

A Web GIS Tool for Disaster Waste Management Planning in New Zealand

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ABSTRACT

To date, the management of waste-streams generated by disasters in New Zealand has been ad hoc, with planning largely taking place post rather than pre event. A valid reason for this is that the severity and consequences of such events varies widely, dictating the type and quantity of waste produced.

To help mitigate problems caused by unplanned waste, a web GIS tool is being developed for use in a pre-event planning exercise and for developing quick early estimates of waste during an event. The tool models the amount of waste generated by different types of disasters, quantifying the amount of waste for different waste-streams. The user can then find the nearest suitable waste disposal location, accounting for barriers.

This tool could be of great value for local government. It is flexible, so that can quickly and simply be extended to other regions and the intention is for regional councils to host the tool within their own GIS environment.

Keywords

GIS, waste, disaster, planning, web-app

INTRODUCTION

The current emergency response planning framework in New Zealand does not include any specific procedures or tools that apply to the management of waste generated in a disaster. In the historical context disaster waste has been managed as a logistical exercise. However the 2011 Christchurch earthquakes, the Rena grounding and, recently, the Kaikōura/North Canterbury earthquake have together contributed to a strong perception that the status quo of ad hoc response is completely inadequate and that a formalised waste management system to deal with the wastes arising from the full spectrum of potential disasters is overdue for development in New Zealand.

Thus a national template that has sufficient flexibility to allow unique regional components to be taken account of is considered to be the optimum strategic goal in the development of a disaster waste management plan for New Zealand. This paper outlines a valuable, supporting component of the Waste Management Template, an interactive web-based GIS tool. This can be used to quantify various waste-streams for different property types and also includes a routing function whereby the user can define a waste source/collection point and find the nearest waste disposal site, taking into account barriers such as closed roads, slips or floods. The tool is intended to be flexible and scalable, so that it can be extended to other regions and model a range of disaster scenarios.

Fundamental functionality includes the ability to be web-supported, making use of cloud computing technology; the use of drop-downs to ensure consistent reporting; the inclusion of district plan and infrastructure data as GIS overlays; and an intuitive, interactive user interface. This functionality has been developed and tested during a number of workshops which included participants from a number of regional councils, comprising the “Project Owner”. These workshops have provided an opportunity to integrate knowledge gained from prior disasters, such as the 2017 and 2004 Whakatane District floods. These case studies have highlighted the need for a dynamic tool, as events of a similar type in the same region have required very different responses to waste

management. The pilot group has also proved invaluable in mitigating the effects of environmental determinism, often inherent in GIS, by considering community level social factors.

BACKGROUND

As identified by Brown et al. (2011), increased urbanisation and dependence on complex infrastructure networks increases a community's vulnerability to a disaster. This also increases the likely amount of waste produced. These large waste volumes can in fact overwhelm existing solid waste management facilities and personnel and can also affect both the response and the long term recovery of a disaster-affected area. For example, in the immediate aftermath of an earthquake, debris can block roads, which in turn impedes rescuers and emergency services reaching survivors. In some cases, such as where hazardous materials such as asbestos, chemicals, radioactive materials and infectious wastes are present, a public and environmental health risk is posed. In the longer term, poor management of debris can result in a slow and costly recovery because, inter alia, rebuilding and repairs cannot be carried out before the waste is removed. The ongoing presence of uncleared wastes, derelict buildings and the like is also a public indicator of the speed and relative completeness of recovery which can itself have possibly unrecognised psychosocial impacts. It is necessary therefore to ensure safe and expedient removal of debris for a variety of reasons. If managed effectively, debris can become a valuable resource in the recovery and rebuilding process and can have a positive effect on social and economic recovery.

It is abundantly clear that a strong need exists to develop an effective disaster waste management response, with as many of the fundamental requirements to optimise this response being in place prior to any event. Establishing such a waste management system in a pre-disaster context is however a complex challenge with a need to balance stakeholder desires, community needs, environmental factors, political will and funding. Adding the impacts of a disaster to the equation adds another level of complexity by introducing the impacts of time pressures and a shocked community.

However these problems and complexities are clearly amenable to a structured planning approach that utilises as wide a range as possible of information resources, databases and spatial planning tools such as GIS mapping, and with these resources supported by a cloud-based computing environment, to derive a detailed and integrated set of procedures and methodologies to effectively manage generated wastes and minimise environmental and public health issues, as applicable and practicable, to reuse wastes as valuable resources to aid economic and social recovery.

This then is the background to the initiative taken by the three regional councils comprising the Project Owner for this project. A national template that has sufficient flexibility to allow unique regional components to be taken account of is considered to be the optimum strategic goal in the development of a disaster waste management plan for New Zealand.

Outside of New Zealand, disaster waste decision tools have been developed to help mitigate the effects of disaster debris. An example is the US Environmental Protection Agency's (EPA) Decision Support Tool (Thorneloe et al., 2007). This provides planning advice for natural disaster scenarios, drawing on historic case studies. Included is a database of disposal facilities. This is a form based web tool but lacks a GIS component.

Previously in the GIS space, there have been few tools developed for waste preparedness planning, particularly in a New Zealand context. In the United States, the Federal Emergency Management Agency (FEMA) has created a GIS hazard loss estimate tool called HAZUS –MH (multi-hazard). This is a desktop based tool and ArcMap extension that identifies locations at high-risk from earthquake, hurricane, flood and tsunami hazards. The flood information tool is able to take user defined elevation and flood datasets and calculate flood depth to use in the HAZUS modelling system. HAZUS is able to model potential loss to exposed areas in regard to structural and economic impact. FEMA is also developing a web portal where users can upload and share hazard datasets. However, currently HAZUS-MH is a desktop application requiring an ArcGIS installation and the Spatial Analysis extension to run the flood modelling. The benefit of the Disaster Waste Management Planning (DWMP) tool is that the intention is to create a flexible web-GIS tool that exploits the spatial analysis capabilities of ArcGIS, but serves them up via a browser interface so they can be used in any location with connectivity. The following section describes the method by which the tool has been created and explains how it supports the DWMP word template.

METHOD

The purpose of the GIS tool is to support sections D and E of the DWMP Word template. These sections involve quantifying waste volumes for various waste streams and planning waste disposal via accessible routes leading to appropriate refuse or recycling facilities. This work is based on experience gained by Rawtec, who undertook a similar planning exercise in South Australia, although without the inclusion of GIS. The work also takes into consideration input from Regional and District Council staff from Canterbury, Waikato and Bay of Plenty, who between them have a wealth of experience dealing with events such as the Kaikoura earthquake, Whakatane floods of 2004 and 2017 and the Rena disaster. A number of workshops were run with the Pilot Group, providing valuable information on the quantity and types of waste streams previously generated, and alerting the authors to the fact that similar events within the same region can require a very different response. This means any tool developed needs to be dynamic and allow a high degree of user input, while still providing guidance. The Pilot Group also provided insight into community concerns, aiding development of a tool that is not environmentally deterministic.

The first stage of tool development involved data procurement. It was necessary in building the tool to obtain, via Memoranda of Understanding (MOUs), the agreement of relevant agencies to make their spatial data available for interrogation by the tool. Bay of Plenty Region was chosen as the pilot study area, in particular Whakatane District. This was chosen due to the availability of historic flood datasets and the experience of Council and CDEM staff. The scope of this work stated that only pre-existing hazard datasets were to be used, so the modelling of hazard datasets was outside the scope of project. Bay of Plenty Regional Council (BOPRC) GIS team provided a wealth of spatial datasets relating to hazard extents, infrastructure and limitations to waste disposal location, such as Significant Natural Areas and cultural heritage sites. These were provided as either file geodatabase or web services, delivered via ESRI map package. A map package is an efficient way to share desktop ArcGIS map documents whereby data is packaged into a geodatabase or preserved as a layer referencing a URL, so long as the recipient has an ArcGIS license. Table 1 lists the hazard datasets initially considered.

Consultation with relevant natural hazard specialists was sought to ensure valid datasets were used for pre-planning pilot exercises. For pre-planning it is important that datasets represent the severity and occurrence for such an event as expected within a particular region. One method for normalizing damage caused by events of varying frequency and severity is to calculate the Annual Average Damage. This is the amount of damage per year that would occur over a long period of time. It is calculated by plotting damage against event probability, firstly using known data, then from extrapolated values with the resulting areas summed. For the Whakatane Region pilot study, we were limited to historic flood extents, but the above approach could be considered for other planning exercises.

Following data procurement, a GIS tool was built using ArcMap desktop software as a proof-of-concept before creating a web tool. The tool is designed to perform the following functions: allow the user to view environmental and hazard overlays, such as landslip-prone areas, protected environmental areas, HAIL sites, bridges etc.; calculate waste for different property types based on different disaster events, for the pilot tool these include earthquake, flood and volcanic event; allow the user to find the nearest waste disposal facility to a specified point accounting for road barriers such as landslides, washed-out bridges or the extent of the disaster event. Figure 1 shows the ArcMap interface with waste calculation tool open.

Data preparation for the waste calculation tool involved assigning District Plan zones to LINZ property address points. These were used as an input to a Python geoprocessing tool which intersected them with the user defined disaster extent, applied a user defined waste factor per property zone per debris type and quantified the results. The results are displayed as an excel table. Debris types include building content waste, building construction material waste, event debris waste. This method uses the “unit” approach as recommended by Brown et al. (2011). The total waste is calculated as the sum of the number of houses in each category multiplied by the quantity of waste. With this formula estimates can be built up based on how much waste is expected from a single type of property and the level of damage sustained. For example, for residential areas, the affected properties could be categorised with respect to the level of damage (say, full demolition, partial repair and minor repairs). Each level could then be divided further based on the type of construction of the property, its age and size. Finer grained ratings data would be required from TA’s in regard to building construction material if this level of analysis were to be performed.

Table 1. Hazard Datasets

Type	Dataset Name	TA
Flood Risk	Overland Flow Path	TCC
Flood Risk	Overland Flow Path Extent	TCC
Flood Risk	Properties Raised Above Min RL	TCC
Flood Risk	Flood Hazard Plan Area (City Plan)	TCC
Flood Risk	Flood Hazard (Extreme Rainfall – 100 Year Event)	TCC
Flood Risk	Harbour Inundation (City Plan) 5k-10	TCC
Flood Risk	Depth and Velocity 100yr Event	TCC
Flood Risk	Floodable Area	WBDC
Flood Risk	Coastal Inundation Area	WBDC
Flood Risk	Waihi Beach Floodable Area	WBDC
Flood Risk	Wairoa Floodable Area	WBDC
Flood Risk	Inundation Risk Zone (DP)	WDC
Flood Risk	Overland Flow Paths (DP)	WDC
Flood Risk	Proposed Coastal Inundation Areas	WBOPDC
Flood Risk	Inundation Risk Zones	WDC
Floods Slips	Historic Flood Slips 2004	BOPRC
Flood Risk	Historic Floods 2004	BOPRC
Flood Risk	Edgecumbe Flood Extent 2017	BOPRC
Tsunami	Max Tsunami Flood Depth 9m Wave	TCC
Tsunami	Tsunami Evacuation Zones	BOPRC
Tsunami	Maketu/Pukehina Tsunami	WBDC
Tsunami	Tsunami Extent 2500ARI	BOPRC
Tsunami	Tsunami Inundation 3m Wave	BOPRC
Landslide	Relic Slip 10k – 10	TCC
Landslide	Stability	WBOP
Landslide	GNS Landslide Catalogue	BOPRC
Liquefaction	Liquefaction Types	WBDC
Liquefaction	GNS Liquefaction	BOPRC
Erosion	Coastal Erosion Risk Zone	TCC
Erosion	Coastal Erosion Area	WBDC
Erosion	Erosion Risk Zones	WDC
Erosion	Proposed Coastal Erosion Lines	WDC

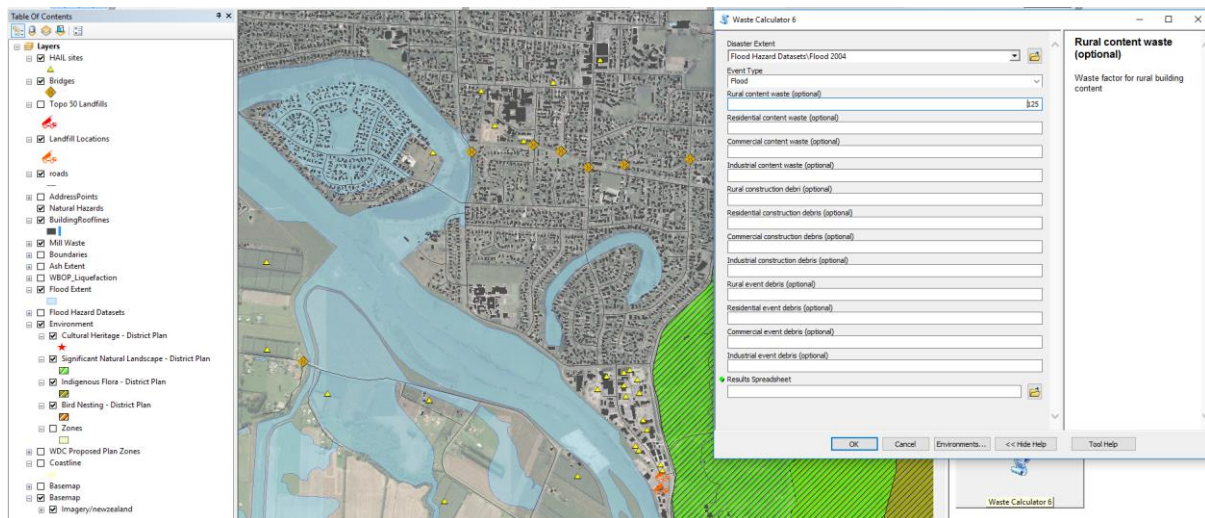


Figure 1. Desktop display interfacing showing waste calculation tool window.

The routing tool tasked with finding the nearest waste disposal site utilized ESRI's Arc Online utility services. These can be configured to use with the desktop Network Analyst toolsets, in this case the "Find Nearest Facilities" tool. Testing compared the route output of the ESRI road network to a custom network created from the LINZ road centerlines. Assessing the two outputs demonstrated that the ESRI routing service performed better, likely due to the time spent modelling traffic rules and drive times for different vehicle types. It was therefore decided that this should be used rather than spending time building a custom road network. Use of the ESRI routing service requires an Arc Online account and can be accessed via an ArcGIS desktop or web application. The tool allows the user to define a start point for the waste disposal journey, either by placing a point on the map or selecting an existing point, define any barriers and choose a waste disposal point layer, from which the closest landfill or recycling facility will be located based on the shortest, uninhibited road route. Driving directions can optionally be outputted to file and the route can be saved as a layer.

The web GIS application is hosted within the organisation's Portal environment. This is the web component of the enterprise GIS architecture. Datasets are published to the Portal environment for use in a web map. The web map is then used as the base for a web GIS application where "out of the box" and custom tools can be added, creating an intuitive GIS viewer where geoprocessing models can be run by users with little to no previous GIS experience. This has been created using ESRI's Web App Builder and includes both the custom waste calculation and waste location tools. The waste calculation is published from a python toolbox and has the same functionality as the desktop tool. The user is able to define a disaster type, waste factors and layer to use as the disaster extent with the results saved to spreadsheet. Figure 2 shows the results of the route finding tool using the flood extent as a barrier layer. In this scenario, the Whakatane floods have cut the western part of Edgecumbe off from Whakatane, making Kawerau the closest landfill facility.

Additional functionality within the web app includes the ability for the user to add their own spatial data from sources such as kmz, gps files, shapefiles or web layers; the ability to export data; and editing data if the ability to create new waste disposal locations is required. Similar to the desktop application, the user can also turn on and off other layers such as environmental overlays.

A further use of the web GIS could be the collection of information via a mobile device. For this purpose, a demo form was created for collecting preparedness actions information. This information can be associated with a person and location and displayed in the web viewer.

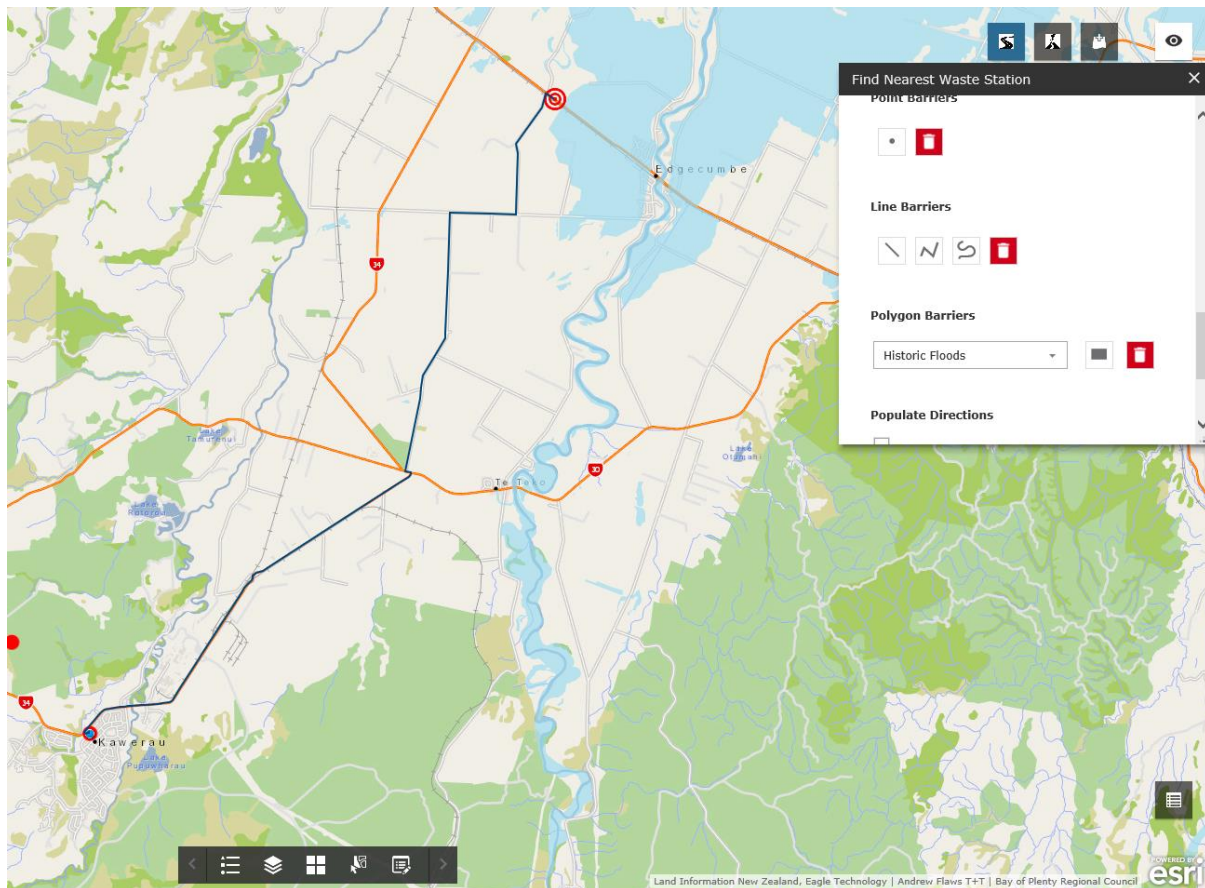


Figure 2. Nearest waste facility tool being used within the web GIS application.

In regard to hosting, it is intended that the web tool will be packaged up and deployed to the Regional Council. The tool script can be downloaded and re-configured for use within the Council's Portal web GIS environment by someone with GIS developer experience. The desktop tool can be shared as a map and geoprocessing package.

DISCUSSION

When planning an organisation's GIS architecture, there are a number of business decisions that must be considered. Questions relating to the functionality required; IT budget; audience/end users; current IT and GIS infrastructure; size of the organisation; and staff capability will all contribute to the final decision regarding which GIS platform to implement. For the DWMP project, time, budget and capability dictated that an ESRI web-app builder solution was best suited. Hosting this in an ArcGIS Portal environment proved favourable as this allowed the inclusion of a custom geoprocessing tool. Such custom functionality is not available, or planned for, via Arc GIS Online (AGOL), as confirmed by conversations with Paul Ross, Senior Product Manager for AGOL at ESRI. The fact that each of the regional councils directing this project already utilise ArcGIS Server and Portal also helped make this decision. In fact, rather than stand up such a web application from scratch, the waste calculator and waste-station finding widget could be added to an existing council disaster viewer, without having to re-build the entire application.

An obvious limitation to the above approach is the cost involved with implementing an ESRI enterprise GIS. Although such architecture is already in place for many New Zealand regional councils, for smaller district councils, smaller Pacific nations and non-profit aid organisations, the cost of the system may make it unobtainable. For this reason, many organisations with limited funding have chosen to deploy open source GIS tools for disaster preparedness planning. An example is the Pacific Catastrophe Risk Assessment (PCRAFI) GIS web tools. These comprise a number of layers and web maps served up from GeoServer via GeoNode, an open source hub for organising and sharing spatial datasets and maps, such as an average annual loss map for the Solomon Islands (http://pcrafi.spc.int/layers/geonode:sb_ward_aal). Such maps allow the user to query and download data, but lack the ability to perform spatial analysis, such as that provided by the waste calculator tool.

Developing such functionality within an open source environment would require greater GIS web developer experience and time than that available for the DWMP project and could provide an opportunity for computer science/GIS post-graduate research.

Here it is worth mentioning the wide adoption of the Open Geospatial Consortium (OGC) standards by local government, predominantly Web Map Services (WMS) and Web Feature Services (WFS). These may be consumed within both open source and commercial GIS desktop and web applications, so potential exists for an output created within an ESRI environment to be published as a WMS or WFS layer and added to an open source viewer. Juhasz et al (2016) used WFS in conjunction with Geoserver and web processing services to create a web GIS application relying on Volunteered Geographic Information (external users) to map inland water hazards within the Carpathian Basin. This tool allowed external users to edit GIS layers and model results, similar to the DWMP tool functionality that allows users to add or edit waste station points or create new disaster extents, illustrating that geoprocessing web tool creation is a developing field within open source GIS.

External to system architecture, room for improvement exists for the mapping and quantification of hazardous substances. This could include flags for buildings of a certain construction type or age to help identify asbestos; factoring in chemicals used for agriculture/horticulture by identifying rural properties (which have been classified by the tool) or stored in garden sheds; and sewage contamination based on flood extent. Waste stations could also be classified and filtered by waste type, so that hazardous materials are disposed of at an appropriate facility. To help calibrate waste factors used per property, disaster waste data from around the world could be analysed. This again could be a worthwhile project for post-graduate research.

CONCLUSION

As disasters, property and infrastructure all have a spatial component, a GIS tool is an integral part of disaster preparedness planning. From simply assessing whether a site may be a suitable location for a landfill by viewing overlays, to performing calculations based on spatial extent, the GIS tool adds value to the DWMP template. It has been developed in a way that it can be used both on and offline and scalable in that the ability to define layers and variables means it can be extended to other regions. Still in the early stages of development, it could be refined further to produce more realistic results. Examples include using building envelopes so that volumetric calculations can be used; using parcel areas to quantify disaster debris; including building material in the construction debris calculation; considering hazardous material; and making further use of community opinion regarding waste disposal location via crowd-sourcing.

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