

Mapping Coastlines in WA Over 75 Years Capturing the Coastline September 2018



Capturing the Coastline

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Amendment record

This guidelines document is reviewed to ensure its continuing relevance to the systems and process that it describes. A record of contextual revisions is listed in the following table.

| Page No. | Context | Revision | Date |
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Executive Summary

The Department of Transport (DoT), has undertaken creation of important datasets for WA coastal managers and planners. This work was carried out on behalf of a multi-agency working group called the Coastal Management Advisory Group (CMAG), which comprises State Government representatives. Historical coastline change information was created, allowing better planning and management of coasts under threat from erosion hazards. The datasets are a collection of coastal lines captured from aerotriangulated aerial photography for all decades from 1940 – 2016, providing a long-term systematic measure of coastline movements around the State with an emphasis on erosion hotspots. This project was funded by DoT over two consecutive financial years for 2016-17 and 2017-18.

A coastal vegetation line represents the boundary between back beach and dune toe where vegetation first appears. By capturing the position of this line over the long term, a given section of coastline can be assessed for its evolution history over time. This coastline movement information is critical and valuable for coastal planning, plus it is included as a key requirement for coastal erosion allowance calculations in Schedule One of *State Planning Policy No. 2.6 State Coastal Planning Policy (SPP 2.6)*. In addition, management of coastal erosion hotspots around WA requires coastline movement information.

There is a large amount of aerial imagery starting from the 1940s to present covering WA's coast. In this project, DoT obtained and aerotriangulated historical aerial imagery from known sources covering erosion hotspots and built-up coastlines. The coastline position was then captured from this imagery to provide for a holistic measure of WA coastline movements for coastal managers and planners.

This project highlights the importance of continued coastline capture at regular intervals into the future through active budgetary and logistical planning. Key recommendations are listed below as outcomes of the project. These recommendations aim to ensure future generations can use this irreplaceable ground-truthed information to manage increasing challenges of coastal change under rising sea levels and a shifting climate.

- 1. DoT to conduct annual management and sourcing of aerial photography runs across the state
- 2. CMAG to source funding towards large scale aerial photography runs in intervals of no less than five years from Kalbarri to Israelite Bay
- 3. DoT to manage ongoing and free public access to coastline movement information through public data hosting services

Glossary of terms

| Aerial imagery: | Imagery taken by aircraft providing a plan view of land and sea below. Important coastal features such as cuspate forelands, spits, river mouths, and beaches can be viewed with aerial imagery. |
|---------------------|---|
| Aerotriangulation: | A specialised workflow applied to aerial imagery to make that imagery accurately placed for spatial analysis. This process uses various reference points to stich aerial imagery together, and allows vegetation line capture to take place using stereoplotting. |
| Coastline | On a sandy coast, the coastline may be identified on aerial photographs or by survey as the seaward extent of ephemeral vegetation on an accreting/stable coast, or the toe of the erosion scarp on an eroding coast. On a non-sandy coast or a coast without a clear vegetation line, the coastline is identifiable by other features such as rocky cliffs and engineered structures. |
| Coastline movement: | The movement of the coast between a discrete time interval in plan-view; this may be approximated from aerial photography by observing the difference over time when mapping the vegetation line or other boundaries (e.g. a cliff face boundary). Coastlines may retreat or advance over time due to the influence of natural coastal processes, anthropogenic activities, or a combination of the two. |
| Control bridging: | This process ascertains the spatial location of features both visible and measurable on aerial imagery. The process involves passing horizontal and vertical information from one aerial image to the next. |
| Hotspot: | A section of coastal land where erosion is highly likely to impact public and private physical assets, requiring management and adaptation action within the coming 25 years. |
| Stereomodel: | A set of overlapped aerial imagery viewable in 3D. |
| Stereoplotting: | The use of equipment and/or software to build a 3D image of aerial photography. This process allows the vegetation line to be more accurately determined from aerial imagery compared to simple tracing over an estimated 2D image boundary. |
| Vegetation line: | This line represents an interpreted interface between the back beach/foredune and the beginning of coastal heath/other vegetation along the coast. Where available, the vegetation line serves as an approximated position of the coastline. This vegetation line may change over time, whereby a retreating coast causes vegetation to be removed and the line moves landward, or an advancing coast allows vegetation to establish on new land and the line moves seaward. |

1. Introduction

1.1 Background

Historical coastline movement information is important for coastal adaptation planning as it:

- Reveals the range of natural dynamic movements in the coastline. Better understanding of this helps avoid ad hoc management actions immediately after severe storm erosion events, which often leads to worse outcomes later.
- Allows identification of long-term trends of erosion or accretion for SPP2.6 allowance calculations. A comprehensive record improves confidence in this calculation.
- Provides unbiased information in comprehensive records with a credible capture technique. This helps to avoid misinterpretation of historical erosion rates caused by skill limitation, bias from use of certain historical coastlines, or limited datasets.
- Directs the development of future adaptation solutions. In particular, the older 1940s and 1950s vegetation lines are rare, valuable datasets critical to understanding historic coastal change and setting context for coastal management.

Coastal erosion hotspots are locations where erosion is expected to impact public and private physical assets that will likely require future management action. In 2016 CMAG identified a need to evaluate the scale and extent of coastal erosion in WA. An erosion hotspot study was completed in July 2016, with a number of coastal locations identified as erosion hostspots; ranging from wave-dominated coasts in the south, up to tide-dominated, cyclone-prone coasts in the north (Seashore Engineering, 2016). These locations, and coastal communities in general, require comprehensive coastline movement information to effectively plan and manage future erosion hazards. This report documents work conducted by DoT to improve coastline movement information around the State, applying funding in 2016-17 and 2017-18.

A large amount of aerial imagery exists starting from the 1940s to present covering coastal sections of WA. This type of imagery is essential to create a baseline for coastline movement analyses at each coastal erosion hotspot. Much of the imagery has been scanned from film to digital format, although there are still some images that only exist on film. Older imagery on film must be digitised before modern spatial analyses can be applied.

Once older film-based imagery has been digitised, this imagery must be aerotriangulated so that capture can take place of the important vegetation line datasets, plus any other important coastal features such as cliffs and engineered structures. In addition to older film-based imagery, there also exists other more recent imagery that has been digitised but still requires aerotriangulation processing before important datasets can be captured.

1.2 Coastline capture for coastal management

Coastline movement information is important for coastal management (see Glossary), providing proxy information about how a given section of coastline evolves over time (Damara, 2016). Coastline movement information is derived in this project from the position of a captured vegetation line for a given snapshot in time, which is progressively mapped over decades. Where a vegetation line could not be captured from aerial imagery, the coastline was defined by other significant features such as rocky cliffs and engineered structures (see Section 2.5).

A vegetation line represents the boundary between back beach and dune toe where vegetation first appears. This project applies this line as an approximation of the coastline position. Figure 1 illustrates where the vegetation line is applied to for accreting, eroding, or stable beaches. If a beach is advancing (accreting), dunes grow and expand seaward, allowing new coastal heath to sprout seaward of established vegetation thus pushing the vegetation line seaward. If a beach is retreating (eroding), the toe of the fore dune is undercut, steepening the beach and removing vegetation to shift the vegetation line landwards.

These changes in the vegetation line are known as coastline movements and can be observed in aerial photography. Over time, changes in the vegetation line position can determine long-term trends and approximate long-term evolution of the coastline (Damara, 2016). Continual recession of the vegetation line represents a coast that is eroding long-term. Continual accretion of the vegetation line represents a coast that is widening over time. A static vegetation line represents a stable coast with minimal net sand movement or supply, while one that fluctuates back and forth over time represents a dynamic coastline whereby sand supply and storage may oscillate.

The importance of coastline movement information can be observed by examining inclusion of historical coastal change in coastal planning policy, such as in Schedule One from SPP 2.6 (WAPC, 2013). Coastline movement information in the context of SPP 2.6 is discussed further in Section 4.





Figure 1: Examples of the captured vegetation line position for accreting, eroding, or stable beaches; adapted from (DoT, 2009)

1.3 Purpose

The purpose of this project was to improve coastal planning and management outcomes, in accordance with State policy and guidelines, by creating robust and comprehensive coastline movement information for WA.

1.4 Aims and objectives

The project aim was to provide coastline movement information for important coastal locations around the State by sourcing and analysing all available aerial imagery. Hotspots and areas of high urban development were the focus for this project, alongside other potentially important areas to manage in the future. Extensive coastline movement information is now available for more than 90% of WA's coastal settlements.

To achieve the project aim, four key steps were taken:

- 1. Source historical coastal aerial imagery
- 2. Digitise older aerial imagery where applicable
- 3. Aerotriangulate aerial imagery where applicable
- 4. Capture the vegetation line and other coastal features from aerotriangulated aerial imagery
- 5. Make all datasets created by this project publicly available and free on-line.



2. Methods

2.1 Software and hardware

The following key software was required to complete project objectives. These tools allow creation of a stereomodel (see Glossary):

- Trimble INPHO Applications Master Match AT (License on Ioan from Landgate)
- ESRI ArcMap
- ERDAS Stereo Analyst for ArcGIS
- ERDAS Imagine

The following key hardware was required for this project (Figure 2):

- 3D capable monitor for viewing aerial imagery in 3D
- 3D viewing glasses for viewing aerial imagery in 3D
- 'Topo' mouse for ergonomic plotting/manipulation of linework on aerial imagery
- High-end video card for high performance requirements of the described software



Figure 2: Hardware required for the project (left to right top to bottom: 3D monitor, glasses, mouse, and video card; individual copyright laws apply to these products)

2.2 Sourcing of aerial imagery

To build a comprehensive record of coastline movement information around WA, aerial imagery was sourced to provide satisfactory precision of coastline change since 1940. For the period of the 1940s to the 1980s inclusive, availability of scarce aerial photos dictated imagery selection. For each location at least one coastline per decade was targeted. From the 1990s onwards two sets of imagery were sourced per location, where available (e.g. imagery from 1990 and 1995 were sourced from Broome for the 1990s). The higher frequency in imagery sourced from the 1990s onwards allows more recent trends in coastline movements to be assessed in greater detail.

Three sources were used to compile required imagery for this project. Imagery sourced externally was requested with accompanying aerotriangulation data for that imagery when possible:

- DoT archives
- Landgate through a special licence agreement
- Photomapping (commercial entity based in New South Wales)

Figure 3 displays the dynamic record of aerial imagery available with four examples at Beadon Creek, Onslow shown between the 1940s – 2010s. This basic imagery was sourced from the DoT archive, though aerotriangulation was needed for older photography which required additional film to be sourced from Photomapping.

Figure 3: Example of aerial imagery available from the DoT archive for Beadon Creek, Onslow: top left from May 1949, top right from September 1971, bottom left from March 1999 (After TC Vance erosion), and bottom right from February 2015

Some imagery required could not be sourced for this project. These images were either missing from existing databases, or never existed in the first place (i.e. no aerial imagery runs took place at various locations for some decades). A full list of imagery that could not be sourced is provided in Table A1 of Appendix A.

2.3 Digitisation of older imagery

Imagery stored on film was digitised by Photomapping for provision to DoT. This film is stored in a refrigerated vault at Photomapping facilities to ensure preservation, requiring individual film removal from storage for scanning to complete digitisation.

File sizes for data to be delivered were excessive, prohibiting digital transfer from file hosting sites. Instead, files were downloaded onto external hard drives and sent by freight from NSW to the DoT Fremantle office. Once imagery required had been sourced, aerotriangulation could take place.

2.4 Aerotriangulation of imagery

Aerotriangulation is a specialised workflow applied to aerial imagery to make that imagery accurately placed for spatial analysis. This process uses various reference points to position and stitch aerial imagery together, and allows the vegetation line to be more accurately determined from aerial imagery compared to simple tracing over an estimated 2D image boundary. Note that some sourced imagery already had aerotriangulation data available for this project, so this task only applied to imagery where these data were missing/did not exist.

An overview of aerotriangulation processes is provided in Appendix B. The Appendix B summary discusses that this critical phase in photogrammetric mapping involves rectifying aerial imagery so that it is correctly positioned on the surface of the earth. To aid this, computer processing has played a major role in driving mapping scientists to develop rigorous and efficient mathematical protocols for improved stereomodel control. This was achieved by use of a minimum number of strategically positioned common ground survey points.

The analytical software used in this project, as listed in Section 2.1, has built-in quality control. This has improved the process of positioning imagery relative to the earth's surface and the quality of photogrammetric mapping.

Figure 4: Aerotriangulation job in progress showing required hardware (monitor and topo mouse)

Aerotriangulation is usually accomplished via the below general sequence:

- 1. Collection of horizontal and vertical coordinate data for aerial imagery
- 2. Conduct control bridging (see Glossary)
- 3. Ensure geometric stability by using a minimum of four points in the imagery corners with established horizontal and vertical locations in a full stereomodel

The specific process to conduct aerotriangulation in this project varied depending on the type of image, whether previous aerotriangulation had been completed for that image, and the age of the image. The main inputs for creating an aerotriangulation project in Trimble INPHO Applications Master Match AT are Global Positioning System (GPS) photo centre points and ground control. Once these are generated for imagery sourced in this project, aerotriangulation usually involved the specific tasks listed below:

- 1. Photo centre coordinates were created by either manual methods or from an existing Landgate GPS file
- 2. Calibration was conducted for the camera used to capture the image
- 3. Once the project was created in Trimble INPHO the GPS points were imported, the imagery directory was linked to these points, and ground control was entered
- 4. An interior orientation was performed on all imagery
- 5. Manual points were used to link each stereomodel to the neighbouring one
- 6. Three control points at a minimum were created and then automatic point measurements were calculated
- 7. Post-processing was carried out repeatedly by re-reading points and adding control until the required results (as per the previous list) were established for the project

Once aerotriangulation was completed, capture of coastline information could begin.

2.5 Coastline capture

Two photogrammetrists conducted vegetation line capture in-house for this project following methods and specifications defined here in addition to standard DoT workflows from (DoT, 2009).

Vegetation line creation to capture the coastline was conducted on all available imagery using the software and hardware listed in Section 2.1. These tools were required to ensure accurate stereoplotting (see Glossary). By using these tools, a 3D image can be manipulated by a photogrammetrist to more readily discern the boundary between fore dune and back beach as described in Section 1.2. Figure 5 illustrates the capture of vegetation lines from aerial imagery.

Figure 5: Vegetation line capture job in progress using specialised hardware (monitor, glasses, and topo mouse)

Many locations around WA do not comprise sandy open coasts as described in Section 1.2. For example, coastal areas may contain rocky cliffs, minimal vegetation on the coastline, coastal protection structures, or rocky underlying substrate that can become intermittently or permanently exposed over time. To account for this, capture of additional lines other than the vegetation line took place. These datasets were also captured alongside the vegetation line where applicable:

- Hard rock/cliff face
- Sand-drift
- Reef and seagrass meadows
- AHD 0m
- Man-made/hard engineered coastlines

The method used to create these extra lines was similar to the process shown in Figure 5. Using these lines in conjunction with the coastal vegetation line allows detailed characteristics of a given area of coast to be identified (Figure 6). Assessment of these datasets together can build a stronger understanding of coastline behavior rather than from interrogation of the vegetation line alone.

In some cases, the various lines captured will blend together, such as where coastal protection structures end and a vegetated fore dune begins (e.g. the dark green lines in Figure 6). Resultantly, interpretation of coastline movements for a section of coastline is best informed by observing all lines described above concurrently (and sometimes by combining line types), to approximate a generalised coastline position for a given year.

Figure 6: Illustration from Albany, Emu Point of different coastal features captured alongside the vegetation line; for example, the dark green lines capture hard rock structures that then blend into the vegetation line

3. Results

3.1 Coverage of created datasets

While capturing coastal erosion hotspot coastlines was the project goal, the final coastline datasets captured in Section 2.5 were comprehensive enough to cover almost all coastal settlements around WA (Figure 7). Note the dark green colouring is also accompanied by light and fluorescent green areas for locations with lower data availability as per the inset in Figure 7. Locations with lower data availability are also outlined in Table A1 of Appendix A. The WA coastal communities with zero coastline capture in this project were Karratha, Djarindjin, and Wyndham.

Figure 7: Spatial coverage of coastline datasets; the inset allows easier observation of all areas covered in the State. Note Cocos (K) Islands and Christmas Island were also covered in this project though are not viewable here A full list of coastlines captured for WA is in Table A2 of Appendix A. This list also provides the distance of coastline capture undertaken for each location. From Table A2, 3,056km of WA's coastline has been captured specifically for these locations between the 1940s to present.

In addition to the coastlines captured in Table A2, extra capture took place for unpopulated coastlines between Kalbarri to Israelite Bay from large-scale flight runs. Coastlines from these large-scale runs were captured for the whole 2015-16 run and part of the 2008-09 run (i.e. from Kalbarri to Augusta). Extra distance captured in these runs had a combined total greater than 2,553km. Thus, the total coastline distance captured in this project was over 5,589km, clearly providing for a substantial amount of coastline movement information for planners and managers.

3.2 Web hosting of created datasets

All datasets in this project were created in DoT offices and stored locally until internet hosting was available for wider accessibility to the public. Three sites for data hosting were used in this project¹:

- 1. Data WA https://data.wa.gov.au/home
- 2. WA Marine Map https://maps.slip.wa.gov.au/Marine/app/
- 3. National Map https://nationalmap.gov.au/

It is noted here that datasets are simplified before upload to web hosting sites to reduce storage requirements and improve accessibility. The main simplification includes combination of various line types described in Section 2.5, such as the hard cliff face line and vegetation line, to provide a more generalised line of coastline position for a given year. This was conducted to provide the closest representation achievable of the coast from a single line. Original datasets with all types of coastline features captured are available on request from DoT.

Data hosting in this project began with upload of vegetation line data to Data WA. This host is managed by the Western Australian Land Information Authority (WALIA). Coastline data were uploaded to this host and can be found in dataset DOT-023 as shown in Figure 8 (WALIA, 2018).

| GOVERNMENT OF WESTERN AUSTRALIA | <mark>data.w</mark> a Providing | access to WA | governr | ment data | Search for data | | Home | Q Data |
|---|------------------------------------|--|-----------------|----------------------|----------------------------------|--------------|-----------|------------------|
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| dian cean Map data © OpenStreeth Tiles by ManBoy | Australia Tosmo Seo | Coastline Mover Spatial representation of | ments - Ve | getation Lines | s (DOT-023) Department of Tra | nsport (DoT) | (WA). The | e Polyline |
| Tiles by MapBox | | feature class contains li | ne work that re | present the position | of the | | | |

Figure 8: Publicly available location of coastline data created in this project (WALIA, 2018)

¹ All links were accurate at the time of the last document update.

Subsequent to hosting by Data WA, development of both a State and national coastal information browser provides greater access to data created in this project. The State level browser that hosts coastline movement information is called the WA Marine Map (WAMM). This browser is managed by Landgate (SLIP, 2018). WAMM is a publicly accessible spatial tool providing users the ability to view operational layers from the following categories:

- Maritime and shipping
- Coastal planning
- Land features and boundaries
- Mining and petroleum
- Marine parks and fishing
- Bathymetry

The datasets created for this project were made available for both viewing and download in WAMM. Coastline movement information was located under the coastal planning category (Figure 9).

Figure 9: Coastline datasets viewable in WAMM (SLIP, 2018)

The national level browser that hosts coastline movement datasets is called the National Map. This browser is managed by the Department of Prime Minister and Cabinet (DoPMC, 2018). The National Map is like WAMM in that coastal information layers may be viewed and downloaded by the public. In addition to this function, the National Map includes non-coastal information as well (such as inland terrestrial vegetation information) and allows users to upload their own spatial information layers. Note that given the wealth of information hosted by this browser, some users may find the National Map takes more time to navigate than the other hosts when searching for a specific set of information.

Coastline movement information created for this project is available for viewing and download in the National Map. The National Map is linked to Data WA; thus, searching for DOT-023 in the National Map should reveal coastline movement information for viewing (Figure 10).

It is noted here that the file hosting services described above were representative at the time of writing. It is acknowledged that the transient nature of online data management may result in these hosts changing or removing coastline movement data from their service. DoT directs that coastline movement data created in this project will still be available by request directly to DoT.

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| + Add data | Data Catalogue My Data | Done |
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| (DOT-023) | Search results | OCEANIA |
| Zoom To Extent About This Data Split Remove 💬 | Coastline Movements - Vegetation Lines (DOT-023) | |
| Opacity: 60 % | | |
| 1875 (1941; 1942; 1942; 1944; 1946; 1948; 1964; 1964 1962; 1954; 1956; 1956; 1957; 1957; 1959 1962; 1954; 1957; 1957; 1957; 1958; 1959 1979; 1971; 1972; 1972; 1974; 1976; 1976; 1977; 1976 1950; 1951; 1952; 1952; 1954; 1956; 1957; 1956; 1959 1950; 1951; 1952; 1952; 1954; 1956; 1957; 1956; 1959 1950; 1951; 1952; 1952; 1954; 1956; 1957; 1956; 1959 1950; 1951; 1952; 1952; 1954; 1956; 1957; 1956; 1959 2000 2001 2005 2005 2005 | | Coastline Movements - Vegetation Lines (DOT-023) Dataset Description Spatial representation of coastline movements data for the Department of Transport (DoT) (WA). The Polyline feature class contains line work that represent the position of the vegetation lines for WA held by DoT. The complete dataset also includes generalised waterlines and line features that mark the extent of sand drift areas along the WA coast. This data is available by request from DoT. This data has been captured using available imagery and photogrammetrical techniques. These Coastline Movement Lines are used by |
| 2009 2010 2011 2012 | | the Department of Transport, WA, to produce coastline movement drawings. These drawings and their associated data are used by coastal engineers to estimate horizontal setback datum used in coastal planning. |
| 2013 2014 2015 | | Service Description |
| -2016 | | WMS |

Figure 10: Coastline datasets viewable in the National Map (DoPMC, 2018)

3.3 Dataset accuracy and ameliorations

There was a wide range of accuracies expected for aerotriangulation of imagery in this project, depending on the age of aerial imagery sourced. Factors affecting horizontal accuracy are discussed in this section, and in Appendix B. Where possible, methods to address accuracy issues are described. Table 1 displays generalised horizontal accuracies expected for ages of imagery sourced due to the discussed factors.

Inclusion of GPS in photo centres

The primary factor in determining accuracy was implementation of differential GPS in survey aircraft from 1992 onwards. This led to an improvement in overall accuracy of aerotriangulation projects whereby GPS coordinates of the photo centre can be used in block calculations. For this project, photo centres of images in projects pre-1992 were manually measured from imagery in ArcMap; these were subsequently used to get an initial block of images imported into Trimble INPHO. This method allowed determination of basic orientation of the photography block. In addition, further tie points were generated both manually and automatically, and these tie points were used to connect all photos.

Imagery control

Survey control points are the most effective means to provide horizontal and vertical control to sourced aerial imagery. As time progresses, use of these control points becomes more difficult due to changes in man-made and natural features (refer back to Figure 3 for a visualisation of this). To overcome this, control was derived by highlighting the same points visible over different years in photography.

Control transfer

Some aerial imagery had control points shifted, removed, created, or replaced at different locations in the image between different years. Error created by control transfer was compounded the further back these changes occurred in time.

Condition of photography

Older film usually generates poorer quality scans than newer film due to inherent problems with storing acetone based film products. Acetate film base deterioration, also known as, 'The Vinegar Syndrome', can affect the quality of the image which effectively reduces resolution and/or the accuracy of identifiable features.

| | Table 1. | Expected | horizontal | accuracy | for imagerv | ages sourced | l (adapted from | n Appendix B |
|--|----------|----------|------------|----------|-------------|--------------|-----------------|--------------|
|--|----------|----------|------------|----------|-------------|--------------|-----------------|--------------|

| Imagery Age | Horizontal Accuracy |
|---------------|---------------------|
| 2005 - latest | ± 3 to 4 pixels |
| 1995 - 2004 | ± 6 pixels |
| 1980 - 1994 | ± 8 pixels |
| 1960 - 1979 | ± 10 pixels |
| 1940 - 1959 | ± 15 pixels |

In Table 1, pixels were used rather than metres to demonstrate expected accuracy of imagery due to different resolutions of imagery flown. Some flights were taken at higher/lower altitudes compared to flights elsewhere, occasionally creating variable spatial coverage per image at different locations from similar years. In addition, older film produced lower resolution images².

To exemplify the above, a flight from the 1940s flown at a scale of 1:25000 and scanned at 15 μ m to create digital imagery would produce a pixel resolution equating to a 0.375m Ground Sample Distance (GSD). The resultant accuracy of imagery scanned from this flight would be ±5.6m. The same flight captured in 2004 at a scale of 1:25000 and scanned at a higher resolution 20 μ m to create digital imagery would produce a pixel resolution equating to a 0.5m GSD. The resultant accuracy of imagery scanned from this flight would be ±5.6m. The same flight would produce a pixel resolution equating to a 0.5m GSD. The resultant accuracy of imagery scanned from this flight would thus improve to ±3.0m.

Most projects fell within the accuracies provided in Table 1, however a small number were worse than expected. In these cases, the required vector information was captured from imagery and then moved into Arcmap to register with newer projects which had a higher expected accuracy.

It is important to note here that the lower horizontal accuracy of older aerial imagery reduces achievable precision when capturing the coastline. The result is that coastlines captured from older imagery may not define the same level of detailed features compared to more recent imagery.

² All non-digital (i.e. film-based) imagery supplied by Landgate was scanned at 20µm. All historical imagery supplied via Photomapping Services from the Geoscience Australia archives was scanned at 15µm.

4. Discussion

4.1 Applications of improved coastline data in WA

The primary purpose for creating a systematic coastline dataset across WA is to inform local coastal managers, State planners, Landgate, and DoT maritime facility planners of historical trends in coastline movement for their coastal investigations, management needs, and planning needs. There are critical requirements in coastal planning policy in WA and specific guidance is provided by SPP 2.6. Schedule One in this policy provides guidance towards calculating allowances for coastal processes that cause erosion (WAPC, 2013).

For a sandy coast the allowance for erosion is calculated as the sum of:

- S1 Erosion allowance for the current risk of storm erosion
- S2 Erosion allowance for historical coastline movement trends
- S3 Erosion allowance for erosion caused by future sea level rise
- Uncertainty allowance 0.2m/yr additional allowance for uncertainty

Coastline movement information provides critical information for the S2 calculation. Figure 11 illustrates how S1, S2, S3, and the Uncertainty allowance collectively define a total erosion allowance calculated using Schedule One of SPP 2.6. In the Figure 11 example of a soft sandy eroding coastline, the beach has experienced long-term erosion, so S2 provides an allowance for this erosion trend continuing.

Figure 11: Schedule One erosion allowance example on a cross-section of sandy eroding coastline; note allowances are illustrative and necessarily not to scale

To calculate S2, SPP 2.6 directs that an annual rate of change must be derived from historical trends in erosion or accretion. If long-term coastline movement trends reveal the coast to exhibit an erosion trend, this annual rate is multiplied by 100 to provide a speculative 100-year coastline movement allowance for S2. The conventional method in WA to derive an annual rate is by observing changes in the coastline from available coastline movement information.

The approach to allowance planning for new developments at Greenfield sites directed in SPP 2.6 has also been used for wider applications, such as assessing hazards in already developed areas (Brownfield sites). Therefore, this approach has important applications to the coastlines of coastal management hotspots around the State. Applying this same method for S2 allowance planning to Brownfield sites occurs in Coastal Hazard Risk Management and Adaptation Planning (CHMRAP) (DoP, 2014). Many such CHRMAP examples exist, including Harvey (Damara, 2016) and Albany (EvoCoast, 2017).

Before this project was undertaken, coastline movement information around the State was created ad hoc and with imprecise data coverage; this often causes reduced confidence in the calculation for S2. For example, a location with a vegetation line available from only one to two decades provides limited information about historical trends over 100 years.

By targeting as many decades as possible in this project, much higher confidence can be gained about how a given piece of coastline is evolving. Resultantly, applying Schedule One of SPP 2.6 now provides improved outcomes for coastal planners and developers. As an example only, Figure 12 provides a closer look at possible planning implications around Drummond Cove (north of Geraldton), showcasing how understanding can been improved for coastline movement trends using the more comprehensive coastline datasets developed in this project.

Figure 12: Drummond cove vegetation line coverage before (left) and after (right) this project; white transect lines are also shown; note the dates on the left image's lines are: left green = 2007, middle green = 2004, pink = 1995, and right green = 2013

Using Figure 12, historical coastline trends can be derived from both the before and after images for coastline movements. Table 2 gives a breakdown of coastline movements measured between each year from the white transect lines in Figure 12. Note that 1940s and 1950s vegetation line capture has not been completed for Drummond Cove at the time of writing.

| Table 2: Drummond cove coastline movement analysis before the project commenced (left image of Figure 12) and with new |
|--|
| vegetation lines created (right image of Figure 12); please note figures are rounded to two decimals |

| Before | | Updated | |
|-----------------------|------------------------|-----------------------|------------------------|
| Period (yr) | Coastline movement (m) | Period (yr) | Coastline movement (m) |
| | | 1965 - 1975 | +2.95 |
| | | 1975 - 1985 | +3.15 |
| | | 1985 - 1995 | -1.84 |
| 1995 - 2004 | +6.29 | 1995 - 2004 | +6.29 |
| 2004 - 2007 | -0.04 | 2004 - 2007 | -0.04 |
| 2007 2012 | 6 60 | 2007 - 2008 | 0 |
| 2007 - 2013 | -0.09 | 2008 - 2013 | -6.69 |
| | | 2013 - 2016 | -11.10 |
| Net change (18yrs) | -0.44m | Net change (51yrs) | -7.28m |
| Trend over last 20yrs | -0.49m | Trend over last 20yrs | -11.40m |
| Net yearly average | -0.02m/yr | Net yearly average | -0.14m/yr |
| 100yr allowance | -2.44m | 100yr allowance | -14.27m |

The increased availability of coastline movement information in Figure 12 and Table 2 creates a different and more informative outcome for understanding coastline movements compared to what could be achieved previously. Before the project commenced, only four unique vegetation lines were available over an 18yr period. At the time of writing, nine unique vegetation lines spanning 51yrs has been analysed.

For the limited record's analysis (left image of Figure 12), Table 2 results indicate Drummond Cove might be a generally stable coastline, with a near-zero average annual rate of change evident at -0.02m/yr (rounded). By forecasting the trend over 20yrs, mild erosion would be expected of -0.49m as seen in Table 2.

The more complete record in the right image of Figure 12 shows a more detailed story: the annual rate of change from Table 2 is greater at -0.14m/yr. This outcome is significant considering the coast showed net accretion in the first 30yrs of the 51yr record. After that, erosion of -11.40m is observed when looking at the latest 20yr trend; this erosion is ~23 times greater than the 20yr trend from the limited record. This clearly demonstrates the differences an updated coastline movement record can entail.

A 100yr planning allowance using SPP 2.6 for S2 is calculated as 100 times the annual rate of change from the historic record. Using the net yearly average erosion rate, an S2 allowance would calculate to -2.44m (after rounding) using the left image of Figure 12. However, this same S2 calculation increases to -14.3m (after rounding) when using the updated right image of Figure 12 which is almost six times greater than the limited record's S2 allowance. Planning implications from these markedly different results are significant. Resultantly, the Drummond Cove example clearly demonstrates the critical importance comprehensive coastline movement information entails.

4.2 Recommended direction for coastline data in WA

As demonstrated in Section 4.1, coastline datasets are an important tool for understanding how the WA coastline changes over time, and how that coastline may continue to evolve in the future. A comprehensive record of coastline movement information is clearly critical to ensure the most accurate, unbiased analysis possible for planning and management purposes. Mindful planning is important to ensure continuous and regular capture of these datasets into the future.

An ongoing plan for collection of aerial imagery is necessary to assist local coastal planners and managers. DoT's annual aerial imagery budget can only target small to medium scale flight runs, usually for maritime facility planning and management purposes. Significant numbers of erosion hotspot locations may not be captured unless a maritime facility already exists nearby. The DoT aerial imagery collection process has been illustrated by a flow diagram in Figure 13; this process can also serve as a guide for other stakeholders interested in ongoing aerial imagery collection.

Figure 13: Flow diagram of aerial imagery collection plan to ensure a consistent coastline movement record is captured moving forward

Figure 13 demonstrates that management of aerial imagery collection is an ongoing and dedicated task if a consistent and comprehensive coastline movement record is to be captured into the future. A sample of the program can be seen in Table A3 of Appendix A. The first recommendation identified by this project is for DoT to continue to conduct this aerial imagery collection program across the State.

A significant limiting factor evident from Figure 13 is the need for continued funds to source aerial imagery. Some runs undertaken historically, such as the large scale run from Kalbarri to Israelite Bay ideally conducted every five years, represent a critical funding requirement. This large-scale run provides the most complete, consistent, and comprehensive aerial imagery record in the entire capture plan. However, its high financial cost and resourcing requirement means ongoing commitment is needed to ensure its continuity moving forward. Expensive runs such as the Kalbarri to Israelite Bay run are considered highly vulnerable to budget limitations and may be missed altogether during low budget years if adequate financial forecasting and planning do not take place. DoT currently adopts an annual plan for sourcing imagery. However, sufficient recurrent funding cannot be guaranteed. Resultantly, another recommendation from this project is for CMAG to plan and budget for infrequent (~five yearly) large-scale aerial imagery projects.

At the time of writing there were three services that host DoT coastline data for free public access (Section 3.2). It is acknowledged that the transient nature of online data management may result in these hosts changing access or removing coastline data from their service entirely. DoT notes that coastline data created in this project will still be available via direct request to DoT if file hosting services are unavailable. However, DoT directs that maintaining public access to these critical datasets through hosting services is the preferred option. Regular review and communication with the entities that manage, or have potential to manage, data hosting services is required as an ongoing task³. Therefore, the final recommendation arising from this project is ongoing data management by DoT to ensure free public access to coastline data through online hosting services.

In summary of this section, a list is provided below defining the key recommendations identified by this project.

- 1. DoT to conduct annual management and sourcing of aerial photography runs across the state
- 2. CMAG to source funding towards large scale aerial photography runs in intervals of no less than five years from Kalbarri to Israelite Bay
- 3. DoT to manage ongoing and free public access to coastline movement information through public data hosting services

³ It is intended that this document will be kept live to allow for updates regarding any future changes to data hosting moving forward.

References

Damara. (2016). Shire of Harvey Coastal Hazard Risk Management and Adaptation Plan. Shire of Harvey.
DoP. (2014). Coastal Hazard Risk Management and Adaptation Planning Guidelines. WAPC.
DoPMC. (2018). National Map. Retrieved from http://nationalmap.gov.au/
DoT. (2009). Coastal Demarcation Lines for Administrative and Engineering Purposes. Department of Transport.
EvoCoast. (2017). Emu Point to Middleton Beach Coastal Adaptation and Protection Strategy, Albany. City of Albany.
Seashore Engineering. (2016). Coastal Erosion Hotspots, Preliminary Analysis Report. Department of Transport and Department of Planning, Lands and Heritage.
SLIP. (2018). WA Marine Map. Retrieved from http://data.wa.gov.au/
WALIA. (2018). Data WA. Retrieved from http://data.wa.gov.au/
WAPC. (2013). State Plannng Policty No. 2.6 - State Coastal Planning Policy. Planning and Develpment Act 2005: Western Australian Planning Commission.

Appendix A - Coastline Dataset Information

Table A1: Aerial imagery from older decades that could not be sourced for this project

| Decade | Location |
|-------------------|------------------|
| Latest (>2010) | Quobba Station |
| 2005-2009 | Coral Bay |
| | Broome Eco Beach |
| 1995-1999 | Point Samson |
| | Onslow |
| 1990-1994 | Broome Eco Beach |
| | Ardyloon |
| | Derby |
| 1980-1989 | Derby |
| 1970-1979 | Derby |
| 1960-1969 | Broome Eco Beach |
| | Ardyaloon |
| | Derby |
| 1950-1959 | Capel |
| | Coogee |
| | Point Samson |
| | Dongara |
| | Augusta |
| | Coral Bay |
| | Broome Eco Beach |
| | Cheynes Beach |
| | Little Grove |
| | Quobba Station |
| | Margaret River |
| | Ardyaloon |
| | Derby |
| 1940-1949 | Onslow |
| | Geordie Bay |
| | Dongara |
| | Hopetoun |
| | Esperance |
| | Mullaloo |
| | Bremer |

Table A2: Location and year of coasts captured from aerial imagery for this project, alongside the distance of coastline captured for that location in the year available

| Location captured | Year | Distance (Km) |
|----------------------------|------|------------------|
| Hillarys to Cottesloe | 2015 | 21.20 |
| Ardyaloon | 2013 | 6.55 |
| Ardyaloon | 2007 | 6.55 |
| Ardyaloon | 2003 | 6.55 |
| Ardyaloon | 1998 | 6.55 |
| Ardyaloon | 1986 | 6.55 |
| Ardyaloon | 1975 | 6.55 |
| Ardyaloon | 1949 | 6.55 |
| Augusta | 2005 | 13.40 |
| Augusta | 2003 | 13.40 |
| Augusta | 1975 | 13.40 |
| Augusta | 1943 | 13.40 |
| Binningup | 2004 | 4.79 |
| Binningup | 1995 | 4.79 |
| Binningup | 1975 | 4.79 |
| Binningup | 1965 | 4.79 |
| Binningup | 1946 | 4.79 |
| Bremer | 2008 | 17.37 |
| Bremer | 1985 | 17.37 |
| Bremer | 1975 | 17.37 |
| Bremer | 1965 | 17.37 |
| Bremer | 1957 | 17.37 |
| Broome | 2015 | 28.10 |
| Broome | 2007 | 28.10 |
| Broome | 2000 | 28.10 |
| Broome | 1995 | 28.10 |
| Broome | 1990 | 28.10 |
| Broome | 1988 | 28.10 |
| Broome | 1970 | 28.10 |
| Broome | 1960 | 28.10 |
| Broome | 1959 | 28.10 |
| Broome | 1947 | 28.14 |
| Broome Eco Beach | 2013 | 1.94 |
| Broome Eco Beach | 2004 | 1.94 |
| Broome Eco Beach | 1998 | 1.94 |
| Broome Eco Beach | 1985 | 1.94 |
| Broome Eco Beach | 1978 | 1.94 |
| Broome Eco Beach | 1947 | 1.94 |
| Cape Peron to Tims Thicket | 2015 | 132.34 |
| Capel | 2015 | 4.11 |
| Capel | 2006 | 4.11 |
| Capel | 2003 | 4.11 |
| Capel | 1995 | 4.11 |
| Capel | 1990 | 4.11 |

| Capel | 1985 | 4.11 |
|---------------------|------|-------|
| Capel | 1975 | 4.11 |
| Capel | 1965 | 4.11 |
| Capel | 1941 | 4.11 |
| Carnarvon | 2015 | 8.98 |
| Carnarvon | 2007 | 8.98 |
| Carnarvon | 2003 | 8.98 |
| Carnarvon | 1997 | 8.98 |
| Carnarvon | 1990 | 8.98 |
| Carnarvon | 1980 | 8.98 |
| Carnarvon | 1970 | 8.98 |
| Carnarvon | 1969 | 8.98 |
| Carnarvon | 1955 | 8.98 |
| Cervantes | 1975 | 5.39 |
| Cheynes Beach | 2015 | 1.48 |
| Cheynes Beach | 2005 | 1.48 |
| Cheynes Beach | 2003 | 1.48 |
| Cheynes Beach | 1995 | 1.48 |
| Cheynes Beach | 1990 | 1.48 |
| Cheynes Beach | 1985 | 1.48 |
| Cheynes Beach | 1975 | 1.48 |
| Cheynes Beach | 1965 | 1.48 |
| Cheynes Beach | 1946 | 1.48 |
| Cockburn Sound | 1990 | 33.53 |
| Coogee | 2015 | 2.20 |
| Coogee | 2003 | 2.20 |
| Coogee | 1995 | 2.20 |
| Coogee | 1965 | 2.20 |
| Coral Bay | 2015 | 7.88 |
| Coral Bay | 2002 | 7.88 |
| Coral Bay | 1992 | 7.88 |
| Coral Bay | 1968 | 7.88 |
| Coral Bay | 1949 | 7.88 |
| Cottesloe to Coogee | 1985 | 20.90 |
| Dawesville | 2015 | 5.90 |
| Dawesville | 1975 | 5.90 |
| Denham | 2015 | 2.40 |
| Denham | 2005 | 2.40 |
| Denham | 2001 | 2.40 |
| Denham | 1998 | 2.40 |
| Denham | 1990 | 2.40 |
| Denham | 1980 | 2.40 |
| Denham | 1978 | 2.40 |
| Denham | 1964 | 2.40 |
| Denham | 1957 | 2.40 |
| Denham | 1949 | 2.40 |

| Derby | 2013 | 9.32 |
|-----------------------------------|------|-------|
| Derby | 2006 | 9.32 |
| Derby | 2004 | 9.32 |
| Derby | 1995 | 9.32 |
| Derby | 1949 | 9.32 |
| Dongara | 2008 | 10.78 |
| Dongara | 2005 | 6.00 |
| Dongara | 2004 | 10.78 |
| Dongara | 2004 | 6.00 |
| Dongara | 1985 | 10.78 |
| Drummond Cove to Separation Point | 1985 | 25.15 |
| Drummond Cove to Separation Point | 1975 | 25.15 |
| Drummond Cove to Separation Point | 1965 | 25.15 |
| Drummond Cove to Separation Point | 1952 | 25.15 |
| Drummond Cove to Separation Point | 1942 | 25.15 |
| Emu Point | 2004 | 2.40 |
| Emu Point | 1965 | 2.40 |
| Esperance | 1990 | 17.96 |
| Esperance | 1975 | 17.96 |
| Esperance | 1956 | 17.96 |
| Exmouth | 2015 | 7.78 |
| Exmouth | 2007 | 7.78 |
| Exmouth | 2003 | 7.78 |
| Exmouth | 1990 | 7.78 |
| Exmouth | 1966 | 7.78 |
| Exmouth | 1942 | 7.78 |
| Falcon | 1975 | 7.78 |
| Geordie Bay | 2016 | 0.71 |
| Geordie Bay | 2006 | 0.71 |
| Geordie Bay | 2003 | 0.71 |
| Geordie Bay | 1995 | 0.71 |
| Geordie Bay | 1990 | 0.71 |
| Geordie Bay | 1985 | 0.71 |
| Geordie Bay | 1975 | 0.71 |
| Geordie Bay | 1965 | 0.71 |
| Geordie Bay | 1955 | 0.71 |
| Gnarabup | 2015 | 4.79 |
| Gnarabup | 2004 | 4.79 |
| Gnarabup | 1990 | 4.79 |
| Gnarabup | 1985 | 4.79 |
| Grey | 2015 | 9.58 |
| Grey | 2004 | 9.58 |
| Grey | 1995 | 9.58 |
| Grey | 1990 | 9.58 |
| Grey | 1985 | 9.58 |
| Grey | 1975 | 9.58 |
| Grey | 1965 | 9.58 |
| Grey | 1956 | 9.58 |

| Hillarys to Cottesloe | 2003 | 21.20 | | | | |
|---------------------------|------|--------|--|--|--|--|
| Hillarys to Cottesloe | 1995 | 21.20 | | | | |
| Hillarys to Cottesloe | 1990 | 21.20 | | | | |
| Hillarys to Cottesloe | 1975 | 21.20 | | | | |
| Hillarys to Cottesloe | 1965 | 21.20 | | | | |
| Hillarys to Cottesloe | 1959 | 21.20 | | | | |
| Hillarys to Port Kennedy | 1965 | 35.33 | | | | |
| Hillarys to Woodman Point | 1995 | 128.74 | | | | |
| Hopetoun | 2008 | 12.57 | | | | |
| Hopetoun | 1975 | 12.57 | | | | |
| Hopetoun | 1956 | 12.57 | | | | |
| Horrocks | 2015 | 13.77 | | | | |
| Horrocks | 1956 | 13.77 | | | | |
| Little Grove | 2015 | 1.36 | | | | |
| Little Grove | 2006 | 1.36 | | | | |
| Little Grove | 2003 | 1.36 | | | | |
| Little Grove | 1995 | 1.36 | | | | |
| Little Grove | 1990 | 1.36 | | | | |
| Little Grove | 1985 | 1.36 | | | | |
| Little Grove | 1975 | 1.36 | | | | |
| Little Grove | 1965 | 1.36 | | | | |
| Little Grove | 1943 | 1.36 | | | | |
| Margaret River | 2015 | 1.86 | | | | |
| Margaret River | 2006 | 1.86 | | | | |
| Margaret River | 2003 | | | | | |
| Margaret River | 1995 | 1.86 | | | | |
| Margaret River | 1990 | 1.86 | | | | |
| Margaret River | 1985 | 1.86 | | | | |
| Margaret River | 1975 | 1.86 | | | | |
| Margaret River | 1965 | 1.86 | | | | |
| Margaret River | 1943 | 1.86 | | | | |
| Monkey Mia | 2012 | 1.20 | | | | |
| Monkey Mia | 2007 | 1.20 | | | | |
| Monkey Mia | 2002 | 1.20 | | | | |
| Monkey Mia | 1990 | 1.20 | | | | |
| Monkey Mia | 1984 | 1.20 | | | | |
| Monkey Mia | 1978 | 1.20 | | | | |
| Monkey Mia | 1964 | 1.20 | | | | |
| Monkey Mia | 1957 | 1.20 | | | | |
| Monkey Mia | 1944 | 1.20 | | | | |
| Ocean Beach (Denmark) | 2015 | 3.59 | | | | |
| Ocean Beach (Denmark) | 2008 | 3.59 | | | | |
| Ocean Beach (Denmark) | 2004 | 3.59 | | | | |
| Ocean Beach (Denmark) | 1995 | 3.59 | | | | |
| Ocean Beach (Denmark) | 1990 | 3.59 | | | | |
| Ocean Beach (Denmark) | 1985 | 3.59 | | | | |
| Ocean Beach (Denmark) | 1975 | 3.59 | | | | |
| Ocean Beach (Denmark) | 1965 | 3.59 | | | | |
| Ocean Beach (Denmark) | 1942 | 3.59 | | | | |

| Onslow | 2015 | 9.95 | | | |
|------------------------|------|-------|--|--|--|
| Onslow | 2005 | 9.95 | | | |
| Onslow | 2003 | 9.95 | | | |
| Onslow | 1993 | 9.95 | | | |
| Onslow | 1986 | 9.95 | | | |
| Onslow | 1961 | 9.95 | | | |
| Peaceful Bay | 2015 | 7.19 | | | |
| Peaceful Bay | 2008 | 7.19 | | | |
| Peaceful Bay | 2004 | 7.19 | | | |
| Peaceful Bay | 1995 | 7.19 | | | |
| Peaceful Bay | 1990 | 7.19 | | | |
| Peaceful Bay | 1985 | 7.19 | | | |
| Peaceful Bay | 1975 | 7.19 | | | |
| Peaceful Bay | 1965 | 7.19 | | | |
| Peaceful Bay | 1943 | 7.19 | | | |
| Point Peron | 1985 | 4.79 | | | |
| Point Samson | 2014 | 5.00 | | | |
| Point Samson | 2005 | 5.00 | | | |
| Point Samson | 2004 | 5.00 | | | |
| Point Samson | 1992 | 5.00 | | | |
| Point Samson | 1987 | 5.00 | | | |
| Point Samson | 1978 | 5.00 | | | |
| Point Samson | 1964 | 5.00 | | | |
| Point Samson | 1946 | 5.00 | | | |
| Port Hedland | 2015 | 16.17 | | | |
| Port Hedland | 2009 | 16.17 | | | |
| Port Hedland | 2004 | 16.17 | | | |
| Port Hedland | 1995 | 16.17 | | | |
| Port Hedland | 1990 | 16.17 | | | |
| Port Hedland | 1985 | 16.17 | | | |
| Port Hedland | 1977 | 16.17 | | | |
| Port Hedland | 1964 | 16.17 | | | |
| Port Hedland | 1957 | 16.17 | | | |
| Port Hedland | 1949 | 16.17 | | | |
| Quinns to Trigg Island | 1975 | 31.74 | | | |
| Quobba Station | 2007 | 5.59 | | | |
| Quobba Station | 2003 | 5.59 | | | |
| Quobba Station | 1999 | 5.59 | | | |
| Quobba Station | 1990 | 5.59 | | | |
| Quobba Station | 1983 | 5.59 | | | |
| Quobba Station | 1977 | 5.59 | | | |
| Quobba Station | 1963 | 5.59 | | | |
| Quobba Station | 1949 | 5.59 | | | |

| Rottnest (Thomsons Bay) | 2016 | 3.59 | | | |
|-----------------------------------|---------|---------|--|--|--|
| Rottnest (Thomsons Bay) | 2006 | 3.59 | | | |
| Rottnest (Thomsons Bay) | 2004 | 3.59 | | | |
| Rottnest (Thomsons Bay) | 1997 | 3.59 | | | |
| Rottnest (Thomsons Bay) | 1990 | 3.59 | | | |
| Rottnest (Thomsons Bay) | 1983 | 3.59 | | | |
| Rottnest (Thomsons Bay) | 1978 | 3.59 | | | |
| Rottnest (Thomsons Bay) | 1964 3. | | | | |
| Rottnest (Thomsons Bay) | 1955 | 3.59 | | | |
| San Remo | 2015 | 3.80 | | | |
| Seabird | 1995 | 7.19 | | | |
| Seabird | 1956 | 7.19 | | | |
| South Bunbury | 2015 | 6.10 | | | |
| The Cut to Casuarina | 1941 | 6.59 | | | |
| Two Rocks to Cape Peron | 2015 | 141.32 | | | |
| Two Rocks to Port Kennedy | 1959 | 141.32 | | | |
| Two Rocks to Trigg | 1942 | 48.50 | | | |
| Two Rocks to Trigg Island | 1990 | 48.50 | | | |
| Two Rocks to Woodman Point | 2004 | 141.32 | | | |
| Useless Loop | 2011 | 3.24 | | | |
| Useless Loop | 2007 | 3.24 | | | |
| Useless Loop | 2002 | 3.24 | | | |
| Useless Loop | 1997 | 3.24 | | | |
| Useless Loop | 1990 | 3.24 | | | |
| Useless Loop | 1989 | 3.24 | | | |
| Useless Loop | 1972 | 3.24 | | | |
| Useless Loop | 1969 | 3.24 | | | |
| Useless Loop | 1957 | 3.24 | | | |
| Waikiki | 1985 | 11.38 | | | |
| Wedge | 2015 | 11.38 | | | |
| Wedge | 2008 | 11.38 | | | |
| Wedge | 2004 | 11.38 | | | |
| Wedge | 1995 | 11.38 | | | |
| Wedge | 1990 | 11.38 | | | |
| Wedge | 1985 | 11.38 | | | |
| Wedge | 1975 | 11.38 | | | |
| Wedge | 1965 | 11.38 | | | |
| Wedge | 1956 | 11.38 | | | |
| Wedge | 1943 | 11.38 | | | |
| Windy Harbour | 2008 | 11.00 | | | |
| Windy Harbour | 2004 | 11.00 | | | |
| Windy Harbour | 1990 | 11.00 | | | |
| Wonnerup to Dunsborough | 1959 | 65.00 | | | |
| Total coastline distance captured | | 3035.82 | | | |

Table A3: Sample of aerial imagery collection program with scheduling, priorities, and capture record

Coastal Aerial Photography Schedule - Updated 15 March 2018 - TS

| Thoto areas should cover previous years extents, so | ne aleas may | fieed to be | | | 7 | | | | | |
|---|-------------------------------|--------------------|---------|---|----------|----------|----------|---------|----------|--|
| | | | Legend | | | | | | | |
| | | | | High priority | | | | | | |
| | | | | Medium priority | | | | | | |
| | | | | Low priority | | | | | | |
| | | | | Lotest evollable in DeT archive | | | | | | |
| | | | | | | | | | | |
| | | | | Only a large scale run available in Dol archive | | | | | | |
| | | | | Review of these cells required | | | | | | |
| | | | | Could not be sourced | | | | | | |
| | | | | Requested/bought but not yet on system | *most | 2016 rur | ns do no | ot appe | ar to be | e in the system yet |
| Location/Facility | Usual Frequency (years) | Latest (on system) | Next | Features to capture | 2015 | 2016 | 2017 | 2018 | 2019 | Notes |
| Kalbarri to Israelite Bay | () = = = () | I | | | | | | | | |
| | 5 | 2015/16 | 2020/24 | At the east of alightly lower resolution, this run | | | | | - | Populated for manning accepting maximum at least once annu fun years |
| Large scale run | 5 | 2015/10 | 2020/21 | At the cost of slightly lower resolution, this full | | | | | | Required for mapping coastime movements at least once every live years |
| | | | | covers the majority of key interest areas | | | | | | |
| Kimberley | | | | | | | | | | |
| Wyndham | 5 | 2016 | 2021 | Townsite and jetty | | | | | | |
| Derby | 5 | 2016 | 2021 | Jetty and peninsula | | | | | | |
| Ardyaloon | 5 | N/A | 2017 | Townsite and beaches | | | | | | |
| Broome | 2 | 2016 | 2017 | Entire point plus estuary w. townsite | | | | | | BBF project cancelled, potential for new works soon, continue annual capture to potentially track any cyclone |
| Pilbara | _ | 2010 | 2011 | | | | | | | |
| Port Hedland | 2 | 2015 | 2017 | Finusana laland, anail bank, town, and basebas | | | | | | Cat yearly ging from at least 2017 2022 alongside apoil hank marine project (atatus of this project is upgeted |
| | 2 | 2013 | 2017 | Finucarie Island, spoli bank, town, and beaches | | | | | | Get yearly fulls from at least 2017-2022 alongside spon bank manna project (status of this project is uncertain |
| Point Samson | 5 | 2017 | 2022 | All coast east of Sams Creek Rd plus harbour | | | | | | |
| Dampier | 5 | 2015 | 2020 | Townsite and local coastline | | | | | | |
| Onslow | 1 | 2017 | 2018 | From Onslow Salt Jetty to ~2km east of Beadon | | | | | | 2016 run was Beadon Creek only. OMSB stage works in 2017 and 2018 so need annual photos for next few |
| | | | | Creek | | | | | | |
| Casaayina | | | 1 | | | | | | | |
| Gascoyne | | | | | | | | | | |
| Exmouth | 3 | 2017 | 2018 | Iownsite, harbour, nearshore, and beaches | _ | | | | | Want 2017 and 2018 following works |
| Bundegi | 5 | 2014 | 2019 | Nearshore, ramp, and beaches | | | | | | |
| Tantabiddi | 5 | 2014 | 2019 | Nearshore, ramp, and beaches | | | | | | |
| Coral Bay | 5 | 2017 | 2019 | Townsite, boat ramp, nearshore, and beaches | | | | | | Annual coverage of Mauds Landing to 2020 to monitor sand buildup around the facility |
| Carnaryon | 5 | 2017 | 2019 | Townsite, Gascovne mouth, and Fascine | | | | | | Ensure to capture Pelican Point sand bar, Boat Harbour, and Teory Channel |
| Monkey Mia | 5 | 2007 | 2017 | Townsite nearshore and beaches | | | | | | Are there any existing serials for Mankey Mia in the Landade archive that are never than 2007 which we can |
| Donhom Maritima Eccility | 2 | 2007 | 2017 | Horbour & optropos shopped + bosebos | | | | | | Not the any existing senars for workey will in the Landgate archive that are newer than 2007 which we can Work 2017 and 2019 following worke |
| | 3 | 2017 | 2010 | | - | | | | | Walit 2017 and 2016 following works |
| Mid West | | | | | | | | | | |
| Kalbarri | 5 | 2017 | 2022 | River mouth, townsite, and beaches | | | | | | |
| Port Gregory | 5 | 2017 | 2022 | Jetty, townsite, nearshore, and beaches | | | | | | |
| Horrocks | 5 | 2016 | 2021 | Townsite, nearshore, and beaches | | | | | | |
| Geraldton | 1 | 2016 | 2017 | Drummond Cove to Cape Burney | | | | | | |
| Port Denison | 5 | 2016 | 2021 | Boat harbour, townsite, and heaches | | | | | | |
| | 5 | 2010 | 2021 | letty townsite peershare and beaches | | | | | | |
| | 5 | 2015 | 2020 | Jetty, townsite, nearshole, and beaches | | | | | | |
| Green Head | 5 | 2017 | 2022 | Jetty, townsite, nearshore, and beaches | | | | | | |
| Wheatbelt | | | | | | | | | | |
| Jurien Bay | 2 | 2018 | 2018 | Boat harbour, townsite, nature reserve, and | | | | | | Capture nature reserve at least once every five years |
| | | | | beaches | | | | | | |
| Cervantes | 5 | 2016 | 2021 | Jetty, townsite, nearshore, and beaches | | | | | | Capture nature reserve as well |
| Lancelin | 1 | 2017 | 2018 | letty townsite nearshore and beaches | | | | | | Capture yearly to monitor changes at GDP |
| Ledge Point | 1 | 2017 | 2018 | Townsite nearshore and beaches | | | | | | Canture yearly to accommodate pending host harhour plans |
| Cechind | | 2017 | 2010 | Teurseite, nearshore, and beaches | | | 1 | | | Capture yearly to accommodate periodity boar handour plans |
| Seabild | 1 | 2017 | 2018 | | | | | | | The forget yearly record from at least 2017-2022 to track seawait initidence on northern beaches |
| Guilderton | 5 | 2016 | 2021 | Iownsite, river mouth, nearshore, and beaches | | | | | | |
| Metropolitan and Peel | | | | | | | | | | |
| North | 1 | 2017 | 2018 | Northern suburbs inc. Two Rocks | | | | | | |
| Central | 1 | 2017 | 2018 | Central suburbs inc. Perth | | | | | | |
| South | 1 | 2017 | 2018 | Southern suburbs inc. Mandurah | | | | | | |
| Rottnest Island | 1 | 2017 | 2018 | Entire island and nearshore environment | | | | | | |
| South West | | 2011 | 2010 | | | | | | | |
| Disagingua | 5 | 2017 | 2010 | Deach and nearshare | | | | | | Already contract yearly within the couthout mater conicil run |
| Binngingup | 5 | 2017 | 2018 | Beach and hearshore | | | | | | Already captured yearly within the southern metro aeria run |
| Bunbury | 2 | 2017 | 2018 | Nearshore, townsite, and beaches inc. The Cut | | | | | | Capture once yearly from 2017-2022 to track Casuarina development. Capture from Dalyellup to top of Lechel |
| Capel | 5 | 2014 | 2019 | Only need Pepperment Grove Beach | | | | | | |
| Busselton | 2 | 2017 | 2018 | Coast from Wonnerup to Dunsborough | | | | | | 2016 was eastern Busselton and Wonnerup only; 2017 was only Port Geographe |
| Margaret River | 5 | 2017 | 2018 | Coast from Margeret River mouth to Gnarabup | | | | | | |
| Augusta | 1 | 2017 | 2018 | Coast from Cape Leeuwin to East Augusta | | | | | | Annual runs until 2020 tracking potential changes from boat harbour construction: capture mobile river mouth |
| Windy Harbour | 5 | 2017 | 2022 | Headland, island, townsite, and beaches | | | | | | |
| Great Southern | Ť | | | | | | | | | |
| Desset Day | - | 0040 | 0004 | Deeph second rown as ready and by the | | | | - | | |
| Peaceiul Bay | 5 | 2016 | 2021 | beach access ramp, caravan park, and beaches | <u> </u> | 11111111 | | I | | |
| Denmark | 5 | 2017 | 2022 | SLSC, nearshore, and beaches | I | | | | | |
| Albany | 2 | 2017 | 2018 | Oyster Harbour, King George Sound, Princess | 1 | | | | | Try to get two-yearly record of Middleton Beach and Emu Point; can capture all other locations discussed ew |
| | | | | Royal Harbour, and Whale World | | | | | | |
| Bremer Bay | 1 | 2017 | 2018 | Harbour to northern edge of White Trail Rd | | | | | | Want 2017 and 2018 following works |
| Goldfields/Esperance | | | | ľ | | | | | | × |
| Hopetoun | 2 | 2017 | 2018 | Culham inlet to 2km east of Honetoun point | | | | | | Try to get yearly record from 2017-2022 since the 2017 breach of Culham Inlet: can track longshore sediment |
| Esperance baseb and hydrographic surgery | 2 | 2017 | 2010 | | | | | | | Can Source and power and power and a second se |
| Esperance beach and hydrographic survey | 2 | 2017 | 2010 | West beach to bailuy creek boat harbour | | anna a' | | | | Carries on narbour and nounsned beaches, litear to capture entire Esperance and Bandy Creek coast at le |

| damage; try to survey at low spring tide |
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east once every four years

Appendix B - Coastal Projects Aerial Triangulation Workflow

A summary of aerotriangulation processes, by experienced photogrammetrist Chris Hartley, is attached after this page as Appendix B.

Coastal Projects Aerial Triangulation Workflow

Hartley Consulting Services

Version 1.4

Chris Hartley

Tuesday, 10 April 2018

Introduction

With the formation of CMAG (Coastal Management Advisory Group) to manage Coastal Erosion Hotspots & Watchspots around the coastline of Western Australia there is a growing need for Coastal Zone information. One very important source of this information is Coastal Aerial Imagery.

There exists a large amount of aerial imagery starting from the 1940's to present. Much of this imagery has been scanned from film to digital format although there is still some of this data that only exists in film format. There are 2 Prime government agencies that manage this imagery, Landgate WA & Geoscience Australia.

Photogrammetry is the science of making measurements from photographs, especially for recovering the exact positions of surface points using overlapping Digital Imagery to create a visual 3D model for topographic mapping.

Aerotriangulation

A critical phase in photogrammetric mapping is rectifying the aerial images to the appropriate tract on the surface of the earth. This is accomplished by collecting horizontal and vertical data, from Landgate, to ascertain the spatial location of a number of features that are visible and measurable on the aerial images. The process is often called control bridging, which refers to passing horizontal and vertical information from one aerial image to the next. Geometric stability requires that a minimum of four points with established horizontal and vertical location spaced in the corners of a full stereomodel be used to fully rectify the model. Computer processing has played a major role in driving mapping scientists to develop rigorous and efficient mathematical protocols that allow for the densification of stereomodel control from a minimal number of strategically positioned ground survey points. This procedure is generally referred to as aerotriangulation. Analytical software available today, with its built-in quality checks, has made aerotriangulation the preferred method of image adjustment to the earth for photogrammetric mapping.

Purpose

The purpose of this document is to describe the current workflow involved in the aerial triangulation of the Coastal Erosion Hotspots & Watchspots using aerial imagery provided by Landgate and Geoscience Australia.

Scope

This workflow covers the methodology used in the creation of aerial triangulation projects used to provide exterior orientation files suitable to set up the stereo imagery for capture of coastal features within the Coastal Erosion Hotspots & Watchspots project areas.

Structure

| Part 1: | Reference Material |
|---------|----------------------------|
| Part 2: | Software Used |
| Part 3: | Project Creation |
| Part 4: | Methodology |
| Part 5: | Outputs |
| Part 6: | Accuracies / QA |
| Part 7: | Important Locations |

Part 1: Reference Material

Photo Centres

To enable projects to be created in INPHO photo centre coordinates are required. Any imagery pre 1992 before GPS positioning of the aircraft this information needed to be manually created. This could be interpolated from existing flight diagrams referenced into ArcMap or if not available created by digitising the photo centres onto aerial imagery.

Camera Calibration Certificates

Calibration data is needed in INPHO to correctly import the images. This enables the raw images to be positioned in the camera as they were when the photograph was captured.

Ground Control

Identifiable points on the ground are required to position the imagery onto the ground in its correct geographical position. These points can either be uploaded from extracted data from the Landgate Geodetic Survey Marks website or if not available will need to be "Post id" points derived from previously captured imagery held by DoT that matches points on the imagery in the project. Control for the older imagery was derived by transferring Id points from newer imagery projects already triangulated.

Mosaics

Existing aerial imagery was used to create both control points and derive photo centre coordinates and also to QA new triangulation projects to make sure the imagery aligned with previous projects.

Part 2: Software Used

Trimble INPHO Applications Master Match AT (Licence on loan from Landgate)

ESRI ArcMap

ERDAS Stereo Analyst for ArcGIS

Imagine

Part 3: Project Creation

The main inputs for creating the project in the INPHO Match AT module are GPS photo centre points and ground control. Once these are generated the project can be created.

Part 4: Methodology

- Photo Centre coordinates are created by either manual methods or from an existing GPS file from the Landgate GPS files.
- A camera calibration is then required for the camera used in the project.
- Once the project is created in INPHO the GPS points can be imported and the imagery directory can be linked to these points and the ground control can be entered.
- An interior orientation is then performed on all imagery.
- Manual points are then read linking each stereo model to the neighbouring one.
- Three control points at a minimum are also required before the Automatic Point measurement can be done on the block.
- After which post processing is carried out repeatedly with points reread and more control added until the required results are established for the project.

Part 6: Outputs

Outputs from the INPHO Match AT project are an extracted directory containing the .SUP files. These files contain the exterior orientations of each frame.

Part 7: Accuracies / QA

There were a wide range of accuracies expected depending on the age of the aerial imagery projects. The main reason for this was the implementation of DGPS (Differential Global Positioning Systems) in the planes in the early 1990's. This lead to an improvement in the overall accuracy of aerial triangulation projects due to the ability to use the GPS coordinate of the photo centre in the block calculations. The photo centres of images in projects pre 1992 were manually measured from imagery in ArcMap to then be used to get an initial block of images imported into INPHO.

When controlling the latest imagery the Landgate Survey control could be utilised more effectively as the points could be better identified in the imagery. The further back in time the imagery progressed the more difficult it became to use these control points due to the changes in the man-made features and physical ground. To overcome this control was derived by highlighting the same points visible in the different years of photography.

From this information the following accuracies were expected.

Due to a number of factors that have an impact on the accuracy of the final Triangulation therefore listing errors based on pixels is the best approach to minimise confusion. These factors include

- Cameras used and the camera calibration. The old cameras pre 1970 had a basic calibration and some of the cameras used for the 1940's imagery had no camera calibration so generic figures for the fiducials were used.
- Lack of control. The further back in time the imagery was captured the less relevant the Landgate SSM data became as these points could not be accurately be positioned due to physical changes of the terrain and infrastructure.
- Transfer of control through differing years of imagery compounded the error of this control the further back the projects went in time.
- No GPS for the photo centres. As previously mentioned any imagery captured pre approx. 1992 did not have GPS coordinates generated for the perspective centre of each image. Therefore these co-ordinates had to be manually measured in a GIS platform and used as a rough base to start the project. From these points the basic orientation of the photography block could be determined from which further tie points were generated both manually and automatically within the block to connect all the photos.
- Condition of the photography. Due to the inherent problems with storing Acetone based film products the older the film the less quality the scans were. The main issues encountered are the likelihood of Acetate Film Base deterioration (The Vinegar Syndrome) this can affect the quality of the image.

| Priority | Project Year | Expected Horizontal Accuracy |
|----------|---------------|------------------------------|
| 1-2 | Latest - 2005 | +/- 3-4 pixels |
| 3-4 | 2004-1995 | +/- 6 pixels |
| 5-6 | 1994-1980 | +/- 8 pixels |
| 7-8 | 1979-1960 | +/- 10 pixels |
| 9-10 | 1959-1940 | +/- 15 pixels |

The majority of projects fell within these accuracies however a small number were worse than expected. In these cases the required vector information was captured from the imagery and then moved in Arcmap to register with newer projects that had a higher expected accuracy.

To better illustrate this.

A project from the 1940's flown at a scale of 1:25000 and scanned @ 15 microns to produce the digital imagery would produce a pixel that related to 0.375m Ground Sample Distance (GSD) therefore the accuracy of the project would be \pm 5.6m.

The same project captured in 2004 at a scale of 1:25000 and scanned at 20 microns would produce imagery with a pixel that related to 0.5m Ground Sample Distance (GSD) with an accuracy of \pm 3.0m

(*Note* All non-digital (Film based) imagery supplied by Landgate was scanned at 20microns. All historical imagery supplied via Photomapping Services from the Geoscience Australia archives was scanned at 15microns)

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