Mapping New Zealand’s stopbank network: a standardised nationwide inventory

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ABSTRACT

Floods are the most frequent natural hazard in New Zealand and responsible for the highest number of declared civil defence emergencies and greatest regular economic loss. In 2017 alone, insured nationwide loss from extreme weather events (primarily flooding) exceeded NZ$ 150 million. Many communities, productive farmland areas and critical infrastructure networks rely on physical flood protection and other mitigation measures to reduce flood risk. Stopbanks (levees) provide a critical role in flood protection in all regions of the country. However, there have been limited and inconsistent records on the location of these stopbanks, as well as their physical and engineering characteristics.

Through collaboration with regional council and unitary authorities, we provide the first standardised inventory of New Zealand stopbanks – named *New Zealand Inventory of Stopbanks (NZIS)*. Outputs of the NZIS provide a geospatial overview of New Zealand’s stopbank network, with total stopbank length of around 5,000 km. The NZIS allows asset managers, owners and regulators to review their stopbank flood protection measures. It can also inform the prioritisation of post-event reconnaissance activities and future investment decisions including maintenance and improvement work.

Ongoing research incorporates the NZIS geospatial dataset, GNS Science’s active faults database and recent QuakeCoRE seismic modelling to assess the exposure of documented stopbanks to fault rupture, ground shaking and liquefaction susceptibility across the country. The research will also be extended to assess the impact of overtopping or the mechanical failure of stopbanks on populations, housing and critical infrastructure (e.g. roads, rail, electrical substations and essential community facilities), informing flood risk and asset management activities.

Keywords: levee, stopbank, dike, flood embankment, flooding, asset, networks, flood risk management, critical infrastructure, disaster risk reduction.

1 INTRODUCTION

New Zealand is a developed island country in the southwestern Pacific Ocean with a population of nearly five million people (Statistics New Zealand 2018). Flooding is New Zealand’s most frequent natural hazard and responsible for the highest number of declared civil defence emergencies. Weather is the largest contributing factor to flood risk, with development and population growth on flood plains, and land use in upper catchments being other important factors (MfE 2008). On average a major freshwater flood occurs every eight months across the country (MfE 2008, Brennan 2015). However, the severity and frequency of such events is increasing in some areas following the removal of indigenous forest cover in upper catchments (Belt et al. 2013), and due to growing populations and new infrastructure development on floodplains (MfE 2004); over one hundred towns and cities are located on flood plains in New Zealand (MfE 2008). Furthermore, climate change and more frequent extreme rainfall episodes are also increasing the severity and frequency of flood events in many areas of the country (MfE 2004, NZCCO 2004, MfE 2008).

Flooding is also one of New Zealand's most costly natural hazards; insurance industry payments for flood damage averaged NZ$ 17 million per year between 1976 and 2004 (McSaveney 2006). Since then, a number of high profile flood events have occurred, including:

- **February 2004** – Intense rainfall caused many rivers to breach their banks. The resulting major flooding impacted unprotected farmland, homes and businesses in the Bay of Plenty, Manawatu-Wanganui and Marlborough regions, with major regional social, economic and environmental disruption, requiring substantial relief from central government (MfE 2008). Catastrophic channel changes and erosion was exacerbated by human activity within the catchments (Fuller 2005). The storms caused an estimated NZ$ 400 million in damage, including NZ$ 112 million in insurance payouts (McSaveney 2017).
- **July 2004** – The eastern Bay of Plenty incurred severe flooding from prolonged and intense rainfall. Water had to be released into the Rangitāiki River to prevent failure of the Matahina Dam, which led to a breach of stopbanks and further flooding of properties and farmland downstream (McSaveney 2017). The Insurance Council of New Zealand estimated insurance payouts of around NZ$ 18 million (ICNZ 2018).
- **January 2011** – Severe flooding occurred in the Upper North Island of New Zealand including Auckland and Waikato as a result of king tides and a following period of heavy rain. There was damage to properties and critical infrastructure in the Auckland region with the king tides breaching sea defences in various locations (Blake 2012). The insured economic loss from the separate coastal and fluvial flood events was around NZ$ 7 and 20 million respectively (Gillies 2011, Blake 2012, ICNZ 2018).
- **April 2017** – Remnants of two tropical cyclones (Debbie and Cook) passed over New Zealand within a week of each other. Resulting flooding affected many areas along the North Island east coast, and a section of river stopbank at Edgecumbe gave way, forcing the evacuation of around 2,000 people from the town and leading to community concerns about the level of flood protection offered (McSaveney 2017, Stevenson and Elliott 2017). Insured loss from extreme weather events in 2017 (primarily flooding) exceeded NZ$ 150 million (ICNZ 2018).

Central government emergency management policy in New Zealand is that "local risks are a local responsibility" (National CDEM Plan Order 2005). As such, central government's role in flood risk management is often recovery focused, with local, regional, city and district councils largely responsible for the daily management activities along with communities (MfE 2008).

Numerous measures can protect against flooding including structural ('hard') and non-structural ('soft') engineering approaches, meteorological and hydrological forecasting, and emergency management and insurance planning. Stopbanks[1] (considered synonymous with the internationally used terms; levees, dikes and flood embankments) currently provide a critical role in flood protection in all regions of New Zealand. Finance for stopbank construction and maintenance is often allocated to individual projects from councils, rather than from a single flood protection budget (Brennan 2015). As a result, many inconsistencies in stopbank construction and maintenance exist between regions.

Recent flood events have demonstrated the importance of stopbanks as a flood protection measure in New Zealand, with breaches or failures of the structures highlighting serious life safety and critical infrastructure impact considerations. For example, a review of actions taken in the response to the April 2017 flooding in Whakatāne recommended that the potential breach of stopbanks should be considered in the district council's flood response plan as a matter of urgency (Kestrel Group Ltd. 2017). Additionally, the 2010-11 Canterbury Earthquake Sequence and November 2016 Kaikōura earthquake have demonstrated that vulnerabilities to stopbanks exist from seismic hazards (Green et al. 2011, Nobes et al. 2015, Marlborough CDEM 2016, Ian Heslop pers comm 06 August 2018).

To our knowledge, there has been no previous nationwide inventory of stopbanks, likely in part due

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[1] We note a lack of clarity on the definition of a stopbank in New Zealand legislation. For the purpose of this research, we adopt the definition of a stopbank from the International Levee Handbook (CIRIA 2013) - that is *"a raised, predominantly earth structure with the primary objective of providing protection against fluvial and coastal flood events along coasts, rivers and artificial waterways that are not reshaped under normal conditions by the action of waves and currents"* (CIRIA 2013). A similar definition is used by Land Information New Zealand, although there is no specific mention of artificial waterways in this case (LINZ 2018).

to the variability and lack of standardised approaches for their management across the country. These factors make comparative studies challenging. There are many unknowns associated with stopbank assets including their:

- Physical location
- Dimensions and batter geometry (length, width, height)
- Age and any degradation over time
- Construction type
- Foundation material and geology
- Design detailing (e.g. earth zoning and/or reinforcement details including rip-rap, geosynthetics, armour)
- Intended purpose (i.e. protection from fluvial, coastal and/or other flood types)
- Design flood and seismic capacity (if applicable).

In addition to these attributes, there are unknowns around exposure – both the exposure of populations and infrastructure to any stopbank breach or failure, and the exposure of the stopbanks themselves to other natural hazard events (besides flooding), including earthquake fault rupture and liquefaction, landslides, and tsunami inundation. Addressing these unknowns will allow for improvements in stopbank flood protection and wider flood risk management and resilience improvement activities across the country. A recent (June 2018) proposal by the Levee Committee of the International Commission on Large Dams (ICOLD – of which New Zealand is a member) to compile a technical report illustrating the similarities and differences between dams and levees introduces further urgency to address existing knowledge gaps.

In this paper, we first discuss the approaches and data sources used to build an initial overview of the geospatial distribution of New Zealand's stopbank network (termed New Zealand Inventory of Stopbanks – NZIS), which includes existing information on physical and engineering characteristics (Section 2). In Section 3, we provide a summary and key statistics on the gathered information in the NZIS, which includes example maps. Then we examine and illustrate some of the challenges and uncertainties associated with the NZIS compilation, and discuss opportunities for refinement and future work (Section 4). Finally, we conclude with a summary of key findings and recommendations (Section 5).

2 APPROACH AND DATA SOURCES

Through collaboration with council river managers, we sought to aggregate existing stopbank data from all regional councils and unitary authorities of New Zealand – sixteen groups in total excluding Chatham Islands Council (see Internal Affairs 2011) into the standardised NZIS database. All sixteen regional councils and unitary authorities were approached directly about the project, primarily through meeting with the council River Managers' Forum in October 2017. Where individual councils were not represented at the Forum meeting, the relevant council river manager was contacted by email, phone, or in person. In addition, we looked to obtain stopbank information from the publically available Land Information New Zealand (LINZ) data (LINZ 2011), and from websites of councils and other organisations using APIs (Application Programming Interfaces). Some contextual information was sought from supporting documents and reports.

Each dataset was checked and processed to ascertain the existing 'state of play' on stopbank attributes associated with physical, engineering and flood risk management characteristics. Data checking and processing consisted of:

- Assigning an object identifier to each stopbank feature, whilst maintaining the details assigned by the original data creator;
- Assessing the datasets for different attributes (i.e. the 'unknowns' listed in Section 1);
- Allocating single terms to individual stopbank features (sometimes previously given different names by different bodies);
- Consideration of the age of the data obtained.

To eliminate duplicate and overlapping data, we prioritised the regional council and unitary authority data. This is because a degree of expert judgement from infrastructure managers who are familiar with the local stopbank network, and sometimes field site visits, are often used in the compilation of such datasets, adding a degree of quality assurance.

3 NEW ZEALAND INVENTORY OF STOPBANKS (NZIS)

Version 1.0 of the NZIS (termed NZIS v1.0 from herein) comprises of 5,978 records[2] with a total length of 6,700 km, which includes duplicated and overlapping data.

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[2] The number of records should be treated with caution due to differences in stopbank classification techniques between individual regional councils and unitary authorities. For example, one council may consider an entire stopbank length as one record, whereas another council may break this stopbank into sections with multiple records.

Table 1 shows the total stopbank length within each region (obtained from the respective regional councils or unitary authorities and LINZ) and approximate percentage of stopbanks by region.

Table 1. Stopbank length per region and approximate percentage of stopbanks by region (using the highest values from the councils / authorities or LINZ).

Region	**Stopbanks from council / authority (km)**	**Stopbanks from LINZ (km)**	**Approx stopbank length by region (%)**
Auckland	0	94.65	2.1
Bay of Plenty	0	229.68	5.1
Canterbury	674.77	499.99	15.1
Gisborne	74.95	65.09	1.7
Hawkes Bay	256.70	184.50	5.7
Manawatu-Wanganui	507.59	322.35	11.3
Marlborough	208.15	185.17	4.7
Nelson	20.73	0	0.5
Northland	86.41	241.46	5.4
Otago	220.89	162.55	4.9
Southland	904.92	361.96	20.2
Taranaki	4.92	0.68	0.1
Tasman	51.17	42.52	1.1
Waikato	579.11	508.01	12.9
Wellington	280.41	111.04	6.3
West Coast	0	123.61	2.8
TOTAL	**3,870.73**	**3,133.25**	100

There were difficulties obtaining data from Auckland Council, and Bay of Plenty and West Coast Regional Councils and only LINZ stopbank data is used for these council areas for the purpose of NZIS v1.0. Data provided by all thirteen of the other regional councils and unitary authorities considered in this study is used alongside LINZ data for the compilation of NZIS v1.0.

When compiling NZIS v1.0, the only cases where ‘clashes’ in stopbank features occurred arose as a result of overlaps between the LINZ dataset and data from each individual regional council or unitary authority (see Section 4.1). Sometimes, the two geospatial datasets directly overlap one another. However, often they do not directly align, despite clearly being for the same stopbank feature. The relative contribution of each data source to NZIS v1.0, including the overlapping data (where there are two data sources for the same features), is shown in Figure 1. Data from LINZ is the most frequently occurring in NZIS v1.0.

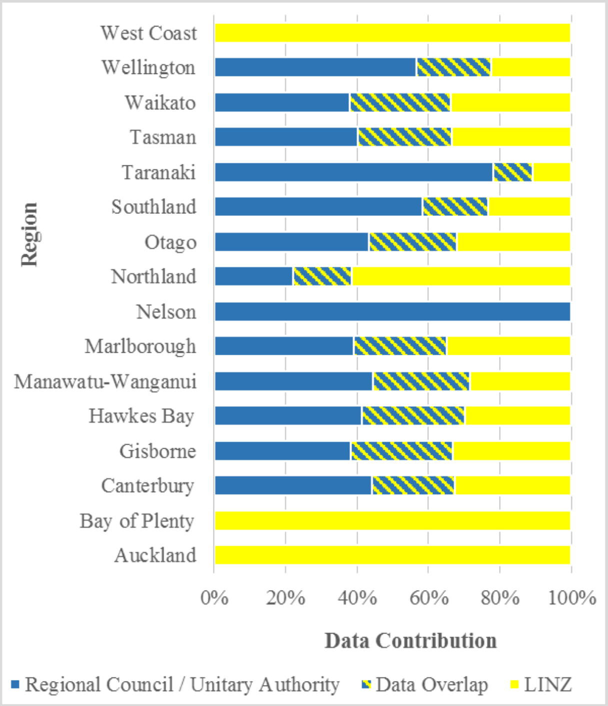

Fig. 1. Relative contribution of each data source to NZIS v1.0.

After the data checking and prioritisation process, which removes multiple cases of the same stopbank, the <u>total length of stopbanks in NZIS v1.0 is calculated at 4920.96 km</u>. These stopbank features will be considered for further analysis (Section 4.2) and are displayed geospatially in Figures 2a and 2b.

Due to inconsistencies in the source data between individual regional councils and unitary authorities, there is currently limited information on physical, engineering and flood risk management attributes nationwide. Attributes relating to the height and width are known for 19 and 25% of all records respectively in NZIS v1.0. Information on stopbank age only exists for some of the features in four of the sixteen regions in NZIS v1.0. Details on stopbank construction material and design flow is even more limited, with records for these attributes in only one region. We have not come across any information on the type of flooding which stopbank features are designed for (e.g. fluvial, tidal, artificial waterways) or specifics on stopbank types (e.g. flood retention structures, sea walls, riverine structures) within the datasets obtained to date.

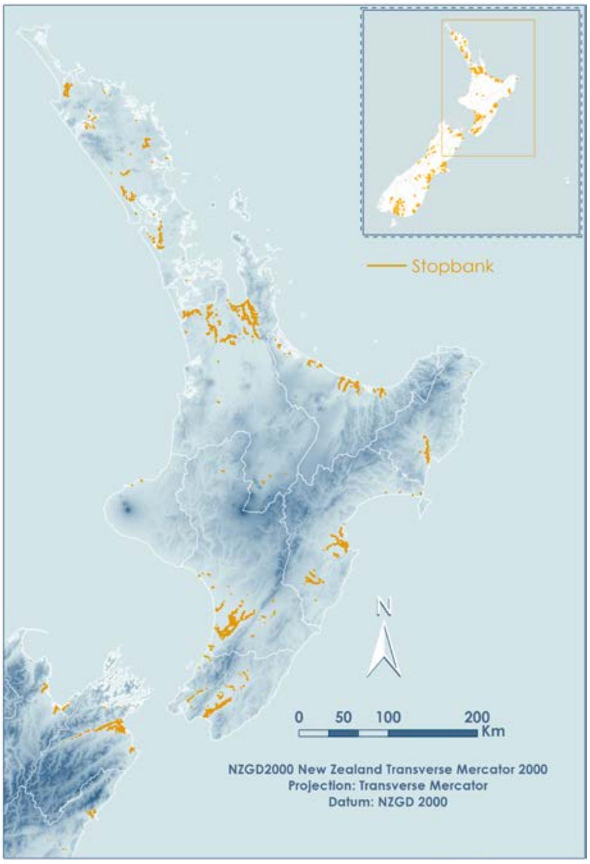

Fig. 2a. Stopbanks in the North Island of New Zealand.

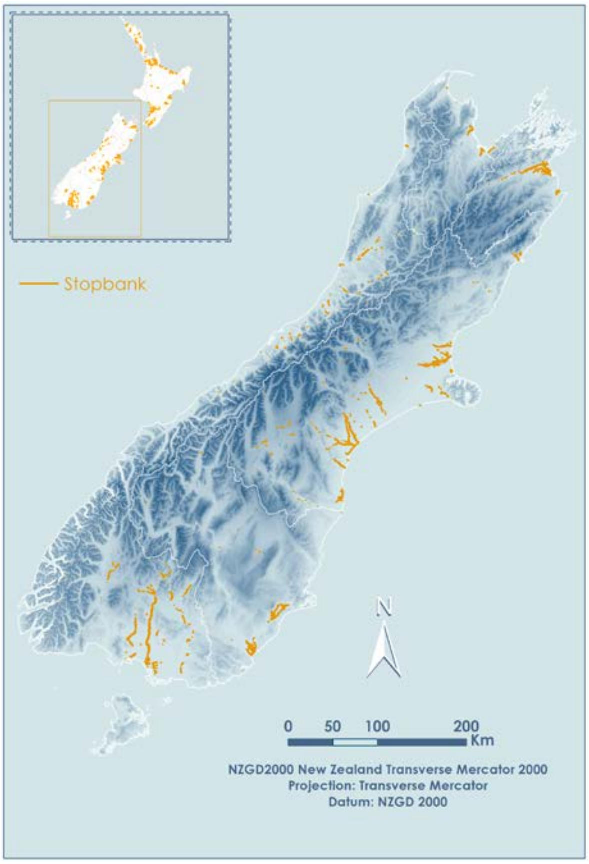

Fig. 2b. Stopbanks in the South Island of New Zealand.

4 DISCUSSION

The approach taken to compile the first nationwide standardised inventory of stopbanks in New Zealand (NZIS v1.0) has been successful in that it aggregates existing geospatial information held by various bodies across the country. However, we stress that there are many opportunities for improvements in subsequent versions of NZIS. This section summarises the key sources of uncertainty in NZIS v1.0 and challenges encountered in its compilation, and potential future work.

4.1 Uncertainties and challenges

There are three key sources of potential uncertainty that we identify in NZIS v1.0:

1. **Completeness** – due to the inconsistencies in collecting stopbank data nationwide, some stopbank records likely remain incomplete. Additionally, some stopbanks are privately-owned, and will remain challenging for councils to document;
2. **Quality** – Some errors were identified and corrected in the datasets obtained such as order-of-magnitude discrepancies. It is possible that some errors were missed during our data checking and processing. Furthermore, there is uncertainty related to the relevance of some data to current time (i.e. changes to stopbanks and their attributes may have occurred since the creation date of the original data);
3. **Terminology** – some uncertainties arise from missing metadata and inconsistencies in the terminology used by different regional councils and unitary authorities for the same stopbank attributes. Best judgement was used to adjust terminology and achieve consistency in NZIS v1.0, although it is possible that some terms were misinterpreted.

We consider the overall uncertainty to be relatively minor and not to substantially affect the database and its intended uses. However, these inconsistencies should be addressed in future cataloguing to improve data quality.

Additional uncertainties in NZIS v1.0 likely result from the processing and necessary modification of some data to achieve a standardised database. Some of these are a result of the following challenges encountered, and adopted adjustments made, during the compilation of the database:

- **Duplicates and overlaps** occur when there is multiple data for the same stopbank feature. For example, we found that parts of stopbanks did not align when it was evident that they represented the same feature. In some cases misalignment of parts of stopbank features extended to ~50m. Other challenges arose from stopbank features crossing, overlapping and/or intersecting one another. To account for these discrepancies, a buffer distance of 35m was used to identify all stopbanks with potential duplicates or overlaps from multiple data sources – i.e. LINZ data and regional council / unitary authority data for NZIS v1.0 (Figure 3). Then a process involving comparison to satellite imagery and prioritisation of features containing greater geospatial information was implemented (Figure 3).

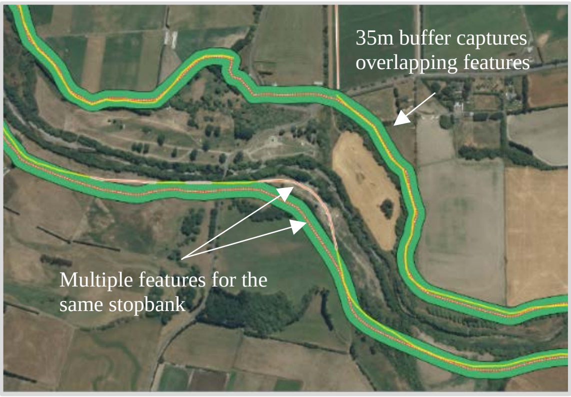

Fig. 3. Example of duplicated and overlapping stopbank features.

- **Regional council areas** (sourced from StatsNZ 2015) sometimes do not cover stopbanks, particularly for features near estuaries and large rivers. A tolerance level of 10 m was thus applied to the boundaries of these areas to ensure that every stopbank was appropriately matched to the relevant area.
- **Conversions** were required due to differences in geospatial data formats in the original source information. This was to achieve LineStrings[3] for stopbanks nationwide in the New Zealand Transverse Mercator 2000 coordinate system. Figure 4 shows an example where such a conversion was required at the intersection of two stopbanks; in this case the stopbanks were represented as polygons in the source data obtained from a regional council. A conversion of polygons to rasters and then centerlines means that there are four resulting LineStrings for the two stopbank features (Figure 4). Conversions to LineStrings were also required when source data was provided in point format. In this case, attribute data such as the asset name and corresponding riverbank were used to create interpolations between grouped points.

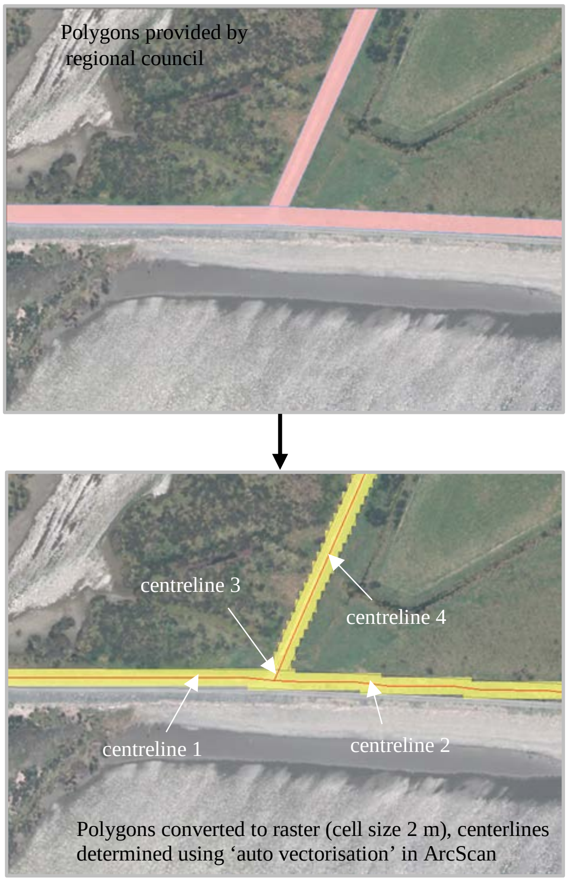

Fig. 4. Example of a conversion from a polygon to centrelines.

- **Retention of existing segmentation detail** occurred where possible. Some stopbanks are subdivided into segments in the original source data, when others are not. With the exception of the conversion of point data into LineStrings (with segments based on existing identifiers), all segment details have been retained in NZIS v1.0 to avoid the loss of any attribute data that may be locally useful.
- **Generalisation** was required in a few cases where detailed geospatial data was provided for specific stopbank features (e.g. stopbank toes, stopbank tops, gabions, concrete walls). Where this occurred a centerline for the stopbank was created. A generalisation step was also implemented when multi string lines existed (creating a single line string instead).

4.2 Future work

We recommend that all projects involving NZIS v1.0 and future work to revise this database should consider the uncertainties outlined above and address

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[3] A LineString is a one-dimensional object representing a sequence of points and the line segments connecting them.

current inconsistencies where possible to improve data quality. Data quality will also be improved as further stopbank information is collected, either from existing data held by organisations or through field studies and remote sensing techniques. We note that some detailed physical stopbank attribute information has already been provided but, as it currently lacks geospatial reference data, has not been added to NZIS v1.0. Furthermore, it is expected that city councils may hold additional stopbank information, which could supplement the information already retrieved from regional councils and unitary authorities. In addition to obtaining new physical attributes for stopbanks, we suggest that upcoming revisions to NZIS focus on filling empty attribute fields associated with engineering characteristics, such as stopbank construction type, foundation materials and age. Further attributes could be added to NZIS as information becomes available. For example, there is currently no information catalogued on stopbank cover type, and the reliability or useful lifespan of stopbank features – all attributes which may assist flood risk management and infrastructure investment planning.

It is anticipated that the appropriate representation of other geographic features (including surface geology, river types and river order) will assist further research; much of this information can be gleaned from existing records such as the source data used for the compilation of the River Environment Classification (Snelder et al. 2010).

To assist flood risk and emergency management planning, hydrological and hydrodynamic flood modelling to assess the consequences of stopbank breaches or failure is recommended. This should include loss calculations and impact assessments for populations, agricultural land and other critical infrastructure networks (e.g. roads, electricity, waste water treatment works).

Other work includes exposure assessments of stopbanks captured in NZIS v1.0 to other natural hazards (besides flooding); this includes investigations into the susceptibility of the stopbank network to rupture from active faults (GNS Science 2018) and other seismic hazards (as modelled by QuakeCoRE).

5 CONCLUSION

Geospatial stopbank data has been sourced from LINZ and thirteen of the sixteen regional councils and unitary authorities in the North and South Islands of New Zealand. Following data checking and processing, the data has been aggregated into a standardised nationwide database (NZIS v1.0), which consists of 4920.96 km of stopbanks.

The sources of uncertainty in NZIS v1.0, are largely associated with completeness, quality and terminology, and often result from inconsistencies between stopbank feature records in the different source data. We have attempted to resolve many of these issues, although new data and future revisions to NZIS should address these further. NZIS v1.0 includes attribute fields covering physical, engineering and flood risk management characteristics for stopbanks. However, information on these characteristics is currently limited and opportunities exist to add further attribute fields as more data is sourced.

NZIS v1.0 is an important first step in achieving an improved understanding of the role of stopbanks for flood protection in New Zealand. It will also assist with wider flood risk and emergency management planning, natural hazard exposure assessments, infrastructure investment decisions, and resilience activities across the country.

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REFERENCES

Belt, M., Bowen, T., Slee, K., Forgie, V. (2013): Flood protection: highlighting an investment trap between built and natural capital. *Journal of the American Water Resources Association,* 49:3, pp.681-692.

Blake, D.M. (2012): Flood report for January 2011, Auckland. *Auckland Civil Defence and Emergency Management Group,* Auckland, New Zealand.

Brennan, S. (2015): Local authority liability for flooding: where should loss fall? Victoria University, Wellington, New Zealand. http://www.nzlii.org/nz/journals/VUWLawRw/2015/6.pdf, Accessed 04 August 2018.

CIRIA. (2013): The International Levee Handbook (C731). *Construction Industry Research and Information Association,* https://www.ciria.org/Resources/Free_publications/ILH.aspx, Accessed 07 August 2018.

Fuller, I.C. (2005): February floods in the lower North Island, 2004: catastrophe – causes and consequences. *New Zealand Geographer*, 61, pp.40-50.

Gillies, A. (2011): Cyclone leaves $25m bill. http://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=10707560, Accessed 01 December 2011.

GNS Science. (2018): New Zealand active faults database. https://data.gns.cri.nz/af/, Accessed 16 August 2018.

Green, R.A., Allen, J., Wotherspoon, L., Cubrinovski, M., Bradley, B., Bradshaw, A., Cox, B., Algie, T. (2011): Performance of levees (stopbanks) during the 4 September 2010 M*w* 6.2 Christchurch, New Zealand, Earthquakes. *Seismological Research Letters*, 82:6, November/December 2011.

ICNZ. (2018): Previous events: cost of natural disasters. *Insurance Council of New Zealand*, Wellington, New Zealand. https://www.icnz.org.nz/natural-disasters/previous-events/, Accessed 05 August 2018.

Internal Affairs. (2011): Council profiles by type. Department of Internal Affairs. http://www.localcouncils.govt.nz/lgip.nsf/wpg_url/Profiles-Councils-by-Type-Index, Accessed 15 August 2018.

Kestrel Group Ltd. (2017): Review of the actions taken by the Whakatāne District Council in the response and early recovery phases of the district's flooding events of April 2017: summary report. *Kestrel Group Ltd.* Wellington. https://www.whakatane.govt.nz/sites/www.whakatane.govt.nz/files/documents/summary_of_kestrel_report_on_whakatane_district_council_april_2017_flood_response.pdf, Accessed 07 August 2018.

LINZ. (2011): NZ embankment centerlines (Topo 1:50k). *Land Information New Zealand: LINZ Data Service.* https://data.linz.govt.nz/layer/50266-nz-embankment-centrelines-topo-150k/, Accessed 14 August 2018.

LINZ. (2018): Topographic data dictionary: NZ Topo – object class embankment_cl, Land Information New Zealand. http://apps.linz.govt.nz/topo-data-dictionary/index.aspx?page=class-embankment_cl, Accessed 09 August 2018.

Marlborough CDEM. (2016): Stopbank information: Spring Creek, Grovetown, Lower Diversion Stopbanks. *Marlborough District Council,* New Zealand. https://www.marlborough.govt.nz/civil-defence-emergency-management/emergencies-in-marlborough/earthquake-14-november-2016/stopbank-information, Accessed 07 August 2018.

McSaveney, E. (2006a): Floods – New Zealand's number one hazard. *Te Ara – the Encyclopedia of New Zealand.* https://teara.govt.nz/en/floods/page-1, Accessed 07 August 2018.

McSaveney, E. (2017): Floods: 21st century floods. *Te Ara – the Encyclopedia of New Zealand.* https://teara.govt.nz/en/floods/page-5, Accessed 07 August 2018.

MfE. (2008): Meeting the challenges of future flooding in New Zealand. *Ministry for the Environment and the Flood Risk Management and River Control Review Steering Group,* Wellington, New Zealand. http://www.mfe.govt.nz/sites/default/files/meeting-challenges-of-future-flooding-in-nz.pdf, Accessed 05 August 2018.

National CDEM Plan Order. (2005): Part 10, 89(2), National Civil Defence and Emergency Management Plan Order 2005, Wellington, New Zealand.

Nobes, D.C., James, M., Kim, T.H., Pullman, C., Vollebregt. (2015): Geophysical imaging of post-earthquake structural integrity of flood-control stopbanks, Christchurch, New Zealand. *Journal of Geophysical Engineering,* 12, pp.857-865.

NZCCO. (2004): Economic impacts on New Zealand of climate change-related extreme events: focus on freshwater floods. *New Zealand Climate Change Office,* Wellington, New Zealand. https://www.mfe.govt.nz/sites/default/files/economic-impacts-extreme-events-jul04.pdf, Accessed 07 August 2018.

Snelder, T., Biggs, B., Weatherhead, M. (2010): New Zealand River Environment Classification User Guide. Ministry for the Environment, NIWA, New Zealand. https://www.niwa.co.nz/freshwater-and-estuaries/management-tools/river-environment-classification-0, Accessed 15 August 2018.

StatsNZ. (2015): Datafinder StatsNZ: Regional council 2015_V1_00 Clipped. https://datafinder.stats.govt.nz/layer/87753-regional-council-2015-v1-00-clipped/metadata/, Accessed 17 August 2018.

StatsNZ. (2018): Population. *StatsNZ,* Wellington, New Zealand. https://www.stats.govt.nz/topics/population, Accessed 03 August 2018.

Stevenson, C., Elliott, J. (2017): Edgecumbe community flood response inquiry: a report to the Whakatane District Council and Bay of Plenty Regional Council. https://www.whakatane.govt.nz/sites/www.whakatane.govt.nz/files/documents/edgecumbe_community_flood_inquiry_-_wdc_responses_june_2017_0.pdf, Accessed 06 August 2018.