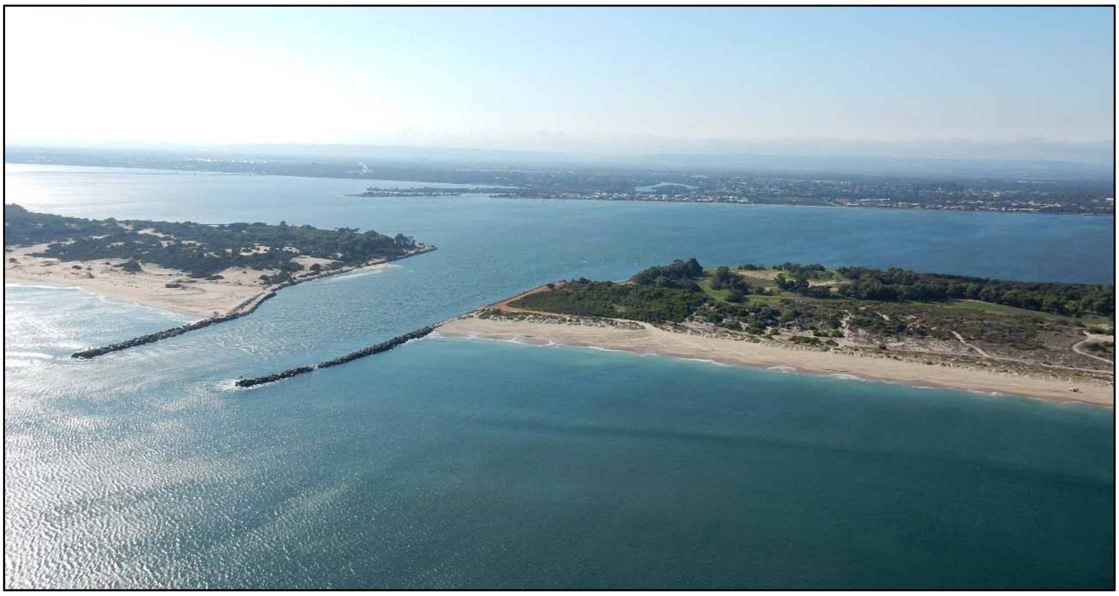
Peron-Naturaliste Partnership
Coastal Monitoring Guidelines



Damara WA Pty Ltd

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Summary

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Document Control

Index	Author	Date	Review	Date	Comment
Outline Obliques	T. Stul	12.5.2015	R. Talbot-Smith E. Bromwell	22.5.2015 12.6.2015	Minor modifications
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Glossary of Terms & Abbreviations

Beach cusps	Rhythmic undulating features along the shore, comprised of alternating bay and horn shapes, typically 5 to 30m apart
LiDAR	Light detecting and ranging
RTK GPS	Real time kinematic geographic positioning system
Scarping	A near-vertical section of sandy beach, created by erosion of the lower part
UAV	Unmanned aerial vehicle

1. Introduction

Peron Naturaliste Partnership (PNP) is a group of nine local governments collectively responsible for coastal management between Cape Peron and Cape Naturaliste (Figure 1-1). Local Government Authorities (LGAs) who are involved in the PNP are:

- City of Rockingham
- Shire of Murray
- Shire of Harvey
- City of Bunbury
- City of Busselton
- City of Mandurah
- Shire of Waroona
- Shire of Dardanup
- Shire of Capel

The Partnership was established to facilitate effective and timely adaptive response to climate change in the coastal zone. As part of ongoing programs for coastal management, the PNP has undertaken to develop an implementation strategy for a sustainable, long-term and standardised coastal monitoring program. Three documents have been prepared to support the overall strategy (Table 1-1). This document is the *Coastal Monitoring Guidelines*, which provides detail on LGA application of the monitoring techniques recommended as the major components of the Program.

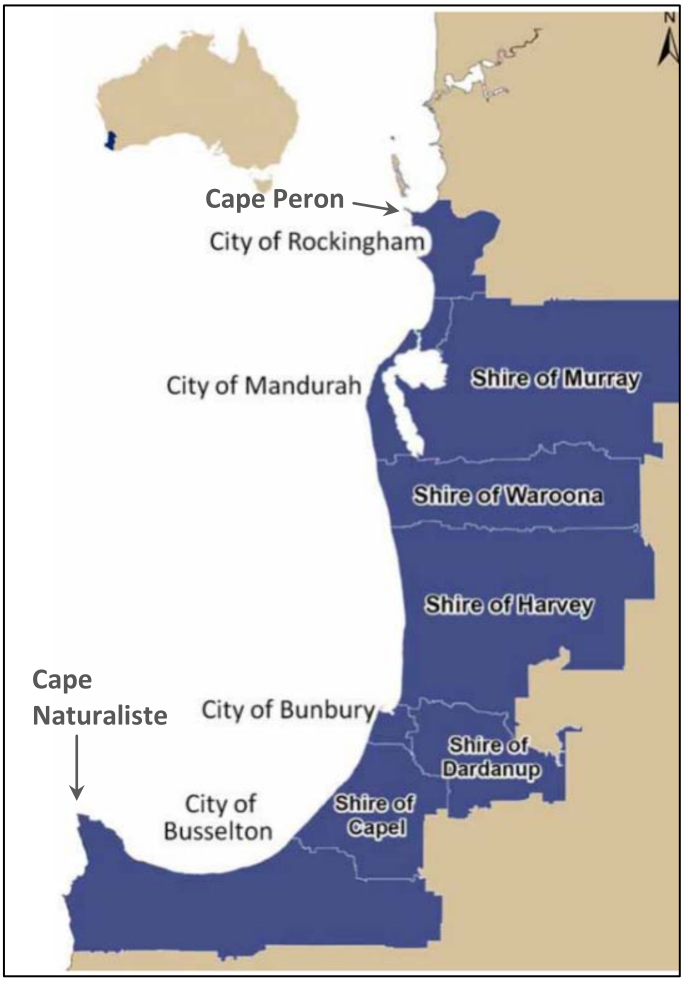


Figure 1-1: PNP members with study area extending from Cape Peron to Cape Naturaliste (Source: PNP website http://peronnaturaliste.org.au)

Table 1-1: Overview of deliverables for the PNP regional coastal monitoring program

Project Documents	Overview
1: Coastal Database Report	A summary report describing a coastal database, which was developed through review of existing datasets and coastal monitoring programs along the PNP coast. The database report considers the coverage of identified data relative to decision-making regarding regional and local erosion and inundation hazards.
2: Coastal Monitoring Action Plan (CMAP)	An outline of coastal monitoring activities recommended to be undertaken over the next 10 years, including actions undertaken by PNP members, State government and community groups.
3: Coastal Monitoring Guidelines (*This report*)	Description of data collection requirements and methods for coastal monitoring outlined in the *CMAP* that can be undertaken by LGA officers.

These guidelines provide information specifically relevant to LGA involvement in coastal monitoring for six techniques:

- Beach Width Measurement;
- Photographic Monitoring (on-ground);
- Dune Migration;
- Oblique Aerial Photography;
- Flood Frequency Assessment;
- Evaluation of Inundation Extent.

Information has been presented to support the collection and analysis of monitoring data by the PNP Local Government Authority (LGA) officers with limited external support.

Some information is provided regarding techniques discussed in the CMAP that are largely completed by external agencies. These include:

- Beach Profiling;
- Vertical Aerial Imagery;
- Survey with Area Coverage;
- Light Detection and Ranging (LiDAR);
- Hydrographic Surveys.

Importantly, this document is not intended as an exhaustive review of available tools and techniques that may be employed to achieve the monitoring recommended for the region. Rather, it provides targeted guidance on how to undertake discrete activities that may be completed largely 'in-house' to assist the PNP achieve their stated aims and objectives with respect to erosion and inundation hazard management over a 10-year planning horizon.

This document includes a brief discussion of the range of monitoring techniques that may be used to collect pertinent coastal data (Section 1.1).

1.1. RATIONALE FOR SELECTION OF TECHNIQUES

The *Coastal Monitoring Action Plan* addresses data collection needs for the PNP to implement a targeted and meaningful monitoring program for the Peron-Naturaliste coastal region. It provides a strategy for systematic, regional physical monitoring of the beaches and coastal systems to inform decision making with respect to ongoing coastal management and adaptation. While the advice provided is necessarily regional in scope, it is also mindful of each local government's ongoing responsibility to manage their own coastline and prioritise their discrete set of management issues.

The approach to monitoring discussed for the PNP is necessarily aimed at LGA level, rather than focused on community or volunteer involvement. It is designed to address the particular monitoring priorities of the PNP region. The information provided does not offer an exhaustive discussion on the wide range of available tools and techniques to monitor the coastal zone as a whole. Rather, it focuses on the specific needs of the PNP and provides pertinent information on targeted approaches, mindful of available resources and organisational capacity, with limited external expenditure.

Data monitoring techniques are separated into six categories (Table 1-2):

- Local feature response (dune migration)
- Photo monitoring
- Cross -shore measurements
- Planform measurements
- Inundation measurement
- Bathymetric information

The full range of available techniques for each of these categories are not presented in this document. In CMAP Section 4, coastal monitoring techniques have been separated according to relative levels (low, medium or high) with respect to the time, resources and money required for their implementation (Table 1-2).

'Low level' techniques may be employed relatively simply, at low cost. They are generally qualitative or semi-quantitative, requiring minimal equipment, staff training and external support. Depending on the spatial extent of the works, these techniques may use mainly LGA staff time for undertaking the monitoring and pre/post processing time. As such, they may be regarded as 'no regrets' monitoring and could be implemented by all LGAs across the region. Conversely, 'high level' techniques are generally high-resolution, quantitative means of monitoring with significant resource implications (time/money/expertise). They should generally not be undertaken in-house by LGAs and should be externally contracted to a service provider.

'Medium level' techniques fall between the extremes of 'high' and 'low' discussed above and can typically be implemented by LGAs in partnership with some external support (State government or private service provider). They are mainly quantitative with moderate resolution and while lower cost than 'high level' techniques, it is likely that external funding will be required for implementation. For example, beach profiles are a 'medium' level monitoring technique that should be undertaken in areas of high infrastructure expenditure with moderate-to-high erosion risk or will be undertaken infrequently. This is only applicable for a small portion of the PNP area, with LGAs already collecting this data, and as such is not included in extended detail within this document.

Mapping and analysis of shorelines or vegetation lines from vertical aerial imagery is another ‘medium level’ technique that is generally undertaken on a site-specific basis for development applications or on a larger scale by State government agencies for regional investigations. It is not included in extended detail within this document because LGA officers will not be co-ordinating the collection of vertical aerial imagery. Clear guidance is already available from the Department of Transport regarding methods for digitising vegetation lines (Appendix A).

Six techniques were selected to be described in this document, based on relatively low cost and their potential to answer key questions for coastal management and adaptation. These techniques are marked with an asterisk in Table 1-2. The six techniques address five of the different types of monitoring, with no technique detailed that is relevant for collection of bathymetric data.

The six techniques are presented in three Sections. The first group of techniques presented in Section 2 monitor erosion and have low cost requirements, generally requiring some allocation of LGA officer time and capacity. These techniques are beach width measurement, photo monitoring and dune migration. Section 3 describes the technique of oblique aerial photography for monitoring erosion, classified as ‘medium’ in terms of cost as it requires hiring a light plane or helicopter, although it can typically be co-ordinated and managed by an LGA officer. Section 4 describes two techniques for monitoring inundation, with low cost and time requirements. These are logging of flood frequency and measuring the maximum spatial extent of storm inundation.

Table 1-2: Monitoring techniques and associated 'levels'
Techniques with * are described in detail in Section 2-4.

	Low	Medium	High
Local feature response	*Dune migration	RTK GPS tracking of dune migration	Repeat LIDAR flown with UAV over a smaller area
Photo monitoring	Community members collect photos from a fixed point *LGA officer collects photos from a fixed point consistent with monthly beach width surveys	Fixed camera	Argus or other video imaging
Cross shore measurements	*Beach width	Profile (with marine extension) RTK GPS tracking of line of key features such as dune toe or +1mAHD	Laser scanning
Planform measurements	Offsets to infrastructure Foreshore buffer change (nature of alongshore change of foreshore buffer, such as dune width)	Vertical aerial imagery *Obliques	LIDAR
Inundation	*Frequency flood logs *Maximum storm inundation extent with handheld GPS	RTK GPS tracking of maximum storm inundation events and levels	Remote sensing imagery collection & analysis to detect wet/dry zones
Bathymetric information	Single point measurements (using a measuring pole to record depths) Soundings	Single-beam Multi-beam	LIDAR Multispectral

Acronyms in Table 1-2:

AHD	Australian Height Datum
LIDAR	Light Detection and Ranging
RTK GPS	Real-time Kinematic Geographic Positioning System
UAV	Unmanned Aerial Vehicle

1.2. DOCUMENT STRUCTURE

Guidance provided for each technique in Sections 2-4 follows the structure below:

What is the Technique?	An overview of the technique recommended.
Why Should I Use It?	What type of information does this monitoring technique provide and how can I apply this to assist with my coastal management and adaptation decision making
Who Does the Monitoring?	LGA officer, LGA ranger or PNP officer.
When is it Undertaken?	What is the recommended frequency and timeframes for this type of monitoring?
Is there Historic Data?	What information on this type of monitoring exists and can I use it to construct a time series upon which contemporary monitoring is based? Are there is existing bench marks or profile locations? For many areas monitoring sites can be co-located with historic data.
Where is this Technique Applied?	The project area is specified as the whole Peron-Naturaliste Partnership coast between Cape Naturaliste and Cape Peron, or at areas with specific management requirements.

Further information is then provided for the following headings:

- Methods
- Schedule and required frequency
- Deliverables
- Cost
- Limitations
- Alternate methods
- References

Section 5 outlines five further 'medium' and 'high' level techniques to be incorporated in the coastal monitoring program for the PNP region. 'Medium level' techniques of beach profiling and vertical imagery require engagement of a surveyor to assist with data capture, along with a coastal expert (possibly Department of Transport staff) and spatial analyst to assist with data analysis. 'Medium' and 'high' level techniques to capture high density datasets for bathymetry, laser scanning or LiDAR to obtain a high resolution digital elevation model require external support by State government agencies with data collection and analysis to be undertaken by external surveyors/consultants.

Information for these five techniques is aimed to provide guidance for LGAs to seek the external support needed to undertake the monitoring. Information included is:

- *Overview* – What is the technique?
- *References* – What are some key references for further reading?
- *Application* – What will the data be used for? What are the benefits of this dataset?
- *Organisation* – Which State government organisation should you discuss the scope and technical specifications with before tendering or undertaking the work?
- *Additional considerations* – Any site-specific guidance for the PNP coast.

1.3. COASTAL DATA STORAGE

A key component of coastal monitoring is ensuring that the data is suitably stored and maintained to support future use, possibly including accessibility to other LGA staff, or even other members of the PNP. As requirements vary considerably between data sets and agencies, the associated costs have not been incorporated into the program estimates. However, factors that should be considered include:

- The cost to establish a database;
- Physical and electronic storage of data;
- Database administration;
- Provision of database accessibility; and
- Maintenance of data quality records.

These questions become increasingly significant for information-heavy datasets, particularly those requiring external assistance (Section 5). The collaborative nature of the PNP provides a possible opportunity for improved database management, although the contractual and funding basis for the PNP to assume this role requires careful review.

2. On-Ground Erosion Monitoring Techniques

Three techniques for monitoring erosion are described in this section that may be undertaken by LGA or PNP officers on site without external support. Of these techniques, beach width measurement and photo monitoring may be undertaken concurrently (Sections 2.1 and 2.2). Monitoring dune migration is only required for coasts with migrating dunes of concern (described further in Section 2.3).

The initial recommendation to assess fluctuations in beach dynamics along the PNP coast is to apply the geomorphic spatial framework developed for the PNP region [1]. Approximately three monitoring locations are recommended for each tertiary cell according to Table 2-1 and Figure 2-1, with further explanation in Section 4 in the CMAP.

Table 2-1: Recommended 86 beach width sites and responsible LGA

Site *	LGA	Site	LGA	Site	LGA
R06A1a.1	Busselton	R06A4b.2	Bunbury	R06C9a.1	Mandurah
R06A1a.2		R06B5a.1		R06C9a.2	
R06A1a.3		R06B5a.2		R06C9a.3	
R06A1a.4		R06B5a.3		R06C9b.1	
R06A2b.1		R06B5a.4	Harvey	R06C9b.2	
R06A2b.2		R06B5a.5		R06C9b.3	
R06A2b.3		R06B5a.6		R06C9b.4	
R06A2c.1		R06B5b.1		R06C9b.5	
R06A2c.2		R06B5b.2		R06C10a.1	
R06A2c.3		R06B5b.3		R06C10a.2	
R06A2d.1		R06B5c.1		R06C10a.3	Rockingham
R06A2d.2		R06B5c.2		R06C10b.1	
R06A2d.3		R06B5c.3		R06C10b.2	
R06A3a.1		R06B6a.1		R06C10b.3	
R06A3a.2		R06B6a.2		R06C11a.1	
R06A3a.3		R06B6a.3		R06C11a.2	
R06A3b.1		R06B6b.1		R06C11a.3	
R06A3b.2		R06B6b.2		R06C12a.1	
R06A3b.3		R06B6b.3	Waroona	R06C12a.2	
R06A3c.1		R06B7a.1		R06C12a.3	
R06A3c.2		R06B7a.2		R06C12a.4	
R06A3c.3		R06B7a.3		R06C12a.5	
R06A3d.1		R06B8a.1		R06D14a.1	
R06A3d.2		R06B8a.2	Mandurah	R06D14a.2	
R06A3d.3		R06B8a.3		R06D14b.1	
R06A4a.1	Capel	R06B8b.1		R06D14b.2	
R06A4a.2		R06B8b.2		R06D14b.3	
R06A4a.3		R06B8b.3		R06D14c.1	
R06A4b.1				R06D14c.2	

* Naming convention follows tertiary sediment cell definition from Stul *et al*. (2012) [1]

[1] Stul T, Gozzard JR, Eliot IG and Eliot MJ (2012) *Coastal Sediment Cells between Cape Naturaliste and the Moore River, Western Australia*. Report prepared by Damara WA Pty Ltd and Geological Survey of Western Australia for the WA Department of Transport, Fremantle

86 sites have been identified across the PNP area (Table 2-1) with the number of sites per LGA summarised in Table 2-6. The sites should be co-located with existing beach profile locations or photo monitoring locations where possible (see *Pre-requisites* and *Datums or controls* in Section 2.1 and 2.2).

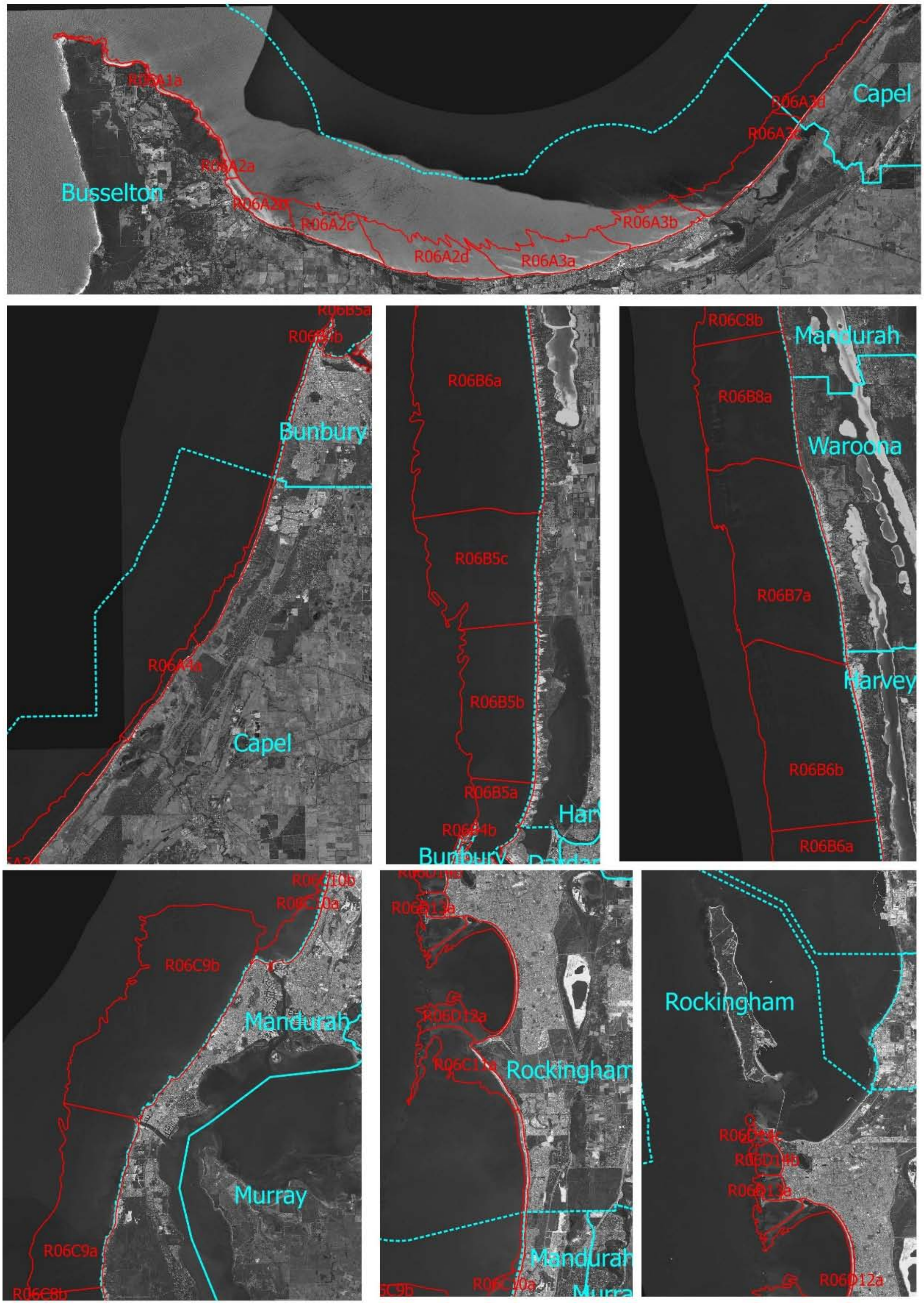


Figure 2-1: Example coverage of three beach width locations per tertiary cell

2.1. BEACH WIDTH MEASUREMENT

What is the technique?	Simple measurement of the horizontal width of the beach, at fixed locations.
Why should I use it?	Beach width measurements are an easily collected dataset to track seasonal and inter-annual beach movements. This type of monitoring has been used effectively on the Perth coast [1,6]. Beach width change information is useful for future shoreline management planning, for example defining hazard setbacks and identifying erosion threats to foreshore structures and recreational activities.
Who does the monitoring?	This is a low-cost, easy to implement monitoring technique which can be carried out by LGA officers.
When is it undertaken?	A three year long program of monthly beach width measurements is recommended to establish the seasonal behaviour and determine appropriate timing for twice-yearly or annual monitoring.
Is there historic data?	Historic beach width information may be extracted from existing profile datasets, where available.
Where should the technique be applied?	The project area is the Peron-Naturaliste Partnership coast, with three locations per tertiary sediment cell (see Section 4 in CMAP).

METHODS

Obtain a measure of the horizontal distance from a fixed landward position to a specified vertical level or feature on the beach.

Pre-requisites

Select three beach-width monitoring locations within each tertiary cell and confirm appropriate sites and benchmarks for measurement. Steps to be undertaken include:

- Identify relevant existing beach profile locations and, where appropriate, co-locate beach width measurement locations;
- Develop a LGA-specific monitoring plan to ensure appropriate monitoring coverage per tertiary cell (e.g. three beach width locations, as described in Section 4 in CMAP and listed in Table 2-1);
- Establish permanent measurement points using GPS waypoints as the landward start point of the survey (See *Datums or controls* below). These waypoints provide a ‘fixed’ point from which measurements are taken for subsequent surveys;
- Determine the dataset custodian within the LGA organisation.

Datums or controls

A set of GPS coordinates should be established as the benchmarks for each of the beach width locations (as described above). A desktop assessment (see *Pre-requisites* above) should be undertaken to identify at least three appropriate profile locations for each tertiary cell within the LGA of interest. These locations should, where possible, be co-located with planned or existing profile survey locations. This includes: 16 sites in City of Busselton [7]; sites between Falcon and Wade Street and Robert Point to Madora in City of Mandurah and other historic sites back to 1974 [4]; and sites within City of Rockingham near Mersey Point and in Safety Bay. Benchmark establishment should only be required once at the outset of the monitoring regime, listed as co-ordinates and a bearing per site.

The GPS benchmarks should be located at the toe or scarp of the primary dune, or at the toe of the seaward foredune if there is no distinct primary dune (e.g. Figure 2-2). Co-ordinates should be recorded as a waypoint and manually documented for redundancy. The bearing should be a measure perpendicular to the coast from the benchmark.

Information that may be used as the basis for future field planning should be complied in a document, including:

- A table of GPS locations and transect bearings;
- Location map;
- Site photos of any identifying features;
- Description of each of the benchmarks (e.g. Table 2-2); and
- Relevant information regarding site access.

Names for each beach width site should be labelled according to the tertiary cell [8] with a .1, .2 and .3 post-fix (refer to Table 2-1).

Table 2-2: Benchmark information for beach width measurements

Site	E / Lat.	N / Long.	Bearing	Description	Site Access	Photo

Spatial density

Three locations within each tertiary cell according to Table 2-1 and Figure 2-1, with further explanation in Section 4 in the CMAP. This amounts to 87 sites in total across the PNP area (Table 2-1) with the number of sites per LGA summarised in Table 2-6.

Equipment

- 50m length tape measure;
- Handheld GPS with waypoints loaded (could use software Mapsource). Spare batteries and sufficient space on GPS;
- Beach width data sheet (example Table 2-3), clip board and pen or data sheet loaded onto a tablet;
- Camera (capable of geotagging photographs is preferable). Spare batteries and sufficient space on camera card.

Field preparation (LGA officer)

The following tasks should be completed before entering the field:

- Determine who will collect the data (2 people per LGA);
- Test all equipment, including GPS to determine waypoints are loaded to assist in navigation to find the sites and correct datum is set (GDA94 UTM50);
- Ensure correct date, time and maximum resolution are set on camera. Turn on geotagging if available;
- Schedule the timing for data collection within a one-week window of the 1st to 7th of every calendar month. The requirements for the field sampling are lower tide, low wind (< 25 km/hr or 14 knots) and inshore wave height <1.5 m ($H_{significant}$). Winds exceeding this level will cause inaccuracy with the measuring tape, and waves exceeding this level will mean the field officer is not able to stand in the mid-swash zone. Field sampling is likely to be appropriate during the morning before the seabreeze and on low tides (during summer). Care should be given to avoid energetic sea breeze conditions. Check forecast wind conditions on the Bureau of Meteorology [2] and Seabreeze [3] websites and check forecast water level conditions from the Department of Transport tide charts and tide gauge observations [4];
- Take the field sheet (hardcopy or digital on tablet; e.g. Table 2-3) pre-filled with information relevant for the sites of interest, as well as the document with the information on benchmarks (see *Datums or controls*).

Table 2-3: Example beach width field sheet (LGA officer)

Date:					**Survey crew members:**				
LGA:					**Weather conditions:**				
Profile	**Co-ords BM (pre-load)**	**Bearing (pre-load)**	**Time**	**WL (mCD) from nearest tide gauge**	**Starting point (toe of scarp/ toe of dune/ toe of seaward foredune)**	**Waypoint of starting point**	**Width (m)**	**Photos**	**Notes on beach state**
R06B4b.1									
R06B4b.2									

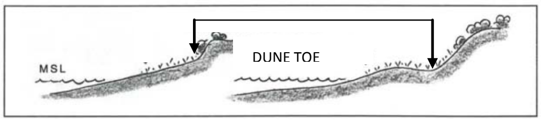
Monitoring techniques

The method suggested is broadly based on the approach used for part of the Perth coast [6], modified for different shore types or erosive states. Beach width will be measured from a landward point to the shoreline using a tape measure. Due to the range of coastal types across the PNP area the landward extent of the beach width measurement will vary:

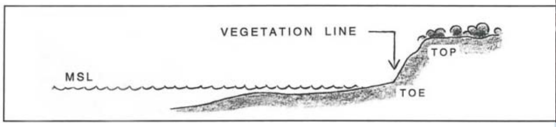
- Beach with dunes – dune toe (Figure 2-2A)
- Eroding dune– toe of scarp (Figure 2-2B)
- Accreting beach with no dominant dunes– toe of seaward foredune (Figure 2-2C).

[2] www.bom.gov.au
[3] www.seabreeze.com.au
[4] http://www.transport.wa.gov.au/imarine/tide-and-wave-data-current.asp

A) Beach width dunes – dune toe



B) Eroding dune – toe of scarp



C) Accreting beach with only foredunes– toe of seaward foredune

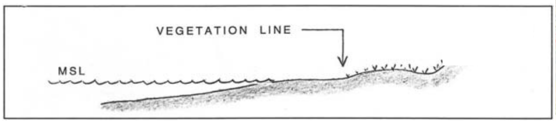


Figure 2-2: Landward feature for beach widths in yellow
Incipient vegetation line, marked in red, should not be used to define widths
Modified from DoT [3]

The seaward extent of beach width measurement is the 'mid-swash' approximation of the shoreline. This location is determined by observing the waves for several minutes and locating the approximate mid-point between the highest level on the beach that the water reaches and the lowest level that the water recedes (Figure 2-3). The mid-swash shoreline position requires correction for water level variations due to tides and surges during the post-processing phase. The accuracy of this tape measure method of beach width determination is considered to be ±5m [6].

Beach width information should be collected by two LGA officers. The width will be measured by extending the tape measure between the landward limit and mid-swash. The officers should line up along the bearing from the benchmark (see *Datums or controls*) and attempt to keep the tape measure as vertically level and taut as possible. If the beach width is >50m the officers will measure the first 50m from the landward limit (e.g. dune toe) and then the officer at the landward limit will rotate around the second officer to reach the mid-swash (Figure 2-4). The final width will be the combination of the two measures and should be recorded (Table 2-3).

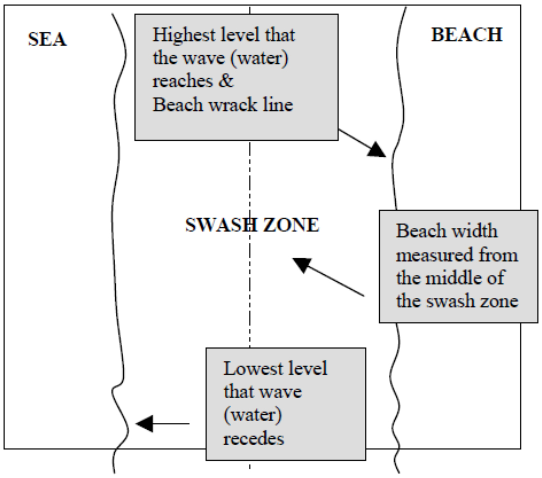


Figure 2-3: Determining mid-swash zone Following DoP [2]

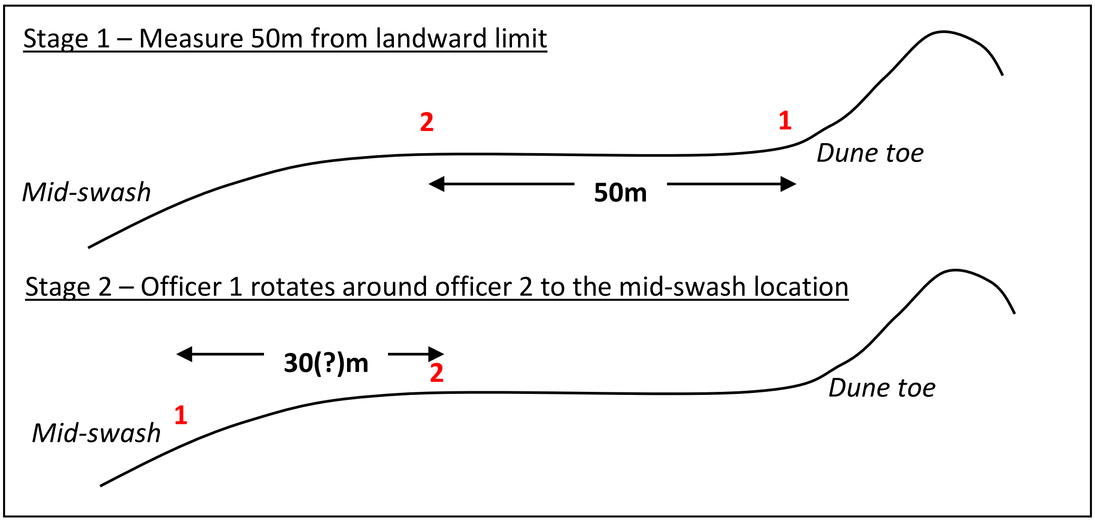


Figure 2-4: Measurement method if beach is wider than 50m

The remainder of the field sheet (Table 2-3) should be filled out including date and time of each beach width site survey, the survey crew members, any notes on the beach state (e.g. steep, narrow, beach cusps, scarp) and if relevant, where photographs were taken. Photographs should be collected at each site co-incident with the beach width measurements following the method outlined in *Photo Monitoring* (Section 2.2).

Post-processing

- Establish a spreadsheet for each LGA prior to the initial field survey. This spreadsheet will have a separate tab per beach width site following the format in Table 2-4. Ensure the profile label, LGA, co-ordinates of the benchmark and bearing (see *Datums or controls* above), gradient used to correct for water level, nearest tide gauge and conversion of chart datum to 0m AHD are input to the top of the spreadsheet tab. Permanent tide gauges within the PNP are Busselton, Bunbury Inner Harbour and Mandurah Ocean Marina, with respective conversions from chart datum to AHD of 0.68m, 0.57, and 0.54m. Water level conversions for each tertiary cell are provided in Table 2-5;

- Enter information from the beach width field data sheets into the spreadsheet for the LGA following each round of monitoring. This includes photo numbers, beach widths, date and time of sampling, the start point feature and the start point coordinates extracted from GPS waypoints. Notes on beach state (e.g. scarping or beach cusps) should also be documented;
- Save photos and process according to instructions in *Photo Monitoring* (Section 2.2).
- Obtain a measure of wind speeds for context on performance of the measuring tape method. An accurate measure of local wind speed and direction may be obtained from a hand-held anemometer, although observations from the nearest Bureau of Meteorology station is generally adequate;
- Information on the local water level at the nearest tide gauge at the time of the beach width measurement should be inferred from the Department of Transport recorded water levels (http://www.transport.wa.gov.au/imarine/storm-surge-data.asp);
- The spreadsheet should have a formula inserted into the column 'Adjusted width (m) – AUTOMATIC' to correct the beach width for water level variations due to tides and surges. This correction will depend on the water level at the time of survey in relation to a fixed vertical level adjusting the beach width according to the beach-face gradient [6]. When using Australian Height Datum, AHD (approximately mean sea level), as the fixed vertical level, the formula should be:

  $$BW_a = BW + \frac{(WL - AHD)}{Grad}$$

  where: BW_a is the adjusted beach width, *BW* is the measured beach width, *WL* is the recorded water level in chart datum at the nearest tide gauge. *AHD* is the level in chart datum that corresponds to 0mAHD (Table 2-5) and *Grad* is the measured swash gradient used to adjust the beach width.

  For example if the measured beach width was 50m, the gradient for conversion is 0.1 and the water level at the time of measurement was 1.05m CD at Busselton gauge (0.68mCD is AHD), the adjusted width would be 53.7m;
- An error check is required if a large erosion or accretion event is identified at a single site. Cross-reference the site photographs to determine if a measurement error has occurred. If the recording is deemed to be real, check whether this constitutes local change attributed to construction, renourishment or earthworks undertaken recently. Subsequently check recent environmental conditions that may have resulted in the observed change. Determine if management action is required.

Table 2-4: Example file format per beach width site (false values in red)

Profile:					R06B4b.1					
LGA:					City of Bunbury					
Co-ords of Benchmark:					XXXXXX mE YYYYYYY mN					
Bearing of beach-width measure:					270°					
Beach profile gradient to correct for water level:					0.1					
Nearest tide gauge (DoT)					Bunbury Inner Harbour					
Adjustment of mCD to 0m AHD at this site (m):					0.7					
Date	**Time**	**WL (mCD) from nearest tide gauge (DoT)**	**Weather, focused on wind (BoM)**	**Start point (toe of scarp/ toe of dune/ toe of seaward foredune)**	**E / lat of start point (from waypoint)**	**N / long start point (from waypoint)**	**Width (m)**	**Photo image number**	**Notes on beach state**	**Adjusted width (m) – AUTOMATIC**
20150504	8:00	1.05	Wind 10 m/s	Toe of dune	371867	6310084	20	567.jpg, 568.jpg	Cusps	23.5
20150602	10:00	0.7	Wind 15 m/s	Toe of scarp	371872	6310082	12	569.jpg, 570.jpg	Scarped beachface	12

Table 2-5: Water Level conversions for each Secondary cell

Cell	Nearest Tide Gauge	AHD Conversion	Cell	Nearest Tide Gauge	AHD Conversion
R06A1	Port Geographe	0.68m CD	R06B8	Mandurah *	0.54m CD
R06A2			R06C9		
R06A3			R06C10		
R06A4	Bunbury	0.57m CD	R06C11	Fremantle	0.76m CD
R06B5			R06C12		
R06B6			R06D14		
R06B7			* Mandurah gauge slightly damps WL ranging		

<u>Analytical techniques</u>

- Time series of beach width measurements (Figure 2-5) indicate if the beach is narrowing or widening, for management and adaptation. It provides a seasonal and inter-annual trend in beach width change. This can be evaluated by plotting adjusted beach width column against the date and time column in the spreadsheet, which may be set to automatically update as further monthly monitoring is conducted.
- The time-series may be compared to acceptable erosion triggers determined by the LGA for that site, following an initial check to determine if any large changes are not errors or due to recent construction or earthworks (see *Post-Processing* above).
- Spatial variation in the time-series of beach widths allows an investigation to determine if beach width response is localised or systemic. It may also be appropriate to compare findings with neighbouring LGAs to determine the extent of response.
- In the long-term, additional analysis of trends and causes could perhaps be undertaken by interested third parties, such as the Department of Transport or university students [5,6]. This could include comparisons with wave forcing, variations in wind drift, shifts in mean sea level and impacts of engineering works.

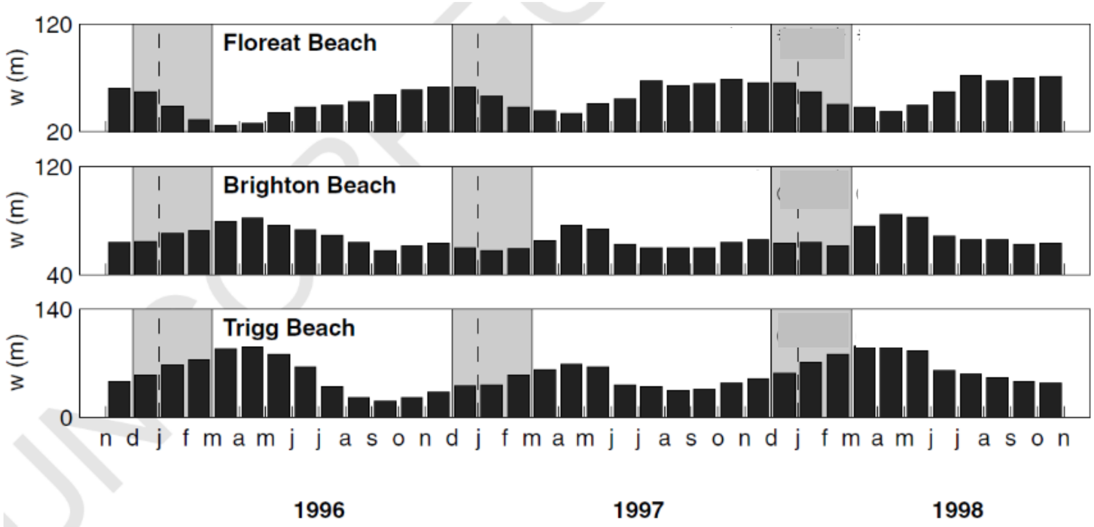


Figure 2-5: Example three year time-series of monthly beach widths
Extract from Perth measurements [6] Shading over summer (Dec – Feb)

SCHEDULE AND REQUIRED FREQUENCY

Monthly within a one-week window of the 1st to 7th of every calendar month. The scheduling of the exact date is linked to tide, winds and wave conditions as described in *Field Preparation*. After an initial 12 month period decisions can be made to reduce the spatial extent or frequency of the monitoring.

A three year long program of monthly beach width measurements is recommended to establish seasonal behaviour and determine timing for twice-yearly or annual monitoring.

DELIVERABLES

All deliverables associated with this monitoring technique are digital. These include:

- Spreadsheet of beach width and water level information per LGA according to format above with name and date format 'PNP Beach width LGA YYYYMMDD' with the LGA to be replaced with shorthand reference to each LGA;
- A folder containing scanned or saved notes pages and any extra photographs than what was required for the formal photo monitoring.

Every three months the spreadsheet should be transferred to the PNP officer co-ordinating the PNP coastal monitoring program, along with the *Photo Monitoring* datasets.

Associated photo deliverables are explained in *Photo Monitoring* (Section 2.2).

COSTS

The costs associated with this simple method listed above are the cost of the initial purchase of the 50m length measuring tape ($35 per LGA), in-kind costs of LGA officers, vehicle costs and post-processing of datasets by LGA officers. It is assumed a GPS and digital camera are already owned by the LGA or available from other projects. If the 87 sites were all surveyed the time required per officer per month may be in the order provided in Table 2-6. This time includes preparation for the field visit (e.g. loading points onto GPS), collection of beach widths accounting for travel time, extracting water levels from Department of Transport tide gauges and post-processing of datasets. Depending on the LGA this averages to 1-2 hours per site.

Table 2-6: In-kind time commitment for beach width measurements per LGA per month

LGA	Number of sites	Hours per month (1 officer)	Rationale for time selected
City of Busselton	25	25	Shorter distance and many sites easier to access. ≈1 hour per site
Shire of Capel	4	7	A bit less time due to scale of field preparation
City of Bunbury	4	6	Sites have easy access
Shire of Harvey	14	25	Assumes some sites accessible by driving on the beach
Shire of Waroona	5	10	Difficult access
City of Mandurah	15	24	Mix of easy and difficult access
City of Rockingham	19	24	Mostly easy access (≈1.25 hours)

LIMITATIONS

This simple approach does not provide an assessment of volumetric change of a beach or quantitative analysis of any other aspects of beach behaviour such as dune migration or beach level lowering. The tape measure method provides beach widths with ±5m accuracy and the GPS waypoint that marks the location of the site has a ±5m horizontal accuracy.

The method described above relies on two LGA officers, which for the 87 proposed sites, provides a large time commitment per month. This is a relatively high in-kind commitment to obtain a moderate accuracy but valuable temporal measure of beach width variability. A means of reducing time commitment may be for only one LGA officer to undertake measurements, with a large peg/stake used to hold the tape measure at the landward end. Possible implications of health and safety hazard for a single LGA officer should be considered, e.g. no immediate assistance for snake bites or trip and fall hazards. This may restrict a single officer to operating adjacent to town sites.

ALTERNATE METHODS

Improved quantification of beach behaviour can be simply obtained on those beaches where there is fixed infrastructure and the beach structure is largely horizontal. Relative vertical movement of the beach can therefore be combined with the beach width change to estimate volume change. The above-listed conditions necessary for this simple supplement to beach width measurement are uncommon long the PNP coast, and therefore have not been included within the recommended procedure.

To cover a small area, fixed camera surveys can be undertaken. The images could then be analysed to detect dune crest and the shoreline position (defined as the intersection between dry and wet beach) to calculate a time-series of beach width [9]. The beach width could be corrected to AHD using a similar method outlined above. It would not be feasible to cover the broader PNP study area using fixed cameras.

Beach widths may be extracted from beach profiles to cover smaller areas. Repeated comparisons of LiDAR may also provide changes in beach width, although at high cost.

REFERENCES

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2.2. PHOTO MONITORING

What is the technique?	Monthly collection of simple beach photographs at a fixed location to provide contextual information on coastal change.
Why should I use it?	Provides temporal information of how the beach is changing [4] as well as important context for beach width, oblique aerial and plan-form change information for further interpretation during time-series analyses.
Who does the monitoring?	This is a low-cost, easy to implement monitoring technique which can be carried out by LGA officers. A sub-set of photo monitoring will be undertaken coincident with beach width measurements (Section 2.1).
When is it undertaken?	Regular photo-monitoring (all sites) shall be undertaken twice yearly, in August and October. This is ongoing. A subset of photo-monitoring is required to support the beach width measurement, which is recommended as a three year program with monthly frequency.
Is there historic data?	Historic data may be available [3,5,6,7,10] which should be integrated with this revised monitoring from 2015 where possible.
Where should the technique be applied?	The project area is the Peron-Naturaliste Partnership coast. Locations for photo-monitoring should be known management hot-spots or indicators of sand availability, such as Roberts Point in Mandurah. It is recommended that sites be identified following three years of oblique aerial surveys. Photo-monitoring to support the beach width measurement program should occur at three locations per tertiary sediment cell (see Section 4 in CMAP). Locations are coincident with beach width measurements (Section 2.1)

METHODS

Photo monitoring involves capturing images of the coast with a specific field of view (FOV) repeated over time. The approach to undertake photo monitoring presented here broadly adheres to the Department of Transport guidelines [4] and modified to meet the monitoring needs of the PNP coast.

Pre-requisites

A set of photo monitoring sites should be established, which include known management hot-spots, or sites which may indicate relative sand availability. Additional sites should be established to support the beach width measurement program.

- For LGAs with existing coastal monitoring programs, including Rockingham, Mandurah and Busselton, it is likely that photo monitoring sites be based on existing historic data and available coastal management experience;
- For LGAs with community-based photo monitoring programs, a subset of the community coverage should be selected;
- For LGAs without a history of monitoring, the program of collecting oblique aerial photographs may be used to identify hot-spots and areas of sand storage.

Establish the field of view (FOV) for each photo monitoring site (see Section 2.1). Existing photo monitoring locations [3,5,6,7,10] should be used where possible. Guidelines for establishing the monitoring point and FOV are defined [4]:

- Select an easily identifiable fixed point landward of the active hydraulic zone along the beach width measurement line (from GPS benchmark along bearing). Examples include established trees, fence posts, corner of a car park, stable rock or structure (e.g. groyne), or an easily identifiable rocky outcrop. If none are available it is recommended to use a GPS benchmark.
- The photo monitoring point should provide an approximately 45° FOV of the beach. An up-coast and down-coast FOV should be established at each monitoring point where relevant. Note if more than two photos are required to capture the main features of the beach from that location.
- The FOV must be easily repeatable by including the same features (e.g. trees, buildings) at the edges of the FOV.
- The FOV should provide coverage of the zone between the low water mark (or further offshore) and the backshore (prominent rear dune or equivalent).

The *How to Photo Monitor Beaches* [4] document provides detailed guidance on how to establish FOV and benchmarks as well as an overview of the monitoring process for different beach types including (1) sandy beaches, (2) rocky coasts and (3) engineered coasts. This document should be used as a key reference when establishing photo monitoring sites.

<u>Datums or controls</u>

A unique site name and monitoring number is assigned to each photo monitoring FOV per site (see *Pre-requisites* above). The names of each of the photo monitoring FOVs should have a post-fix of A and B (or C if required) following the name of the site derived from the tertiary sediment cell [11] name (Table 2-1). For example the monitoring site R06A4b.2 in the Shire of Capel would have photo monitoring FOV of R06A4b.2A and R06A4b.2B.

Important survey information should be collated in a document including:

- A table of the GPS locations of the site e.g. Table 2-7;
- A map of the sites and FOV on an aerial photograph;
- Height of the camera from the ground;
- Description of permanent features that frame the FOV of the photo (or a bearing);
- Site photo of the benchmark;
- Site access location; and
- An example photo to use as the basis for field planning in future.

Examples are demonstrated in *How to Photo Monitor Beaches* [4] and the *Geraldton Volunteer Beach Monitoring Manual* [8].

Table 2-7: Photo monitoring field of view information

Site & FOV	E / Lat.	N / Long.	Height of camera from ground when photo was taken	Description of permanent features that frame the FOV of the photo (or a bearing)	Site Access	Example Photo

Spatial density

A minimum of two photos will be required at each photo monitoring site, with further explanation in Section 4 in the CMAP.

Equipment

- Handheld GPS with waypoints of benchmarks loaded (could use software Mapsource). Spare batteries and sufficient space on GPS;
- Camera (geotag photographs if available). Spare batteries and sufficient space on camera card. Use the time and date stamp function. DoT [4] recommend 35mm digital camera with resolution ≥ 6 megapixels. Alternatively, a smartphone with geotagging capacity may be used;
- Tape measure to ensure consistent approximate height from the ground for camera;
- Notepad (clipboard and pen) or tablet to record the photo numbers and site observations onto the beach with data sheet (example Table 2-3).

Field preparation

Before entering the field the following tasks should be completed:

- Test all equipment, including GPS to ensure waypoints are loaded to assist in navigation to sites and correct datum is set (GDA94 UTM50);
- Ensure camera has correct date and time and is on the maximum resolution. Turn on geotagging if available;
- Review word document collating information on T benchmarks and fields of views for the photo monitoring (see *Datums or controls*);
- If the photo monitoring is to be conducted in parallel with the beach width measurement program, it is subject to the program's schedule and operational constraints (Section 2.1).

Monitoring techniques

Navigate to the site of interest using the GPS and take the photos with the specified FOV according to the information collated in the pre-prepared document outlining the photo monitoring (see *Datums or controls*). Note the date and time of the photograph (capture on the image if possible), as well as the photo number (example Table 2-3). DoT [4] recommend taking the photos between 9am and 3pm if possible to minimise sun glint off the water.

Post-processing

The photos should be saved per site and FOV following these conventions:

- Highest level folder should be titled 'PNP Photo Data - LGA' with the LGA replaced with shorthand reference to each LGA;

- Within that folder, a series of folders should be saved per tertiary cell, e.g. R06A4b;
- Within each tertiary cell folder, a series of folders should be named by monitoring point and FOV, e.g. R06A4b.2a;
- After each monitoring round, upload all photos for the specified FOV into the relevant folder. They will automatically be stored by time and date;
- The field sheet with beach observations is scanned or saved and placed into the highest level folder with name 'Field Sheet – YYYYMMDD'.

This information should be updated *monthly* into a relevant folder on the PNP ftp site, which may require overwriting photos for efficient photo transfer.

It may be possible to establish a database for beach monitoring photos to allow easy access for the community. DoT [4] provide a useful set of recommendations that should be adopted to guide formulation of such a database at a later date.

Analytical techniques

The photos may be used to:

- Cross reference with beach width measurements to validate direction and magnitude of change;
- Track seasonal behaviour of beachface features, for example, accumulation and movement of wrack, beach state, migration of secondary landforms (e.g. foredunes, step, berm); and
- Provide context for other quantitative measures such as change measured from beach profiles or vertical aerial imagery.

SCHEDULE AND REQUIRED FREQUENCY

Regular photo-monitoring (all sites) shall be undertaken twice yearly, in April and October. This is ongoing. Higher frequency may be appropriate at intensive monitoring sites, such as Mandurah northern beaches.

A subset of photo-monitoring is required to support the beach width measurement, which is recommended as a three year program with monthly frequency (Section 2.1 *Schedule and Required Frequency*).

DELIVERABLES

All deliverables associated with this monitoring technique are digital. Two deliverables:

- Photo monitoring plan with GPS locations of the site, a map of the sites and field of view on an aerial photograph, height of the camera from the ground, description of permanent features that frame the FOV of the photo (or a bearing), site photo of the benchmark, site access location and an example photo to use as the basis for field planning in future. The file should have the name and date format 'PNP Photo Sites – LGA YYYYMMDD' with the LGA replaced with shorthand reference to each LGA.
- The highest level folder of the photo storage, including all photos and field sheets. The name of the folder should have the name format 'PNP Photo Data - LGA' with the LGA replaced with shorthand reference to each LGA.

This information should be provided to the PNP either via the ftp site or through transferring photos on a disc/USB every three to six months for archiving.

COSTS

Costs associated with photo monitoring are in-kind, relating to the need for LGAs to access and photograph their sites. The commitment is estimated to be two days per year to capture the photographs and two days per year of post-processing and data storage.

Photo monitoring to support the (monthly) beach width measurement program is assumed to be included within the time commitment as part of the beach width measurement task (Section 2.1).

LIMITATIONS

Photo monitoring is a relatively time intensive monitoring approach, due to the need to access each site. Getting FOV consistent can be difficult on coasts without fixed features. The technique is recommended to have limited temporal and spatial coverage and hence may not capture storm response and recovery as suggested by DoT [4] and apparently intended for the City of Mandurah's established monitoring program [5].

ALTERNATE METHODS

The fixed point photo monitoring method recommended is monitors beaches concurrently with other data collection through the beach width measurement technique. However, additional sites and photo monitoring at other times may be possible if it satisfies other management or monitoring objectives.

Photo monitoring can be undertaken as a nested approach with multiple techniques covering different areas of the coast. Four techniques are listed below in order of expense to the LGAs from community monitoring through to ARGUS, the most expensive. There is increased control and accuracy of the imagery with progress through the four levels. Alternate methods for photo monitoring are:

- Community – where fixed benchmarks and FOV are set and community members are responsible for taking photos and logging them in a database [8,9]. Difficulty with this system is discontinuous records and requirement for staff to maintain volunteers and the database.
- Fixed point – the method outlined in this section, after DoT [4].
- Fixed camera – remote imagery units designed to take photos at pre-defined intervals at a fixed site, with telemetry of imagers to web portals [2]. This would not be feasible to cover the whole PNP, with existing monitoring undertaken in City of Mandurah.
- High frequency video monitoring – such as Argus or equivalent [1,12], that is able to be used to monitor other beach characteristics. This would not be feasible to cover the whole PNP coast.

<u>Photomon</u>

An option to support community monitoring is using the *Photomon* smartphone application [9]. This would require discussion with the Northern Agricultural Catchments Council (NACC) about setting the app up for use in the PNP area, including establishing guide photos for each site and FOV. The app would need to be specially modified to link the app to a PNP dedicated database. This option requires payment to the developer for amending the app and maintenance of the new database. For further information see *Customising Photomon* in the user manual [9]. This has not been costed.

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[12] Turner I, Aarninkhof S & Holman R. (2006) Coastal Imaging Applications and Research in Australia, *Journal of Coastal Research*, 22 (1): 37-48.

2.3. DUNE MIGRATION ASSESSMENT

What is the technique?	Measurement of the rate of landward dune migration for mobile sand dune areas. It can be used in conjunction with vertical aerial imagery to provide a spatial extent of dune movement for the area of interest.
Why should I use it?	Allows measurement of dune migration and evolution that supports more rapid decision-making than using aerial imagery. Assists in justification of ongoing dune revegetation efforts for blow-out areas and helps prioritise areas for future efforts.
Who does the monitoring?	This is a low-cost, easy to implement monitoring technique which can be carried out by PNP officers or members of the public given appropriate instructions.
When is it undertaken?	Annually (at minimum). Twice yearly may be required to determine whether mobility occurs mainly in summer or winter.
Is there historic data?	While dune migration information has not been explicitly collected in a co-ordinated manner through the area of interest, it is possible to extract information on dune mobility for the area of interest from aerial photo analysis.
Where should the technique be applied?	From Capel River mouth to Preston Beach N (Cells R06A4a to R06B7a; Figure 2-6) in areas with active blowouts.

METHODS

This technique involves a simple measurement of inland sand migration from the landward edge of a coastal dune. Measurements are taken relative to a fixed point, a star picket or post hammered into the ground.

It is possible to map the landward dune toe from aerial photography at a consistent scale to provide information on plan-form change. Dune migration and evolution measured at fixed points along the dune can then be interpreted in the context of this alongshore, planform change.

Pre-requisites

Identify the dunes to be monitored.

Datums or controls

A desktop assessment should be undertaken to identify which dunes require monitoring using this technique. Supplementary information may be provided by beach width measurement (additional to that in Section 2) to provide context for the dune migration rates. Monitoring sites should following the naming convention of tertiary cells where possible (Table 2-1; Stul *et al.* 2015) with post-fix of .DM1 and .DM2 for the dune migration sites.

For the initial campaign of establishing monitoring sites approximate locations of the intended sites should be loaded onto a handheld GPS to assist with navigation. On site, the co-ordinates of each star picket should be recorded as a waypoint and manually documented for redundancy.

Information that may be used as the basis for future field planning should be complied in a document. This should include (Table 2-8):

- A table of GPS locations of installed star pickets;
- Location map;
- Site photos of any identifying features; and
- Site access location.

Table 2-8: Benchmark information for dune migration

Site	Seaward (1) E / Lat.	Seaward (1) N / Long.	Landward (2) E / Lat.	Landward (2) N / Long.	Site Access	Photo
R06A4a.DM1						

Spatial density

No set spatial density is required, with two separate sites recommended for each dune area of interest. The area of coast where mobile dunes may be monitored in this way are likely to be located is from Capel River mouth to Preston Beach N (Figure 2-6), which includes tertiary sediment cells R06A4a to R06B7a.

Equipment

- 2 x galvanised star pickets and high-visibility caps per site, possibly with a third for rapidly migrating sites.
- Block hammer for initial set up and if additional star pickets are required.
- High visibility boundary tape.
- Measuring tape.
- Handheld GPS with waypoints loaded (could use software Mapsource). Spare batteries and sufficient space on the GPS.
- Data recording sheets (example Table 2-9), clip board and pen or data sheet loaded onto a tablet.
- Camera (geotag photographs if available). Spare batteries and sufficient space on camera card.

Field preparation (LGA officer)

The following tasks should be completed before entering the field:

- Test all equipment, including GPS to determine waypoints are loaded to assist in navigation to find the sites and correct datum is set (GDA94 UTM50).
- Take the field sheet (hardcopy or digital on tablet; e.g. Table 2-9) pre-filled with information relevant for the sites of interest, as well as the document with the information on benchmarks (see *Datums or controls*).

Table 2-9: Example dune migration field sheet (LGA officer)

Date:					Survey crew members:				
LGA:					Weather conditions (wind speed and direction):				
Profile	**Seaward (1) E / Lat.**	**Seaward (1) N / Long.**	**Seaward (1) height (cm)**	**Landward (2) E / Lat.**	**Landward (2) N / Long.**	**Landward (2) height (cm)**	**Along surface distance (m)**		**Photos**
R06B4b.DM1									
R06B4b.DM2									

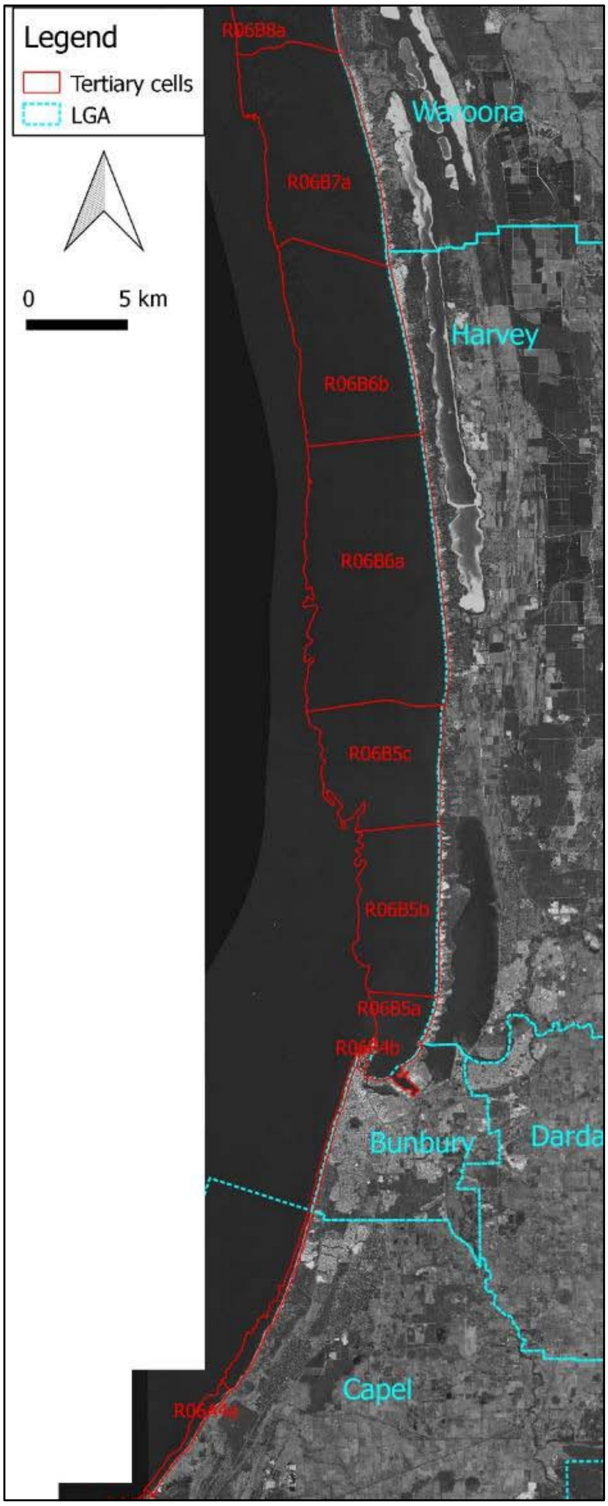

Figure 2-6: Tertiary cells where dune migration monitoring could be considered

<u>Monitoring techniques</u>

It is recommended that two star pickets are configured as per the diagram in Figure 2-7, with one the landward edge of the dune toe (point 1, denoted Seaward) and a 10m horizontal distance further landward (point 2, denoted Landward). The star pickets act as a reference point for the ongoing horizontal and vertical measurement and thus must be securely fixed into sand with a GPS waypoint recorded at each (Table 2-8).

Potential safety issues associated with deployment of star pickets should be managed with due care (see *Limitations*).

Measurements should be taken, typically at an annual frequency, by measuring the distance from the top of the pole to the dune surface (i.e. the length of star picket not covered by dune sand) at both star pickets and the distance along the sand surface from the base of the two star pickets (Table 2-9). If the star picket at the seaward side (point 1) is being smothered and less than 20cm of star picket is above the surface, a further star picket (point 3) should be added 10m landward of the second star picket, to support continuing measurement (Figure 2-7). Ensure all three posts are measured simultaneously at least once before attempting to remove the seaward star picket.

Estimate the wind speed and direction observations while in field as an indication of the relative accuracy of tape distance measurements. An accurate measure of wind may be obtained using a hand-held anemometer, although typically a qualitative description of speed (calm, light, moderate, strong or gusty) is adequate.

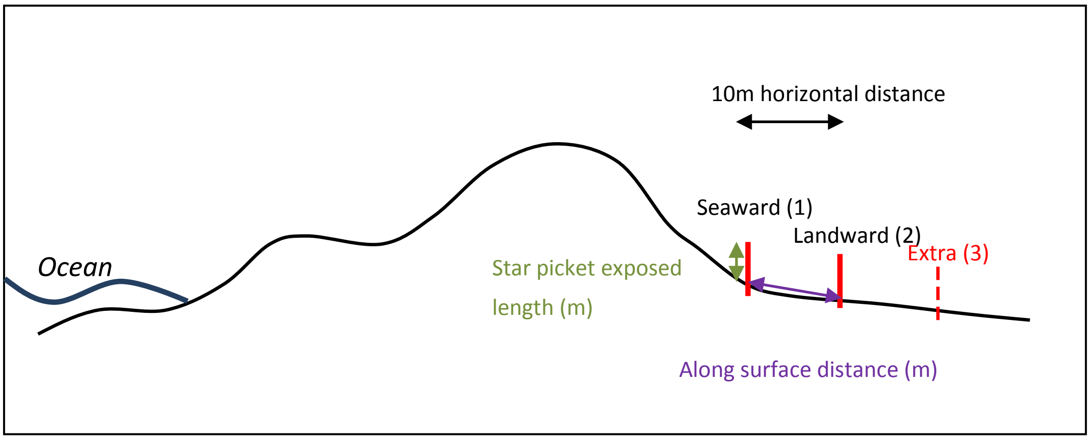

Figure 2-7: Dune migration monitoring method

<u>Post-processing</u>
The vertical measurements for star picket 1 (seaward) and star picket 2 (landward) should be recorded as heights in centimetres from the top of the post to the sand surface in a spreadsheet. The distance measurement along the sand surface from the bottom of the two star pickets should also be recorded, as well as noting the numbers of the site photos.

Once a time-series is established it is useful to check the measurements upon entry to the spreadsheet for any potential measurement error.

Any management actions undertaken on the dunes throughout the year should be documented. This information may provide context for the rates of change measured. Information on the type of dune management, such as planting or fencing, and the dates the works were undertaken can be useful to track the success of the management works on slowing rates of dune migration.

Analytical techniques

The following information can be inferred at a single point from the annual measures from the star pickets:

- Rate of vertical change;
- Change of grade; and
- Horizontal movement.

The single-point measures of vertical change and change of grade at the star pickets can then be compared with the rates of horizontal movements of the broader dune identified from vertical aerial imagery using GIS (Figure 2-8). The vertical measurements add another dimension to be able to undertake gross estimates of volumetric change in the dune.

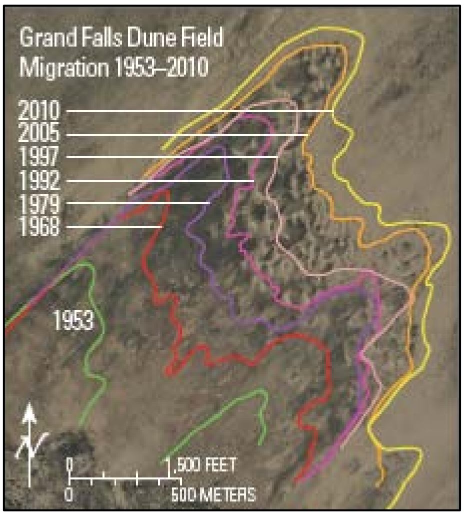

Figure 2-8: Example of dune field mapping and migration
From United States Geological Survey [2]

SCHEDULE AND REQUIRED FREQUENCY

At a minimum, dune monitoring should be conducted annually, at a consistent time each year. For most mobile dunes along the PNP coast, the end of winter is typically an appropriate time. Twice yearly monitoring may be required to determine whether mobility occurs mainly in summer or winter.

Opportunistic monitoring may be undertaken more frequently.

DELIVERABLES

All deliverables associated with this monitoring technique are digital. This includes:

- spreadsheet of star picket locations, dates and measured heights per LGA according to format above with name and date format 'PNP Dune migration LGA YYYYMMDD' with the LGA to be replaced with shorthand reference to each LGA.

This information should be submitted to PNP officers following completion of the annual monitoring. In addition, the table of ongoing dune management actions should also be provided saved with the name and date format 'PNP Dune management actions LGA YYYYMMDD'.

COSTS

The costs associated with this simple method are the cost of the purchase of the star pickets, then in kind-costs of LGA officers, vehicle costs and post-processing of datasets by LGA officers. It is assumed a GPS and digital camera are already owned by the LGA or available from another project. It is estimated approximately 2-3 hours per year would be required per site including loading the site waypoint to the GPS, travel, monitoring and post-processing.

LIMITATIONS

Limitations of this technique include the potential smothering of the star pickets, vandalism or theft of the star pickets and that the star pickets may provide a trip/impaling/driving hazard.

Methods to address safety issues associated with deployment of star pickets will vary from site to site. At the least, this should include the use of high-visibility capping to reduce exposure of sharp edges. Where view of the pickets is potentially obscured, say by vegetation, high visibility boundary tape may be used to mark off an area containing the pickets. In instances where the dune face is used for recreation, these risks are increased and it is recommended to use reduced monitoring without the seaward picket. This restricts collected information solely to horizontal dune movement.

Occasional survey may be used to reduce the risk of theft or vandalism. However, the added cost associated with surveys would stop this being a low-cost measurement technique.

ALTERNATE METHODS

Rates of horizontal dune migration can be measured using vertical aerial imagery. However, due to the accuracy of imagery, this technique is mainly valid for sand sheet movement, over decadal or longer time scales.

Information regarding dune movement could also be obtained from feature surveys undertaken by surveyors with RTK GPS. If any dune migration is encroaching on high value infrastructure, such as a road, further analysis of vertical levels and rates of migration could be obtained from repeated terrestrial laser scanning, LiDAR or UAV surveys of the area [1,2]. These represent relatively high cost approaches towards obtaining information regarding dune mobility and will therefore only be practical where such information is already being collected for a separate purpose.

REFERENCES

[1] Mitasova H, Overton M and Harmon R. (2005) Geospatial analysis of a coastal sand dune field evolution: Jockey's Ridge, North Carolina, *Geomorphology*, 72: 204-221.

[2] Redsteer MH, Bogle RC and Vogel JM. (2011) *Monitoring and analysis of sand dune movement and growth on the Navajo Nation, southwestern United State*s. U.S. Geological Survey Fact Sheet 2011–3085, 2 p., available at http://pubs.usgs.gov/fs/2011/3085/.

3. Off-site Erosion Monitoring Technique

Oblique aerial photography is a ‘medium’ level monitoring technique that is a relatively low-cost dataset that may provide information along the entire length of the PNP coast.

3.1. OBLIQUE AERIAL PHOTOGRAPHY

What is the technique?	Photographs taken from an elevated position over water, at an angle (not directly perpendicular) to the coast.
Why should I use it?	Provides an extra dimension for detecting change compared to ortho-imagery, giving a contextual dataset. Imagery may be collected outside summer months, which is the focus of the Landgate vertical aerial imagery monitoring program. The technique can be used to assess gross changes along the coast, and provides context to other coastal measurements. It is a useful communication tool to demonstrate coastal dynamics.
Who does the monitoring?	Requires external support through a helicopter or plane and cannot solely be conducted by LGA/PNP officers. An LGA or PNP officer is required to take the photography.
When is it undertaken?	Twice-yearly
Is there historic data?	Time-series already available for whole PNP includes 2008 [2,3], December 2014[5] (PNP), April 2015 (PNP). Additional information is collected for the City of Busselton [4].
Where should the technique be applied?	Monitoring should cover the entire PNP coast, between Cape Naturaliste and Cape Peron, including photography of the eastern side of Penguin Island

METHODS

This technique requires a PNP officer and a contracted helicopter/light-plane with pilot.

Pre-requisites

It is recommended the frequency of the collection of this dataset is discussed with the City of Busselton, who undertake oblique aerial monitoring of the City of Busselton coast [4]. If possible, data collection for the broader PNP could be undertaken simultaneously with some of the City of Busselton monitoring to reduce overall monitoring cost.

Datums or controls

None required for this technique.

Spatial density

Photos with overlap. Total number of photos of 230 to 450 dependent on angle of camera.

Equipment

- Camera with inbuilt GPS tracking. Sufficient batteries and space on camera card, with a spare camera card for redundancy.
- Separate handheld GPS for redundancy or for non-GPS cameras. Batteries.

[5] Processing yet to be completed due to GPS error

- Warm clothing (gloves, beanie, jacket) for photographer.

Field Preparation (PNP or LGA Officer)

Schedule helicopter/light-plane and ensure pilot agrees to nominated flight path, with booking to be weather dependent.

Before entering the field ensure all equipment should be tested, including:

- If the camera is on correct setting to collect high-resolution imagery (for GPS-tracking camera select maximum resolution).
- Date and time are correct on the camera, with time and date stamp function turned on.
- GPS in camera can be activated (15s logging).
- Imagery when loaded to computer is in the order of 3MB with spatial information included.
- Check to see if the trial GPS track log information can be transferred to the computer and matches area mapped in GIS.

Monitoring techniques

Take photos at a 45° forward angle with plane/helicopter at 300m from the coast and 150m elevation (e.g. Figure 3-1). Photos should have small overlap. Before taking photos, ensure GPS is activated for 15s interval logging in camera and tracklog on separate GPS for redundancy.

Figure 3-1: Example of oblique aerial image

Post-processing

- Save original images and GPS tracklogs.
- Copy the photos folder and cull photos to ensure only minimal number needed with overlap (removing interest photos or any in opposite direction of flight path)
- Rename photos to increase numerically from 001.jpg ensuring no missing numbers using batch renaming software (e.g. Faststone photo resizer).
- Generate a shapefile of points. Points represent where photo was taken, rather than centroid of image, to reduce post-processing time as it is automated. For photos that are geo-tagged this can be undertaken using the python script created by BMT Oceanica, with shapefile attributes updated to reflect DoT metadata requirements (Table 3-1). This task may be undertaken by an external consultant.

Table 3-1: DoT metadata requirements for oblique aerial imagery

	Example
Picture_ID	DSC_0002
Lat	-33.68286667
Lon	121.83
Altitude	68
Direction	0
Heading	0
Datum	WGS 84
Title	Esperance to Border Village oblique aerial
TimeStamp	12/01/2009 23:18
Original	DSC_0002.JPG
Thumb	DSC_0002_small.jpg
WebPage	DSC_0002.htm
East	391550.25
North	6272392.08
curZone	51 S
LocalTime	13/01/2009 7:18
	1:00
LocalTimePlus1	13/01/2009 8:18
WptName	
Track	0
Speed	0.2
GPSValid	Yes
Camera	NIKON D80 Ver.1.10

Analytical techniques

- Shapefiles of multiple datasets can be opened simultaneously in spatial viewers to extract photos for comparison across multiple dates.
- For areas of ongoing concern update word documents with time-series of oblique aerials collected for the site.

SCHEDULE AND REQUIRED FREQUENCY

Twice yearly in March-April and August-September, noting the tide, winds and likely sun-glare when scheduling the flights.

DELIVERABLES

All deliverables associated with this monitoring technique are digital. Two deliverables:

- Photos labelled according to naming convention above saved in a folder with name and date format 'PNP Obliques YYYYMMDD'.
- Point layer in shapefile format in UTM50 GDA94 projection according to format above with name and date format 'PNP Oblique points YYYYMMDD'.

Digital images and point layer shapefile to be provided to PNP and DoT. Each LGA should ensure dataset is added to Intramaps or equivalent GIS software.

COSTS

Total cost per dataset is $3,220.00 - $3,715.50 (inc-GST) in 2014-2015.

- Helicopter/plane hire: $3027.50 (3.5 hours) for helicopter. $2,532.00 (5 hours) for plane with additional transport costs of staff from Mandurah to Jandakot.
- Time by PNP officer: 12 hours in-kind.
- Post-processing of images, points shapefile and attributes: $688 (4 hours, $172/hr).

LIMITATIONS

It is difficult to create directly comparable datasets of oblique imagery because of lack of a consistent distance from shore, elevation and angle of photography. Imagery of interest can be manually cropped to ensure they match between datasets.

Additional post-processing is required if the geotagging of photos does not work for the camera. A link between the GPS tracklog and the photo timestamps must be established.

ALTERNATE METHODS

It may be possible in the future, as technology improves, that capture of the oblique dataset may transition to georeferenced high-definition videography [5] and monitoring with Unmanned Aerial Vehicles [1].

REFERENCES

[1] Drummond C, Harley M, Turner I, Matheen A & Glamore W. (2015) UAV Applications to Coastal Engineering, In: *Proceedings of Coasts & Ports 2015 Conference*, Wellington New Zealand, 15-18 September 2015.

[2] Gozzard JR. (2011a) *WACoast – Cape Naturaliste to Lancelin*. Geological Survey of Western Australia digital dataset.

[3] Gozzard JR. (2011b) *WACoast –Rottnest Island*. Geological Survey of Western Australia digital dataset.

[4] Shore Coastal Pty Ltd. (2013) *Busselton Coastal Management Program* (2014-2018). Report SCR1211. Section 3.2.1 Photographic Sites.

[5] Wynja V, Demers A-M, Laforest S, Lacelle M, Pasher J, Duffe J, Chaudhary B, Wang H & Giles T. (2015) Mapping coastal information across Canada's northern regions based on low-altitude helicopter videography in support of environmental emergency preparedness efforts, *Journal of Coastal Research*, 31 (2): 276–290.

4. Inundation Monitoring Techniques

The PNP manages a number of foreshore areas which may be subject to coastal inundation, including extensive areas of estuarine shore. This hazard affects all PNP member agencies, and is the main coastal hazard faced by the Shires of Murray and Dardanup.

Inundation may interrupt nearshore amenity, damage foreshore structures, flood low-lying roads and buildings, and in extreme cases require emergency management such as sand bagging or evacuation [2]. Although tide gauges managed by the Department of Transport provide a quantified means of measuring floods, the extent of inundation varies locally due to differences in wind set-up or wave conditions. Measuring the inland extent, elevation and frequency of inundation events allows LGA officers to track the frequency with which unsafe water levels are experienced at a local scale. This may inform decision-making on siting of infrastructure, the need for signs to warn of unsafe flooding levels or the requirement to redirect traffic.

Two simple techniques are presented here to enable collection of flood frequency information (Section 4.1) and the maximum extent of coastal inundation as a result of storm events (Section 4.2).

It is suggested that monitoring locations for these techniques be based on a combination of local knowledge (of areas with existing inundation hazard) and overlay of extreme-event (100-year ARI) inundation mapping [1]. Storm inundation monitoring may be triggered if observed water levels for the nearest tide gauge [6] reach a nominated threshold listed (Table 4-1). These levels approximate a 25-year average recurrence interval, but do not include wave effects.

Table 4-1: Water level triggers at tide gauges for extent of storm inundation monitoring

Tide Gauge	CD level of 0m AHD	Water Level (mCD) [7]	Relevant LGA
Port Geographe	0.68m	2.1m CD	City of Busselton, Shire of Capel
Bunbury Inner Harbour	0.57m	2.0m CD	City of Bunbury, Shire of Harvey, Shire of Dardanup (near Collie River).
Mandurah Ocean Marina	0.54m	1.5m CD	Shire of Waroona, City of Mandurah (estuary), Shire of Murray.
Fremantle Fishing BH	0.76m	1.9m CD	City of Mandurah (ocean), City of Rockingham

[6] On the Department of Transport storm surge website.
[7] These trigger levels will require reassessment as the monitoring program matures.

An LGA ranger should co-ordinate a monitoring sequence for flood frequency logs to be collected at sites where assets of value are located with known inundation risk. Records may also be gathered by interested community members where inundation events are occurring in proximity to their property. The records collected by community members should be viewed as supplementary, ad hoc measurements that complement the core LGA monitoring.

4.1. FLOOD FREQUENCY LOGS

What is the technique?	Determine frequency of actual inundation during storm events for areas of high value or key infrastructure locations.
Why should I use it?	Provides temporal information of the frequency of inundation combining water levels and waves. This information can be compared to tide gauges that measure still water level at one location. This information allows LGA officers to determine how frequently 'safe' water level thresholds for infrastructure are surpassed which has implications for flood warning and emergency management procedures.
Who does the monitoring?	LGA Rangers or other relevant LGA officers with assistance from local community members, if appropriate.
When is it undertaken?	During storm events
Is there historic data?	Historic data may be located within LGA records, however it is sufficient to start the monitoring from 2015.
Where should the technique be applied?	In areas identified as subject to inundation hazard in the *CMAP* that have values threatened by inundation (e.g. road intersections).This applies to all nine LGAs, including Shire of Murray and Shire of Dardanup.

METHODS

Collection of flood frequency logs is a simple technique that may be undertaken by LGA officers to track the frequency with which an area of the foreshore experiences inundation [2]. Vertical measurements may also be collected relative to bench marks, where possible, to provide information on the relative occurrence of flood depths for foreshore assets.

Pre-requisites

Each LGA should identify sites that are important to monitor, based upon trigger still water levels at the nearest tide gauge, specified in Table 4-1. Potential sites to monitor for inundation may be identified from ranger knowledge or by overlaying inundation mapping [1] on cadastre and road information. It may be determined that for certain low-lying sites, with a direct connection to the coast, a lower water level may trigger the monitoring than that listed in Table 4-1. Each site should have a benchmark established.

Datums or controls

For each site a fixed vertical benchmark should be established with its base surveyed to obtain co-ordinates for future monitoring and provide a vertical level for evaluation of flood depth. Benchmarks should be fixed infrastructure that is unlikely to be removed or lost during an inundation event, accessible during a flood and be at least 1 m high to extend above most inundation events. Examples of useful benchmarks may include street light poles, high retaining walls or street signs.

The same benchmark should be used for all monitoring at each site, unless the benchmark is removed. If the benchmark is removed a new benchmark should be identified.

Spatial density

Not relevant for this technique as it is a temporal measure at specific sites of value. However, it is noted that flood frequency logs at multiple locations along the shore may support development of flood risk maps. This application has not been evaluated as part of the Monitoring Manual.

Equipment

- Camera, with spare batteries and sufficient space on camera card.
- Frequency of flood log form (hardcopy or tablet device).
- Measuring tape or staff – optional.

Field preparation (LGA ranger and community member)

Event-specific monitoring is undertaken by an LGA ranger, with multiple sites visited for the same event. The information will be collected on a field sheet (hardcopy or digital on tablet; Table 4-2) that includes all relevant locations, benchmarks and coordinates, entered ahead of the field visit. To reduce the number of sites to visit during each field campaign it is recommended to determine the likely sites of inundation for the event of interest ahead of time.

Table 4-2: Example flood frequency log sheet – event specific (LGA officer)

Date:							**Person monitoring:**		
Location	**Benchmark (BM) description**	**BM base (mAHD)**	**BM E/lat.**	**BM N/long.**	**Max elev. above BM (m)***	**Time**	**Inundated (Y/N)**	**Photo**	**Notes**

*Note *: if safe to record after the inundation event is concluded*

Monitoring of a designated site to be undertaken by a community member should be recorded using Table 4-3. This will be a time-series of monitoring at a designated site. Therefore the previous monitoring form should be taken into the field (hardcopy or digital on tablet).

Table 4-3: Example flood frequency log sheet (community member)

Location:					**Benchmark (co-ords, level mAHD and description):**	
	Date	**Time**	**Photo**	**Inundated (Y/N)**	**Max elevation above mark (m) – if safe to record after the inundation event is concluded**	**Notes**
1						
2						
3						

Monitoring techniques

All flood waters should be avoided for the safety of personnel.

Where monitoring is being undertaken at a single site only (e.g. by a community member), the following tasks should be carried out:

- Note the date and time the site was visited.
- Take a photo of the inundation including the benchmark.
- Note if the benchmark is inundated.

- If possible, obtain a vertical measurement of the maximum elevation of inundation on a benchmark from the base using a measuring tape or staff (m). This measurement should only be undertaken if the inundation is subsiding and it is safe to access the benchmark.

If an LGA ranger is monitoring multiple sites for a single event; the location and benchmark information will already be available in the field sheet. The timing of the survey, a photo record and whether or not the benchmark was inundated should be recorded while in the field. If possible, obtain a vertical measurement of the maximum elevation of inundation on a benchmark from the base using a measuring tape or staff (m). This measurement should only be undertaken if the inundation is subsiding and it is safe to access the benchmark.

Post-processing

- Save log sheets and photos. If hardcopy log sheets are used, ensure they are scanned at a minimum and preferably digitised into a spreadsheet for a long-term dataset.
- If a community member has been undertaking the site-specific monitoring ensure the updated data are emailed to the relevant LGA officer.
- If possible, it is recommended that an LGA officer note the meteorologic and oceanographic conditions when the inundation event being measured occurred. A simple method is to take screen shots of websites and paste in a word document. Information includes: (1) Synoptic charts from the Bureau of Meteorology, (2) Rainfall, wind and atmospheric pressure for the previous 48 hours from latest weather observations on the Bureau of Meteorology, (3) Total water level and storm surge at the nearest tide gauge from Department of Transport, (4) Storm surge comparison chart for all stations from Department of Transport to identify continental shelf waves. This word document can then be saved.

Analytical techniques

Most of the recommended analyses should be undertaken once datasets of a sufficient length have been obtained. In addition, the information collected in this task can be compared to the wrack or inundation line datasets (Section 4.2).

Analyses that could be conducted using this dataset include:

- Provide frequency information of inundation of asset of value (e.g. road) in format of X times in Y years. This can be useful to inform community and for management, such as determining if a change of land-use is appropriate.
- Provide a spatial distribution for inundation for different flood events, in conjunction with the post-event inundation extent datasets (Section 4.2). Spreadsheets can easily be converted to GIS point shapefiles to provide an indication of spatial coverage.
- Refine return periods and probabilities of occurrence of flood levels for design and risk management.
- Heights from fixed benchmark can provide an indication of whether thresholds for safety of pedestrians/vehicles or siting of infrastructure are being surpassed (Engineers Australia [3] Table 9.6.1 and Table 9.6.2; FEMA [4] Table 5-2). An example is that water levels lower than 0.3m tend to be safe for pedestrian access. Most of these thresholds are a combination of depth and velocity. While the information collected using this technique provides insight into depth alone, it acts as a useful guide to inform the requirement for ongoing hazard or emergency response management and indicates areas where it may be necessary to gather other more detailed information.

SCHEDULE AND REQUIRED FREQUENCY

Monitoring is required for any event likely to result in inundation. It is recommended to collect this data as an ongoing task to ensure a long-term dataset is available.

DELIVERABLES

All deliverables associated with this monitoring technique are digital.

- Spreadsheet of data collected according to field sheets (Table 4-3 or Table 4-2) saved with name and date format 'PNP Frequency of Flood Logs YYYYMMDD'.
- If collected, the metocean conditions during the event in a word document with name and date format 'PNP Metocean Conditions Event YYYYMMDD'.
- A digital folder containing photographs and metocean conditions during the event with name and date format 'PNP Flood Event YYYYMMDD'.

Each LGA should store the dataset in the same location as previous frequent of flood logs. For redundancy this information should also be provided to PNP.

COSTS

In-kind costs of LGA rangers and vehicle costs, with possible in-kind time for community members.

LIMITATIONS

A limitation is ensuring safety of individuals assessing the inundation.

This method does not capture depth or duration of inundation. It is not practical to measure duration beyond identifying whether it was a short peak or sustained flood. It is not encouraged to measure the depth of inundation due to safety concerns.

ALTERNATE METHODS

Community photographs collected during inundation events may provide a useful supplement to the flood frequency logs.

In locations where fixed cameras are installed, such as for beach monitoring, the imagery may also be used to evaluate the frequency of flooding above an identified threshold.

REFERENCES

[1] Damara WA. (2012) *Coastal Hazard Mapping for Economic Analysis of Climate Change Adaptation in the Peron-Naturaliste Region*. Prepared for Peron-Naturaliste Partnership Coastal Adaptation Decision Pathways (PNP-CAPS) project: Developing Flexible Adaptation Pathways for the Peron Naturaliste Coastal Region of Western Australia, Report 169-01.

[2] Emergency Management Australia: EMA. (2009a) *Flood Preparedness*. Manual 20.

[3] Engineers Australia. (2013) *Safety Design Criteria*, Australian Rainfall & Runoff Guidelines, Book 9, Chapter 6, Draft. Authors Cox R & Smith G. http://www.arr.org.au/wp-content/uploads/2013/Draft_Chapters/ARR_b9_ch6_draft_131209.pdf

[4] Federal Emergency Management Agency: FEMA. (2011) *Coastal Construction Manual*. Fourth Edition.

4.2. INUNDATION EXTENT SURVEYS

What is the technique?	Determine actual inundation extent through measuring high water mark or debris left from seawater incursion as a result of a storm event. On occasion the inundation extent may also be due to interaction with rainfall runoff flooding.
Why should I use it?	Provides spatial coverage of combined still water level and wave run-up. This information can be compared to tide gauges that measure still water level at one location.
Who does the monitoring?	Simple: LGA/PNP officers (anyone with a GPS and measuring tape) Higher accuracy: Licensed Surveyors
When is it undertaken?	Post-event for storms with tide gauge levels above a certain criteria
Is there historic data?	Historic PWD/DoW/WAWA records, such as PWD 51019-1 to 8 for Bunbury to Dunsborough in Tropical Cyclone Alby (1978).
Where should the technique be applied?	Any areas identified as subject to inundation hazard in the *CMAP*

METHODS

This technique can be undertaken by a PNP or LGA officer as a measure of actual extent of inundation from a storm event.

<u>Pre-requisites</u>

None required. However, areas likely to experience storm inundation can be identified from maps of previous inundation extent lines (if available) or projected inundation mapping [2].

<u>Datums or controls</u>

None required for this technique.

<u>Spatial density</u>

If using the track log setting on a handheld GPS, the recording undertaken is essentially a point logged at 15s time intervals in the areas walked. Locations were high water mark can be noted on structures will be available only at certain points.

<u>Equipment</u>

- Handheld GPS. Spare batteries and sufficient space on GPS.
- Camera. Spare batteries and sufficient space on camera card.
- Measuring tape.
- Note taking implements (e.g. digital on tablet or notepad)

<u>Field preparation (LGA officer)</u>

The area to be targeted for post-event inundation extent monitoring should be refined based on maximum water level measured at the nearest tidal gauge in relation to 25-year ARI levels (Table 4-1), previous inundation mapping [2] or previously measured inundation extent lines (previous application of this method).

Before entering the field the following tasks should be completed:

- All equipment should be tested, including to determine if GPS has track log turned on, correct logging frequency (15s intervals) and correct datum (GDA94 UTM 50).
- Ensure camera has correct date and time and is on maximum resolution.
- Check to see if the trial GPS track log information can be transferred to the computer and matches area mapped in GIS.

The field visit should be scheduled within two days following the storm surge peak to ensure evidence is still visible. If the event coincides with a high rainfall event two visits may be required to capture the peak storm water level and the runoff flood peak.

Monitoring techniques

Upon arriving at the field site, turn on track log on the GPS and walk the most-landward high water mark from the storm. This should represent the maximum extent of saturation, wrack or debris and will often be shore parallel, except for low points which may have been inundated. Examples of evidence of inundation extent include wet marks on buildings/structures or wrack lines along the ground of:

- sand or gravel;
- seagrass wrack and other leaves;
- grass clippings; or
- shells.

The most landward of these debris lines should be logged.

Where records of high water inundation are taken relative to coastal structures, a measuring tape can be used to record vertical heights. For example, the vertical height that the water level appears to have reached can be measured from a fixed point on buildings or street light poles and then surveyed in for vertical accuracy at a later date. If this type of measurement is being undertaken it is important to ensure a GPS waypoint and photo is taken at each location for future reference [1].

Note the start and end times of each inundation area that is walked with the GPS track log on for redundancy when analysing the track logs. Supporting photographic records should be captured while in the field to record evidence of wrack and high water marks. The locations of each photograph should be marked by a waypoint and recorded in field data sheets with any other relevant supporting information.

Post-processing

- Save track logs, photos and notes pages.
- Generate a shapefile of polylines to indicate the recorded extent of inundation by separating the track log according to the start and end times for monitoring each inundation area. The lines may be generated by splitting the track log files or digitising over the track log files. The lines do not have to be continuous, but should all be within one shapefile for an event.
- Prepare a shapefile of points to indicate any vertical heights measured from a fixed point. Include attributes of height, coordinates and location of the base of measurements for future reference for surveyors.
- If possible, it is recommended that an LGA officer note the meteorologic and oceanographic conditions when the inundation event being measured occurred. A simple method is to take screen shots of websites and paste in a word document. Information includes: 1) Synoptic charts from the Bureau of Meteorology, 2) Rainfall

and wind for the previous 48 hours from latest weather observations on the Bureau of Meteorology, 3) Total water level and storm surge at the nearest tide gauge from Department of Transport, 4) Storm surge comparison chart for all stations from Department of Transport to identify continental shelf waves. This word document can then be saved.

- Prepare a document with simple maps of the inundation extent lines and example photos if desired to communicate with stakeholders. Presentation could replicate the Public Works Department [4] measurements following TC Alby (eg Figure 4-1).

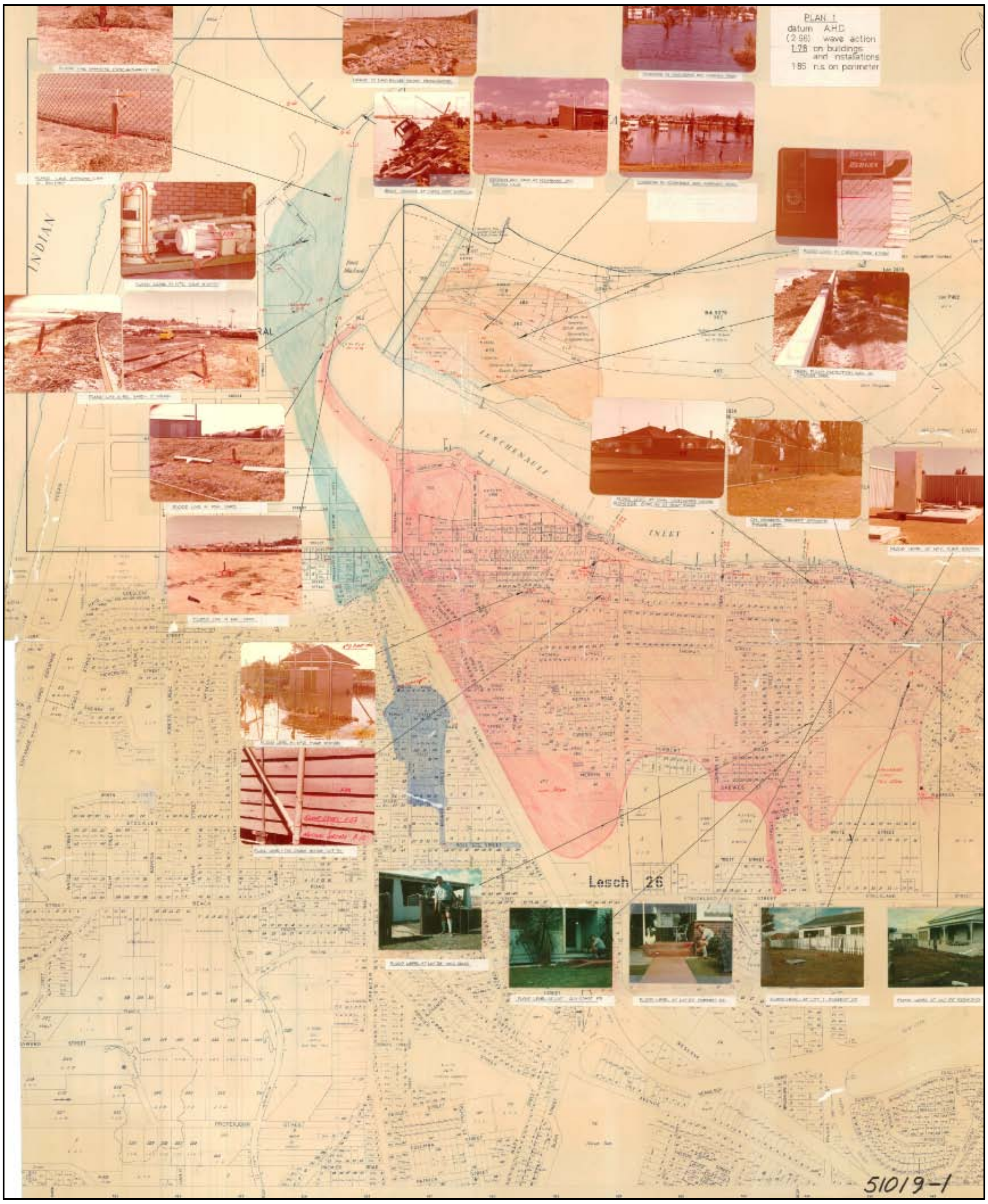

Figure 4-1: Example simple maps of inundation extent
From Public Works Department [4]

- Extension: approximate ground elevations along the track logs could be inferred from a digital elevation model or the DoW (2008) LiDAR, with vertical accuracy of approximately 0.2m. This is an additional task not expanded on in this section.
- Extension: Surveyors could return to GPS waypoints of locations on buildings where vertical inundation mark measurements were taken by measuring tape to provide an inundation height in mAHD.

Analytical techniques

- Visual: Polyline file can be overlaid with cadastre, road, infrastructure and aerial photography in GIS to clarify inundation hazards in relation to values.
- Visual: once a time-series of events have been collected, any discrepancies in inundation for different types of events can be identified through visual comparison of different polylines.
- Compare extent of measured inundation of still water level and wave run-up with predicted inundation hazard lines [2]. It should be noted that the measured values include still water level, wave run-up and local interactions with surface runoff and ponding.

SCHEDULE AND REQUIRED FREQUENCY

This monitoring is only required for events likely to result in inundation. Once an inundation event has been mapped for an area it will only be necessary to revisit for an inundation event likely to have a higher inundation level or if there is a higher runoff anticipated. For areas of frequent inundation that are of concern for reducing infrastructure functionality (e.g. road flooding) the *Flood Frequency Log* method should also be used (Section 4.1).

DELIVERABLES

All deliverables for this technique are digital.

- Polyline layer of extent of inundation in shapefile format in UTM50 GDA94 projection according to format above with name and date format 'PNP Inundation line YYYYMMDD'.
- Point layer of any levels measured by measuring tape in shapefile format in UTM50 GDA94 projection according to format above with name and date format 'PNP Inundation vertical heights by tape YYYYMMDD'.
- A folder containing scanned or saved notes pages and photographs.

This information should be provided to PNP. Each LGA should store the dataset in the same location as previous inundation lines and add it to Intramaps (or equivalent GIS software).

COSTS

Costs for the simple method listed above include in-kind costs of PNP/LGA officers, vehicle costs and post-processing of datasets by LGA GIS officers.

LIMITATIONS

This simple approach does not provide any local inundation height measurements and only provides ±5m horizontal accuracy. The alternate methods below are appropriate if accurate heights are required. Elements of this information may be obtained at a later date by following the previous inundation tracks/polylines using RTK GPS.

ALTERNATE METHODS

A more expensive option that incorporates increased horizontal accuracy and provides vertical levels (±0.02m) of the ground at the point of maximum inundation is to organise surveyors to track the wrack lines or high water marks using RTK GPS. A useful example of this is provided by ACASA [1].

If sufficient data are available of evidence of inundation on buildings or poles (ie not wrack lines on the ground) it may be possible to generate a water surface. Flood depths can therefore be evaluated by comparing the water surface to a digital elevation model. Further details are available in NOAA [3] page 20. This is considered unlikely to be necessary for PNP study areas.

REFERENCES

[1] Atlantic Climate Adaptation Solutions Association: ACASA. (2011) *Survey Grade GPS Storm Surge High Water Mapping*. Prepared by Webster T, McGuigan K and Webster C from Applied Geomatics Research Group - Centre Geographic Sciences, Nova Scotia Community College, Nova Scotia Community College. http://atlanticadaptation.ca/sites/discoveryspace.upei.ca.acasa/files/ACASA%20PEI%20High%20Water%20Mapping%20GPS_1.pdf

[2] Damara WA. (2012) *Coastal Hazard Mapping for Economic Analysis of Climate Change Adaptation in the Peron-Naturaliste Region*. Prepared for Peron-Naturaliste Partnership Coastal Adaptation Decision Pathways (PNP-CAPS) project: Developing Flexible Adaptation Pathways for the Peron Naturaliste Coastal Region of Western Australia, Report 169-01.

[3] National Oceanic and Atmospheric Administration: NOAA. (2012) *Mapping Coastal Inundation Primer*. Prepared by the NOAA Coastal Services Center. http://coast.noaa.gov/digitalcoast/_/pdf/guidebook.pdf

[4] Public Works Department. (1978) *Tropical Cyclone Alby Inundation Maps*. PWD 51019-1 to 8.

5. Techniques Requiring External Support

Information regarding five additional 'medium' and 'high' level techniques for erosion and inundation hazard monitoring is included, to guide LGA interaction with the external agencies required to undertake the monitoring. Techniques includes beach profiling, vertical imagery, area surveys (e.g. laser scanning, RTK GPS on quad bike), bathymetry and LiDAR. Information on each technique, several relevant references, its application, external organisation support and additional considerations when applied to the PNP coast are presented in Sections 5.1 through 5.5.

5.1. BEACH PROFILING

Technique	**Beach Profiling**
What is the technique?	Beach profiles are two-dimensional cross section surveys of the beach surface, depicting the morphology of the beach at the time of survey. The choice of how to monitor will depend on local budgets, the availability of equipment and the availability and training of staff (whether internal or contractors) for measuring and analysing the required data.
Relevant references	Clarke D & Eliot I. (1983) Mean sea level and beach width variation at Scarborough, Western Australia. *Marine Geology*, 51: 251-267. Florida Department of Environmental Protection: FDEP. (2014a) Beach Profile Topographic Surveying, In: *Monitoring Standards for Beach Erosion Control Projects*, Division of Water Resource Management, Department of Environmental Protection, State of Florida, Section 01000, pp. 6 – 12. Florida Department of Environmental Protection: FDEP. (2014b) Offshore Profile Surveying, In: *Monitoring Standards for Beach Erosion Control Projects*, Division of Water Resource Management, Department of Environmental Protection, State of Florida, Section 01100, pp. 13 – 18. Dingler J & Reiss T. (2002) Changes to Monterey Bay beaches from the end of 1982-83 El Nino through the 1997-98 El Nino. *Marine Geology*, 181: 249-263. Harley M, Turner I, Short A & Ranasinghe R. (2011) Assessment and integration of conventional, RTK-GPS and image-derived beach survey methods for daily to decadal coastal monitoring, *Coastal Engineering*, 58(2): 194-205. Kraus N. (2006) Beach Profiling, *In: Encyclopaedia of Coastal Science*, Schwarz M. (ed.), pp. 781-783. Thom B & Hall W. (1991) Behaviour of beach profiles during accretion and erosion dominated periods, *Earth Surface Processes and Landforms*, 16: 113-127.

Why should I use it?	Surveys of the beach profile are conducted to determine the shape or morphology of the beach in response to changing coastal processes, to evaluate the performance of shore-protection projects, to monitor the volume of sediment in the beach and to determine where eroded sediment is being transported. The key benefit of measuring the profile is the ability to distinguish between erosion (sand loss) and cross-shore sand movement, typically storm-driven, which may be subject to rapid recovery. Of interest to managers is whether a beach profile is outside the normal range caused by storm erosion and recovery cycles. Once sufficient surveys have been captured, it is possible to identify an envelope containing all profiles. Future changes can then be assessed relative to this envelope. From a management perspective profiles located landward of this envelope indicate erosion.
External organisation	Department of Transport for guidance on what information to collect before contracting surveyors, as well as the appropriate timing.
Additional considerations for the PNP coast	The micro-tidal nature of the PNP coast determines that a complete profile requires a mixture of land and vessel based surveys. Due to their relative cost, beach profiles are often conducted using land-based methods, out to wading depth. This typically reaches 0.5 to 1.0m below mean water level. It is recommended that beach profiles are extended offshore to at least the tertiary cell offshore boundary on a 5-yearly basis. It is recommended to use a high accuracy survey technique for beach profiling, such as RTK GPS or theodolite for this coast, rather than simple and lower accuracy profile methods, such as the Emery method. If a large number of beach profile sites are proposed to be collected it may be worth considering a survey with area coverage (see Section 5.3). Beach profile sites should be collocated with existing datasets where possible. These exist mainly at population centres and near infrastructure e.g. at Mandurah, Busselton, Bunbury Harbour, Rockingham. Some additional information is contained within historic Public Works Department records.

5.2. VERTICAL AERIAL IMAGERY

Technique	Vertical aerial imagery or vegetation lines
What is the technique?	The use of vertical aerial imagery has formed the basis for broad-scale coastal monitoring and mapping in Western Australia since the 1940s. Collection of a vertical aerial imagery across the State is undertaken by Landgate for various programs, including a dedicated coastal run, which has been collected approximately every 5 years. Vertical aerial imagery are taken from a high point, above the centre of the area being photographed, providing a view directly downwards. Vertical aerials have conventionally been captured using a camera mounted on the bottom of an aircraft, collected with spatial co-ordinates and camera elevation. Contemporary application of vertical aerials in coastal monitoring usually involves the comparison of geo-rectified images or ortho-photographs at different temporal scales to derive time series of coastal change. Imagery captured at 1:5,000 to 1:20,000 scales is typically suitable for identification of several indicators of coastal position, including waterline, swash line, wrack lines and coastal vegetation line. The most typical application in Western Australia has been to map vegetation lines (using photogrammetry or heads-up digitising) to track long-term coastal change as required by the State Coastal Planning Policy SPP 2.6. Mapping of historic vegetation lines formed part of the Public Works Department coastal management program, with data sets available for the PNP region from the 1950s.
Relevant references	Boak EH & Turner IL. (2005) Shoreline Definition and Detection: A review. *Journal of Coastal Research*, 21 (4): 688-703. Byrne A, Rogers M & Byrne G. (1987) Dawesville Channel, Western Australia – Coastal Process Studies. *8th Australasian Conference on Coastal and Ocean Engineering*, Launceston, 30 Nov – 4 Dec, 1987. Department of Transport: DoT. (2009) *Coastal Demarcation Lines for Administrative and Engineering Purposes. Delineation Methodology and Specification*. [Appendix A] Dolan R, Hayden B & Heywood J. (1978) A new photogrammetric method for determining shoreline erosion. *Coastal Engineering*, 2: 21-39. Thieler ER & Hapke CJ. (2006) Photogrammetry, In: *Encyclopaedia of Coastal Science*, Schwarz M. (ed.), pp. 764-768. Thieler ER, Himmelstoss EA, Zichichi JL & Ergul A. (2009) *Digital Shoreline Analysis System (DSAS) version 4.0— An ArcGIS extension for calculating shoreline change.* U.S. Geological Survey Open-File Report 2008-1278. http://woodshole.er.usgs.gov/project-pages/DSAS/version4/images/pdf/DSASv4.pdf Western Australian Planning Commission: WAPC. (2013) *State Planning Policy 2.6: State Coastal Planning Policy*. Prepared under Part Three of the State Planning and Development Act 2005, Perth.

Why should I use it?	Vertical aerial imagery provides a means of identifying coastal change that is consistent with long-term historic records that is readily accessible (through Landgate), simple to use in a qualitative manner and can be used quantitatively with moderate resolution of coastal change when applied to the PNP coast. A time-series of vegetation lines or dune toe has been mapped along most of the PNP coast, providing a basis for evaluation of chronic coastal change (S2 setback allowance for SPP 2.6). A time-series of geo-referenced or ortho-rectified aerial photographs can be used in GIS to track long-term trends in coastal change, the width of coastal buffers to assets, changes in land use and coastal infrastructure. Many changes can be identified using simple visual comparison of images. The time-series of imagery may also be useful to check if any changes in dunes or foredunes are likely to have increased inundation hazard to landward that may require management.
External organisation	It is not expected that PNP members will commission the capture of vertical imagery. Landgate should be consulted for sourcing vertical aerial imagery. If additional vertical aerial imagery may be required, discussions should be held with PNP and Department of Transport, in conjunction with Landgate, to ensure no duplication of work. Department of Transport should be consulted for guidance on how to map features (DoT 2009) and if information is already being collected to ensure no duplication of work.
Additional considerations for the PNP coast	For most investigations along the PNP coast it is recommended to consider change occurring for at the whole secondary cell containing the area of interest. If the site is close to a secondary cell boundary it is recommended to also capture the adjacent secondary cell. Vegetation lines provide a proxy for coastal change, as seasonal beach variability and the majority of small storm events do not reach the vegetation. They also do not provide an indication of vertical change, and therefore can be biased if coastal change is vertical, such as foredune growth or adjacent to a structure. It may have limited application when the coast is accreting, and does not provide a measure of coastal change if there is fencing or revegetation works have been undertaken. It is recommended to always view the imagery before deciding if it is appropriate to map the coastal vegetation line. Where possible, a geo-rectified image (.gtiff, or .ecw) should be obtained along with the vegetation line to confirm mapped changes are real. Focus in contemporary times has been on summer photographs and does not incorporate seasonal variability. See beach width (Section 2.1) and oblique aerials (Section 3.1) for extension.

Additional considerations for the PNP coast (continued)	Vertical aerials exist for the PNP coast extending back as far as the early 1940s. Coverage is patchy and discontinuous over the study area for the early record but more comprehensive since the late 1990s. Time series of vegetation lines have been extracted from these vertical aerials, using mainly photogrammetric techniques, and are available from the State Government (https://mapsengine.google.com/09372590152434720789-17447516222354999649-4/mapview/?authuser=0) with LGA-specific coverage noted in the PNP coastal monitoring database. Contemporary analysis should build on the State dataset and be consistent with their approach and metadata storage pro-forma. Photogrammetric techniques provide more accurate mapping of vegetation line, compared to heads-up digitising. Additional vertical aerial imagery has been captured by Nearmap, with coverage for the LGAs documented in the PNP coastal monitoring database. This information can be checked visually to provide further context for seasonal variability in beach dynamics and position. However, it is not recommended to use the imagery for tracking of vegetation lines or other features without confirming that the spatial accuracy is consistent with the Landgate information. Using satellite imagery to track coastal change or digitising vegetation lines is not recommended at this stage due to the relatively low resolution of the imagery.

5.3. SURVEY WITH AREA COVERAGE

Technique	**Survey with Area Coverage** **(e.g. laser scans)**
What is the technique?	When considering change in beach systems across broad areas or where a large number of beach profile sites (Section 5.1) are required, it may be cost-effective to consider a survey with area coverage. These provide rapid collection of three-dimensional beach survey data. Example techniques include: • ATV-mounted RTK GPS – Real-Time Kinematic Global Positioning System mounted to an all-terrain vehicle. • TLS – Terrestrial Laser Scanners. • LiDAR collected from a UAV – Light Detection and Ranging from an unmanned aerial vehicle. RTK-GPS is a high-accuracy measurement with vertical error of approximately 3cm. An example of its use mounted to an all-terrain vehicle to cover a large spatial area is provided by Harley *et al.* (2011). In an 8-hour period they managed to collect over 10,000 irregularly spaced points across a beach. It is also possible to run the ATV across a profile to capture profile datasets. TLS is terrestrial laser scanning, or field LiDAR, which can capture a point cloud from a fixed tripod on land or from the water when mounted on a vessel. This is a relatively recent technique with further investigation required to resolve ideal resolutions and controls. The rapid rate of capture of high resolution data makes this technique appealing. Two recent articles (Feagin *et al.* 2015, Schubert *et al.* 2015) discuss its applicability for tracking coastal change. One paper suggests that a grid of 0.5m x 0.5m is required. LiDAR on UAV is relatively new technology (Klemas 2015) that is likely to be used in future as payload capacity and battery life of the UAVs increases. A LiDAR transmitter/receiver (Section 5.4) and GPS system is mounted on a small unmanned fixed-wing or multirotor helicopter. It has the capacity to capture LiDAR over a small area at a higher frequency than obtained from a manned aircraft. Post-processing of the UAV data requires specialist expertise. It is not considered viable in 2015 for this technique to be employed by any of the PNP councils. Limitations of each of the techniques is covered in *Additional considerations for the PNP coast* below.

Relevant references	Feagin R, Williams A, Popescu S, Stukey J & Washington-Allen R. (2015) The use of terrestrial laser scanning (TLS) in dune ecosystems: the lessons learned. *Journal of Coastal Research*, 3(1): 111-119. Harley M, Turner I, Short A & Ranasinghe R. (2011) Assessment and integration of conventional, RTK-GPS and image-derived beach survey methods for daily to decadal coastal monitoring, *Coastal Engineering*, 58(2): 194-205. Klemas V. (2015) Coastal and environmental remote sensing from unmanned aerial vehicles: an overview, *Journal of Coastal Research*, published pre-print online 13 April 2015. Schubert J, Gallien T, Majd M & Sanders BF. (2015) Terrestrial laser scanning of anthropogenic beach berm erosion and overtopping. *Journal of Coastal Research*, 31(1): 47-60.
Why should I use it?	Area survey techniques provide potentially high resolution methods to detect and describe three-dimensional coastal geomorphology. This evaluation may be important where coastal change is complex, such as switching between a convex and concave plan-form. Locations in the PNP where area survey techniques are considered most applicable include sand traps and disposal sites for sand management at Mandurah, Dawesville, Bunbury and Wonnerup. Area survey techniques may provide high resolution quantification of beach volume, and may therefore particularly useful to support decision-making that requires volumes for sand management. Area survey is useful to track three-dimensional beach changes over the time-period of interest over a large area. If the TLS or LiDAR is applied it may be useful to determine if any changes have occurred to the dunes or foredunes that could have modified inundation hazard to landward that may require management.
External organisation	Landgate and Department of Transport’s spatial groups should be consulted at any stage of considering undertaking a survey with area coverage. They will be able to provide advice on appropriate techniques, spatial resolution and accuracies as well as specifications for surveyors.

Additional considerations for the PNP coast	Information should build on existing DoT/Landgate datasets and be consistent with their approach and metadata storage pro-forma. Correction for measurement errors due to collection techniques, post-processing of cloud datasets and purpose-specific software are all additional expenses and time for this type of survey. In all methods the optimal spatial resolution of the cloud of data is likely to be determined by the vertical error of the measurements. The horizontal and vertical resolution of the features that require capture should be considered when designing the survey. ATV-mounted RTK GPS is difficult to undertake for discontinuous coasts interrupted by large rock features. There is a relatively high initial capital cost for this survey setup. Corrections are required for ATV sinking, tilting, shaking and controls. Information has been collected by UWA post-graduate students for parts of Comet Bay in City of Mandurah. TLS is a relatively new technology with further investigation required into ensuring adequate controls. It is presently not easily applied to vegetated areas as it captures the vegetation surface and not the ground level. Further information is required on the expected error in relation to ground control points, with many surveyors comparing the datasets to RTK GPS for quality control. In addition, errors associated with point cloud registration, point cloud resolution and errors introduced by interpolation should be discussed for their impact on TLS datasets, as well as the interaction of all of these factors. The approach has recently been used to determine coastal change for the Wheatstone project as well as trialled near Alkimos. UAV LiDAR is restricted at present due to insufficient battery life to cover a large distance. There is a high cost relative to the pay load capacity of the vehicles. There are safety restrictions on operating the UAVs in populated areas which also limits the areas that may be surveyed. At present there is limited optimisation for achieving an appropriate altitude to obtain sufficient spatial coverage and resolution to capture changes of interest (>10cm). Applicability to the PNP coast is further restricted due to the inability to use UAVs in strong wind environments. This approach has been used for the Gorgon and Cape Preston projects. Post-processing of UAV data requires specialist expertise. For expensive survey techniques like those listed above, it should only be undertaken if deemed cost effective compared to traditional survey techniques and if the anticipated detectable change is greater than instrument error.

5.4. LIGHT DETECTION AND RANGING (LIDAR)

Technique	Light Detection and Ranging (LiDAR)
What is the technique?	Light Detection and Ranging (LiDAR) is a high-cost method to obtain high-resolution topographical and bathymetric information over a large area (up to regional scales). LiDAR data are georeferenced, irregularly distributed 3D point clouds of high altimetric accuracy. The technique is a laser transmitter/receiver mounted on an aircraft with high accuracy GPS, with the receiver measuring the energy and time lapse of the reflectance from the land surface, the air-water interface and the seabed. LiDAR can produce a 10cm vertical accuracy at spatial resolutions of one measurement per square meter. LiDAR has many proprietary specific names including Laser Airborne Depth Sounder (LADS) and SHOALS, both used for bathymetric information. A recent development has been capturing LiDAR using UAVs (Section 5.3) which may have limited application along the PNP coast due to the prevailing strong winds, as well as other factors. References provided below provide an overview of LiDAR, its applications, strengths and weaknesses. However, it should be noted that most of these applications of LiDAR are for coasts with high-value infrastructure in high hazard areas, coasts with large areas of high-magnitude coastal change, coasts with high ecological function in areas of high risk, or for research purposes. Another technique that captures surface elevation information on a broad scale is laser altimetry from satellites.
Relevant references	Brock JC & Purkis SJ. (2009) The emerging role of lidar remote sensing in coastal research and resource management, *Journal of Coastal Research,* SI53: 1-5 (and remainder of special issue). Florida Department of Environmental Protection: FDEP. (2001a) LiDAR Topograhic Mapping & Aerial Photo Acquisition, In: *Statewide Coastal Monitoring Program I. Regional Data Collection and Processing Plan,* Office of Beaches and Coastal Systems, Department of Environmental Protection, State of Florida, Section 03000 of Appendix I – Contact Scope of Works and of Appendix II – Technical Specifications. Florida Department of Environmental Protection: FDEP. (2001b) LiDAR Bathymetric Mapping, In: *Statewide Coastal Monitoring Program I. Regional Data Collection and Processing Plan,* Office of Beaches and Coastal Systems, Department of Environmental Protection, State of Florida, Section 03100 of Appendix I – Contact Scope of Works and of Appendix II – Technical Specifications. Heurtefeux H. (2008) LiDAR technology and beach survey: history, experimentation and assessment, In: *Beach Erosion Monitoring, Results from BEACHMED-e / OpTIMAL Project*, Pranzini E & Wetzel L (eds.), pp 147-148.

Relevant references **(continued)**	Heurtefeuz H, Lesaignoux A & Denamiel C. (2008) Assessment, validation and further uses of LiDAR survey in the Western part of French Mediterranean sea, In: *Beach Erosion Monitoring, Results from BEACHMED-e / OpTIMAL Project*, Pranzini E & Wetzel L (eds.), pp 149-161. Klemas V. (2011) Beach profiling and LIDAR bathymetry: an overview with case studies. *Journal of Coastal Research*, 27 (6): 1019-1028. Klemas V. (2015) Coastal and environmental remote sensing from unmanned aerial vehicles: an overview, *Journal of Coastal Research*, published pre-print online 13 April 2015. Leatherman SP, Whitman D & Zhang K. (2006) Airborne Laser Terrain Mapping and Light Detection and Ranging, *In: Encyclopaedia of Coastal Science*, Schwarz M. (ed.), pp. 21-24. Pe'eri S & Long B. (2011) LIDAR technology applied in coastal studies and management. *Journal of Coastal Research*, SI62: 1–5 (and remainder of special issue). Preti M, Monti M, de Nigris N & Morelli M. (2008) Bathymetric survey: a comparison between Airborne LiDAR Bathymetry (ALB) and conventional methods of measure, In: *Beach Erosion Monitoring, Results from BEACHMED-e / OpTIMAL Project*, Pranzini E & Wetzel L (eds.), pp 163-182. Royal Australian Navy: RAN. (2015) *Laser Airborne Depth Sounder*, https://www.navy.gov.au/fleet/aircraft/laser-airborne-depth-sounder Ramsey EW III. (2006) Remote Sensing of Coastal Environments, *In: Encyclopaedia of Coastal Science*, Schwarz M. (ed.), pp. 797-804.
Why should I use it?	LiDAR is useful to obtain high resolution datasets covering a broad area. In many assessments of coastal erosion and inundation collecting high resolution topography and bathymetry are used for numerical modelling of flood and erosion hazard. This information is already available from 2008 and 2009 for the study area. Repeat surveys can be used to quantify coastal change. However, in Western Australia these have only been associated with response to large oil and gas infrastructure projects or ports due to the associated cost. It is also useful for coasts that experience changes over a large spatial area over the time period of interest to justify the expense of monitoring large areas with LiDAR.
External organisation	It is not expected PNP members will be commissioning the capture of LiDAR. Landgate's Satellite Remote Sensing Services are the main organisation to liaise with at any stage of considering undertaking LiDAR capture. In addition, the Departments of Planning and Water have experience in the collection of the 2009 LADS dataset of the PNP coast and 2009 dataset of terrestrial LIDAR.

Additional considerations for the PNP coast	Information should build on the DoT/Landgate datasets and be consistent with their approach and metadata storage pro-forma. Adequate controls are critically important to the success of LiDAR surveys. The high cost of obtaining LiDAR makes it most cost effective for large to very large areas, measured infrequently. However, even with high resolution, much of the change occurring is likely to either be too small to detect, or too dynamic to interpret change between surveys. Repeat surveys at the scale of entire PNP are viable every 20 to 40 years, due to the limited area of coast and inner shelf where detectable change is anticipated, as well as the expense of data collection and post-processing. The spatial extent of LiDAR should cover between the offshore and onshore area of secondary sediment cells where possible, depending on what features are being measured. When designing the collection of LiDAR datasets the spatial resolution and vertical accuracy should be appropriate for the intended analysis. Dataset storage and format provision also need to be considered carefully. Ideally, post-processing and formatting should support comparison with existing bathymetric and topographic datasets at several scales. Significant post-processing by users should be discouraged, as this may effectively create multiple data sets. Comparison of LiDAR to other bathymetric or topographic datasets using different techniques requires an estimation of the errors of both collection techniques as well as the post-processing analyses. A common error is having an incorrectly matched vertical datum, horizontal datum and projections between datasets. Detailed metadata should be prepared for all datasets to allow this in future. Laser Airborne Depth Sounder (LADS) bathymetric information was collected in 2009 for the whole PNP coast and onshore LiDAR terrestrial information was collected in 2008 by the Department of Water.

5.5. HYDROGRAPHIC SURVEYS

Technique	Hydrographic Surveys
What is the technique?	Hydrographic surveys focus on the measurement and description of the seabed for the primary purpose of navigation, including shallowing of dredged channels. However, this information is also useful for monitoring coastal change and determining offshore features that modify sediment transport. Methods to measure the seabed can be as simple as noting down a depth from the boat's echo sounder through to spatially-extensive collection of depth-penetrating LiDAR. The hierarchy of monitoring from least expensive to most expensive is: • Simple measure using a sounding pole adjacent to a wall to measure depths or noting down depths on the echo-sounder as a boat passes over an area of interest. This is useful to estimate shoaling or lowering adjacent to a wall (which could lead to failure). • Single-beam echo sounder measures distance using the reflection of sound off the seabed in a single line directly under a vessel. • Multi-beam echo-sounder or swath echo-sounder measures the reflection of sound from a fan of acoustic beams adjacent to a vessel. This provides greater coverage than single-beam, with a wider fan of beams in greater water depths. In waters <5m depth, there may be little difference between single beam and multi-beam surveys. • Laser Airborne Depth Sounder (LADS) or other Airborne LiDAR bathymetry (ALB) which measures depths using a laser, considering the reflectance and transmissivity of water and the seabed. Each technique has a range of other equipment required to ensure accuracy, such as RTK GPS, side-scan sonar and motion reference units. Also each technique has limitations for use in certain environments.

Relevant references	*Department of Transport standards for hydrographic surveying*. Florida Department of Environmental Protection: FDEP. (2001b) LiDAR Bathymetric Mapping, In: *Statewide Coastal Monitoring Program I. Regional Data Collection and Processing Plan,* Office of Beaches and Coastal Systems, Department of Environmental Protection, State of Florida, Section 03100 of Appendix I – Contact Scope of Works and of Appendix II – Technical Specifications. International Hydrographic Organisation: IHO. (2011) *Manual on Hydrography*, 1st Edition, Publication C-13, Published by the International Hydrographic Bureau. National Oceanic and Atmospheric Administration: NOAA. (2014) *Field Procedures Manual*. NOAA Office of Coast Survey. http://www.nauticalcharts.noaa.gov/hsd/fpm/2014_FPM_Final.pdf National Oceanic and Atmospheric Administration: NOAA. (2015) *NOS Hydrographic Surveys Specifications and Deliverables*. Office of Coast Survey, National Ocean Service, NOAA, U.S. Department of Commerce. http://www.nauticalcharts.noaa.gov/hsd/specs/specs.htm Preti M, Monti M, de Nigris N & Morelli M. (2008) Bathymetric survey: a comparison between Airborne LiDAR Bathymetry (ALB) and conventional methods of measure, In: *Beach Erosion Monitoring, Results from BEACHMED-e / OpTIMAL Project*, Pranzini E & Wetzel L (eds.), pp 163-182. Royal Australian Navy: RAN. (2015) *Laser Airborne Depth Sounder*, https://www.navy.gov.au/fleet/aircraft/laser-airborne-depth-sounder
Why should I use it?	Bathymetric datasets provide information on submerged landforms, geological controls and potential rates of change of submerged features. Bathymetric datasets can be used to extend terrestrial datasets offshore by extending beach profile information or terrestrial laser scans, RTK GPS surveys or LiDAR (with errors accounted for by timing offsets). With suitable overlap, this may help determine whether beach change is a result of local onshore-offshore sand transfer or a net change in sand volume (erosion or accretion). Comparison of two or more bathymetric datasets in the same location can be used to quantify: • Rates of shoaling and therefore hazards to navigation;. • Rates of shoaling as an indicator of potential rates of loss of sediment from a beach system; • Potential rates of migration of submerged landforms (e.g. bars) as an estimate of when a local sediment source may decrease in a rate of supply to a beach.

External organisation	Department of Transport spatial information section (Hydrographic survey and Geographic Information teams) should be consulted to determine coverage of existing datasets and ensure adequate specifications are provided. It may be possible to contract the Department of Transport Hydrographic Survey team to incorporate surveys within their existing programs. Proposals submitted by private surveyors should be checked by Department of Transport.
Additional considerations for the PNP coast	Information should build on the DoT datasets and be consistent with their approach and metadata storage pro-forma. Adequate controls are critically important to the success of hydrographic surveys. Performance of different techniques varies according to depth and environmental conditions, and therefore some surveys may require a mixture of techniques. When designing hydrographic surveys the spatial resolution and vertical accuracy should be appropriate for the intended analysis. Extend offshore to the edge of the secondary sediment cell where possible, noting that in many areas historic monitoring is restricted to areas of focal navigation concerns (ie shoaling of dredged channels or harbour areas). The ability to detect change through comparison of successive surveys is limited by instrument error (e.g. tide correction, wave energy correction, turbidity errors, insufficient strength of the system mount, dynamic draft correction). If the error is similar scale to the expected coastal change, monitoring should be focused on a smaller area, or an alternate method used. When comparing surveys, ensure the dataset is provided in a compatible format to existing bathymetric datasets, for ease of analysis. Comparison of bathymetric datasets using different techniques requires an estimation of the errors of both collection techniques as well as the post-processing analyses. Common errors include having an incorrectly matched vertical datum, horizontal datum or spatial projections between datasets. Detailed metadata should be requested for all datasets to support analysis. Records of historic bathymetry are available from Department of Transport with some non-digital records available in old Public Works Department planbooks. Some bathymetric comparison analysis requires digitising the old planbooks. LADS bathymetric information was collected in 2009 for the whole PNP coast.

Appendix A – DoT (2009) Coastal Demarcation Lines