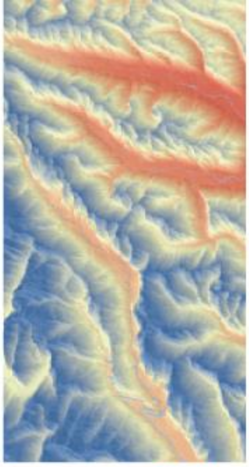
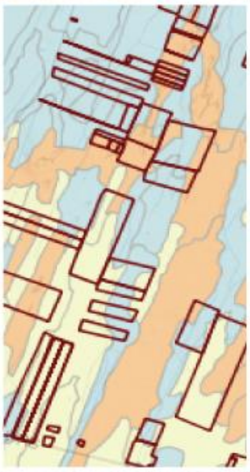
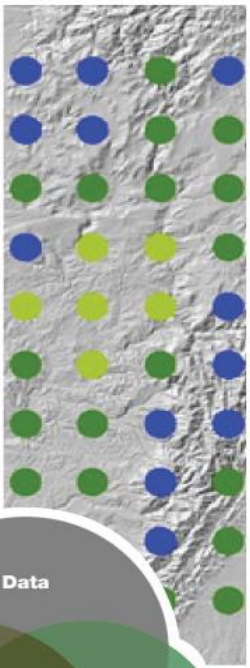
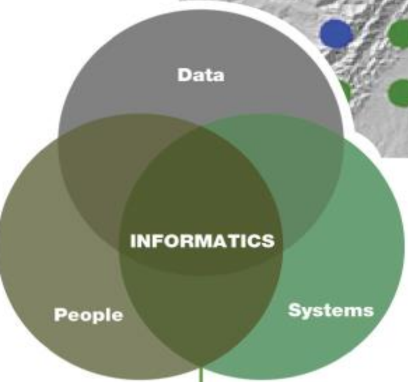


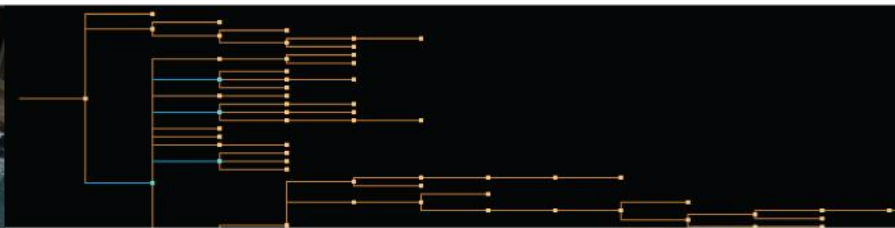




Options for creating a DEM of the Gisborne District coastal area

Envirolink Advice Grant: 1516-GSDC118





Landcare Research
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Options for creating a DEM of the Gisborne District coastal area

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Contents

Summary

Project and Client

- Gisborne District Council requires digital elevation model (DEM) information for the purposes of mapping coastal hazard zones (e.g. at risk from tsunami and sea level rise) within its district. Under Envirolink Advice Grant 1516-GSDC118 Landcare Research was contracted to recommend options on which DEMs are most fit for the council's purpose. This work was carried out in July–August 2014.

Objectives

- Define terms used in relation to elevation models, satellites and sensors.
- List the current freely-available sources of national DEM data.
- Describe the main sources of commercial data for creating DEMs.
- Give generic costs (per km^2) for data and processing.
- Make recommendations for the scenarios listed.

Recommendations

(1) A 2-km-wide coastal strip. Required accuracy of at least 1 m, preferably 0.5 m or better.

- If the prime need is for monitoring sea level rise, then a LiDAR survey will give the best, 0.5m or better, baseline height information. I understand that the cost for a survey of this area is estimated to be around $200 000.00 (Kim Smith, pers comm.)
- If you programmed a 0.5-m-resolution satellite service to collect the 2-km-wide coastal strip, and the coast is at least 180 km long, then the cost would be around $80,000 – $90,000 to acquire the stereo imagery, carry out the fieldwork to collect some ground control points, and to create the DEM.

(2) Extend coverage to SH 35 between Tokomaru Bay and Te Araroa, taking in Ruatoria and Te Puia and much of the Waipaoa flood plain. Required accuracy as for (1).

- For LiDAR costing, you would need to go back to the LiDAR service providers for a quotation for this.
- If you programmed a 0.5-m-resolution satellite service to collect a 10-km-wide (on average) coastal strip, and the coast is at least 180 km long, then the cost would be around $160,000 – $200,000 to acquire the stereo imagery, carry out the fieldwork to collect some ground control points, and to create the DEM.

(3) Acquisition of height information for the whole district, 5-m contours, or better.

- I recommend acquisition of SPOT-5 2.5-m stereo-pairs. The whole of the district would be contained within four 60 × 60 km scenes – three running down the coast and one more for the inland (western-most) part.
- For SPOT-5 panchromatic or colour bundle stereo-pairs, then the cost would be around \$150,000 – \$200,000 to acquire the stereo imagery, carry out the fieldwork to collect some ground control points, and to create the DEM. Data cost for panchromatic imagery would be around \$80,000; for colour bundle (pan-sharpened colour) it would be around \$120,000.

(4) Acquisition of very precise height information for the Gisborne City area for several projects, especially detailed stormwater modelling.

- For this application, LiDAR is really the only practicable solution. Council should approach the LiDAR operators for the costs of an urban survey.

(5) Best overall solution

Combining the need for best quality height information for the urban area, the near-coastal floodplains, and the whole East Coast coastal strip, with the need for better, but not the best, quality height information for the whole district:

- Bite the bullet and get a LiDAR strip.
- Use SPOT-5 2.5-m-spatial-resolution imagery for a district-wide DEM with ~ 5-m postings.

1 Introduction

Gisborne District Council requires digital elevation model (DEM) information for the purposes of mapping coastal hazard zones (e.g. at risk from tsunami and sea level rise) within its district. Under Envirolink Advice Grant 1516-GSDC118 Landcare Research was contracted to recommend options on which DEMs are most fit for the council's purpose. This work was carried out in July–August 2014.

2 Background

The coastline of Gisborne District, north-eastern North Island, extends from the Wharerata Hills in the south (boundary with Wairoa District, Hawke's Bay Region) to Lottin Point in the north. Its western boundary is the Raukumara Range, which separates it from Opotiki District, and its south-western boundary is Te Urewera National Park. The length of the coastline is estimated at c. 180 km.

Gisborne District Council requires DEM data for its coastal areas for a number of applications, particularly tsunami hazard modelling. The coastal areas of most importance are marked in green in Figure 1. These are the inhabited areas. The orange and yellow colours show where the council already has LiDAR available.

At the moment, the council has DEM information that has been derived from Land Information New Zealand (LINZ) 20-m contour maps and also has LiDAR for the near-coastal floodplain areas of Gisborne and Tolaga Bay. LiDAR of the whole coastal strip would be desirable but is an expensive option; with its low population density and low levels of development, the council finds it difficult to justify such an expense The council therefore wishes to investigate other options and may be prepared to compromise some spatial resolution for cost considerations.. However, the council still requires tools to help identify areas susceptible to coastal flooding (and tsunami) to enable them to plan any new developments to avoid the risk, and to better understand the seriousness of the existing risks.

Thus Gisborne District Council's prime need is for quality data of its coastline, to be used for mapping coastal hazard areas subject to storm flooding and tsunami, and for providing benchmark data on the current position of the coastline for comparing with future locations and also understanding the impact of sea level rise. Since sea level rise is most likely to be gradual, the finest resolution DEMs available are, without a doubt, the best current option for tracking these particular changes.

The possible scenarios for DEM purchase are:

1. To get a 2-km-wide coastal strip OR to extend the coverage inland to encompass State Highway 35 between Tokomaru Bay and Te Araroa, therefore taking in Ruatoria and Te Puia townships, as well as a lot of the Waipaoa flood plain. An accuracy of at least 1 m, preferably 0.5 m or better, is required for this.
2. Acquisition of height information for the whole of the district, preferably with contours at 5-m intervals, or better.
3. Acquisition of very precise height information for the Gisborne City area for several projects, especially detailed stormwater modelling.

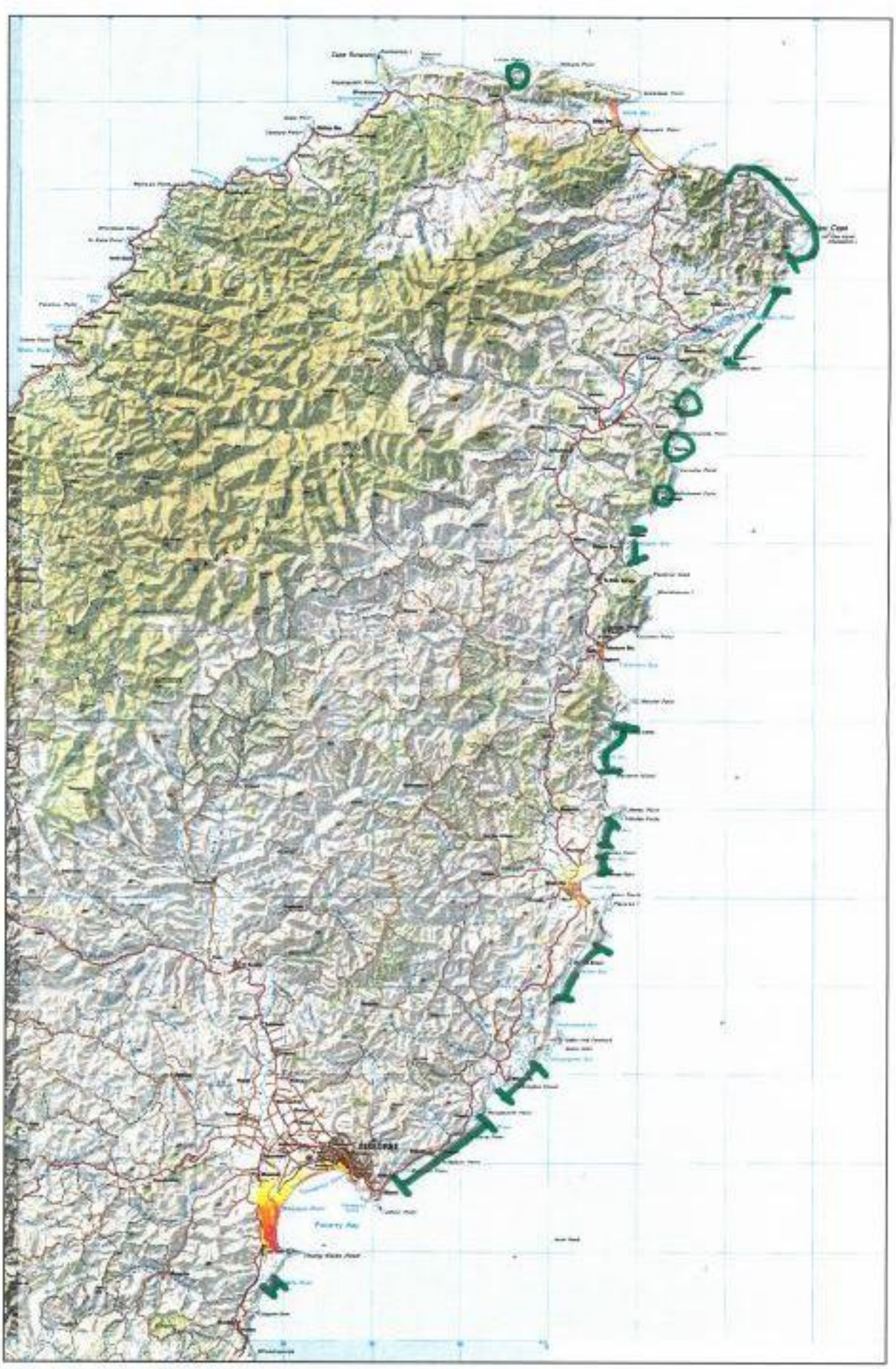

Figure 1 Coastline of Gisborne District showing areas where DEMs are required for tsunami hazard risk mapping (green) and those for which LiDAR already exists (yellow and orange).

3 Objectives

- Define terms used in relation to elevation models, satellites and sensors.
- List the current freely-available sources of national DEM data.
- Describe the main sources of commercial data for creating DEMs.
- Give generic costs (per km^2) for data and processing.
- Make recommendations for the scenarios listed above.

4 Definitions and background information on satellites and sensors

4.1 Digital elevation models (DEMs) and digital terrain models (DTMs)

There is no universal definition of the terms digital elevation model (DEM), digital terrain model (DTM) and digital surface model (DSM), and sometimes the three are used interchangeably. In most cases the term DSM refers to the surface of the earth including all the objects on it, such as buildings and trees. The term DEM is frequently used to define the surface of the earth with objects such as trees and buildings removed. The term DTM is more loosely defined, but is sometimes used in a more general sense to describe models of elevation, slope, curvature, and so on. On other occasions, a DTM refers to what we have defined as a DEM, with terrain heights measured at strategic positions (Intergovernmental Committee on Surveying and Mapping, ANZLIC). However, the usage of these terms is not universal, and the definitions used here might not be adopted elsewhere.

In all cases, the terms DSM, DEM, and DTM can be used to represent terrain elevations for ground positions at regularly spaced horizontal intervals. In this report we will use DEM throughout, and will qualify the degree of processing involved.

4.2 'Accuracy' and quality of DEMs

The accuracy of DEMs is frequently stated in different ways and with different meanings and it can be difficult to (a) drill down to what is being said, and (b) compare one DEM source with another.

The *absolute accuracy* is a measure of how accurate the elevation is at each pixel. That is, how closely the measured values are to the true values.

The *relative accuracy* describes how accurately the morphology of the surface is being represented by the DEM.

Factors affecting the quality of a DEM include the sampling density, the grid resolution or pixel size of the source data, the roughness of the terrain in relation to the resolution of the source data, the quality of the algorithms that are interpolating the data and analysing the terrain, and the availability of reference 3-D products such as coastlines and lakes. Some DEM accuracies will be quoted as RMSE – root mean square error. This is a measure of the accuracy of the data similar to the measure of standard deviation, if there is no bias in the data.

We generally prefer to quote two figures for the accuracy of a DEM – the bias and the standard error. The bias refers to how closely, on average, the measured DEM values are to the true DEM values. The standard error is the estimated standard deviation between the measured DEM values and the true DEM values, once the bias is removed. Generally, we want the bias to be zero (within experimental error), and the standard error to be as small as possible.

The bias and the standard error are preferred over the RMSE since the first two measure separately the effects of absolute and relative accuracy. When the bias of the DEM is precisely zero, the RMSE is the same as the standard error.

When organisations are quoting the accuracy of their DEMs, the figures are generally for 'ideal' topographic areas – not too hilly, not too much high vegetation. A DEM may be accurate to the specifications on, for example, open rolling areas of country, and a bit under-specification over a bush-clad mountainous area.

4.3 LiDAR/Lidar

Light detection and ranging (LiDAR, or Lidar, or just lidar), also known as laser altimetry, uses discrete pulses of laser light emitted from, and then reflected back to, a sensor to measure distances. LiDARs have sampling rates that produce highly accurate elevation points – a point cloud; these are used to generate 3-D versions of the earth's surface. Modern LiDAR instruments can be flown to produce DEMs with absolute accuracies down to 10 cm or better.

Point spacing is a way to describe the resolution of the LiDAR data. It tells you how far apart the measurements are and is analogous to the pixel size of an image. It is also sometimes referred to as 'pings' per square metre (pings/m^2).

LiDAR can be flown at day or night but, unlike radar, LiDAR cannot penetrate clouds, rain or dense haze and must be flown in good weather. Typically, LiDAR data is gathered from aerial platforms and, although there have been some space-based LiDAR systems, the data they have gathered does not have the spatial resolution required for high-resolution mapping.

4.4 Optical sensors/optical satellites

Optical sensors are sensitive to visible and infrared wavelengths. They can be panchromatic (black and white) or multispectral (collecting several spectral bands of information at once) or hyperspectral (dozens to hundreds of different bands at once). Most of the high-resolution optical satellite services collect panchromatic data at one resolution – say 0.5 m – and multispectral (blue, green red and near infrared typically) at a somewhat lower spatial resolution – say, 2 m – and then pan-sharpen the imagery to produce high-resolution colour imagery. Imagery for DEM generation is collected either from across-track (over more than one day) or from along-track (same day) stereo-pairs.

4.5 Radar/SAR

Radar detection and ranging (radar), or synthetic aperture radar (SAR), uses microwaves emitted from and then reflected back to a sensor to measure distances. Radar can operate day or night and in any weather conditions. The most common wavelengths for SAR data to be collected are X-band (3 cm), C-band (5.6 cm), and L-band (23 cm).

Radar images can be combined to create DEMs in the same manner as optical stereo (thus, radar stereo). Alternatively, radar images can be combined in interferometry (sometimes called InSAR or IfSAR) to create DEMs by allowing the radar images to interfere coherently. Interferometry can also be used to detect the rate of change of terrain movement, under suitable imaging conditions, which is useful for deformation studies.

4.6 Swath width

The swath, or swath width, is the strip of the Earth's surface from which imagery is collected by a moving vehicle such as a satellite, aircraft or ship. For example, the SPOT satellite series, which can collect imagery over the whole earth every 26 days, have swath widths of 60 km at nadir and up to 80 km when collecting imagery across-track. Many of the high-resolution satellite services have swath widths between 12 and 20 km.

5 Current DEMs and DEM sources

5.1 Free DEMs

All the DEMs described in this section are available free of charge. None of them are really suitable for applications that require height difference information of 5 m or less (Blackwell & Wells 1999). However, they can provide an excellent baseline dataset for the whole district.

5.1.1 Contour-derived DEMs

Most DEMs of New Zealand have been derived from LINZ 20-m contours. These have been processed, often with the incorporation of additional information such as spot heights, to generate DEMs at several spatial resolutions. Landcare Research has/uses one such DEM with 25-m postings and another that has been resampled to 15 m.

The differences between the different DEMs are due to the way they have been processed. For example, in reconstructing the DEM from contours, one could use all the contour and spot height information and try to get the terrain map that most closely fits the available data. Alternatively, one could use other information (e.g. knowledge of the river network) to generate a terrain map where the derived hydrological flow most closely fits the available flow network information. The DEMs that result from these two different approaches may produce slightly different information, and the preference for one over the other depends on the application. Clearly, if one is interested in hydrological flow, then a DEM generated with drainage enforced would be preferred.

5.1.2 Space Shuttle Radar-derived DEMs

New Zealand is also covered by the Global Shuttle Radar Topography Mapping Mission (SRTM) 90-m DEM. This DEM is derived from C-band SAR data that was collected in 2000. Approximately 45% of New Zealand is covered by the DLR (German Space Agency) X-band SRTM DEM that was also operated on the 2000 Shuttle mission. One pixel of the DEM files corresponds to approximately 25 × 25 m on the ground. The horizontal accuracy of the SRTM X-SAR DEMs is ±20 m (absolute) or ±15 m (relative); both are 90% circular errors. The vertical accuracy is ±16 m (absolute) or ±6 m (relative); both are 90% linear errors. However, there does not appear to have been any SRTM data collected over the East Cape area.

5.1.3 Combination DEM

There is also a DEM derived from a combination of Landcare Research's contour-derived DEM with 25-m postings and an SRTM DEM data with 30-m postings. The latter SRTM 30-m DEM was sourced from the US military. This combination DEM was created by SKM (now Jacobs New Zealand) and then used to orthorectify DigitalGlobe images that were used to create the KiwImage dataset. Although originally only available to KiwImage consortium members, this SRTM/SKM/Landcare DEM is now available to whole-of-Government (along with all the KiwImage data). Therefore, any CRI/territorial authority may use these data, but may not give the data away or sell it – the usual Terms and Conditions of imagery/data usage. This particular DEM cannot be released under Creative Commons. It comes with the following statement of use:

> This DEM has been merged from the Landcare Research DEM generated from the LINZ topographic data and the SRTM DEM. Please see technical reports for more detailed information. This DEM can be distributed and used by New Zealand Government agencies only. There is no stated accuracy for this DEM. Use is at the risk of the user.

It is likely that this DEM would be no better than other LINZ contour-derived DEMs for most places in New Zealand. An exception is areas of low and subdued topography – floodplains, low-lying coastal areas – where the 30-m postings of the defence-grade SRTM data would be adding considerable information. This is the DEM that was used to derive the 0–3 and 3–5 m information for the areas shown in Figure 2.

5.1.4 8-m DEM from Geographix

Geographix (a privately-owned mapping and cartographic design company) has developed an 8-m-spatial-resolution terrain model. The company says, 'This is a nation-wide dataset, derived mainly (but not wholly) from LINZ Topo50 contour and height point data. It is designed primarily for cartographic use and supports mapping to larger map scales than our earlier 20m terrain.' Spatial accuracy is nominally the same as for the LINZ source data: 90% of well-defined points are within ±22 m horizontally and within ±10 m vertically. These data are now available from LINZ using their data service.[1] A full description of how the DEM was generated can be obtained from the layer's metadata.

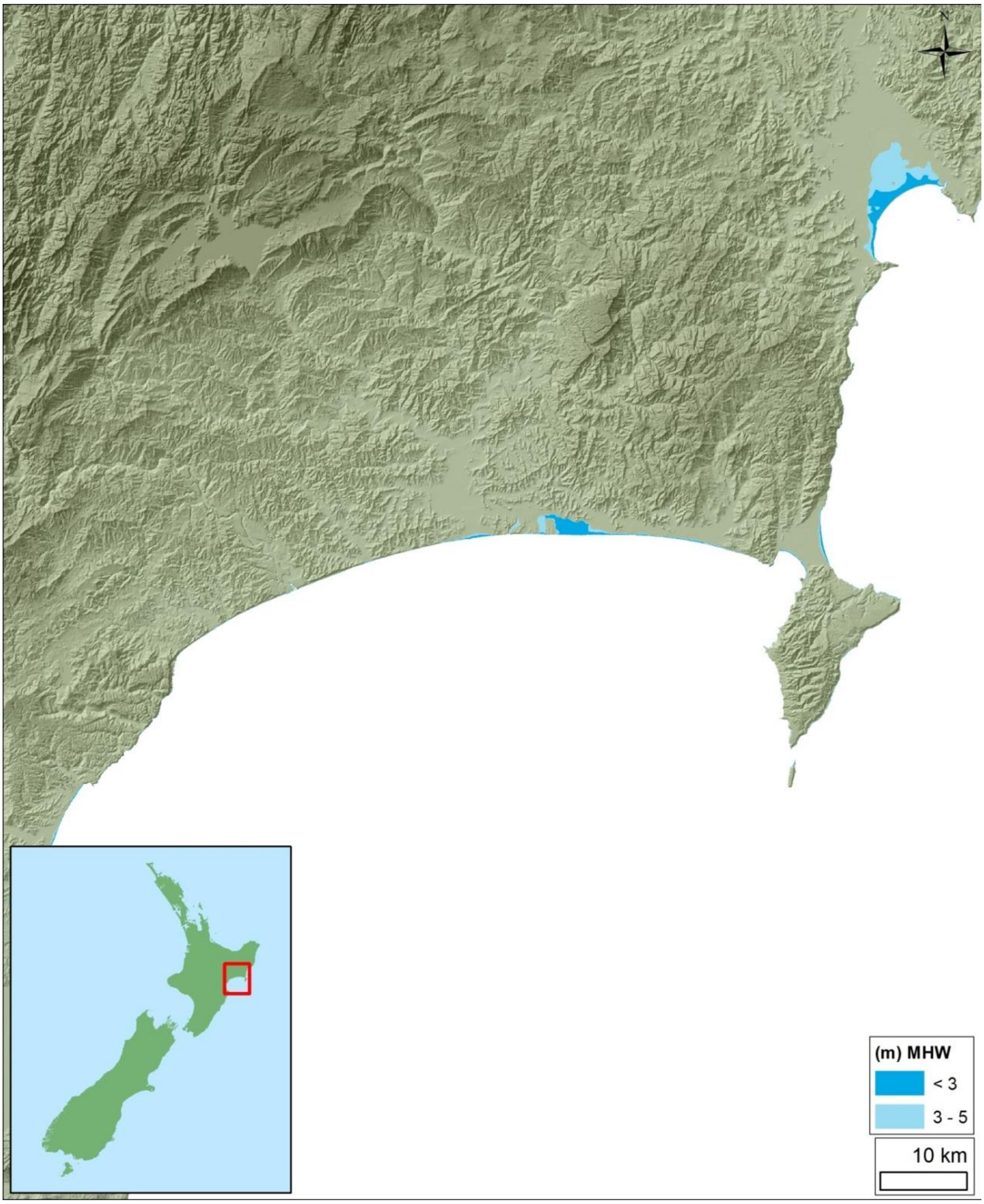

Figure 2 Layers (0–3 and 3–5 m) derived from an SKM-enhanced DEM based on the Landcare Research and NASA SRTM data (see text for more information about this DEM). Wairoa and Gisborne floodplain information created by NIWA for Gisborne District Council.

[1] https://data.linz.govt.nz/layer/1768-nz-8m-digital-elevation-model-2012/

5.1.5 ASTER (optical) satellite derived DEM

There is a DEM derived from stereo-pairs of images from an optical satellite sensor called ASTER. ASTER DEM standard data products are produced with 30-m postings and 1 × 1 degree tiles, and have height accuracies generally between 10 m and 25 m root mean square error (RMSE).

These data are available to download, free of charge from NASA Reverb,[2] LP DAAC Global Data Explorer,[3] and J-spacesystems ASTER GDEM.[4] Users are advised:

> …that the data contains anomalies and artefacts that will impede effectiveness for use in certain applications. The data are provided "as is," and neither NASA nor METI/Japan Space Systems (J-spacesystems) will be responsible for any damages resulting from use of the data.

5.2 Commercial DEMs

DEMs can be generated from:

- Aerial photography
- Satellites, either from optical stereo imagery – across-track stereo-pairs or by along-track stereo-pair/triplets, or synthetic aperture radar imagery – either by interferometry or by radar stereography
- Airborne LiDAR

DEMs could also be made by processing series of point-based information such as that collected by GPS.

5.2.1 Aerial photography

New Zealand Aerial Mapping (NZAM) typically flies its aerial photographic surveys with overlaps between images so that they can be used to generate DEMs. The height at which the photography is flown will determine the resolution that can be achieved. Normally, when you acquire a DEM via aerial photography you also acquire the photographs so these are also available for other mapping and monitoring purposes. Generating DEMs from aerial photographs is a relatively expensive process. You should contact NZAM for details.

5.2.2 Satellite imagery

Any satellite service that can collect stereo-pairs or interferometric pairs of images can be used to form DEMs. Here, I have restricted the list to satellite services that are capable of

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[2] http://reverb.echo.nasa.gov/reverb/

[3] http://gdex.cr.usgs.gov/gdex/

[4] http://www.jspacesystems.or.jp/ersdac/GDEM/E/index.html

creating DEMs with postings of 5 m or better. The characteristics of all the satellite services that may be mentioned in this report are summarised in Table 1.

Table 1 Main characteristics of the medium–high-resolution satellite services that are used to provide data for DEM generation

Satellite sensor	*Spectral bands & spatial resolutions*	*Swath width*	*Comments*
ALOS Prism	Panchromatic at 2.5 m	35 km	Prism-2 (planned launch 2016) will have a spatial resolution of 0.8 m and a swath width of 50 km
SPOT-6 and -7	Panchromatic at 1.5 m, Blue, green red, NIR at 6 m	60–80 km	Wide area coverage from a single dataset
Pleiades	Panchromatic at 0.5 m Blue, green red, NIR at 2 m	20 km	
Geoeye	Panchromatic at 0.46 m Blue, green red, NIR at 1.84 m	15.2 km	
Worldview	Panchromatic at 0.46 m Blue, green red, NIR at 1.84 m Plus red edge, coastal, yellow and NIR-2 at 1.84 m	16.4 km	Data available either as a 4-band + panchromatic, or 8-band + panchromatic.
TerraSAR-X/Tandem-X	X-band satellite service at 1 m, 3 m and 18 m, depending on the mode	10–30 km	X-band SAR satellite service
Radarsat	C-band satellite service with resolutions down to 1 m and 3 m, depending on the mode	18 km	C-band satellite service

Note that the resolutions and swath widths in Table 1 refer to images taken at nadir (looking straight down from an orbit directly over the test site). Most of the time, high-resolution satellite services are collecting imagery at off-nadir angles and the spatial resolutions of the data are less than the stated maximums. For example, a sensor with a spatial resolution of 1.8 m at nadir would be more like 2.4 m at an off-nadir angle of 20 degrees.

It is feasible to generate DEMs from these data without the use of any local control points, but the best accuracies are gained when some high-quality GPS points/ground control points are also used in the processing to ensure that the DEM has the best fit to area.

Most of the time, there is no or only some stereo imagery available over the area of interest and so the satellite service is programmed to collect the imagery required. Another reason to custom-programme is to collect up-to-data imagery, which can be used for other applications – land cover mapping for example, as well as for the DEM generation. With SAR imagery, it is a little more likely that imagery is already available since the data can be collected independently of light levels and weather conditions.

The usual way to create a DEM is:

- Arrange for a programming request to collect new satellite imagery
- Once received, carry out a fairly brief site investigation to collect some ground truth
- Process the imagery to create the DEM and supply along with the source data.

5.2.3 Satellite optical stereo or triplets

High resolution Pleiades/Worldview/Geoeye

All these satellite services can be tasked to collect both panchromatic and multispectral imagery, which is processed to form a DEM. The absolute accuracy of the surface so formed is likely to be equal to about double the spatial resolution of the sensor. That is, if the spatial resolution of the imagery source is 0.5 m, then the accuracy of the surface should be around 1 m. Of course, this can be very hard to quantify/prove if the DEM so-formed is the best available since there would be no equivalent surface with which to compare it.

Pleiades, Worldview, Geoeye and other high-resolution satellite services all have narrow swath widths, so, if a large area is required, the data have to be collected over a number of days. Landcare Research has produced a DEM of Chatham Island from Geoeye satellite stereo imagery at 0.5-m spatial resolution. There were some cloudy areas in the data, which had to be in-filled with height information from another older, coarser DEM, but overall, this DEM is accurate to ~ 1–3 m. Figure 3 shows a typical high-resolution satellite image of the Gisborne environs.

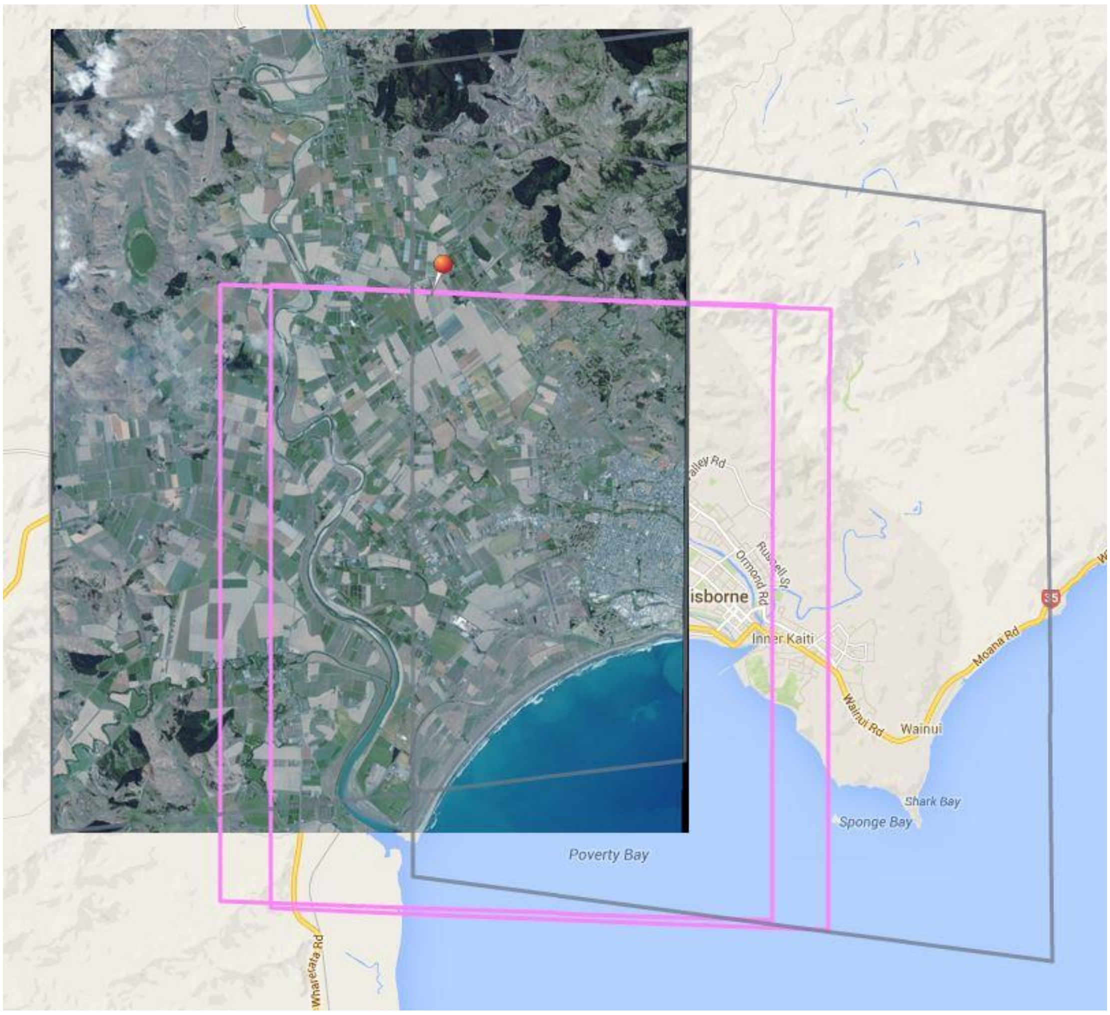

Figure 3 Sample of high resolution image coverage – IKONOS-2 – taken on 14 March 2014. These data have a spatial resolution of 1-m panchromatic and 4-m multispectral and a swath width of 11 km.

Earlier this year, the US Government relaxed the constraints on the permissible resolutions on high-resolution satellite services so that where, at present, the imagery has been resampled to 0.5 m before distribution, this will now reduce to around 40 cm and, when the next generations of satellites are launched (August 2014 onwards) this will reduce to 30 cm and, perhaps, even lower. While this cannot compete with LiDAR for spatial resolution, it will make these services very cost competitive for situations where the application can be met with slightly lower specifications.

Medium–high-resolution SPOT

SPOT-5, with up to 2.5-m spatial resolution, and SPOT-6 and -7, with 1.5-m resolution, can be used to generate DEMs over large areas of territory at reasonable costings compared with the higher resolution satellite services. Because these satellites have such a wide swath (60 km) the processing is easier since there are fewer different datasets to deal with and therefore the costs or processing would be somewhat lower (than those for higher resolution but narrower swath services).

Landcare Research has had experience deriving DEMs from SPOT panchromatic stereo-pairs; however, this was some years ago when the spatial resolution of these source data (from SPOT-3) was 10 m – so the overall accuracy of these DEMs was outside the scope of Gisborne District Council's current request. Figure 4 shows the area covered by a single 60 × 60 km SPOT image. Imagery from SPOT-6 and -7 can also be ordered and collected per square kilometre, with a minimum scene size of 500 km^2; SPOT-5 data can be purchased per full (60 × 60 km), half (42 × 42 km), quarter (30 × 30 km), and eighth (15 × 15 km) scenes.

Figure 4 Quick-look image of a SPOT-6 60 × 60 km scene taken on 19 March 2014.

Medium–high-resolution ALOS PRISM

ALOS PRISM is an along-track panchromatic sensor that collected imagery forward, behind, and directly below (fore-, aft-, and nadir triplet imagery) the satellite with a spatial resolution of 2.5 m. Landcare Research has used these data to create a DEM of the coastal Hawke's Bay from Napier to Porangahau. This DEM is accurate to ~ 3–5 m. This satellite is no longer operating and the replacement with higher spatial resolution is not due to be launched until 2016. However, there is some archival imagery over the Gisborne District (Figure 5). ALOS was a research satellite and, although the data it collected are sold commercially, the prices are very reasonable in comparison with other commercial satellite services. Although the cost of the data processing (per square kilometre) is similar, the much lower data cost makes ALOS PRISM a very attractive option for situations where the application can be satisfied with 3–5 m accuracy.

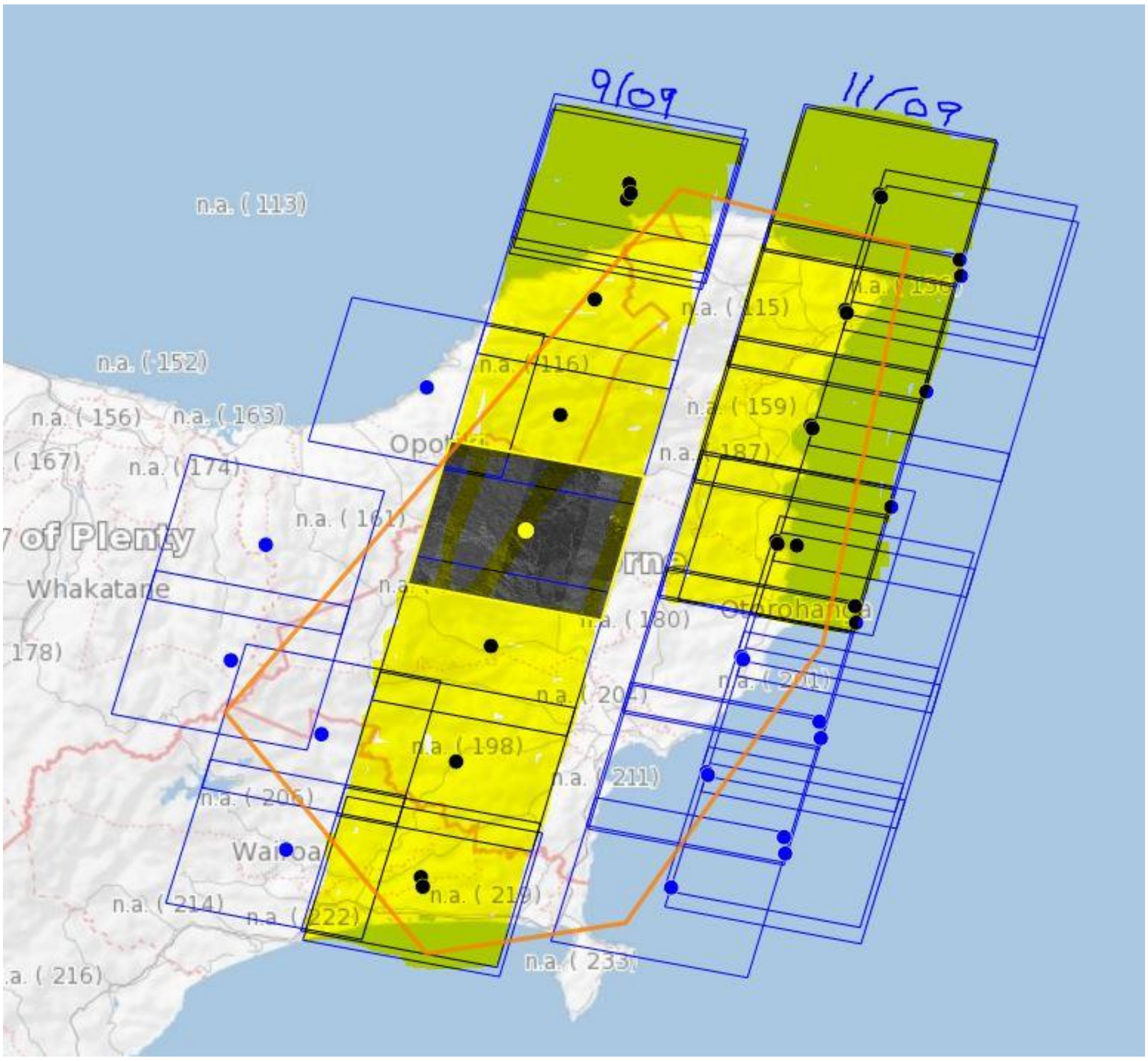

Figure 5 Archival ALOS PRISM triplet stereo imagery for the Gisborne District. The yellow-coloured rectangles show the imagery that is cloud-free or almost completely cloud free. Unfortunately, all the imagery around Gisborne City is cloudy. The handwritten figures above the orbit tracks are the dates the imagery was collected – September 2009 (2/9/09) for the inland run and November 2009 (16/11/09) for the coastal strip. The sun elevation angles in the inland strip vary from 38 degrees at the top to 37 degrees at the bottom; for the coastal strip these are 62–61 degrees. This high sun-elevation-angle imagery would be excellent for DEM generation.

5.2.4 SAR interferometry and SAR stereo

Pairs of SAR satellite images, either stereo-pairs or interferometric pairs, can be used to generate DEMs. Medium-resolution satellite services can be reasonably cost effective and can be particularly useful in areas where there is persistent cloud cover. However, the resolution from these medium-resolution SAR satellite services is not up to the 5 m or better spatial resolution requirement. SAR services that offer high-resolution imagery (1–3 m nominal spatial resolutions) are quite expensive and have fairly narrow swath widths so they are not described in detail since they are not the most appropriate services for Gisborne District Council's current requirements.

TerraSAR-X/TanDEM-X: However, it is worth mentioning that DLR (the German Space Agency) is currently beginning to produce a global DEM derived from high-resolution X-band radar collected by the TerraSAR-X and Tandem-X pair of satellites. This DEM will have 12-m postings and 2-m relative height accuracy for flat terrain. These accuracy figures are probably only for low-slope areas and for areas without forest. With other terrain or field data, this accuracy could be achieved by locally fitting the TanDEM-X data to other data, but in general the total accuracy is what is required.

5.2.5 LiDAR

DEMs produced using LiDAR data offer a high-resolution alternative for surface modelling in low-relief areas. The prime benefit offered by LiDAR is its capability to capture small variations in relative surface relief with a vertical accuracy of 0.1–0.2 m (NOAA 2012).

- In New Zealand, LiDAR has been flown for many/most of our urban centres and floodplains. It has also been flown for the Bay of Plenty (at 1 ping/m^2 for urban areas and 0.25 ping/m^2 in the rural areas) and the Wellington Region (at 1.25 pings/m^2). Gisborne District Council has LiDAR for part of the floodplain south of the city and for a small part of Tolaga Bay (see Figure 1).

6 Costs

For most satellite services, the actual processing costs to generate the DEM are very similar; the difference is in the cost of the source data. This can vary enormously depending on the size of the area required, the timeliness of the data, and upon the pricing at the time (satellite services can have 'specials'). Table 2 gives a series of generic costs for satellite and LiDAR data per square kilometre.

Note that costs can vary depending on the location and size of the area flown/imaged, competition between services to gain a contract, other data that may be collected at the same time, etc. The information in Table 2 is a guide: pricing is in New Zealand dollars and does not include GST.

Most satellite services have minimum order sizes and scene side sizes. For most high resolution services, the minimum scene size is 25–50 km^2. Larger scenes can be any shape but no side can be less than 5 km wide. Therefore, if you were to order imagery of, say, a coastal strip, then this strip would have to be a minimum of 5 km wide at all points.

Table 2 Indicative costs (NZ$/km^2) of data acquisition and processing to create custom DEMs

DEM source type	*Conditions/constraints*	*Data cost/km^2*	*Processing cost/km^2*	*Total cost/km^2*
High resolution (2.5 m) optical stereo satellite data	ALOS PRISM Triplets Panchromatic, 35-km swath	1.5–2.0	35	37
High resolution (2.5 m) optical stereo satellite data	SPOT-5 2.5-m panchromatic	5.60	35	40.60
High resolution (2.5 m) optical stereo	SPOT-5 2.5-m pan-sharpened colour	8.40	35	43.40
High resolution (1.5 m) optical stereo satellite data	SPOT-6 and -7 4-band, 60-km swath	15	35	50
High resolution (0.5 m) optical stereo satellite data	Pleiades, 4-band, 20-km swath	45–50	40	85–90
High resolution (0.5 m) optical stereo satellite data	Geoeye, 4-band 15-km swath	45–50	40	85–90
High resolution (0.5 m) optical stereo satellite data	Worldview, 4-band 16.4-km swath	75–80	40	115–120
High resolution (0.5 m) optical stereo satellite data	Worldview, 8-band 16.4-km swath	80–90	40	120–130
LiDAR	Assume 1 ping/m^2	100–120	100–120	200–240

7 Recommendations re the best options for Gisborne District Council

7.1 Conclusions

Obviously, LiDAR offers the highest resolution DEMs, but the cost of flying the whole district could be unaffordable, so council has to consider justifiable costings.

There has been some talk in Government circles of consortia being formed to commission LiDAR over large areas, to produce a number of products including DEM generation. Co-benefits of using LiDAR could include, for example, canopy height models, indigenous vegetation stratification, and ecosystem classifications. So the potential exists for entities such as the Department of Conservation, Ministry for the Environment, LINZ and so on to put in funds to assist a territorial authority to afford the survey and processing. This type of arrangement is outside the scope of this brief report. Here, I am considering the costings and options for Gisborne District Council alone.

7.2 Recommendations regarding council options

I will make a recommendation for each of the options Gisborne District Council raised as examples. These will be accompanied by a rough costing – these are indicative only; for accurate costings we would need to be in a position to make a formal quotation.

(1) A 2-km-wide coastal strip. An accuracy of at least 1 m, preferably 0.5 m or better, is required for this.

If the prime need is for monitoring sea level rise, then a LiDAR survey will give the best, 0.5m or better, baseline height information. I understand that LiDAR for the Gisborne District Council's 2-km-wide coastal strip has been costed at NZ$200,000 and that this is for the survey plus the post-processing to create the DEM.

If you programmed a 0.5-m-resolution satellite service to collect the coastal strip, and the coast is at least 180 km long (and as mentioned above, the minimum strip width you can order is 5 km), then the cost would be around $80,000 – $90,000 to acquire the stereo imagery, carry out the fieldwork to collect some ground control points, and to create the DEM.

(2) Extend the coverage to encompass State Highway 35 between Tokomaru Bay and Te Araroa, therefore also taking in Ruatoria and Te Puia townships, as well as a lot of the Waipaoa flood plain. An accuracy of at least 1 m, preferably 0.5 m or better, is required for this.

To incorporate the highway and the coastal area, I will assume that the coastal strip would need to be 10 km wide, on average. For LiDAR costing, you would need to go back to the LiDAR service providers for a quotation for this.

If you programmed a 0.5-m-resolution satellite service to collect a 10-km-wide (on average) coastal strip, and the coast is at least 180 km long, then the cost would be around $160,000 – $200,000 to acquire the stereo imagery, carry out the fieldwork to collect some ground control points, and to create the DEM.

(3) Acquisition of height information for the whole of the district, preferably with contours at 5-m intervals, or better.

Ideally, the ALOS PRISM satellite service would be a cost-effective option, but there is only suitable imagery for the coastal East Cape area. Instead, I would therefore recommend the acquisition of SPOT-5 2.5-m stereo-pairs. The whole of the district would be contained within four 60 × 60 km scenes – three running down the coast and one more for the inland (western-most) part of the district.

If the council used SPOT-5 panchromatic or colour bundle stereo-pairs, then the cost would be around $150,000 – $200,000 to acquire the stereo imagery, carry out the fieldwork to collect some ground control points, and to create the DEM. Note that the data cost for panchromatic imagery would be around $80,000; for colour bundle (pan-sharpened colour) imagery it would be around $120,000.

(4) Acquisition of very precise height information for the Gisborne City area for several projects, especially detailed stormwater modelling.

For this application, LiDAR is really the only practicable solution. Council should approach the LiDAR operators for the costs of an urban survey.

7.3 Best overall solution

Combining the need for best quality height information for the urban area, the near-coastal floodplains, and the whole East Coast coastal strip, with the need for better, but not the best, quality height information for the whole district, I would:

- Bite the bullet and get a LiDAR strip.
- Use SPOT-5 2.5-m-spatial-resolution imagery for a district-wide DEM with ~ 5-m postings.

8 Acknowledgements

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9 References

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