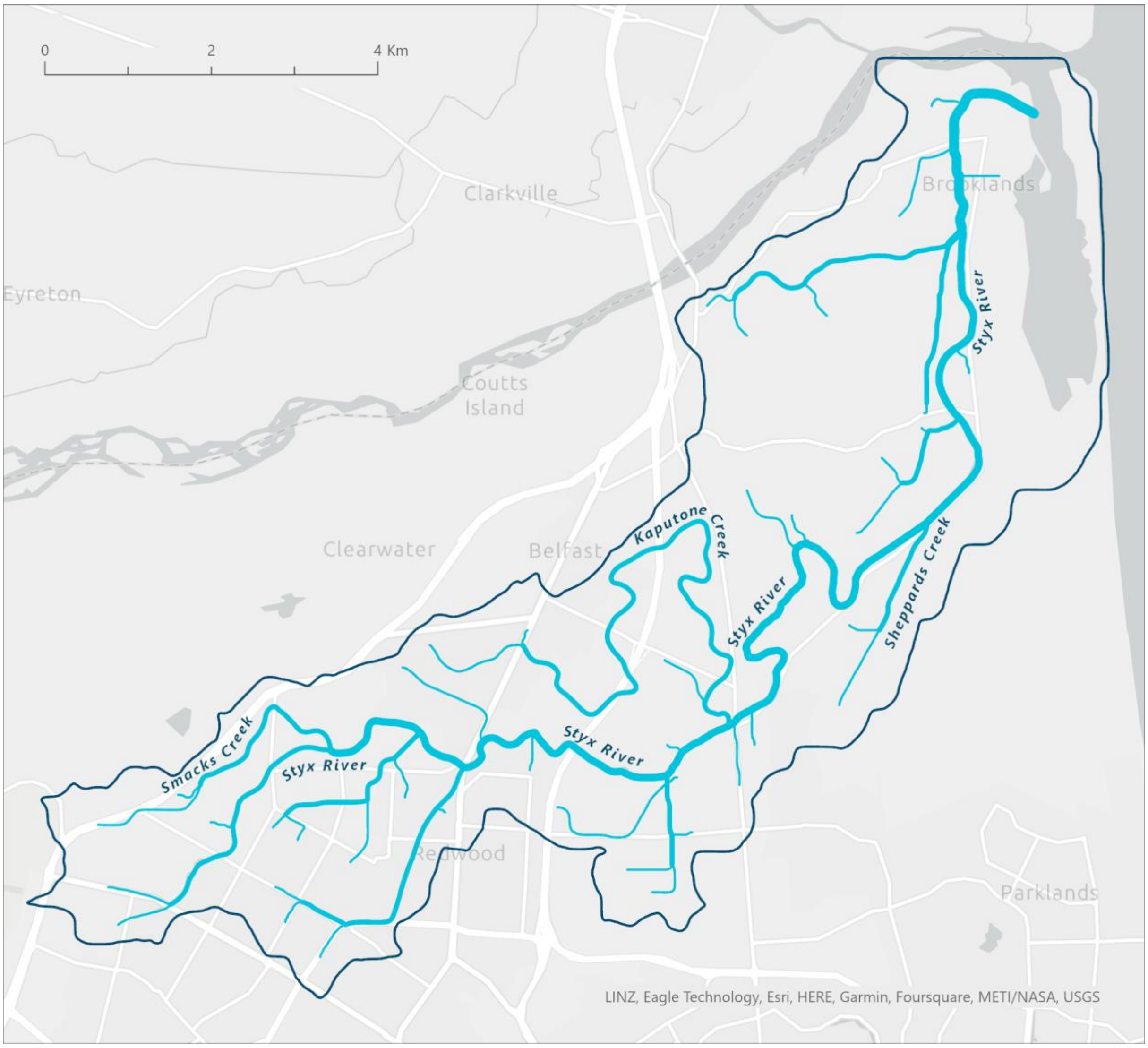


Figure 1 – Study area showing the Styx catchment and the Styx river and its tributaries.

The Styx/Pūharakekenui catchment is approximately 53 km^2. Historically, a large area of the catchment was covered with wetlands and sand dunes. The area was an important source of flax for harvesting and mahinga kai (Christchurch City Council, 2000; Environment Canterbury, 2019). Development since European arrival and human activities such as drainage, farming and urbanisation have extensively modified the natural landscape of the catchment. A long-term vision and management plan was established in 2000 to maintain and enhance the earlier natural values of the area (Christchurch City Council, 2000).

Data sources

We sourced data for this project through several platforms; these sources include public data and unpublished data from a previous project (Table 1).

Table 1 – Data used for the analysis and data sources.

Data	Sources
Styx river and tributaries	River Environment Classification (National Institute of Water and Atmospheric Research, 2004)
Styx catchment boundary	River Environment Classification (National Institute of Water and Atmospheric Research, 2004)
Flood hazard high	Christchurch City Council (Christchurch City Council, n.d.-a)
Flood ponding	Christchurch City Council (Christchurch City Council, n.d.-b)
Depth to groundwater	Environment Canterbury (original source) (Doscher, 2019)
Canterbury Plains DEM	Landcare Research (original source) (Doscher, 2019; Landcare Research, 2010)
Soil drainage	New Zealand Land Resource Inventory (Landcare Research, 2000)
Soil order	S-Map Online (Landcare Research, 2019)
Historical data - Black Maps	Environment Canterbury (Environment Canterbury, n.d.)
Land use zones	Canterbury Maps (Canterbury Maps, 2021)
Vegetation cover	Landcare Research (Landcare Research, 2020)

Methodology

We followed a similar methodology to van Lonkhuyzen et al. (2004), as their approach had several advantages: readily available data, inclusion of urban areas, and a model with a straightforward approach.

We broke the analysis in three parts. First, we took into consideration environmental factors: hydrology and soils. Then, we compared the results of environmental factors to historical data and included the historical data in the analysis. Finally, we considered current land use zones and vegetation cover.

We chose to place more weight on hydrology and soils to align with the proposed wetland delineation protocol for New Zealand. Historical wetlands were also more heavily weighted; these areas may already have the appropriate hydrology and soils, and wetland re-establishment may be easier to achieve (van Lonkhuyzen et al., 2004). Vegetation and land use was given a lower weighting. We did this for two reasons: first, this approach matched the methodology of van Lonkhuyzen et al. (2004); second, the vegetation cover data available was coarse and inaccurate in places.

All data used in the analysis was converted to a 1x1 m raster layer in the New Zealand Transverse Mercator 2000 (NZTM2000) projection.

Part 1 – Hydrology and Soils

We considered only hydrology and soils for the first part of the analysis. Hydrological factors included proximity to streams, depth to groundwater and flooding areas (Table 2). Soil factors included soil types and soil drainage (Table 3). We ranked each of these factors from 1 (low suitability) to 10 (high suitability).

Hydrology

We compared the River Environment Classification data set with a waterways data set published by the Christchurch City Council. Streams not present in the Christchurch City Council data set were removed from the River Environment Classification data set.

To calculate proximity to streams, we used the "stream order" field, range 1-7, from the River Environment Classification data set. Headwater streams are allocated a lower value, and this value increases as tributaries meet and form main streams (Snelder et al., 2004). We used a lower buffer distance for streams of lower order, and progressively increased the buffer distance for higher order streams (Table 2, Appendices

Appendix 1 – Streams buffer data process).

To calculate depth to groundwater, we subtracted a Digital Elevation Model (DEM) layer from a water level layer. Negative (meaning groundwater above ground) and zero values were considered more suitable for wetlands, and positive values not suitable (Table 2, Appendix 2 – Depth to groundwater data process).

Table 2 – Hydrology scores and weights applied to the variables in the GIS model.

Variable	Weight	Data	State	Suitability
Hydrology	3	Proximity to streams	Streams layer buffered, based on stream order Order 1: 10 m Order 2: 45 m Order 3: 85 m Order 4: 125 m	10
			All other values	1
		Depth to groundwater	Negative depth to groundwater	10
			Positive depth to groundwater	1
		Flooding	Flood hazard high plus flood ponding zone	10
			Flood hazard high	5
			Flood ponding zone	5

			All other values	1

To create the flooding layer, we combined the flood hazard and flood ponding layers into one layer. Areas where both flood layers overlapped were given the highest ranking; areas where only one of the layers was present were given an intermediary ranking; areas where none of the layers were present were considered not suitable (Table 2, Appendix 3 – Flooding data process).

Soils

We used the information present on the S-Map data set to extract soil drainage information. We then augmented this data set with information available on the tool S-Map online (Landcare Research, 2019) and added soil order information to the existing S-Map data set. We then ranked soil orders based on information available in the Soils portal of Landcare Research (Hewitt, 2013; Landcare Research, n.d., Table 3, Appendix 4 – Soils data process).

Table 3 – Soil scores and weights applied to the variables in the GIS model.

Variable	**Weight**	**Data**	**State**	**Suitability**
Soils	3	NZSC Soil Order	Gley and organic soils	10
			Recent soils	5
			All other types of soils	1
		Soil drainage	Very poor	10
			Poor	8
			Imperfectly drained	5
			Well drained	1

Hydrology and Soils suitability model

We created a model using the tool Suitability Modeler in ArcGIS Pro 3.0, with a suitability scale of 1 to 10, weighted by multiplier. We assigned a weight to each input raster layer, and classified the suitability of each category or class present in the raster (Table 2, Table 3). Although we used Suitability Modeler, the same process can be achieved with other GIS software, by reclassifying each raster layer and then summing the values of overlapping pixels.

The model can be defined by the following formula:

$$\text{Suitability}_{HS} = \text{Proximity to stream}_{(1\text{-}10)} * 3 +$$
$$\text{Depth to groundwater}_{(1\text{-}10)} * 3 +$$

$$\text{Flooding}_{(1\text{-}10)} * 3 +$$
$$\text{NZSC Soil Order}_{(1\text{-}10)} * 3 +$$
$$\text{Soil drainage}_{(1\text{-}10)} * 3$$

The lowest value a cell in the resulting layer can have is 15, and the highest is 150. A location that scored 150 would be close to streams, have a negative depth to groundwater, be both a flood hazard and a flood ponding area, and have very poor draining gley or organic soils.

Part 2 – Hydrology, Soils and Historical data

We compared the results of Part 1 with historical data (Appendix 7 – Historical data. Then, we extended the model created in Part 1 to include historical data, considering areas that historically were wetlands or river channels as more suitable for wetland restoration (Table 4, Appendix 5 – Historical data process).

Table 4 – Historical data scores and weights applied to the variables in the GIS model.

Variable	Weight	Data	State	Suitability
Historical data	3	Black Maps – Land Cover (Vegetation)	Wetland	10
			River channel	10
			All other	1

Hydrology, Soils and Historical data suitability model

The model can be defined by the following formula:

$$\text{Suitability}_{\text{HSHd}} = \text{Proximity to stream}_{(1\text{-}10)} * 3 +$$
$$\text{Depth to groundwater}_{(1\text{-}10)} * 3 +$$
$$\text{Flooding}_{(1\text{-}10)} * 3 +$$
$$\text{NZSC Soil Order}_{(1\text{-}10)} * 3 +$$
$$\text{Soil drainage}_{(1\text{-}10)} * 3 +$$
$$\text{Black Maps: Land Cover (Vegetation)}_{(1\text{-}10)} * 3$$

The lowest value a cell in the resulting layer can have is 18 and the highest is 180.

Part 3 – Hydrology, Soils, Historical data, Land use zones and Vegetation cover

We extended the model built in Part 2 to include land use zones and vegetation cover.

Land use zones

We only used a subset of land use zones, as some zones are not available for wetland restoration (e.g., residential and industrial areas). We considered open space zones the most suitable for wetland restoration, and rural and specific purpose zones less suitable. Any areas that belong to other land use zones were removed from the analysis (Table 5, Appendix 6 – Land use zones and vegetation cover data process).

Table 5 – Land use zones scores and weights applied to the variables in the GIS model.

Variable	Weight	Data	State	Suitability
Land use	1	Land use zones	Open space	10
			Rural	5
			Specific purpose (cemetery, golf course, flat land recovery)	5

Vegetation cover

We couldn't directly apply the methodology of van Lonkhuyzen et al. (2004) to land cover types in New Zealand. Instead, we used our professional judgement and information contained in the New Zealand land cover database.

Table 6 – Vegetation cover scores and weights applied to the variables in the GIS model.

Variable	Weight	Data	State	Suitability
Vegetation cover	1	Vegetation cover	Urban Parkland/Open Space Herbaceous Saline Vegetation Estuarine Open Water Lake or Pond River Indigenous Forest Herbaceous Freshwater Vegetation	10
			Low Producing Grassland	8
			Deciduous Hardwoods High Producing Exotic Grassland Mixed Exotic Shrubland Gorse and/or Broom	5
			Exotic Forest Built-up Area (settlement) Short-rotation Cropland Forest – Harvested Orchard, Vineyard or Other Perennial Crops	1

We considered the following types of vegetation cover to be the most suited for wetland restoration: open space areas, areas covered by water, areas where vegetation associated with water is present, and indigenous forest. We ranked low producing grassland next, as this land cover type has low economic value for farming and may be a good candidate for wetland conversion. Areas with non-native trees, exotic shrubs and exotic grasslands were ranked in the middle; these land cover types may require more effort to convert to wetlands due to the presence of invasive species, and in the case of high producing exotic grassland, there may be less willingness for conversion, as these grasslands have high economic value for farming. We considered forestry, crops and built-up areas as the least suitable, as these areas have high economic value and are less likely to be converted to wetlands (Table 6, Appendix 6 – Land use zones and vegetation cover data process).

Hydrology, Soils, Historical data, Land use and Vegetation cover suitability model

The model used in Part 3 can be defined by the following formula:

$$\begin{aligned} \text{Suitability}_{\text{HSHdLuVc}} = {} & \text{Proximity to stream}_{(1\text{-}10)} * 3 + \\ & \text{Depth to groundwater}_{(1\text{-}10)} * 3 + \\ & \text{Flooding}_{(1\text{-}10)} * 3 + \\ & \text{NZSC Soil Order}_{(1\text{-}10)} * 3 + \\ & \text{Soil drainage}_{(1\text{-}10)} * 3 + \\ & \text{Black Maps: Land Cover (Vegetation)}_{(1\text{-}10)} * 3 + \\ & \text{Land use zones}_{(1\text{-}10)} * 1 + \\ & \text{Vegetation cover}_{(1\text{-}10)} * 1 \end{aligned}$$

The lowest value a cell in the resulting layer can have is 20, and the highest is 200.

Results

Part 1 – Hydrology and Soils

The results of the model, using hydrology and soils as variables, show that suitable areas for wetland restoration are primarily in the surroundings of the lower half of the Styx river, and of some of its tributaries – Sheppards creek and Kaputone creek. Part of the Styx Mill Conservation Reserve and some surrounding areas were also classed as suitable by the model (Figure 2).

The results also show that large areas of the suburb of Marshland, the western part Brooklands, and the lower part of the Styx suburb are suitable for wetland restoration. These areas have gley or organic poor draining soils, a negative depth to groundwater, and in the case of Brooklands and the lower Styx suburb, are prone to flooding (Figure 2).

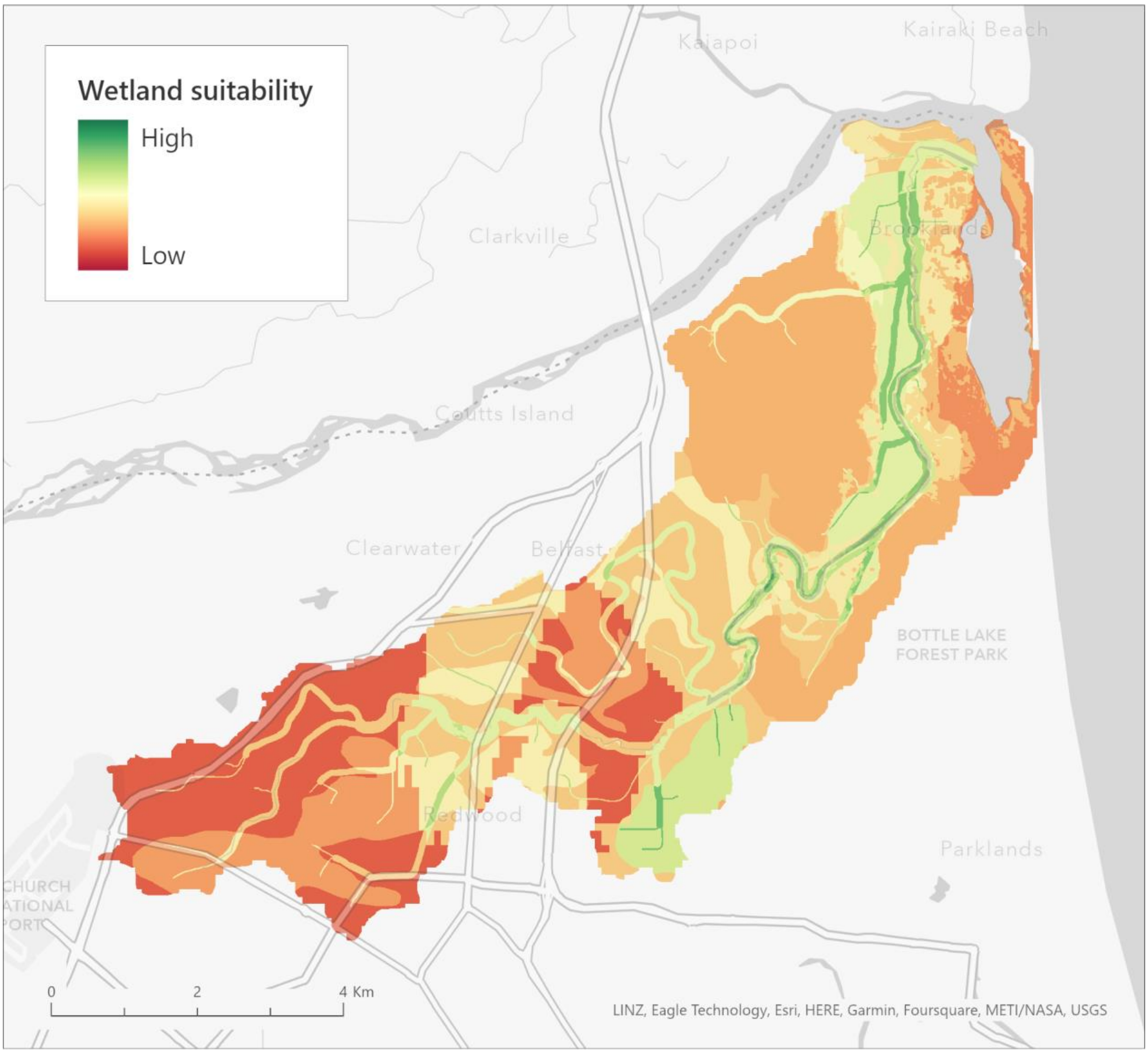


Figure 2 – Wetland suitability results using hydrology and soils as variables.

Part 2 – Hydrology, Soils and Historical data

We compared the results from Part 1 with existing historical wetland data (Appendix 7 – Historical data. There was a large overlap in the detected areas, particularly around Marshland, Brooklands and the Styx suburb, but historical wetland areas in the upper part of the Styx river were classed as being of low suitability for wetland restoration by the model (Figure 3).

Adding historical data to the model reinforced the suitable locations identified on Part 1. Other locations become more suitable, particularly the The Styx Mill Conservation Reserve, and areas near the reserve where the Styx meanders through. Two locations that were previously classed as of low suitability become more suitable: an area north of Kaputone Confluence Conservation Park and another area in the suburb of Ouruhia (Figure 3).

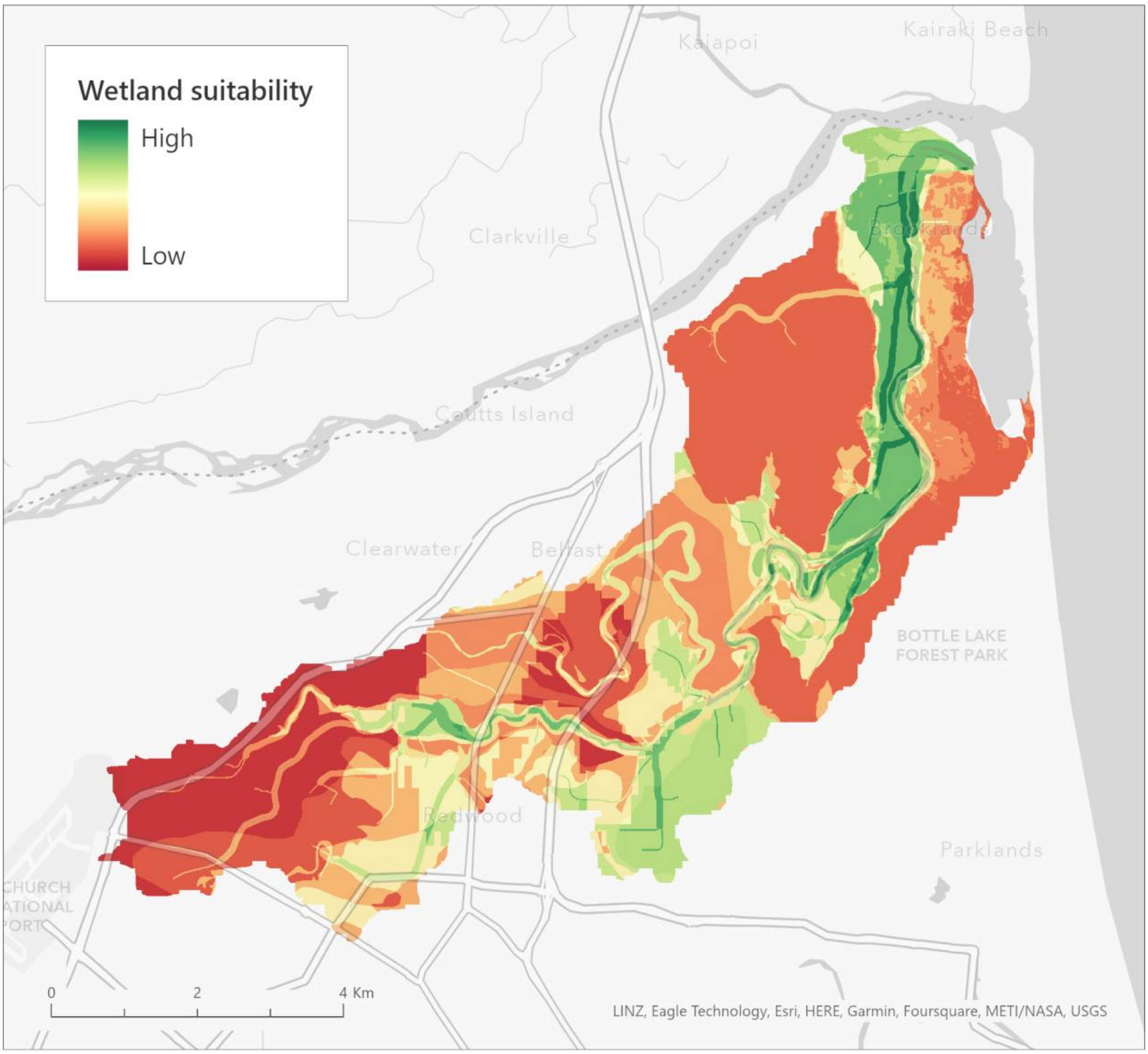


Figure 3 – Wetland suitability results using hydrology, soils and historical data as variables.

Part 3 – Hydrology, Soils, Historical data, Land use and Vegetation cover

Adding land use zones and the existing vegetation cover to the model drastically reduced the areas classed as being highly suitable for wetland restoration. The most suitable areas are on the margins of the lower half of the Styx river and on the margins of Sheppards creek. Some areas in Marshland, Brooklands, the lower Styx suburb, and on the margins of the upper Styx river were also classed as suitable, but with a lower ranking (Figure 4).

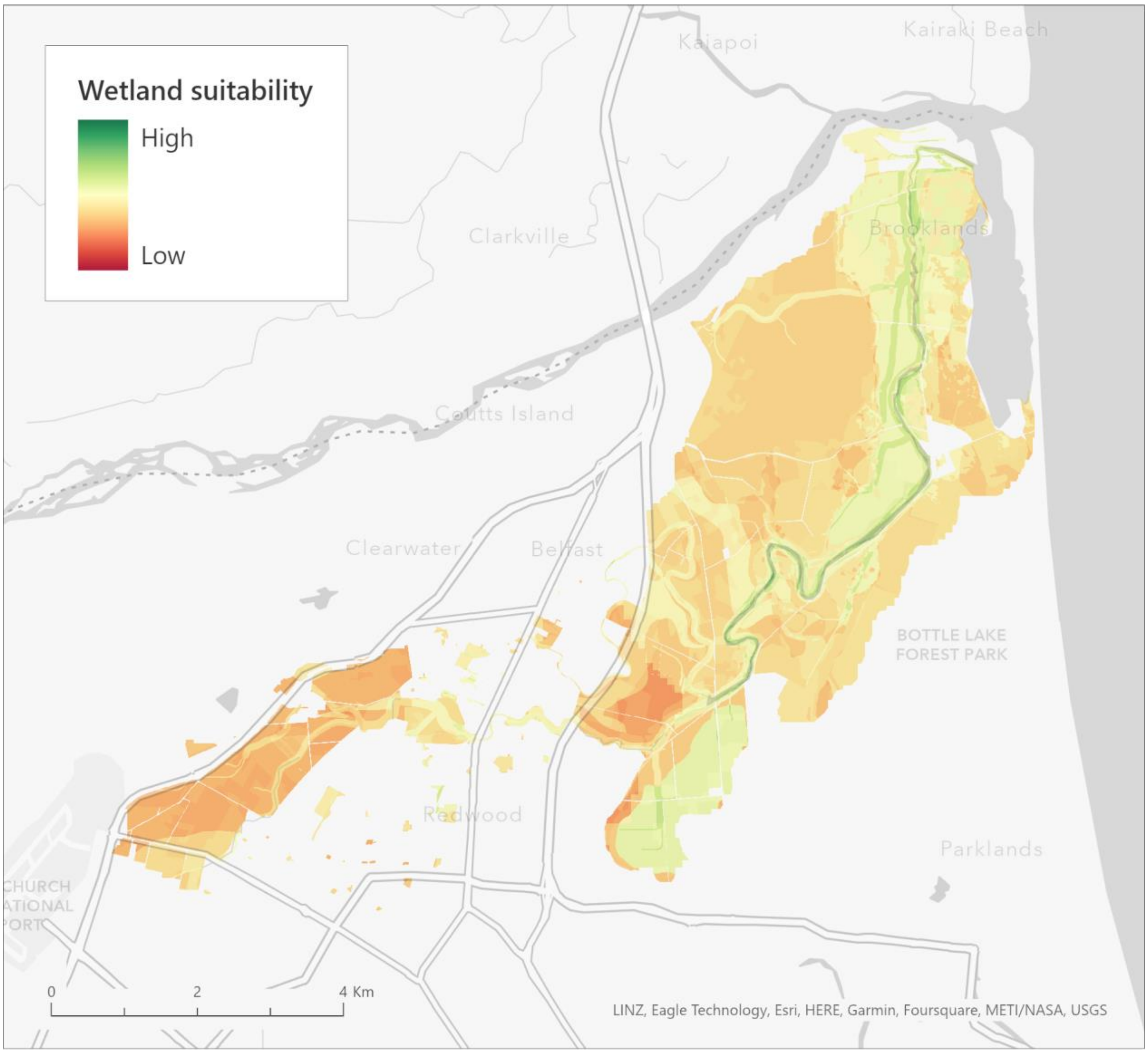


Figure 4 – Wetland suitability results using hydrology, soils, historical data, land use zones and vegetation cover as variables.

Discussion and conclusion

Limitations and future work

Methodology

As highlighted by a meta-study by Bendor & Kleiss (2015), we found very little agreement between the models, scoring and variables of previous studies using GIS for wetland restoration. We look forward to having a complete wetland delineation protocol for New Zealand, and to the creation of a GIS methodology that can be applied in conjunction with it.

Many areas that were classed as suitable for wetland restoration in earlier steps of the model became less suitable once we added land use zones and vegetation cover as variables. While this might reflect the reality, we may have weighted one or both of these factors too heavily.

We couldn't perform any ground-truthing of our models but are aware this is an important step for validating any GIS model. We highly recommend that the results are validated in the field, or by someone with a good knowledge of the area.

Data sets

We used the River Environment Classification data set to find and calculate the streams buffer. This data overlaps but doesn't fully match a waterways data set published by the Christchurch City Council (Christchurch City Council, n.d.-c).

To calculate the depth to groundwater, we used two raster layers of 100x100 m resolution. A more detailed layer would likely yield slightly different and possibly more accurate results.

The vegetation data set we used has a coarse resolution at an urban scale and is incorrect in places. To our knowledge, there is no other data set available with better accuracy and more detail. We look forward to developments in remote sensing technology and to the publication of a more accurate land cover database.

Conclusion

Our models have identified potential areas for wetland restoration in the 53 km^2 of the Styx/Pūharakekenui catchment. While still in need of ground-truthing, we believe our models can help direct and prioritise the efforts of the Styx Living Laboratory Trust and contribute to the Styx: Vision 2000-2040 long term plan.

Acknowledgements

I'd like to thank Crile Doscher for agreeing to supervise this research placement and providing technical support and guidance. Jon Sullivan and Adrian Paterson for facilitating this research placement. The Styx Living Laboratory Trust for initiating the Styx Living Laboratory Trust Mapping Project and giving me the opportunity to work on it. Samuel Lin for collaborating in the data compilation and editing process of the mapping project.

References

Ausseil, A. G. E., Dymond, J. R., & Shepherd, J. D. (2007). Rapid mapping and prioritisation of wetland sites in the Manawatu-Wanganui region, New Zealand. *Environmental Management*, *39*(3), 316–325. https://doi.org/10.1007/s00267-005-0223-1

Bendor, T., & Kleiss, B. (2015). Prioritizing wetland restoration sites: A review and application to a large-scale coastal restoration program. *Ecological Restoration*, *33*(4), 358–377. https://doi.org/https://doi.org/10.3368/er.33.4.358

Canterbury Maps. (2021). *Canterbury Operative District Plan Zones Overview [Data set]*. https://opendata.canterburymaps.govt.nz/datasets/23a22a2c16754579ab083f8b6651bbb0_0/explore?location=-43.687865%2C171.762450%2C7.00

Christchurch City Council. (n.d.-a). *Layer: DistrictPlanFloodHazardHigh (ID: 68) (Version 10.91) [Data set]*. https://gis.ccc.govt.nz/arcgis/rest/services/CorporateData/DistrictPlanOperative/MapServer/68

Christchurch City Council. (n.d.-b). *Layer: DistrictPlanFloodPonding (ID: 25) (Version 10.91) [Data set]*. https://gis.ccc.govt.nz/arcgis/rest/services/CorporateData/DistrictPlanOperative/MapServer/25

Christchurch City Council. (n.d.-c). *Layer: WcWaterCourse (ID: 15) (Version 10.91) [Data set]*. https://gis.ccc.govt.nz/arcgis/rest/services/CorporateData/WaterCourse/MapServer/15

Christchurch City Council. (2000). *Vision 2000-2040 - The Styx*. https://ccc.govt.nz/assets/Documents/Environment/Water/Vision-2000-2040-The-Styx.pdf

Clarkson, B. (2018). *Wetland delineation protocols*. https://www.landcareresearch.co.nz/uploads/public/Discover-Our-Research/Biodiversity/Species-ecosystem-services/Restoring-wetland-ecosystem-functioning/Wetland_delineation_protocols.pdf?vid=5

Clarkson, B. R. (2013). *A vegetation tool for wetland delineation in New Zealand*. https://doi.org/10.7931/J2TD9V77

Clarkson, B. R., Ausseil, A.-G. E., & Gerbeaux, P. (2013). Wetland ecosystem services. *Ecosystem Services in New Zealand – Conditions and Trends*, 192–202. https://www.landcareresearch.co.nz/uploads/public/Publications/Ecosystem-services-in-New-Zealand/1_14_Clarkson.pdf

Darwiche-Criado, N., Sorando, R., Eismann, S. G., & Comín, F. A. (2017). Comparing two multi-criteria methods for prioritizing wetland restoration and creation sites based on ecological, biophysical and socio-economic factors. *Water Resources Management*, *31*(4), 1227–1241. https://doi.org/10.1007/s11269-017-1572-2

Doscher, C. (2019). *[Geodatabase for mapping nitrate contamination vulnerability in Canterbury] [Unpublished data]*. Lincoln University.

Dymond, J., Sabetizade, M., Newsome, P., Harmsworth, G., & Ausseil, A.-G. (2021). Revised extent of wetlands in New Zealand. *New Zealand Journal of Ecology*, *45*(2), 1–8. https://doi.org/10.20417/nzjecol.45.32

Environment Canterbury. (n.d.). *Layer: Land Cover (Vegetation) (ID: 10) (Version 10.81) [Data set]*. https://gis1.ecan.govt.nz/arcgis/rest/services/Public/BlackMapsVector/MapServer/10

Environment Canterbury. (2019). *Black Maps - Digitised*. https://opendata.canterburymaps.govt.nz/maps/c5f7d946b8fb43ce80fd3441cde5b78e/explore?location=-43.458842%2C172.647888%2C11.21

Environmental Laboratory. (1987). *Corps of engineers: Wetlands delineation manual*. https://www.lrh.usace.army.mil/Portals/38/docs/USACE%2087%20Wetland%20Delineation%20Manual.pdf

Fraser, S., Singleton, P., & Clarkson, B. (2018). *Hydric soils – field identification guide*. https://www.landcareresearch.co.nz/uploads/public/Discover-Our-Research/Biodiversity/Species-ecosystem-services/Restoring-wetland-ecosystem-functioning/hydric_soils_fieldguide.pdf?vid=6

Hewitt, A. (2013). *Survey of New Zealand soil orders*. https://soils.landcareresearch.co.nz/assets/pdfs/Hewitt_2013_Survey_of_New_Zealand_soil_orders.pdf

Higginbottom, T. P., Field, C. D., Symeonakis, E., Caporn, S. J. M., Rosenburgh, A. E., & Wright, A. (2018). High-resolution wetness index mapping: A useful tool for regional scale wetland management. *Ecological Informatics*, *48*, 89–96. https://doi.org/10.1016/j.ecoinf.2018.08.003

Landcare Research. (n.d.). *Soil orders*. https://soils.landcareresearch.co.nz/topics/soil-classification/nzsc/soil-orders/

Landcare Research. (2000). *New Zealand land resource inventory [Data set]*.

Landcare Research. (2010). *NZDEM South Island 25 metre*. https://lris.scinfo.org.nz/layer/48127-nzdem-south-island-25-metre/

Landcare Research. (2019). *S-Map online*. https://smap.landcareresearch.co.nz/

Landcare Research. (2020). *LCDB v5.0 - Land Cover Database Version 5.0, Mainland, New Zealand (Version 5) [Data set]*. https://lris.scinfo.org.nz/layer/104400-lcdb-v50-land-cover-database-version-50-mainland-new-zealand/

Lin, J. P., & Kleiss, B. A. (2007). *A wetland restoration spatial decision support system for the Mississippi Gulf Coast*. https://apps.dtic.mil/sti/pdfs/ADA471738.pdf

National Institute of Water and Atmospheric Research. (2004). *River Environment Classification [Data set]*. https://data.mfe.govt.nz/layer/51845-river-environment-classification-new-zealand-2010-deprecated/

Palmeri, L., & Trepel, M. (2002). A GIS-based score system for siting and sizing of created or restored wetlands: Two case studies. *Water Resources Management*, *16*, 307–328. https://doi.org/https://doi.org/10.1023/A:1021947026234

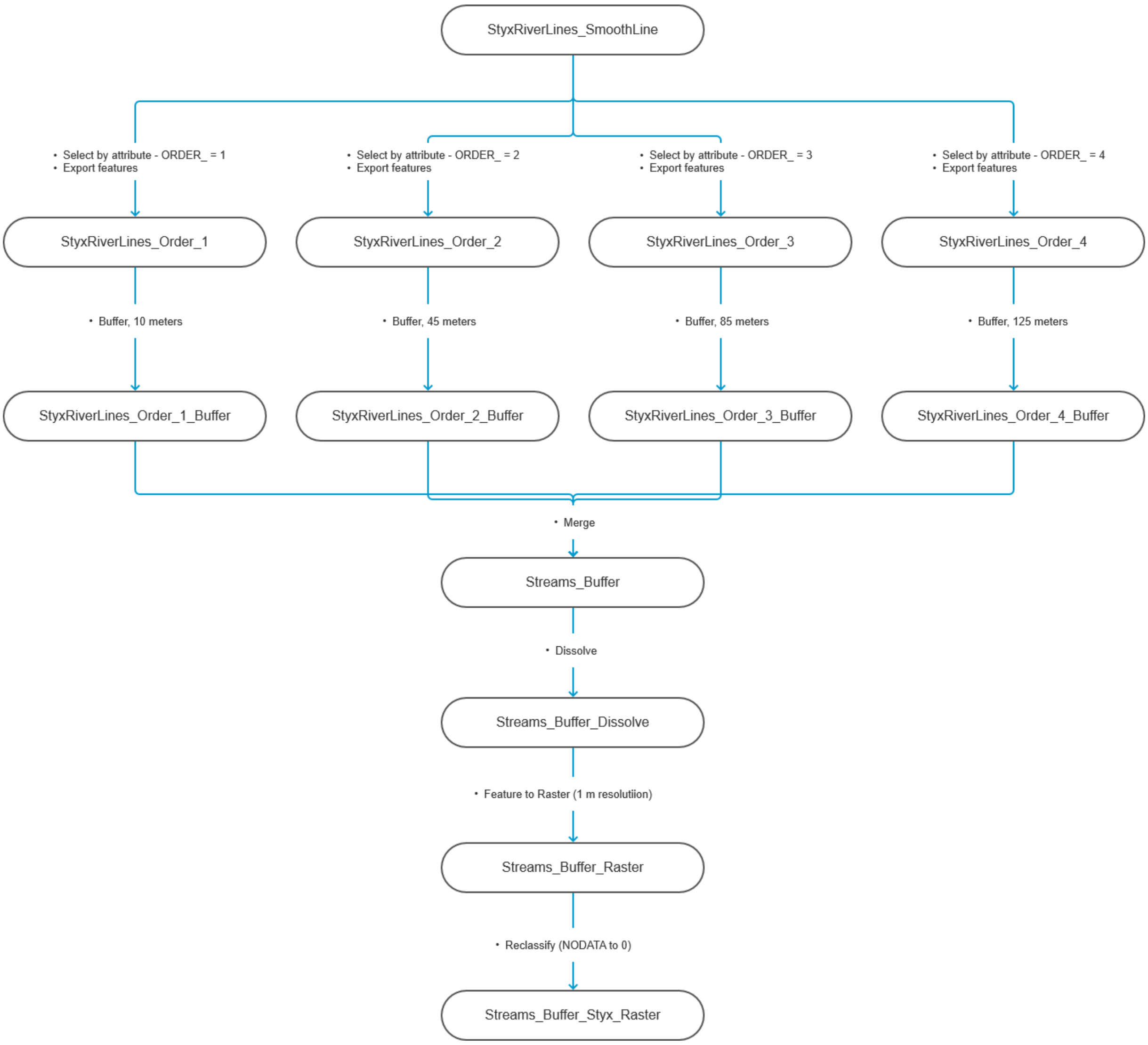
Snelder, T., Biggs, B., & Weatherhead, M. (2004). *New Zealand river environment classification user guide*.

Styx Living Laboratory Trust. (n.d.). *The Styx environment*. https://www.thestyx.org.nz/styx-environment

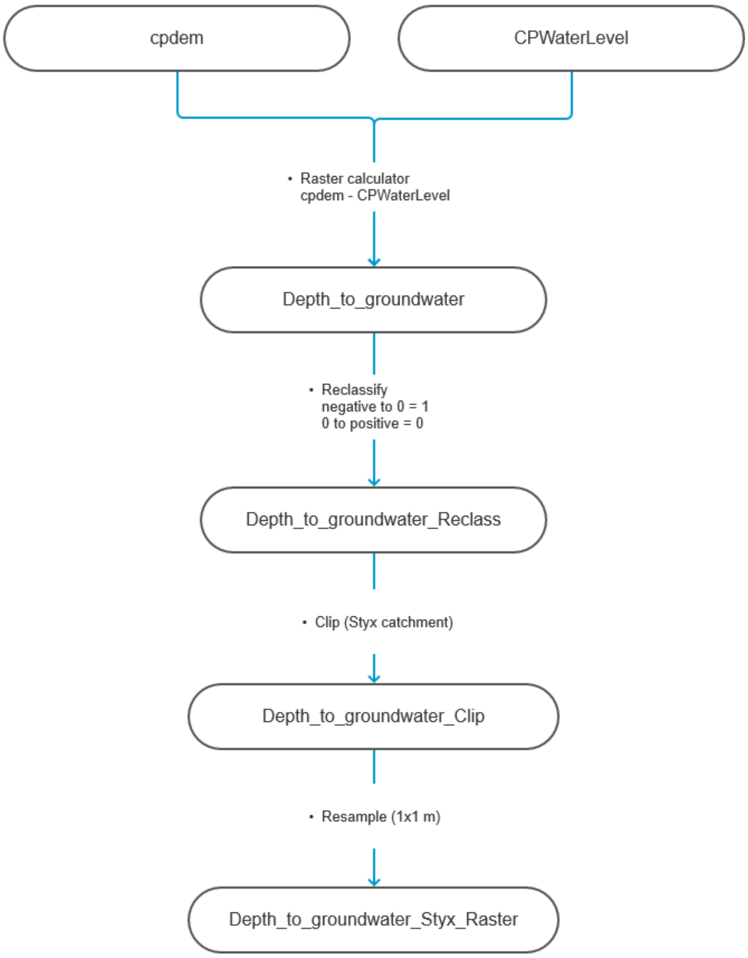
van Lonkhuyzen, R. A., Lagory, K. E., & Kuiper, J. A. (2004). Modeling the suitability of potential wetland mitigation sites with a geographic information system. *Environmental Management*, *33*(3), 368–375. https://doi.org/10.1007/s00267-003-3017-3

Appendices

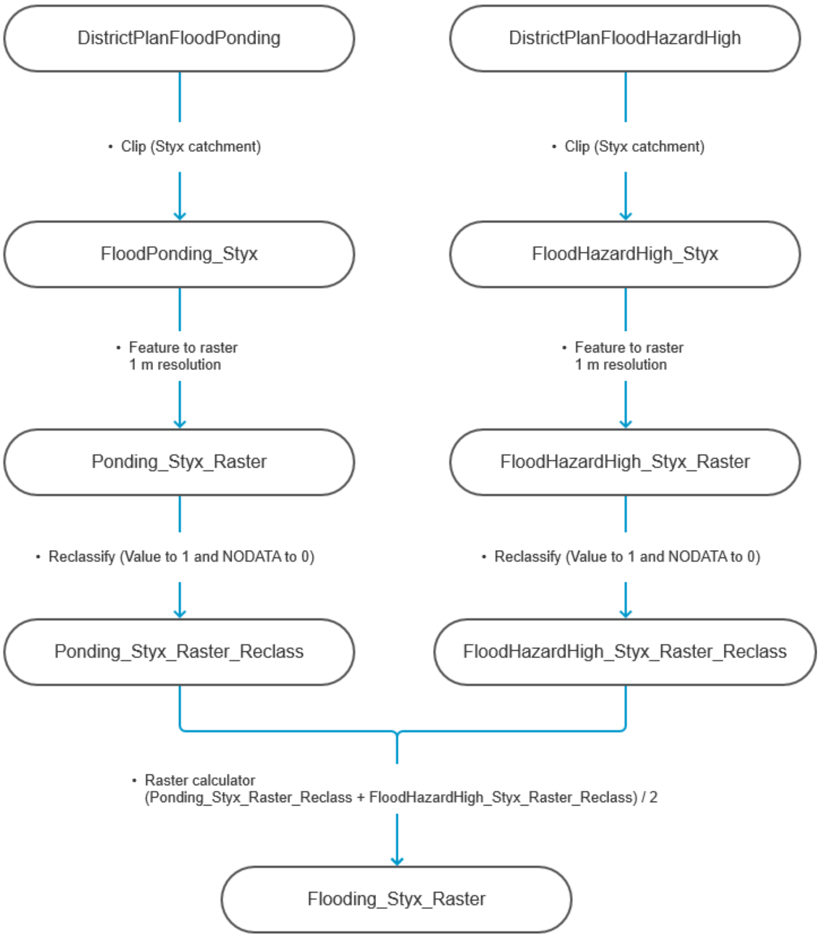
Appendix 1 – Streams buffer data process



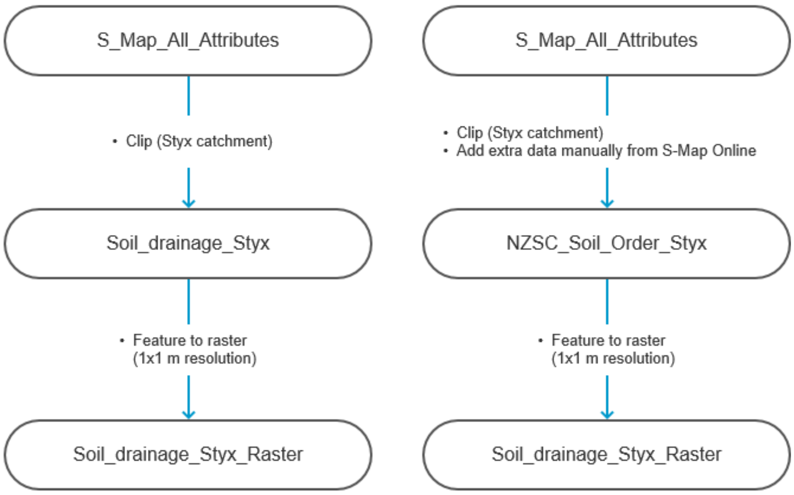
Appendix 2 – Depth to groundwater data process



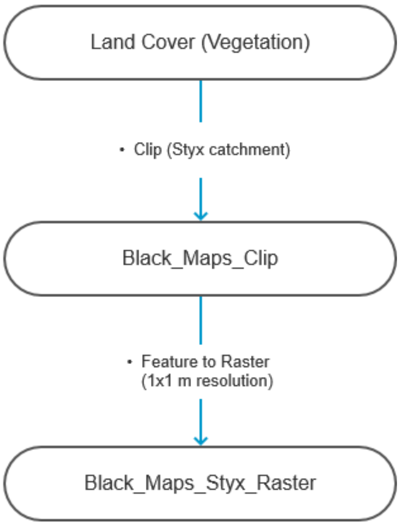
Appendix 3 – Flooding data process



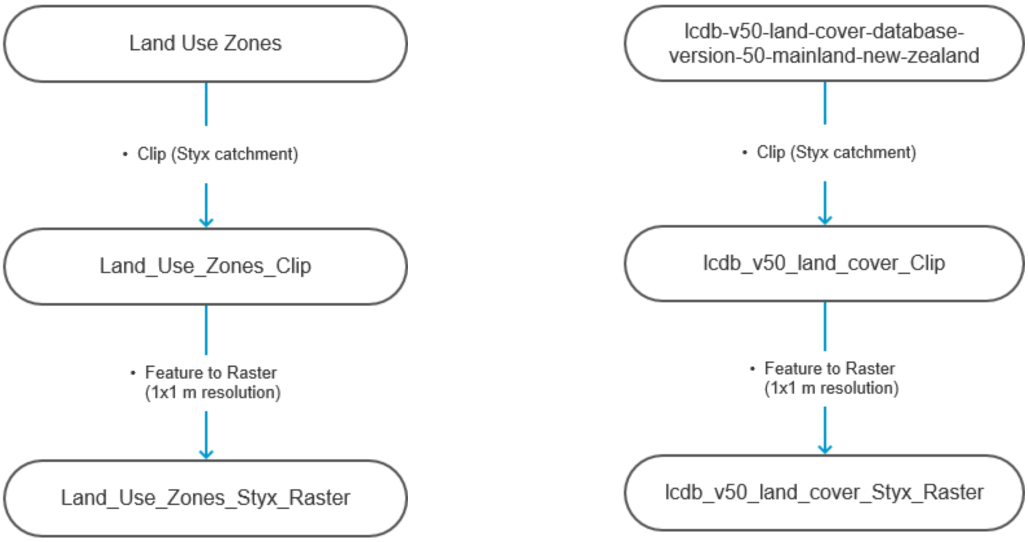
Appendix 4 – Soils data process



Appendix 5 – Historical data process



Appendix 6 – Land use zones and vegetation cover data process



Appendix 7 – Historical data