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Risk assessment for historic coastal landfills in the Waikato region

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Prepared by:
Jessica Green, Michelle Begbie and Stephen Hunt

For:
Waikato Regional Council
Private Bag 3038
Waikato Mail Centre
HAMILTON 3240

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Peer reviewed by:
Rob Bell and Stephen Gardner | Date | July 2021

Approved for release by:
Mike Scarsbrook | Date | April 2022

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Abstract

Landfills are a widespread hazard. They can cause issues while they are operational, but also create ongoing potential hazards once they have closed. Historic landfills, those that operated prior to regulation and need for assessment of effects, pose the greatest uncertainty on hazard-related impacts (i.e., risk). Depending on the environment where these historic landfills were placed, they can cause significant human health and environmental impacts.

This report has designed a framework for relative risk assessment of historic coastal landfills in an accessible way. In this study, historic landfills are classified as coastal if they are within 200 m of the shoreline, either on the open coast or inside estuaries. Using national level datasets with localised scale where possible, parameters are defined and assigned severity scores ranging from one to five (least to highest risk, respectively). A likelihood index, consequence index, and overall risk score are generated by a summation and normalisation of parameter scores. A weighted risk score is also produced by weighting the likelihood index, given the risk can be minimised if a landfill breach can be avoided in the first place.

With the available data and records at time of publishing, no known sites in the Waikato region pose an extreme and imminent risk. However, the awareness that this risk-screening method is not failsafe needs to be kept in mind. Unknown site characteristics stemming from incomplete or inaccurate records as well as the potential for the existence of unknown sites adds uncertainty to the model. Additionally, there are some sites that do pose a relative risk above the midway score, which will require attention from the relevant policy makers and stakeholders.

This report presents a model to consistently analyse and evaluate the relative risk posed by historic coastal landfills. The model was validated by the historic Kaiaua landfill, which was actively eroding into the Firth of Thames, being ranked as the highest relative risk (noting this landfill has now been remediated). In the Waikato region, there are over 200 other sites that will need to be assessed in the near future. The recommendation is to use this risk assessment framework and modify the parameters to evaluate the impacts of the historic riverine landfills as a next step.

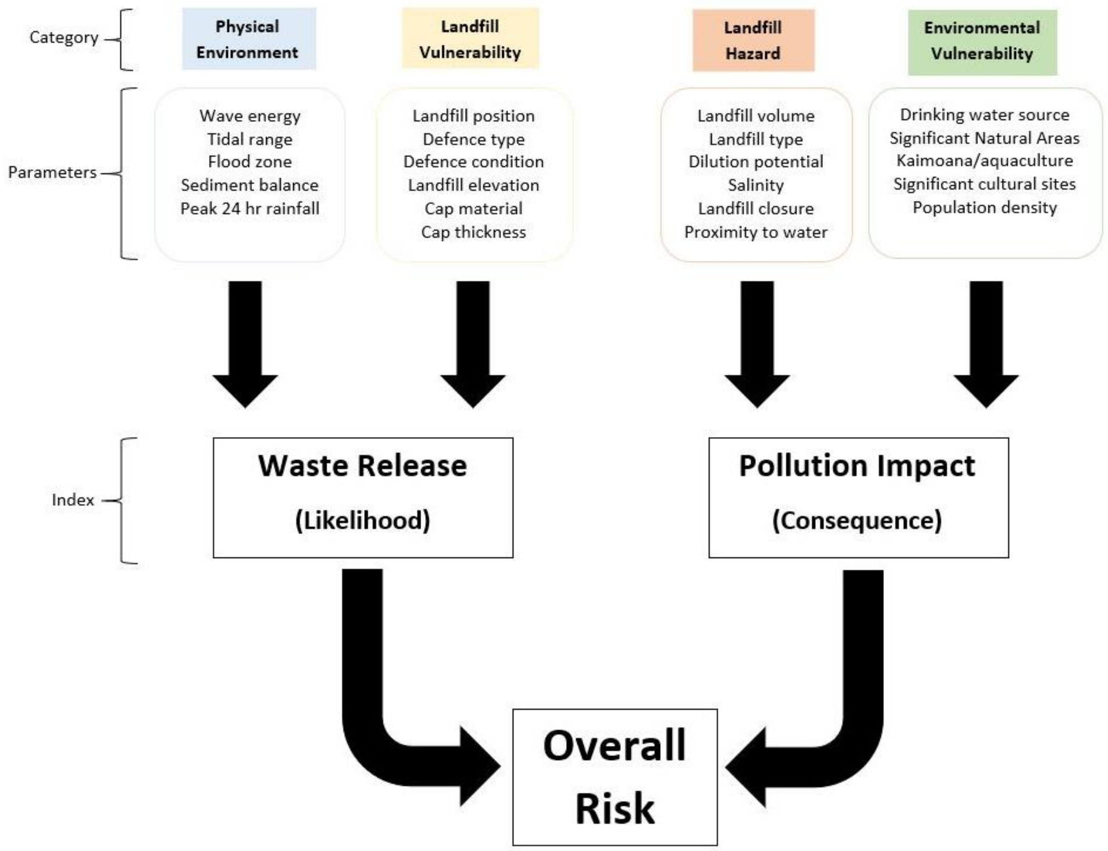
Executive Summary

Globally, prior to public health and environmental legislation, waste deposition sites operated with few regulations or restrictions. Historically, many landfills[1] were placed in locations that by today's standards would be considered dangerous. The lack of regulation and assessments of effects, coupled with the dubious placement near waterways, means many historic landfills have the potential to pose significant and ongoing risks such as leaching contaminants into their surroundings which can potentially impact human and environmental health. These risks will only be exacerbated by climate change and rising sea level.

For the purposes of this report, a landfill has been defined as any site classified as "G3" (landfill sites) on the Hazardous Activities and Industries List (Ministry for the Environment, 2011) that is no longer active. Using this definition, sites such as small-scale farm tip sites, middens, and current operational landfills. Cleanfill sites are also excluded from analysis in this study as by definition cleanfill "will have no adverse effect on people or the environment" (Ministry for the Environment, 2021).

Within the Waikato region there are more than 200 historic landfill sites, with many located near a body of water. The proximity to water increases the risk of waste being released due to the dynamic nature of rivers and the coastline. Different processes will influence the risk between coastal and riverine sites. For this reason, this study focusses only on the historic coastal sites, with the goal of assessing riverine sites later. Coastal sites are defined by this study as those located within 200 m of the coastline.

To address the potential risk posed by these historic coastal sites, a risk assessment model has been developed as a screening exercise (see diagram below) to provide a relative ranking of sites most at risk.



[1] In this report, the term 'landfill' means a site that has historically been designated for waste disposal, usually for use by a community. They are unlikely to include farm landfills (for which records are poor) or middens (which largely contained organic or cleanfill materials) and our intention is not to include modern cleanfill sites that do not include refuse.

A common description of risk is a combination of the hazard, likelihood of occurrence, and the consequences of a particular event. The hazard events of concern in a coastal environment are erosion and inundation. The potential for waste to be released through these mechanisms is the likelihood of the event. The consequence of an event is the potential pollution impact that is influenced by factors such as the type and size of landfill. These factors can be divided further into two categories each. The physical coastal environment and the vulnerability of the landfill describe the waste-release index; the landfill hazard and the vulnerability of the receiving environment describe the pollution impact index.

The parameters for each category are assigned a severity score from one to five. Five represents the highest level of severity of that parameter, where one is the lowest. The severity scores for each parameter are summed, and then normalised to generate the respective indices on a relative scale from zero to one. The indices are then averaged to generate an overall risk score.

The results of this relative risk assessment show that there are no existing sites within the Waikato Region that pose an extreme and imminent risk, now that the Kaiaua landfill has been remediated. However, there are some sites that warrant a more detailed investigation of risk. Though the model has returned a somewhat narrow range of overall risk scores, validation of the model shows its capability to reflect the highest risk sites in the final ranking list.

The purpose of this study is to rank the existing historic coastal landfill sites according to the potential risk they pose. It is primarily to inform decisions and help provide clarity of the priority sites for policy makers, stakeholders and iwi/hapū. This study is not intended to provide advice on management or remediation actions. To determine management options, in-depth site investigations will need to be completed followed by evaluation of options using cost-benefit or other economic analysis, to reveal opportunities and challenges of the various remediation options, in collaboration with stakeholders and iwi/hapū.

The authors note that collaboration and co-design with local iwi/hapū is a critical element to coastal management in New Zealand. However, while enquiries to iwi/hapū were made, the time frames and resources available to this project did not facilitate active iwi/hapū engagement. The authors acknowledge that this is a shortcoming of this work, and signal that any detailed analysis and consideration of next steps will need to include consultation with, and guidance from, iwi and hapū, and that these phases should be scoped with adequate time and resources to enable this.

1 Introduction

The practice of depositing waste onto and into land is long-standing and ubiquitous. Middens, or historical waste deposition sites, have been found on every continent with human settlement (Stein, 1992). Typically, middens consist exclusively of organic material such as animal bones, shells, ash/charcoal and plant fibres (Heritage New Zealand, 2016). Often middens were located directly on coastlines, lakeshores, and riverbanks (Heritage New Zealand, 2016; Stein, 1992). Due to their age and contents, middens pose no risk to human health or the environment despite their placement in dynamic environments. However, with the increase in permanent settlements, the advent of manufacturing, large quantities of organic food waste, and the use of synthetic chemicals, middens have evolved into the modern practice of landfilling. Landfills are currently broadly defined in New Zealand as “facilities for the final controlled disposal of waste in or onto land” and are further categorised depending on the type of material they accept (Ministry for the Environment, 2021). Unlike middens, if not properly managed, landfills can pose significant human and environmental risk due to their size, contents, and exposure to natural hazards due to their location (Slack, et al., 2005; Baziene, et al., 2020; Jarup, et al., 2002).

Globally, prior to public health and environmental legislation, waste deposition sites operated with little to no regulation or assessments of cumulative effects. This means that waste of all types was indiscriminately buried or burned regardless of potential contamination or threat to human and environmental health (Louis, 2004). Historically, many landfills were placed in locations that by today’s standards would be considered incredibly dangerous. Riverbanks, coastlines, and stream gullies were popular places to place refuse in many countries (Brand, et al., 2018; Louis, 2004), which exposes them to natural hazards and ongoing climate change impacts. In this report, a historic landfill has been defined as any site classified as “G3” (landfill sites) on the Hazardous Activities and Industries List (Ministry for the Environment, 2011) that is no longer active. Using this definition, sites such as small-scale farm tip sites, middens, and current operational landfills are excluded. Cleanfill sites are also excluded from analysis in this study as by definition cleanfill material “will have no adverse effect on people or the environment” (Ministry for the Environment, 2021).

Unfortunately, New Zealand is no exception. Within the Waikato region there are more than 200 historic landfill[2] sites, with many located near a body of water. The proximity to water largely increases the risk of waste being released due to the dynamic nature of rivers and the shoreline with ongoing climate change and sea-level rise. These historic sites, though often largely unnoticed, can pose a large risk to human health and the environment. Though risk of exposure of these sites can occur through urban development and earthworks, there are controls to mitigate and manage those effects where uncontrolled exposure to natural hazards poses a more pertinent risk.

1.1 Out of Sight, Out of Mind?

Most of these historic sites have been covered for decades. Despite their innocuous appearance they can pose significant risk to present-day human and environmental health. The events in 2019 at Fox River dramatically demonstrate the contemporary impact these historic sites can have when exposed to natural hazards.

In March 2019, an extreme weather event hit the West Coast and caused immense flooding, erosion, and infrastructure damage. One of the major consequences of this event was the release of waste from a historic landfill that was on the bank of Fox River. The waste was carried by the river to the coastal environment were, due to infrastructure failures, volunteers had to

[2] In this report, the term ‘landfill’ means a site that has historically been designated for waste disposal, usually for use by a community. They are unlikely to include farm landfills (for which records are poor) or middens (which largely contained organic or cleanfill materials) and our intention is not to include modern cleanfill sites that do not include refuse.

be flown in by helicopter to clean up by hand. Extraordinary financial costs were associated with this clean-up effort, as well as the cost in time and damage to local relationships.

The event at Fox River markedly illustrates the importance of gathering information about any existing closed landfill. Ideally, all landfill sites would be located and directly remediated, however, time and resources are not infinite. Therefore, it is important to prioritise the known historic landfill sites according to the risk they pose to human health and the health of the environment.

1.2 Value

Though this issue has been caused by decisions and actions many decades prior, they have the potential to cause immediate risk now or emergent risks as climate-related hazards increase. These latent liabilities must be assessed for the potential impact they could have from now on. The purpose of this study is to produce a risk assessment methodology that can be successfully applied not only in the Waikato region, but to all historic coastal landfill sites across New Zealand. The outcome of this study is meant to inform the Waikato region's councils, public, and stakeholders on the relative risk associated with each known historic landfill site in the coastal environment.

We can never predict the future, especially with more uncertainty from a changing climate, but based on current information we can estimate the risk that each of these sites pose relative to each other. This relative risk assessment will provide guidance for stakeholders around which sites pose the highest level of risk from inundation and coastal erosion, and therefore which sites should be prioritised for further investigation or potential remediation. However, future uncertainty such as the likely increasing strength and frequency of weather events may also affect sites outside the top priority list.

2 General Risk Assessment

Risk assessment is a methodical way of identifying, analysing, and evaluating the uncertain danger or negative consequences posed by hazardous situations and how likely it might occur within a given planning timeframe (International Organization for Standardization (ISO), 2018). Risk assessments are utilised in numerous applications ranging from risk associated with natural hazards to financial risk when investing (Rausand, 2013). Risk is commonly described as the interaction between the likelihood of an event (or exposure to an event) and the consequence or impact if that event does occur.

Using the lens of historic coastal landfills, the likelihood is the probability of an erosion or inundation event occurring and the consequence is the level of impact that the event would have on present-day human health, cultural values, and the receiving environment.

2.1 Landfill Risk Assessment

Historic landfills are a global legacy issue – every country with permanent settlement has landfills in one form or another. As a result of the ubiquitous nature of the issue, there are many studies from various countries that address issues that these historic landfills present. Many studies have been done to investigate the impact of the landfills where they sit, such as their impact on groundwater, the surrounding soil, and potential emissions (Singh, et al., 2009; Green, et al., 2014; Laner, et al., 2011). An overwhelming theme with many of these studies is the focus on quantifying the impact these sites have on the environment in the present. However, with climate change and rising frequency of extreme weather events, it becomes increasingly imperative to estimate the potential future impact as well. The way to estimate the relativity of potential impacts associated with landfills is through risk assessment, noting the uncertainty of multiple possible futures and climate-related hazards depending on greenhouse gas emission and sea-level rise trajectories. This report focuses on present-day coastal risk exposure of landfills at or near shorelines to determine the priority for near-term risk reduction and remediation. However, over time, ongoing climate-change including sea-level rise, will progressively impact landfill sites further down the present-day priority risk ranking.

Due to the impact of the 2019 Fox River event, public interest has grown in New Zealand regarding the risk these historic sites pose to present-day human health and environmental standards. As such, a national effort was undertaken to develop a methodology that could help each region assess all landfill sites to determine which are likely to experience a waste release scenario. This initial model was released by Tonkin & Taylor Ltd in 2020 using datasets across three regions: Canterbury, Southland, and West Coast. This pilot study included information regarding coastal inundation, coastal erosion, river scour, and river and surface water flooding. The model developed in 2020 was utilised by this report as an exposure assessment for the Waikato region historic landfill sites.

3 Adapted Methods

At a broad scale, the Tonkin & Taylor (2020) methodology was useful in determining which sites are at risk of coastal (proximity to coastline) or riverine impacts (proximity to rivers). However, including both riverine and coastal impact factors in the same framework causes a loss of granularity. By aggregating the risk, the extreme values can become diluted and potentially missed (Singh, et al., 2009). Therefore, this study focusses solely on those sites at risk from coastal factors (erosion and inundation).

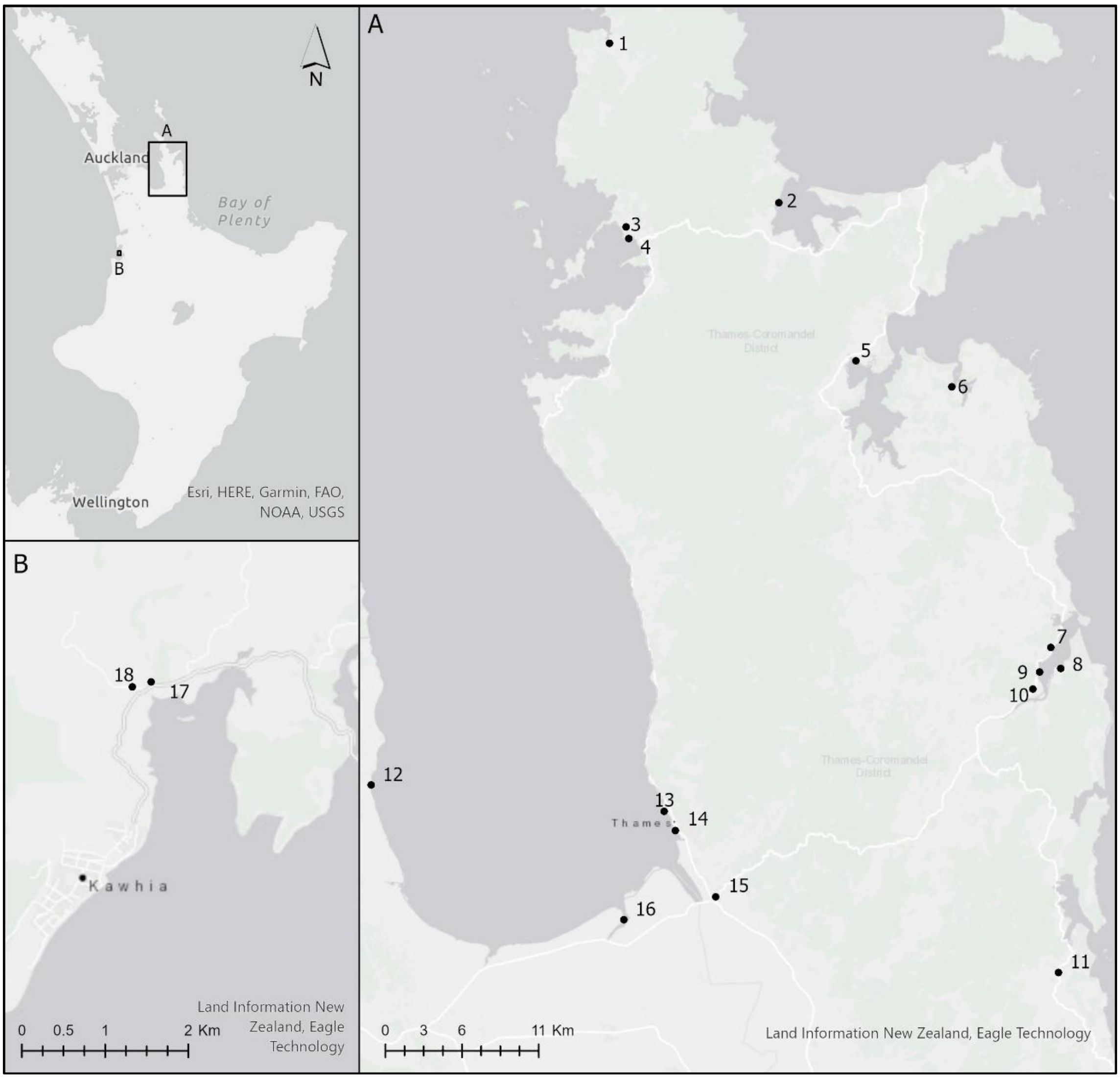


Figure 3.1 Map of study area and individual sites. A: Colville (1), Whangapoua (2), Hauraki Road (3), Wharf Road (4), Whitianga (5), Cooks Beach (6), Tairua Closed (7), Pauanui (8), Tairua Private Tip (9), Tanners Sawmill (10), Whangamata (11), Kaiaua (12), Thames Closed (13), Queen Street (14), Thames Timber Dump (15), Pipiroa (16) and B: Kawhia older (17) and newer (18).

From the initial exposure analysis, 26 sites within the Waikato region were identified by the Tonkin & Taylor (2020) model as potentially at risk due to their proximity to the coastline. This means that 26 sites classed as "G3 – Landfill sites" on the Hazardous Activities and Industries List (HAIL) that are no longer operational in Waikato Regional Council records were within 200 m of the shoreline. Upon further research the number of historic coastal landfills dropped to 18 (Figure 3.1). Some site locations were updated which placed them outside the coastal zone, where other sites were shown to be entered in error or were unable to be verified.

To better capture the risks specific to coastal landfills, a more detailed description of coastal risks unique to landfill sites was needed. English scientists Brand and Spencer (2018) created a risk assessment framework specifically for screening risks for historic coastal landfills. Their modular risk assessment methodology incorporates multiple physical aspects of a coastal environment beyond proximity to the shoreline. Additionally, their final calculations normalise category scores to avoid a "smoothing" effect from simple averaging. Their approach was used to inform risk assessment completed here.

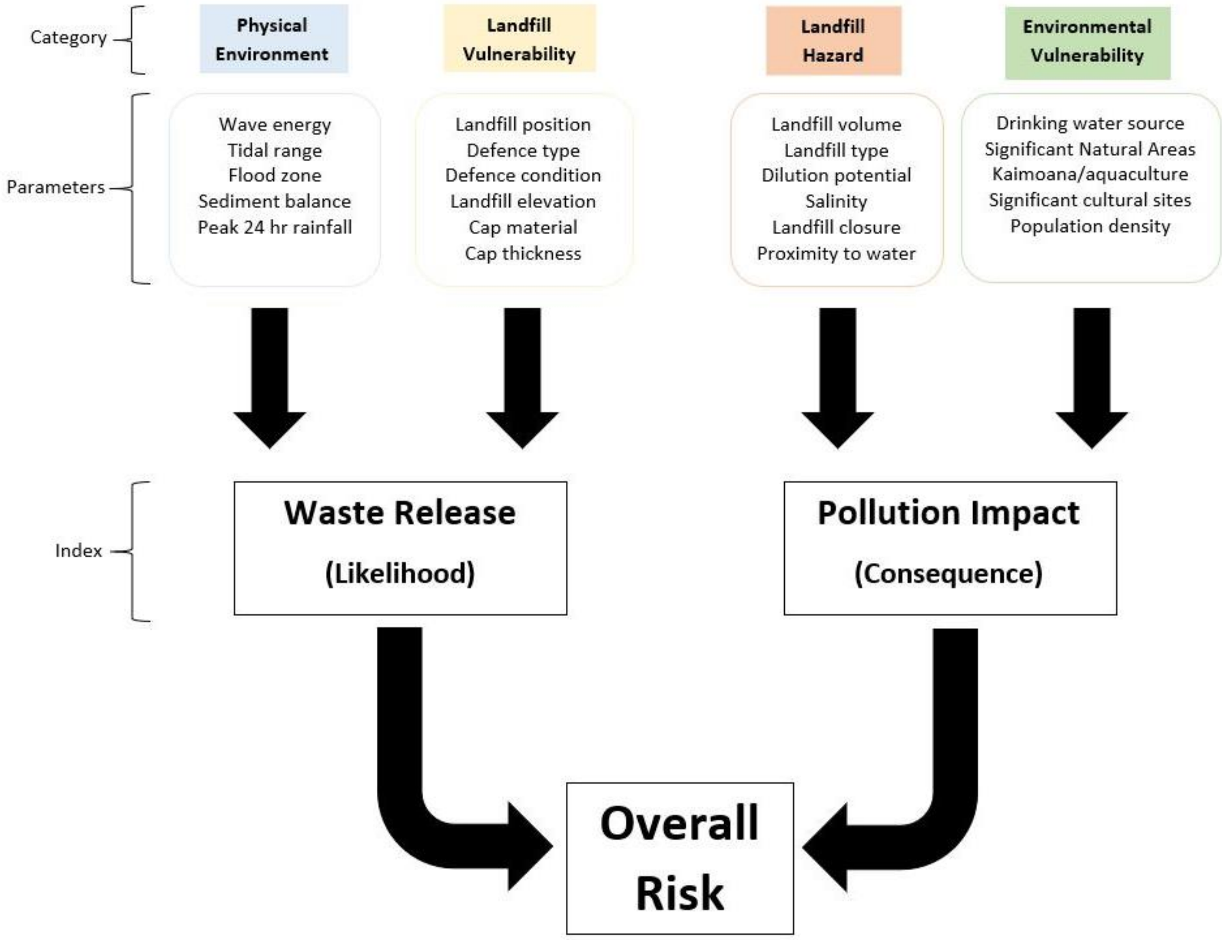


Figure 3.2 Schematic showing overall risk assessment framework with relevant terminology. Adapted from Brand & Spencer (2018).

The overall risk is a result of the likelihood and potential consequence of a given event. Pointed towards coastal landfills, the likelihood is the potential for waste to be released, and the consequence is the potential pollution impact. These indices can be divided further into two categories each. The physical coastal environment and the vulnerability of the landfill describe the waste release; the landfill hazard and the environmental vulnerability of the receiving area describe the pollution impact See Figure 3.22 for a graphical representation of the risk assessment framework.

The following sub-sections detail the selection of parameters chosen to describe each site with as accurately as possible, while using readily available data sources that other regions could also access. All GIS-based analysis was performed using ArcGIS Pro version 2.6.0 (Esri Inc., 2020).

3.1 Waste Release (Likelihood)

The waste release index describes the likelihood of the hazard occurring. In the scope of this study, this is the probability of coastal erosion or inundation impacting the historic coastal landfill sites. This index can be divided into two categories: the physical environment where the landfill sits, and the vulnerability or condition of the landfill.

3.1.1 Physical Environment

The parameters included in this category illustrate the potentially hazardous conditions to which a given historic landfill site is exposed. In this study, parameters are describing the coastal environment where the landfill is located. Parameters included in the physical environment category are wave energy, tidal range, flood zone, sediment balance, and maximum 24-hour rainfall.

Wave energy

The wave energy parameter is a description of the potential amount of force of the waves as they interact with the shore. The size of waves has a positive correlation with the amount of energy they contain. The strength of wind as well as the distance it can blow unobstructed across the sea's surface (fetch) determines wave size. The relative isolation of New Zealand means that fetch is effectively unlimited (Gorman, et al., 2003). The dominant wind directions in New Zealand are from the west and southwest, with the highest wind speeds also originating from those directions (Stephens & Gorman, 2006; MetOceanView, 2019). Accordingly, the largest mean significant wave heights are measured along the southern and western coastlines (MetOceanView, 2019; Stephens & Gorman, 2006).

In line with the national characteristics of wave climate, the highest energy waves in the Waikato region are found along the west coast. The east coast, by comparison, is a lower energy environment. Smaller mean significant wave heights are observed and modelled on the east coast, primarily due to its leeward shores (MetOceanView, 2019; Stephens & Gorman, 2006).

When moving away from the open coast and into estuaries, the wave energy becomes more complex to estimate. Study sites along estuaries were divided by their geomorphology, as described by Hume et al. (2016). A distiction was made between estuary types that generally experience wind wave generation and those that do not (see appendix

Table A.0.2).

Tidal Range

Tidal range is the difference in height between high tide and low tide levels. Here, the difference between tides has been measured during a spring tide (Hume, et al., 2016). Generally, tidal ranges are described as microtidal (<2m), mesotidal (2-4m), or macrotidal (>4m). As the greatest storm damage occurs when the storm surge coincides with high tide, microtidal environments have a higher probability of experiencing an erosion or inundation event (Stephens, et al., 2020) and are consequently assigned the highest severity score. In New Zealand tides are generally mesotidal, with the exception of the central eastern seaboard (Land Information New Zealand, 2021). The remaining severity score criteria reflects the narrower national tidal range with sites exhibiting a tidal range greater than 3.5 m assigned the minimum severity score.

Flooding Exposure

This parameter is the relationship between the landfill site and the flood risk maps generated by Waikato Regional Council. These maps are created on a regional scale. Though they should not be used for consenting or land use planning, when viewed at the recommended scale (1:50,000), the map provides a useful indication of flood risk for the landfill sites. The highest exposure is where sites are located within the flood zone. The lowest exposure is assigned to sites outside of the flood zone. Though a site may be protected by a flood defence, there is residual risk resulting from the chance of an asset failure. For this reason, a medium severity score is assigned to those sites within a protected flood zone.

Sediment Balance

The current state of the coastal environment is an important factor when determining risk. If a given section of coast is known to be eroding, an event capable of impacting the associated landfill site is more likely. Conversely, there is lower risk exposure where a shoreline is known to be accreting. The erosion/accretion value was determined by analysing the relevant historic shorelines based on historic aerial imagery (see appendix Table A.0.1).

Peak 24-hour Rainfall

In New Zealand, the most widespread form of erosion in New Zealand is shallow landslides triggered by rainfall events (Basher, 2013). Therefore, areas with higher rainfall rates tend to experience higher risk of erosion. Data gathered from The National Climate Database (NIWA, 2021) was used to find the maximum one-day rainfall (mm) at stations closest to each site (appendix Table A.0.3). The maximum value was selected from the most recent 5 years on record for each station. This time range was selected due to annual variability in rainfall and because some sites do not have measurements for the same time periods. The severity scores are based on the maximum 24-hour rainfall measurements as a percentage of national annual mean rainfalls (NIWA, 2010).

3.1.2 Landfill Vulnerability

The parameters in this category describe the overall siting and condition of each landfill. The condition of the landfill, including its location, determine the level of vulnerability to an erosion or inundation event. The vulnerability, or condition, of the landfill has a direct impact on the likelihood of waste being released. Parameters included in the landfill vulnerability category are landfill position, defence type and condition, landfill elevation, and cap material and thickness.

Landfill position

The landfill position is the distance from the landfill boundary to the coastline. The coastline along open coasts or estuaries, as used in this study, is based on the mean high-water springs mark. The proximity to the coastline is one of the single most important factors when assessing coastal risk. Logically, the closer a site is to the shoreline, the higher the chance of a coastal event impacting on the site.

Defence type

The presence of any type of coastal defence protecting the site will lessen the risk to the landfill. The material of the defence will have an impact on the degree of protection offered to the landfill. Hard defences will offer the highest level of protection to the immediate area, while soft defences offer the least. As any structures in the coastal environment should be consented, each region should have the capability to gather this data. In addition to consented structures, the Waikato Regional Council has a partial record of undocumented or informal structures in the coastal marine zone (Waikato Regional Council, 2006).

Soft Defences

The wave attenuation properties of mangroves are complex and there is no simple number to describe their buffering capacity (Zhang, et al., 2012; Alongi, 2008). Though there is some evidence to suggest wave attenuation at vegetation widths of 100 m, a conservative approach is taken in this study. Where present with a minimum width of 400 m, mangroves will be considered a soft defence in excellent condition. The wave attenuation properties of saltmarshes are generally stronger than those of mangroves of equal width (Shepard, et al., 2011; Zhang, et al., 2012). However, saltmarshes are difficult to classify, and the only suitable national dataset (Landcare Research New Zealand Ltd, 2020) does not classify areas of saltmarsh, but "herbaceous saline vegetation" instead. For this lack of specificity, saltmarshes will be included in the same "soft" defence criteria. So, if the combined width of mangroves and saltmarsh is greater than 400 m, it will be considered a soft defence in excellent condition. If the combined width of salt marsh and mangroves is between 100 m and 400 m, the defence condition is considered average. Any width under 100 m will not be considered as a defence.

Defence condition

In addition to the presence and material type of a defence, the condition of the defence is also important. A well-maintained structure will be more effective in redirecting wave energy than an old and neglected structure. The severity score criteria are defined to match the defence condition recorded in asset datasets held by Waikato Regional Council.

Landfill Elevation

The landfill elevation is the average elevation across the footprint of the landfill. Elevation, similar to landfill position, has a strong influence on the potential risk. Sites at a higher elevation will be less likely to experience inundation than lower elevation sites, with all else being equal. Though higher elevation sites can still experience erosion, the risk is lower than sites that are closer to sea level. From the landfill sites included in this analysis, none were located on a coastal cliff. However, adjustment to this parameter will need to be made if other regions find coastal cliff sites in order to account for a higher erosion risk despite having a higher elevation.

Cap Material

This parameter is the predominant material from which the landfill cap is made, if there is a cap present. Landfills that are capped with clay will be less likely to release their contents, or at least will require an extreme event, relative to those that are either uncapped or capped with a more permeable substance. Therefore, clay represents the lowest level of likelihood, where uncapped or unknown capping material represent the highest severity score.

Cap Thickness

Similar to the cap material parameter, the average depth of the cap material can make a large impact on the overall permeability. Present-day standards suggest that a properly engineered cap, including required topsoil, should be just over 1 m to follow national guidelines (Tonkin & Taylor Limited, Ministry for the Environment, Landfill Review Group, and Landfill Review Panel, 2001). In addition to the effect on permeability and therefore leachate generation, the cap thickness also determines how easily it can be damaged. A thicker cap will be more resistant to an erosion or inundation event, where thinner caps will require less energy to become damaged and are therefore more vulnerable and likely to release waste.

3.2 Pollution Impact (Consequence)

The pollution impact index describes the potential impact of an event if erosion or inundation were to occur. The consequence of the event has been divided into two categories: landfill hazard and environmental vulnerability. These two categories describe the toxicity of the landfill and the sensitivity of the receiving environment.

3.2.1 Landfill Hazard

This category of parameters is describing the relative toxicity of each historic landfill site. The parameters were chosen to illustrate the potential impact of the landfill with minimal information. As most records from past periods when the landfills were operational are incomplete, generalisations were made to capture as much information as possible without setting unrealistic expectations around the availability of data. The parameters included in the landfill hazard category are landfill volume, landfill type, dilution potential, salinity, landfill closure date, and the landfill’s proximity to other water bodies.

Landfill volume

The volume of waste contained within a landfill is incredibly important when assessing the hazard potential of a given landfill. Records of amounts of waste placed in historic landfills are unusual. When sifting through files held by Waikato Regional Council, Hauraki District Council, and Thames-Coromandel District Council, no sites had recorded amounts of waste. The nearest proxy for waste volume is from site investigations. Few sites have undergone site investigations, and the techniques for volume estimation are often just a best guess based on historic imagery.

As records are nearly non-existent, this parameter will only ever be an estimation or proxy of volume rather than a recorded measurement. Volume is perhaps the single most important parameter to include, even if it is based on estimation. It is the only indication of how much waste, and therefore contamination, will potentially be released into the environment if an event is to occur.

To determine volumes of these sites, orthorectified imagery from the closest date to the start of the landfilling activity was used to create a historic digital elevation model (DEM) of the area. This historic DEM was then compared with a recent DEM to determine the overall change in volume. When calculated in this way, the volume estimation will include any cap and cover material. Though this will over-estimate the volume of the actual refuse, if an erosion event (or remediation) does occur, the entirety of the landfill will need to be dealt with. Additionally, as these are historic sites, the state of most of the refuse is likely to be degraded, making the distinction between refuse and cover material difficult.

The severity score criteria for this parameter are based on the range of the largest and smallest landfills in the region. As there are no national datasets with historic landfill volume estimates, the severity score had to be ranked on a regional scale.

Landfill type

The type of waste enclosed in a landfill is the direct determinant of the level of toxicity of contaminants. Therefore, the landfill type is a strong indicator of the potential pollution impact. Generally, waste types are divided based on their relative toxicity. In New Zealand, landfills are separated into four categories: cleanfill (or inert waste), municipal solid waste (MSW), industrial waste, and hazardous waste (Centre for Advanced Engineering, 2000).

The severity scores align with the four categories, with a few small distinctions. Landfills operating in recent history must cope with plastics, synthetic chemicals, bituminous substances, industrial wastes, and many other types of waste that were not introduced into middens or landfills that operated in the first half of last century (Vergara & Tchobanoglous, 2012). The 1960s had the first recorded instance of plastic pollution in the oceans, and an awareness of environmental impacts of synthetic chemicals was growing (Ostle, et al., 2019; Finn & O'Fallon, 2017). A national recognition of the potential impact from synthetic chemicals was growing, which manifested in legislation regulating the use of such chemicals from the 1960s to today (Ministry for the Environment, 1998). To capture the shift in prevalence of material types, a distinction is made for MSW landfills before and after 1960. Landfills that will have closed prior to 1960 are likely to have relatively less harmful contents than those landfills that operated after 1960.

As there were fewer (or no) restrictions actively regulating many of the historic landfill sites, the waste types do not always align closely with the present-day definitions. The severity scores used in this study, from highest to lowest, are as follows: hazardous or contaminated, MSW post 1960 or unknown, MSW pre 1960 or construction, organic or domestic, and inert or cleanfill. Even as late as 1986, most landfills were not monitored, therefore it is impossible to confidently state everything that was dumped (Gunn, 1986). As a result of this uncertainty, where multiple waste types were deposited, the severity score assigned to the highest relevant waste type for each site should be used.

Dilution Potential

The potential amount of dilution that can occur will have a large effect on the overall environmental and human health impacts. For instance, the historic landfill site is directly on the open coast, the contents will be heavily diluted due to the large body of water and therefore pose less of a risk to human health and the environment than if the contents of a landfill site were discharged into a small and enclosed system (Brand & Spencer, 2019).

A modified tidal prism is the best way to estimate a proxy measurement for the level of dilution that will occur if an inundation or erosion event takes place. The modified tidal prism used here

(Equation 3.1) combines the riverine and tidal inputs over a tidal cycle (Hunt & Jones, 2020; Sheldon & Alber, 2006).

Equation 3.1 Equation for calculating a modified tidal prism (Sheldon & Alber, 2006).

$$Modified\ Tidal\ Prism\ = T_p + \frac{1}{2}V_{river}$$

The values for T_p and V_{river} used in this study were obtained from the estuary classifications made by Hume et al. (2016). Using these values allows the same standard to be applied nationally, rather than calculating new values for each estuarine system. The associated severity scores are based on the average minimum (Waituna-type lagoon) and maximum (deep drowned valley) modified tidal prism values present nationally.

Salinity

Contaminants, specifically heavy metals, have been shown to be more mobile in saltwater compared with freshwater (Brand & Spencer, 2020; Schäfer, et al., 2009). Therefore, including a parameter for relative salinity will capture the higher risk for full saline environments compared to mixed or freshwater environments. For this study, the salinity measurements were approximated based on their location (open coast or estuarine). Additionally, those situated in an estuary were further distinguished based on their geomorphology and size, as described by Hume et al. (2016).

Landfill Closure Date

This parameter is the number of years since the landfill was closed. Unfortunately, poorly managed historic sites are likely to have been leaching contaminants somewhat continuously due to the lack of an appropriate liner and cap. Therefore, the longer a landfill has been closed, the more contaminants will have already been lost. Additionally, after an initial generation period, the risk associated with landfill gas decreases over time. Though the calculations of landfill gas are varied and complex, on average the amount of landfill gas produced increases in roughly the first 20 years after closure, and then proceeds to drop significantly after 30 years (Tonkin & Taylor Limited, Ministry for the Environment, Landfill Review Group, and Landfill Review Panel, 2001). Therefore, the landfill age serves as a proxy for the amount of contaminants contained within the landfill as well as the risk associated with landfill gas, both exhibiting declining risk over time.

Proximity to Water

This parameter is the distance from the landfill boundary to the nearest body of water (stream, river, or lake) other than the shoreline (i.e. a separate parameter to the distance to shoreline measure). Inclusion of this parameter is meant to incorporate the added risk associated with proximity to multiple sources of water. Any event is going to have a much larger impact if it is sited near another source of water in addition to the coast, as waste generally spreads faster and further across water than land. The pollution impact potential is much higher if there is an additional risk of spreading the released waste and increases the potential for human health impacts. Even smaller tributaries need to be considered as an event is likely to occur during heavy rainfall events, and therefore even small tributaries carry the potential to disperse waste much further than otherwise likely.

3.2.2 Environmental Vulnerability

The parameters in this category are describing the severity of impact to the area around each historic landfill site if an erosion or inundation event were to take place. The impact to the natural environment as well as potential cultural and human health impacts are included in this category. The parameters included are the relative population and distances to drinking water sources, significant natural areas, kaimoana and aquaculture, and tangata whenua sites of significance.

A distinction between upstream and downstream distances is made by Brand and Spencer (2018) in their landfill risk assessment. However, the majority of historic coastal landfill sites in the Waikato region are located along tide dominated estuaries. If an event were to occur, the distance that waste will be carried is highly dependent on the timing within the tidal cycle. Therefore, a general buffer distance corresponding to the severity score criteria is applied both upstream and downstream of the landfill.

Drinking Water Source

One of the most detrimental ways an erosion or inundation event could impact on human health is by releasing waste into a source of drinking water. Drinking water contamination has the potential to have wide-reaching impacts. Therefore, the proximity of drinking water sources to the historic landfill sites has been included. The distance calculated is between the drinking water source and the landfill boundary.

Significant Natural Areas

This is the distance to the nearest significant natural area. For this report, a significant natural area has been defined as the combination of outstanding landscapes, the collation of significant natural areas, and all protected areas defined in GIS layers held by Waikato Regional Council (see appendix Table A.0.1). Due to their higher environmental value, the sites included within this list would have a relatively greater impact if an event were to occur in or near their boundaries. The distance calculated is between the significant natural area and the landfill boundary.

Kaimoana and Aquaculture

This parameter captures the risk to kaimoana and aquaculture practices if a landfill site were to erode or become inundated. The hazard here has the potential to impact on the environment as well as human health. Unfortunately, there is little research regarding the potential impact of cumulative impacts on marine ecosystems (Pope, et al., 2011; Brand & Spencer, 2019). If a landfill were to release waste into the marine environment, it is likely each individual contaminant would be below set environmental thresholds due to the age of the landfills and the likely contaminant load remaining, but the cumulative impact of leachates and gross material (including plastics) could have severe consequences on marine life and therefore potentially human health as well.

Proximity of Cultural Sites

This parameter is meant to include the potential impact to culturally significant sites. Collaborative consultation was sought from iwi in the region with the potential to be affected by a historic coastal landfill event (Hauraki, Maniapoto, and Waikato-Tainui) for guidance in including significant cultural sites. However, due to the sensitive nature of the location of cultural sites, competing priorities for iwi time, and the timeframe of this study, information beyond what is currently held by Waikato Regional Council could not be incorporated into this risk assessment.

Without significant study of this parameter, the authors acknowledge that this work is entirely deficient in this area. However, one limited screening parameter has been included in the interim. Known marae locations and heritage sites listed as wahi tupuna or wahi tapu areas in Waikato Regional Council records were used to provide a limited interim cultural impact screening parameter. To reflect the values of the entire marae site, the property boundary of the marae was used, opposed to just the building itself. The distance between the landfill boundary and the nearest marae or heritage site is used in the analysis. The restricted incorporation of cultural places presented here serves as a placeholder for how Te Ao Māori perspectives may be woven into this assessment. The need for further incorporation of Te Ao Māori perspectives is acknowledged and is further discussed in section 4.2.2.

Population

The population parameter refers to the density of people living around the given site. The human health consequence of an event will be much larger in urban areas relative to rural locations as the potential number of people affected and exposed will be greater. This parameter was determined by the most recent population statistics published by StatsNZ (2020). The severity scores align with the population categories determined by StatsNZ, with sites near higher populations receiving higher severity scores.

3.3 Excluded Parameters

There are many potential parameters that could be included in this risk assessment framework. However, keeping in line with the goal to use robust and readily available datasets some possible parameters were excluded. This analysis does not explicitly include parameters relating to substrate, groundwater impact, geohazards, or cumulative impacts. Additionally, the decision was made to concentrate efforts on present-day coastal risk exposure of landfill sites, and therefore does not include risks posed by climate change and sea level rise.

Substrate

The predominant substrate, when considered with the wave energy of an environment, has a strong relationship to erosion and deposition rates (Hjulström, 1935). There is a broad scale dataset describing the substrate of the coastal environment of the Waikato region. This dataset is useful, but unfortunately does not extend to the estuarine environments on the west coast (Gardiner & Jones, 2020). Due to this gap, substrate has been excluded from the analysis.

Groundwater

In this analysis, groundwater is not considered. Highly detailed information regarding water table levels and aquifer boundaries is not readily available. Additionally, as the landfill records are sparse at best, there is very little confidence with regards to how the sites could potentially impact on the groundwater system.

Geohazards

Geohazards (tsunamis, earthquakes, wildfires, landslides etc.) are difficult to predict. Though the occurrence of a geohazard could have a large impact on the historic landfill sites, their unpredictable nature makes them unfeasible to include in the scope of this risk assessment. Additionally, if a large magnitude geohazard does occur, there will likely be higher priority concerns than the effects from a historic landfill (Laner, et al., 2009).

Cumulative Impacts

This study does not account for the potential of cumulative impacts. This needs to be considered by territorial authorities where multiple sites exist along the same exposure pathway. For example, there are four sites along the Tairua estuary. Though they may not pose a high risk individually, the risk to the Tairua estuary will be relatively higher if a significant event impacts them all. However, similar to geohazards, if a large magnitude event does occur, it is likely that there will be impacts of greater concern than the historic landfills.

Climate Change

The focus of this study is present-day risk exposure for historic coastal landfills. As such, the explicit inclusion of factors, such as sea level rise, are not explored. More detailed risk assessments of the priority sites will need to incorporate the changing climate and the associated risk factors (increased storm strength and frequency, sea level rise, etc.).

Table 3.1 Description of each parameter contributing to relative risk and the associated severity score criteria.

Parameter	Description	Severity Score Criteria 1	2	3	4	5
Wave Energy	Relative wave climate	Estuary - no wind waves	Estuary - with wind waves	Semi-enclosed embayment (e.g. Firth of Thames)	Open Coast - East	Open Coast - West
Tidal Range	Spring tidal range	>3.5 m	3-3.5 m	2.5-3 m	2-2.5 m	Microtidal (<2 m)
Flood Zone	Site relationship to flood zone maps	Not in flood zone	-	In protected zone	-	In flood zone
Sediment Balance	Coastline change - trend over time	Accretion	-	No Change	-	Erosion
Peak 24hr Rainfall	Peak 1 day rainfall event over past 5 years (mm)	<50 mm	50-75 mm	75-100 mm	100-125 mm	>125 mm
Elevation	Average elevation of the landfill site (metres above mean sea level)	≥15 m	10-15 m	5-10 m	2.5-5 m	<2.5 m
Landfill Position	Distance from landfill boundary to mean high water springs (m)	>50 m	35-50 m	20-35 m	5-20 m	≤5 m
Defence Type	Type of coastal defence, and predominant material type	Hard	Mixed	Soft	Partly undefended	No defence or landfill is defence
Defence Condition	If present, the condition of defence	Excellent/Excellent-Good	Good/Good-Average	Average	Poor/Poor-Average	No Defence
Cap Material	Predominant material used for capping	Clay	-	Composite/ Aggregate	-	No Cap or Unknown
Cap Thickness	Thickness of cap if present (m)	>1 m	0.75 m-1 m	0.5 m-0.75 m	≤0.5 m	No Cap or Unknown

Table 3.1 cont.

Parameter	Description	Severity Score Criteria 1	2	3	4	5
Landfill Volume	Estimated volume of landfill (m^3)	<5,000 m^3	5,000-15,000 m^3	15,000 - 50,000 m^3	50,000 - 100,000 m^3	>100,000 m^3
Landfill Type	Type of waste deposited*	Inert/Cleanfill	Organic/Domestic	MSW (pre1960) /Construction	MSW (post1960)/ Unknown	Contaminated /Hazardous
Dilution Potential	Modified tidal prism (m^3)	≥100,000,000 m^3 or Open Coast	≥5,000,000-100,000,000 m^3	≥10,000,000-50,000,000 m^3	≥1,000,000-10,000,000 m^3	<1,000,000 m^3
Salinity	Expected salinity class	Freshwater	River dominated	Mixed Estuarine	Tide dominated	Open Coast
Landfill Closure Date	Years since closure (yrs)	≥40 yrs	35-40 yrs	30-35 yrs	20-30 yrs	≤20 yrs
Proximity to Waterways	Distance from landfill boundary to streams/rivers of any size and/or lakes (m)	≥250 m	100-250 m	50-100 m	10-50 m	≤10 m
Drinking Water	Distance to a drinking water source (m)	≥1 km	500 m-1 km	100-500 m	≤100 m	0 m (in drinking water source)
Significant Natural Areas (SNA)	Distance to a SNA (m)	≥1 km	500 m-1 km	100-500 m	≤100 m	0 m (in SNA)
Kaimoana/ Aquaculture	Distance to marine farm or customary fishing area (m)	≥1 km	500 m-1 km	100-500 m	≤100 m	0 m (in farm or fishing boundaries)
Culturally significant sites	Distance to significant cultural sites (m)	≥1 km	500 m-1 km	100-500 m	≤100 m	0 m (in significant cultural site)
Population Density	Population classification where the landfill is sited	Rural (other)	Rural Settlement	Small Urban	Medium Urban	Large or Major Urban

*Where the parameter falls into more than one criterion, use the highest relevant severity score.

3.3.1 Parameters Included by Proxy

Mangroves

Initially, the presence of mangroves and saltmarsh ecosystems was a stand-alone parameter. However, it was removed as an independent parameter to avoid representing the same factor twice. Whether the defence is natural or manmade, the ultimate impact to the landfill site will be the same. Therefore, the decision was made to exclude mangrove and saltmarsh presence and width as its own parameter and include it under the defence type parameter.

Landfill Gas

There is no parameter to explicitly incorporate the risk of landfill gas. However, the landfill age parameter is meant to serve as a partial proxy for landfill gas. Generally, the landfill age correlates to the risk of landfill gas, with younger sites (<20 years old) exhibiting higher volumes of gas generation compared with older sites (Tonkin & Taylor Limited, Ministry for the Environment, Landfill Review Group, and Landfill Review Panel, 2001).

3.4 Calculating Overall Risk

The overall risk is calculated first by the summation of severity scores for each category, and then by a normalisation of the category score so it lies in a range from zero to one, with one being the highest potential severity. For each site, each category of parameters is normalised (Equation 3.2). From the four normalised scores, the physical environment score and the landfill vulnerability score are averaged together to provide a waste release index (akin to the likelihood of an event occurring). Similarly, the landfill hazard category and environmental impact category are averaged to provide a pollution impact index (consequence of an event).

Equation 3.2 Formula for calculating a normalised category score (Brand & Spencer, 2018).

$$\textbf{Normalised category score} = \frac{\boldsymbol{\Sigma severity\ scores - minimum\ possible\ score}}{\boldsymbol{maximum\ possible\ score - minimum\ possible\ score}}$$

Table 3.2 Minimum and maximum scores for each category to be used in normalisation (Brand & Spencer, 2018).

Category	Minimum Possible Score	Maximum Possible Score
Physical Environment	5	25
Landfill Vulnerability	6	30
Landfill Hazard	6	30
Environmental Impact	5	25

Two categories have six parameters each (landfill hazard and landfill vulnerability) and the remaining two categories (physical environment and environmental vulnerability) have five parameters each. The categories with fewer parameters will have a slightly higher influence on the overall risk calculation. This slight bias in the method is minimal and can be overlooked, as the combined number of parameters for the waste release index and the pollution impact index are equal.

It is important that no parameter has zero risk – all landfills and associated factors have residual risk. Although the methodology is designed to be a relative risk assessment tool, all landfills and associated factors have residual risk. It would be misleading to inadvertently communicate a zero likelihood of risk. By designating one as the lowest possible severity score, rather than zero, we are accounting for that residual risk. Additionally, where the parameter falls across more than one criterion (see Table 3.1), choose the relevant criteria with the highest severity score.

3.4.1 Weighting Overall Risk to Likelihood of Occurrence

In addition to the pure risk score, a weighted overall risk score is generated as well (Equation 3.3). As this methodology only accounts for the impact to human health and the environment, there is no inclusion for the negative attention and public perception changes if an event does occur. Rather than weighting the pollution impact index, the waste release index is weighted. This is because more emphasis needs to be placed on the potential for an event to occur in the first place to better inform and prioritise risk reduction and remediation measures, than on the environmental or human health consequences, as the negative attention will result from the event, regardless of the scale of impact.

Equation 3.3 Formula for calculating a weighted overall risk score.

$$\textbf{Weighted overall risk} = \frac{(\boldsymbol{Waste\ Release\ index} \times \mathbf{2}) + \boldsymbol{Pollution\ Impact\ Index}}{\mathbf{2}} \times \frac{\mathbf{1}}{\mathbf{1.5}}$$

The waste release index is multiplied by two. It is then added to the pollution impact index and then averaged. That number is then divided by 1.5 to provide the values in a range from zero to one.

Even if the risk to human health and the environment is low, there is likely to be a high consequence in negative attention if an event does occur. This negative attention is tied to the likelihood of the event occurring, rather than the potential pollution impact. Therefore, the waste release index is weighted opposed to the pollution impact index.

3.5 Outcomes

The 18 unique historic coastal landfill sites were put through the described methodology and the results are presented in Table 3.3. The mean overall risk score is 0.5. There is a normal distribution about the mean covering a range of 0.39 to 0.58. Interestingly, the mean waste release index score is 0.53, whereas the mean pollution impact index score is 0.41. The severity scores for waste release, on average, are higher than the severity scores for pollution impact.

Table 3.3 Table with waste release index, pollution impact index, overall risk, and weighted overall risk scores. The top 20 percent (roughly the top 4 or 5 sites) for each score is presented in bold, with the overall risk and weighted overall risk shaded.

Site	Waste Release	Pollution Impact	Overall Risk	Weighted Overall Risk
Colville Closed Landfill	0.58	0.30	0.44	0.49
Cooks Beach/Purangi Closed Landfill	0.47	0.39	0.43	0.44
Hauraki Rd landfill	0.35	**0.53**	0.44	0.41
Kaiaua Closed Landfill (pre-remediation)	**0.81**	0.35	**0.58**	**0.66**
Kawhia Closed Landfill (newer)	0.43	**0.53**	0.48	0.46
Kawhia Closed Landfill (older)	0.51	0.47	0.49	0.50
Pauanui closed landfill	0.40	0.38	0.39	0.39
Pipiroa Landfill	0.53	0.39	0.46	0.49
Queen St Landfill	0.53	0.39	0.46	0.48
Tairua Closed Landfill	0.45	**0.51**	0.48	0.47
Tairua Private Tip	0.60	0.28	0.44	0.50
Tanners Sawmill Ltd Dump	0.52	0.33	0.43	0.46
Thames Closed Landfill	0.55	**0.50**	**0.52**	**0.53**
Thames Timber Dump	0.36	0.43	0.39	0.38
Whangamata Closed Landfill	0.48	**0.51**	**0.50**	0.49
Whangapoua Closed Landfill	**0.65**	0.27	0.46	0.52
Wharf Road Tip, Coromandel	**0.66**	0.41	**0.53**	**0.58**
Whitianga Closed Landfill	**0.63**	0.37	**0.50**	**0.54**

The top 20% with the highest overall risk, in descending order, are Kaiaua (pre-remediation), Wharf Road Tip (Coromandel), Thames closed landfill, with Whitianga closed landfill and Whangamata closed landfill tied. The highest risk site, Kaiaua (pre-remediation) scores 15 percent higher in the waste release index than the next highest site (Wharf Road Tip, Coromandel). Interestingly, none of the top four sites with the highest pollution impact score are present in the highest 20 percent (top five) for overall risk, although the 5th highest pollution impact score is posed by Thames closed landfill which is one of the top four overall risk sites. There are no sites included in this analysis that score in the highest 20 percent (top four) in both waste release and pollution impact. This indicates that the highest risk landfill sites in the Waikato region are located in areas more prone to erosion or inundation but fortunately have a relatively low to moderate potential to cause severe impacts or consequences.

Table 3.4 Table comparing the pre- and post- remediation values for the Kaiaua closed landfill site.

Kaiaua	Waste Release	Pollution Impact	Overall Risk	Weighted Risk
Pre-remediation	0.81	0.35	0.58	0.66
Post-remediation	0.42	0.29	0.35	0.37

The range of overall risk scores vary from 0.39 (Pauanui and Thames Timber Dump) to 0.58 (Kaiaua, pre-remediation), where the range for overall weighted risk scores are from 0.38 (Thames Timber Dump) to 0.66 (Kaiaua, pre-remediation). The narrow range of risk values reflects the similarity between sites in the Waikato region, given that the severity score criteria was designed nationally. Additionally, sites in this analysis share many similarities, such as waste type, and some share very similar physical environment characteristics as the majority are sited around the Coromandel. The narrow range also reflects the equal weighting of the parameters. At this stage, weighting individual parameters was not done due to the subjective nature of choosing which parameters to weight and the danger in amplifying uncertainty. For example, landfill volume could be considered worth weighting, but as it was determined by proxy, weighting that parameter would only amplify any associated error.

Despite the small range, the model can generate higher or lower scores to reflect a wider variety of sites. Kaiaua, located within the Hauraki District, posed a large risk to human health and the environment and has now been fully remediated (all waste removed). Though the actual size of the landfill was quite small relative to other sites, it was actively being eroded into the Firth of Thames. Because it has been fully remediated, it provides an excellent opportunity to validate the overall risk assessment framework.

The overall risk score for Kaiaua prior to remediation is 0.58 where after remediation, the score drops to 0.35 (Table 3.4). Ideally, the relative risk for sites where all waste has been removed should be closer to zero as the waste volume is approximately zero and the risks stem from waste exposure. However, only a multiplicative model with a severity score option of zero would return a near-zero risk. As discussed, a severity score of zero is misleading as there will always be residual risk. Even if waste has been removed, there is minimal residual risk around nearby waste that may have been missed. Additionally, an additive model was chosen as the best way to represent the relationships between parameters, with the potential for individual weighting to occur at a more detailed level of assessment.

3.6 Weighted Risk Scores

Weighting the waste release index incorporates the occurrence of an event in the first place and the potential for consequential negative attention, reputational risk and set-back in relationships. There is a small shift between the overall risk scores and the weighted risk scores. The landfill sites representing the top 4 (approximately akin to top 20%) for overall weighted risk are the same subset of sites, but slightly different descending order from Kaiaua (pre-remediation), Wharf Road (Coromandel), Whitianga closed landfill and Thames closed landfill (Table 3.3).

Although the top 4 ranking didn't change, the different ranking order for the weighted risk score does identify the influence on risk of sites that have a higher likelihood of releasing waste. Opposed to simply looking at the highest scores for the waste release index, this weighting methodology also incorporates the environmental and cultural impacts.

The mean weighted risk score is 0.49, which is only slightly lower than the mean overall risk score of 0.5. Though the average change between overall risk and the weighted risk is small, some sites outside the top 4 sites shifted by up to 6 places in the ranking based on the weighted risk. For example, the Whangapoua closed landfill moved up to 5th rank from 11th and the Kawhia closed landfill (newer) moved down to 13th from 7th.

4 Discussion

There is a range of moderate to low potential pollution impact (consequences) across historic coastal landfill sites in the Waikato region. However, the chance of an erosion or inundation event where waste could potentially be released is mostly moderate or above. In other words, most of the coastal sites are located in areas more likely to be affected by erosion and inundation, but their potential pollution consequence is less on a relative scale. Many of the analysed sites have small volumes, are of similar waste types and there are few high risk types such as hazardous/industrial waste, which explains this potentially lower pollution impact if they were breached.

The overall and weighted risk values for Kaiaua (pre-remediation) are justified as the site was actively being eroded into the Firth of Thames, and therefore it is not surprising it was the highest risk site in the region and confirms the risk assessment methodology is sound. The Wharf Road Tip (Coromandel) is also right next to the shoreline with poor quality defences. It also lies within a flood zone and experiences a high rate of rainfall. For these reasons, it is the 2nd highest weighted risk site in the region. The Thames Closed Landfill is an interesting case. It does not rank in the top 4 (akin to highest 20 percent) of either the waste release index or the pollution impact index. However, it is the only site to score towards the top end in both indices. For this reason, it is justifiable that the Thames closed landfill ranks highly in overall risk (3rd) but drops to 4th on a weighted risk ranking.

It is interesting to note that there is no site that ranks in the top 4 in both waste release and pollution impact, which would pose an even higher risk. The lack of high-scoring sites reflects the scoring derived from national values and we can conclude that there are no sites in the Waikato region that pose an extreme present-day risk (now that the Kaiaua closed landfill has been remediated). The moderate range of relative risk scores reflects the moderate level of risk associated with the analysed sites in this risk screening assessment, considering the severity scores are defined by a national range. Despite more weighted overall risk scores reaching the 0.5 mid-way score (7 sites) in comparison with the straight overall risk scores (5 sites), none of the sites pose an extreme risk. Again, this aligns well with the similarity of sites in the Waikato region when considering the national potential.

An additional methodology of weighting some of the individual parameters in Table 3.1 was considered. As an initial trial, wave energy, landfill position, landfill elevation, and cultural sites were given a double weight. In this trial, the mean overall risk score remains similar and the range of overall risk scores remained the same (see Table A.0.4). Additionally, the priority sites remained similar with very little fluctuation in the remaining sites (the exception being Whangamata which drops from an overall risk score of 0.5 to 0.46 in the individual weighting trial). In addition to the subjective nature of determining which parameters are worthwhile to weight, the data reliability introduces limitations with individual parameter weighting. For example, landfill volume could be considered a critical parameter, but is has been estimated by proxy. Any additional weighting of this parameter would amplify the associated error. Due to the relatively small variation produced by the individual weighting combined with the potential for increasing uncertainty, individual parameter weighting was not explored further in this report. Weighting individual parameters could be considered for more detailed investigations into high priority sites, where geotechnical assessments and specific measurements can be taken.

We conclude that the relative risk-screening approach does adequately reflect the risk associated with each site when considered in a heuristic sense. Additionally, though overall risk is important, it may be equally important to consider the likelihood of an event occurring in the first place, separately from the consequence of the event. It is recommended to first consider the weighted risk score as the most significant, and to use the waste release index and pollution impact index to further understand what is driving the ranking.

This framework can be updated if further information becomes available about an existing site, or if other sites are identified. Using the same methodology to analyse all relevant sites means that the results can be compared directly with one another. It is important to utilise the same framework where possible, to provide a standardised result across all analysed sites.

4.1 Preventative or Reactionary?

All too often, hazard events place policy makers and stakeholders in a reactionary space. Reacting to an event, as opposed to pro-actively reducing the likelihood and mitigating consequences, ultimately limits options, including the opportunity to pre-emptively plan for the additional impacts from ongoing rising sea level and climate-change. Completing a brief comparative case study between the events at Fox River and the proactive remediation undertaken by Hauraki District Council at the historic Kaiaua landfill exemplifies the value of pre-emptive measures.

The Kaiaua landfill was a small community tip site right on the shoreline of the Firth of Thames. The best estimated volume of the site done in preliminary site investigations averaged the landfill to be roughly 1,100 tonnes (de Laborde, 2017). The actual amount removed from the site ended up being 3,220 tonnes, according to the weigh slips at the landfill where the waste was deposited. The total cost for the remediation was $642,769, which works out to roughly $200 per tonne of waste removed. Despite the tripling of volume, and the associated increase in costs, the risk has been effectively removed from the community.

There was no existing volume measurement of the Fox River landfill, prior to the erosion event in 2019. However, it is likely to have been a minimum of 22,000 tonnes (Golder Associates (NZ) Limited, 2021). The clean-up effort, Operation Tidy Fox, flew volunteers into the affected area to remove rubbish from the landscape by hand. The overall cost for Operation Tidy Fox was around $300,000 but the volunteers were only able to remove 350 tonnes (Bencich 2021, pers. comm.). This works out to roughly $850 per tonne of waste removed. This estimate also does not account for the thousands of tonnes that will have likely washed out to sea, contributing to ocean waste or washing back to shores over time.

The Fox River event also incurred additional costs removing the remaining eroded landfill (final estimate 8,710m^3, Golder, 2021), building a new cell at the Hokitika landfill to contain the waste, and trucking the refuse over to Hokitika. Though the final reports have yet to be published, the estimated total financial cost for this event is somewhere in the realm of $3 million (Bencich 2021, pers. comm.). Additionally, because the waste was indiscriminately torn from the landfill and spread across the river and coastline, refuse is still surfacing on the surrounding riverbanks and coastline due to shifting sediments. This requires continual monitoring, and cost and effort to remove.

Kaiaua and Fox River are two very different cases, each with their own set of challenges. However, the cost of reactionary efforts such as those implemented at Fox (removing eroded waste spread through the environment by hand as well as the remainder in situ) will likely always be the highest cost option, financially as well as environmentally. Being placed in a reactionary space means communities and stakeholders have limited options and are forced into rushed decisions, protracted clean-up costs and actions that will likely incur a range of direct (financial, environmental, human health, etc.) and indirect (public perception, relationship damage, negative media coverage, etc.) costs. The Fox event garnered negative international attention, and lead to multi-agency negotiations into liability and ability to pay. People from across the country volunteered to assist, the Defence Force was brought in and the whole event was hugely significant for the local community and those involved. The events at Fox River were handled in the best way possible given the urgent situation, however, there were limited options to choose from once the landfill was eroded. Conversely, preventative measures offer the ability to develop a plan and conduct a cost-benefit analysis to determine the best course of action.

The range of options available before an event occurs are full remediation, creating or reinforcing existing protective measures and structures, a combination of removal and reinforcement, or choosing to do nothing. Full remediation and removal of the refuse is the only option to effectively avoid the risk. By defending the historic landfill sites from the risk of erosion or inundation, it may be protected in the near future, but there is always residual risk that a large event will breach those defences and/or ongoing climate change and sea-level rise results in the protection reaching the end of its shelf life. If a site is exposed to low erosion or inundation risk, a choice may be made to do nothing. However, in a changing climate, future events at the coast will become more frequent with higher magnitude and reach, which will exacerbate the level of future risk facing the communities and councils where these sites are located. In this context, the risk screening ranking also provides a longer list of sites that may progressively become higher risks as sea level rises, groundwater rises and rainstorms become more intense, which can be factored into adaptive land-use planning and 30-year infrastructure strategies.

Communities and stakeholders will need to determine if the financial cost is worth the peace of mind. A detailed site investigation and a cost benefit analysis will need to be done to determine the best way to move forward with remediation options for each site.

4.2 Limitations of the Assessment

A model is a simplification of a complex and changing coastal lowland system. As such, there are limitations to what can be achieved. The main limitations associated with this study stem from data reliability, insufficient time and resource to properly collaborate with iwi/hapū on risks from Te Ao Māori perspectives, the inherent complexity estimating the likelihood of erosion and inundation and several unknowns, such as the effect of groundwater and assessing residual risk from historic berms or stop banks.

4.2.1 Quality of Data

The quality of data used in any analysis will have a heavy impact on the overall quality of the final output. In this study there are two main limitations associated with the quality of data. The first data limitation is the quality of and access to relevant records. An additional data limitation is common with many GIS-based analyses regarding the quality of elevation data.

The data regarding the specific landfill sites is pulled from records kept by the regional council and the respective territorial authorities. Records from the relevant time periods are often unorganised, incomplete, or in some cases, non-existent. From a survey completed in 1986, the knowledge of local government about waste disposal practices was very erratic (Gunn, 1986). Most territorial authorities in the Waikato Region indicated that they did not have complete knowledge of what types of waste was being dumped at the local landfills or the extent of illegal dumping present in their territory (Gunn, 1986). Due to the unpredictable nature of the existing records, the amount and quality of data varies between sites. For this reason, there has been a conscious effort to include only the most vital site-specific details to keep the model as robust as possible.

A well-known limitation with any GIS analysis that utilises elevation data is the influence of the original DEM data on the reliability of the results (Coveney & Fotheringham, 2011). If the original DEM is of poor collection methods, the output will be unreliable. The DEM data used in this study, based on LiDAR land surface topography, are accurate to within a root mean square error of 0.15 m at the 68% confidence level. The dataset is intended to be used for “hydraulic modelling, flood hazard mapping, water catchment investigations, shoreline landscape assessments, storm and sewer scheme investigations, and planning processes” (NZ Aerial Mapping Ltd. and Waikato Regional Council, 2018). As this study is within the same spatial scale as the intended purposes, this DEM data set is appropriate to apply to the current study.

4.2.2 Iwi Consultation

One vital and necessary missing component of this study is the almost complete absence of cultural data. Efforts were made to connect with relevant iwi/hapū. However, due to the limited timeframe of this study and other priorities competing for iwi/hapū attention, a shared approach could not be taken for this piece of work. The risk from historic landfills on cultural sites and values is a critical component that is yet to be addressed adequately; and any future decisions need to be made taking a co-governance approach. This may mean that in the future, this risk assessment framework may need to be altered, have overlying layers or simply form a foundation on which to apply a Te Ao Māori worldview.

4.2.3 Model Complexity

This study is constricted by temporal limitations. The model uses the most accurate data available at the time. There is potential that previously unknown historic landfill sites may be found, or conversely, that one of the existing sites is found to have been remediated decades ago. Overall, a model is a simplification of a complex system. For this reason, we can never entirely capture the full range of factors that influence the historic coastal landfill risks, but the model incorporates the most robust datasets available and does apply a consistent framework that at least enables a relative ranking of risks between sites (even if the quantum of risk is not initially known until a detailed risk assessment is undertaken).

Erosion and inundation are difficult to predict independently, let alone in conjunction as a compound hazard event. There are myriad influences that impact the likelihood and level of erosion or inundation. The purpose of this study is to rank each site according to the risk of an erosion or inundation event relative to other sites. This is not meant as an ultimate risk evaluation for coastal processes. This study utilises the best available datasets to describe the risk consistently across sites to provide some structure in assessing which are the critical sites.

An additional limitation related to the overall model is the need to re-run analyses if various layers are updated. For instance, if the extent of mangroves is updated, the analysis will need to be re-done to update the potential impact to each site. Fortunately, this is not very labour intensive for most parameters, but it should be considered when using this model.

5 What next?

Historic landfills provide an environmental challenge for the modern day. The legacy of the "buried" past must now be managed with the sparse records that remain. This has presented a daunting task to contemporary policy makers and regulators. This report and risk-screening assessment approach will aid policy makers, planners, stakeholders and iwi/hapū partners in helping to prioritise the historic coastal landfill sites that pose the greatest emergent risks in a changing climate and rising sea level.

By collecting information regarding historic sites and applying relatively readily accessible data sets, historic landfill sites can be methodically assessed according to the relative level of risk they pose. Rather than viewing all historic landfills as an insurmountable task to be dealt with, the methodology described here outlines a way forward in ranking these sites, to help organise the sites that should be assessed in more detail and options or pathways determined ahead of other sites. This process identifies the sites that pose the highest risk of being impacted by a coastal event (erosion or inundation). The value of this information can help policy makers reach out to potentially affected communities and iwi/hapū and begin the tough work of collaborating on steps toward remediation.

There is potential for the risk assessment framework presented here to also assess different hazards. Riverine sites would be the next category of historic landfills that should be assessed. By replacing coastal parameters such as wave energy and tidal range with river flow rate and water level, riverine risk could be estimated. However, this next step would need to address the complex relationship between rainfall and river flooding and incorporate residual risk from the extensive network of stopbanks in the Waikato Region.

This study is not meant to provide management recommendation. This study was done with the goal to provide stakeholders and local government with a way to systematically rank the risk of historic coastal landfill sites in the region. To determine management options, in depth site investigations will need to be completed followed by evaluation of options using cost-benefit or other economic analysis, to reveal opportunities and challenges of the various remediation options, in collaboration with stakeholders and iwi/hapū.

6 References

Alongi DM 2008. Mangrove forests: Relilience, protection from tzunamis, and responses to global climate change. Estuarine, Coastal and Shelf Science 76(1): 1-13.

Basher LR 2013. Erosion processes and their control in New Zealand. In: Dymond J ed. Ecosystem services in New Zealand: Conditions and trends. Lincoln, Manaaki Whenua Press, Landcare Research. 363-374.

Baziene K, Tetsman I, Albrektiene R 2020. Level of pollution on surrounding environment from landfill aftercare. International Journal of Environmental Research and Public Health, Volume 17.

Brand JH, Spencer KL 2018. Risk screening assessment for ranking historic coastal landfills by pollution risk. Anthrophocene Coasts 44-61.

Brand JH, Spencer KL 2019. Potential contamination of the coastal zone by eroding historic landfills. Marine Pollution Bulletin 146: 282-291.

Brand JH, Spencer KL 2020. Will flooding or erosion of historic landfills result in a significant release of soluble contaminants to the coastal zone? Science of the Total Environment 724:138150.

Brand JH, Spencer KL, O'Shea FT, Lindsay JE 2018. Potential pollution risks of historic landfills on low-lying coasts and estuaries. WIREs WATER 5(1).

Centre for Advanced Engineering 2000. Landfill guidelines towards sustainable waste management in New Zealand. Christchurch, Centre for Advanced Engineering, University of Canterbury.

Coveney S, Fotheringham AS 2011. The impact of DEM data source on prediction of flooding and erosion risk due to sea-level rise. International Journal of Geographical Information Science 25(7): 1191-1211.

de Laborde A 2017. Closeout report: Kaiaua Historic Landfill. Paeroa, Hauraki District Council.

Esri Inc 2020. *ArcGIS Pro.* s.l., s.n.

Finn S, O'Fallon L 2017. The emergence of environmental health literacy - From its roots to its future potential. Environmental Health Perspectives 125: 495-501.

Gardiner S, Jones H 2020. Habitat mapping for the Waikato region coastal marine area: Bathymetry and substrate type. Waikato Regional Council Technical Report 2017/34. Hamilton, Waikato Regional Council.

Golder Associates (NZ) Limited 2021. Site validation report Fox River Landfill Remediation, Christchurch, Golder Associates (NZ) Limited.

Gorman RM, Bryan KR, Laing AK 2003. Wave hindcast for the New Zealand region: Nearshore validation and coastal wave climate. New Zealand Journal of Marine and Freshwater Research, 37(3): 567-588.

Green ID, Boughey K, Diaz A 2014. Potentially toxic metals in historic landfill sites: implications for grazing animals. Water, Air, & Soil Pollution 225:2110.

Gunn AS 1986. Local authority attitudes to hazardous waste management: A report for the New Zealand Department of Health. Hamilton, University of Waikato.

Heritage New Zealand 2016. Archaeological remains of middens and rubbish dumps. s.l., s.n.

Hjulström F 1935. Studies of the morphological activity of rivers as illustrated by the River Fyris. Uppsala, Almqvist & Wiksells.

Hume T, Gerbeaux P, Hard D, Kettles H, Neale DM 2016. A classification of NZ coastal hydrosystems, Hamilton, NIWA.

Hunt S, Jones HFE 2020. The fate of river-borne contaminants in the marine environment: Characterising Regions of Freshwater Influence (ROFIs) and estuary plumes using idealised models and satellite images. Marine Pollution Bulletin 156.

International Organization for Standardization (ISO) 2018. ISO 31000:2018 Risk management - Guidelines. Geneva, International Organization for Standardization (ISO).

Jarup L, Briggs, D, de Hoogh C, Morris, S, Hurt, C, Lewin, A, Maitland, I, Richardson S, Wakefield J, Elliott, P 2002. Cancer risks in populations living near landfill sites in Great Britain. British Journal of Cancer 86: 1732-1736.

Land Information New Zealand 2021. Standard port tidal levels. Wellington, Land Information New Zealand.

Landcare Research New Zealand 2020. Land Cover Database LCDB_v50_NZ. S.l., s.n.

Laner D, Fellner J, Brunner PH 2009. Flooding of municipal solid waste landfills: An environmental hazard? Science of the Total Environment 407: 3674-3680.

Laner D, Fellner J, Brunner P H 2011. Future landfill emissions and the effect of final cover installation: A case study. Waste Management 31:1522-1531.

Louis G 2004. A historical context of municipal solid waste management in the United States. Waste Management & Research 22(4): 306-322.

MetOceanView 2019. Hindcast Data. [S.l.], Meteorological Service of New Zealand Ltd.

Ministry for the Environment 1998. Reporting on persistent organochlorines in New Zealand. Wellington, Ministry for the Environment.

Ministry for the Environment 2011. Hazardous Activities and Industries List (HAIL). Wellington, Ministry for the Environment.

Ministry for the Environment 2021. Types of landfills. https://environment.govt.nz/guides/types-of-landfills/. [accessed May 2021].

NIWA 2010. Mean monthly rainfall (mm). https://niwa.co.nz/education-and-training/schools/resources/climate/meanrain . [accessed June 2021].

NIWA 2021. The National Climate Database. https://cliflo.niwa.co.nz/ [accessed 05 May 2021].

NZ Aerial Mapping Ltd, Waikato Regional Council 2018. LiDAR 0.5m Contours. s.l, s.n.

Ostle C, Thompson, RC, Broughton D, Gregory L, Wootton M, Johns, DG 2019. The rise in ocean plastics evidenced from a 60-year time series. Nature Communications 10(1): 1-6.

Pope ND, O'Hara SCM, Imamura M, Hutchinson TH, Langston WJ 2011. Influence of a collapsed coastal landfill on metal levels in sediments and biota - a portent for the future? Journal of Environmental Monitoring 13(7): 1961-1974.

Rausand M 2013. Risk assessment: Theory, methods, and applications. Hoboken, NJ, Wiley.

Schäfer J, Norra S, Klein D, Blanc G 2009. Mobility of trace metals associated with urban particles exposed to natural waters of various salinities from the Gironde Estuary, France. Journal of Soils and Sediments 9: 374-392.

Sheldon JE, Alber M 2006. The calculation of estuarine turnover times using freshwater fraction and tidal prism models: A critical evaluation. Estuaries and Coasts 29(1): 133-146.

Shepard CC, Crain CM, Beck MW 2011. The protective role of coastal marshes: A systematic review and meta-analysis. PLoS ONE, 6(11): e27374.

Singh RK, Datta M, Nema AK 2009. A new system for groundwater contamination hazard rating of landfills. Journal of Environmental Management 91: 344-357.

Slack R, Gronow J, Voulvoulis N 2005. Household hazardous waste in municipal landfills: Contaminants in leachate. Science of the Total Environment, 337(1-3): 119-137.

Stein JK 1992. Deciphering a shell midden. San Diego, Academic Press.

Stephens SA, Bell RG, Haigh ID 2020. Spatial and temporal analysis of extreme storm-tide and skew-surge events around the coastline of New Zealand. Natural Hazards and Earth System Sciences 20: 783-796.

Stephens SA, Gorman RM 2006. Extreme wave predictions around New Zealand from hindcast data. New Zealand Journal of Marine and Freshwater Research 40(3): 399-411.

Tonkin & Taylor Ltd, Ministry for the Environment, Landfill Review Group, Landfill Review Panel 2001. A Guide for the management of closing and closed landfills in New Zealand. Wellington, Ministry for the Environment.

Tonkin & Taylor Ltd 2020. National Landfill Risk Assessment. Christchurch, Tonkin & Taylor.

Vergara SE, Tchobanoglous G 2012. Municipal solid waste and the environment: A global perspective. Annual Review of Environment and Resources 37: 277-309.

Waikato Regional Council 2006. Coastal Structure Data Set. Hamilton, Waikato Regional Council.

Zhang K, Liu H, Li Y, Xu, H, Shen, J, Rhome J, Smith III TJ 2012. The role of mangroves in attenuating storm surges. Estuarine, Coastal and Shelf Science 102-103: 11-23.

Appendix A

Table A.0.1 Table of each GIS-based parameter and the related metadata for associated GIS layers used in this study's analysis.

Parameter	Source of Data
Flood Zone	Regional Flood hazard: http://oradblive.wairc.govt.nz:8080/ords/f?p=135:12:0::NO::P12_METADATA_ID:7989
Sediment Balance	Historic shorelines: http://oradblive.wairc.govt.nz:8080/ords/f?p=135:12:0::NO::P12_METADATA_ID:972
Elevation	0.5m LiDAR dataset: http://oradblive.wairc.govt.nz:8080/ords/f?p=135:12:0::NO::P12_METADATA_ID:3328
Landfill Position	Coastal Shoreline 2017: http://oradblive.wairc.govt.nz:8080/ords/f?p=135:12:0::NO::P12_METADATA_ID:3188
Defence Type and Condition	Coastal Structures: http://oradblive.wairc.govt.nz:8080/ords/f?p=135:12:0::NO::P12_METADATA_ID:904 ; Shoreline protection structures | Waikato Regional Council Mangrove and Saltmarsh: http://oradblive.wairc.govt.nz:8080/ords/f?p=135:12:0::NO::P12_METADATA_ID:2382
Proximity to waterways	Hydro 50K Reservoir/River/Spring/Lake/Pond: http://oradblive.wairc.govt.nz:8080/ords/f?p=135:12:0::NO::P12_METADATA_ID:976
Drinking Water	Drinking water supply 2017: http://oradblive.wairc.govt.nz:8080/ords/f?p=135:12:0::NO::P12_METADATA_ID:1051
Significant Natural Areas	SNA collation: http://oradblive.wairc.govt.nz:8080/ords/f?p=135:12:0::NO::P12_METADATA_ID:462; RPS2 Outstanding Landscapes: http://oradblive.wairc.govt.nz:8080/ords/f?p=135:12:0::NO::P12_METADATA_ID:1061;
Kaimoana	coastal marine farm and marine farm IRIS: http://oradblive.wairc.govt.nz:8080/ords/f?p=135:12:0::NO::P12_METADATA_ID:1038; iwi customary fishing areas: http://oradblive.wairc.govt.nz:8080/ords/f?p=135:12:0::NO::P12_METADATA_ID:913
Mana whenua	Iwi marae IRIS: http://oradblive.wairc.govt.nz:8080/ords/f?p=135:12:0::NO::P12_METADATA_ID:984 Iwi waahi tapu: http://oradblive.wairc.govt.nz:8080/ords/f?p=135:12:0::NO::P12_METADATA_ID:981 Iwi sites of significance: http://oradblive.wairc.govt.nz:8080/ords/f?p=135:12:0::NO::P12_METADATA_ID:1186
Population Density	Urban Rural 2020 (generalised) - GIS | | GIS Map Data Datafinder Geospatial Statistics | Stats NZ Geographic Data Service

Table A.0.2 Table showing the wave energy and salinity (as described by this study) for each estuary classification defined by Hume et al. (2016); subclasses omitted for simplicity, see reference for full classification descriptions.

Hume et al. (2016) classification	Wave Energy	Salinity
1 – Damp sand plain lake	No wind waves	Freshwater*
2 – Waituna-type lagoon	Wind Waves	River-dominated
3 – Hāpua-type lagoon	No wind waves	River-dominated
4 – Beach stream	No wind waves	Freshwater*
5 – Freshwater river mouth	No wind waves	River-dominated
6 – Tidal river mouth	Low wave energy	River-dominated
7 – Tidal lagoon	Low wave energy	Well-mixed
8 – Shallow drowned valley	Wind waves	Tide-dominated
9 – Deep drowned valley	Wind waves	Saline

*Can be brackish, see Hume et al. (2016) for clarification.

Table A.0.3 List of landfill sites and the associated rainfall stations obtained from the National Climate Database (NIWA, 2021).

Landfill Site	Rainfall Station (CliFlo)
Colville Closed Landfill	Coromandel (1513)
Cooks Beach/Purangi Rd	Whitianga Aero AWS (1520)
Hauraki Rd Landfill	Coromandel (1513)
Kaiaua Closed Landfill	Firth of Thames EWS (38619)
Kawhia Newer	Owhiro (2141)
Kawhia Older	Owhiro (2141)
Pauanui Closed Landfill	Onemana (1536)
Pipiroa	Firth of Thames EWS (38619)
Queen St Landfill	Thames 2 (1529)
Tairua Private Tip	Onemana (1536)
Tairua Closed Landfill	Onemana (1536)
Tanners Sawmill	Onemana (1536)
Thames Timber Dump	Thames 2 (1529)
Thames Closed landfill	Thames 2 (1529)
Whangamata Closed Landfill	Whangamata (1544)
Whangapoua	Whangapoua 2 (17465)
Wharf Rd	Coromandel (1513)
Whitianga Closed landfill	Whitianga Aero AWS (1520)

Table A.0.4 Example of weighting individual parameters (wave energy, landfill position, landfill elevation, and cultural sites). Shaded column are the overall risk scores presented in Table 3.3 in this study. Highest 20 percent risk scores are in bold in both columns.

Site	Overall Risk	Individual Weighting Trial overall risk
Colville Closed Landfill	0.44	0.40
Cooks Beach/Purangi Closed Landfill	0.43	0.42
Hauraki Rd landfill	0.44	0.41
Kaiaua Closed Landfill (pre-remediation)	**0.58**	**0.57**
Kawhia Closed Landfill (newer)	0.48	0.45
Kawhia Closed Landfill (older)	0.49	0.47
Pauanui closed landfill	0.39	0.38
Pipiroa Landfill	0.46	0.45
Queen St Landfill	0.46	0.47
Tairua Closed Landfill	0.48	0.47
Tairua Private Tip	0.44	0.41
Tanners Sawmill Ltd Dump	0.43	0.38
Thames Closed Landfill	**0.52**	**0.53**
Thames Timber Dump	0.39	0.38
Whangamata Closed Landfill	**0.5**	0.43
Whangapoua Closed Landfill	0.46	0.43
Wharf Road Tip, Coromandel	**0.53**	**0.52**
Whitianga Closed Landfill	**0.5**	**0.48**
Mean	0.47	0.45
Range	0.19	0.19