Department of Transport

Coastal Sediment Cells for the Northampton Coast

Between Glenfield Beach and the Murchison River, Western Australia

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The custodian of the digital dataset is the Department of Transport.

Photographs used are from WACoast[30].

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Geological Survey of Western Australia

Seashore Engineering

Executive summary

The aim of this report is to identify a hierarchy of sediment cells to assist planning, management, engineering, science and governance of the Northampton coast.

Sediment cells are spatially discrete areas of the coast within which marine and terrestrial landforms are likely to be connected through processes of sediment exchange, often described using *sediment budgets*. They include areas of sediment supply (sources), sediment loss (sinks), and the sediment transport processes linking them (pathways). Sediment transport pathways include both alongshore and cross-shore processes, and therefore cells are best represented in two-dimensions. They are natural management units with a physical basis and commonly cross jurisdictional boundaries.

Sediment cells provide a summary of coastal data in a simple format and can be used to:

1. Identify the spatial context for coastal evaluations;
2. Provide a visual framework for communicating about the coast with people of any background;
3. Support coastal management decision-making;
4. Support a range of technical uses largely relating to coastal stability assessment, such as interpreting historic rends, understanding contemporary processes and basis for projection of potential future coastal change; and
5. Reduce problems caused by selection of arbitrary or jurisdictional boundaries.

Boundaries of sediment cells have been identified for the Northampton coast between Glenfield Beach (north of Geraldton) and Nunginjay Spring Coast N (north of Kalbarri) in Western Australia. Three primary cells, seven secondary cells and 12 tertiary cells were identified between the Glenfield Beach and Nunginjay Spring Coast N. The cell hierarchy for the Northampton coast is presented as maps and tables in this report, and in electronic datasets available from the Department of Transport. They were defined in three steps through selection of:

1. Points along the shoreline (beachface);
2. Offshore and onshore boundaries; and
3. Alongshore boundaries connecting the beachface points to the offshore and onshore boundaries.

This focuses on boundary definition at the beachface where the highest rates of sediment transport are likely to occur.

The cells have been mapped as a hierarchy of primary, secondary and tertiary levels to incorporate three space and time (spatio-temporal) scales. This hierarchical representation of cells gives a basis for implementation of integrated planning and management at a number of scales, from small-scale engineering works, through to large-scale natural resource management.

- Primary cells are related to large landforms, and are most relevant to potential change in large landform assemblages or land systems over longer coastal management timescales of more than 50 years.
- Secondary cells incorporate contemporary sediment movement on the shoreface and potential landform responses to inter-decadal changes in coastal processes.
- Tertiary cells are defined by the reworking and movement of sediment in the nearshore and are most relevant for seasonal to inter-annual changes to the beachface. Mapping of tertiary cells was limited to the beachface point because of insufficient resolution of the available datasets.

Common use of cells is intended to facilitate better integration of coastal management decision-making between governance, science and engineering at a regional and local level.

Contents

Introduction

This report presents a hierarchy of sediment cells along the Northampton Coast for application in engineering, science, planning, management and governance of the region.

Sediment cell boundaries were mapped and identified at three spatio-temporal scales, along approximately 145km of the Western Australian coast between Glenfield Beach (north of Geraldton) and north of the Murchsion River. The area includes a length of coast in the lee of the Houtman Abrolhos (approximately 45km offshore) and coastal lands of the Chapman Region and southern Victoria Plateau (Figure 1; Figure 2; Figure 3; Appendix A). The three scales range from small, local landforms and the day-to-day processes affecting them to large coastal systems changing over millennia in response to global processes. At each scale the cells identify boundaries within which to consider the potential implications of proposed coastal engineering works as well as for assessment of coastal planning and management practices.

The hierarchy of cells facilitates understanding of contemporary sediment movement, encourages projection of future coastal change at a conceptual level, and establishes a context for qualitative investigations. Additionally, the hierarchy is intended to assist identification of differences in the processes driving coastal change at each scale.

Cells within this report are labelled according to a system described in *Cell labels*.

What are sediment cells?

Sediment cells are spatially discrete areas of the coast within which marine and terrestrial landforms are likely to be connected through processes of sediment exchange, often described using *sediment budgets*. Each includes areas of sediment supply (sources), loss (sinks), and areas through which sediment is moved between sources and sinks (pathways)[1]. These components are illustrated in Figure 4 for all levels in the hierarchy. Cells are natural management units with a physical basis and commonly cross jurisdictional boundaries.

Box 1: Literature on sediment cells

Sediment cells are spatially discrete areas of the coast within which marine and terrestrial landforms are likely to be connected through processes of sediment exchange, often described using *sediment budgets*. Extensive global literature related to coastal sediment cells and sediment budgets is available and has previously been reviewed[2,3,4,5,6,7,8]. The literature includes a number of terms similar in meaning to coastal sediment cell, with slight disparities in their use, although the broad concepts underpinning cell identification and sediment budget estimation are well established[6].

Alternative terms for coastal sediment cell at varied spatial scales are littoral cell[1,9], coastal compartment[10], coastal sector[11], beach compartment or coastal segment[12], sediment cell with smaller coastal process units or sub-cells[13], coastal cell[14], process defined management unit or coastal management unit[15,4], coastal tract[5] and three nested systems of coastal behaviour systems, shoreline behaviour units and geomorphic units[16]. The term sediment cell is used in this report for the Northampton Region.

Sediment cells are commonly identified as self-contained where little or no sediment movement occurs across cell boundaries[16,8]. This concept is most applicable at a broad scale, such as when defining the scale and limits of coastal investigations[5]. Restriction of sediment movement is not a fundamental characteristic of cells at a fine scale or those not markedly compartmentalised by extensive rocky headlands. The cell approach retains meaning for these coasts, although their cells may have substantial sediment exchange across their boundaries[2,17].

Constraints to sediment transport vary over time for different spatial scales and types of cell boundaries. For example, some rocky headlands are bypassed under infrequent high-energy conditions, but are a major constraint to sediment transport on a seasonal basis. Similarly, on sandy coasts cell boundaries may correspond to ephemeral areas of sediment transport convergence which indicate zones of reduced transport[18,19].

This variability in sediment bypassing at boundaries prompts the incorporation of time-dependence between levels within a cell hierarchy[10], with the boundaries of the larger (primary) cells being related to longer-term processes.

Cell boundaries defined in this document extend landward from points on the shoreline to include terrestrial landforms, and seaward to encompass the nearshore marine environment in which waves and currents are most active. The offshore and onshore boundaries of cells should be determined by the scale of sediment transport processes operating within a cell, as well as by topographic features.

Why use sediment cells?

Sediment cells define natural units with each cell encompassing adjoining marine and terrestrial environments. The cells thereby provide a base for integrated coastal management in which the components of each cell is considered holistically as an interactive system. In this context sediment cells aid interpretation of historic trends, add to an understanding of contemporary processes and provide an important basis for projection of future coastal change. The objectives of determining a three-scale hierarchy of cells were to:

- Identify sediment cells which are recognisable as natural management units for regional, sub-regional and local scale coastal studies;
- Establish a framework for linking marine and terrestrial projects that is founded on the connectivity of subaqueous and submarine coastal landforms, and which supports integrated coastal planning and management;
- Identify areas of coast where sediment budget estimates may provide a useful tool for coastal planning and management based on landforms at varying time and space scales[20,21,22]; and
- Avoid clashes of policy and practice where coastal management is required by neighbouring coastal agencies, particularly local government authorities, within single or adjacent cells.

Characteristics of the sediment cell approach which make it a fundamental tool for assessment of hazards to land use caused by coastal change are that[23]:

- There is a plausible connectivity of geology, landform and hydrodynamics for coastal evolution and change that can be established and used in identification of the cells[24];
- It focuses on the integration of coastal and marine processes with landform responses to them rather than more static, quasi-equilibrium approaches such as those forming the basis for numerical models of beach profile change; and
- The consistent methodology applied to identifying the cell hierarchy facilitates up-scaling and down-scaling in assessments of coastal change, a capability recommended in the assessment of coastal vulnerability to meteorologic and oceanographic change[25].

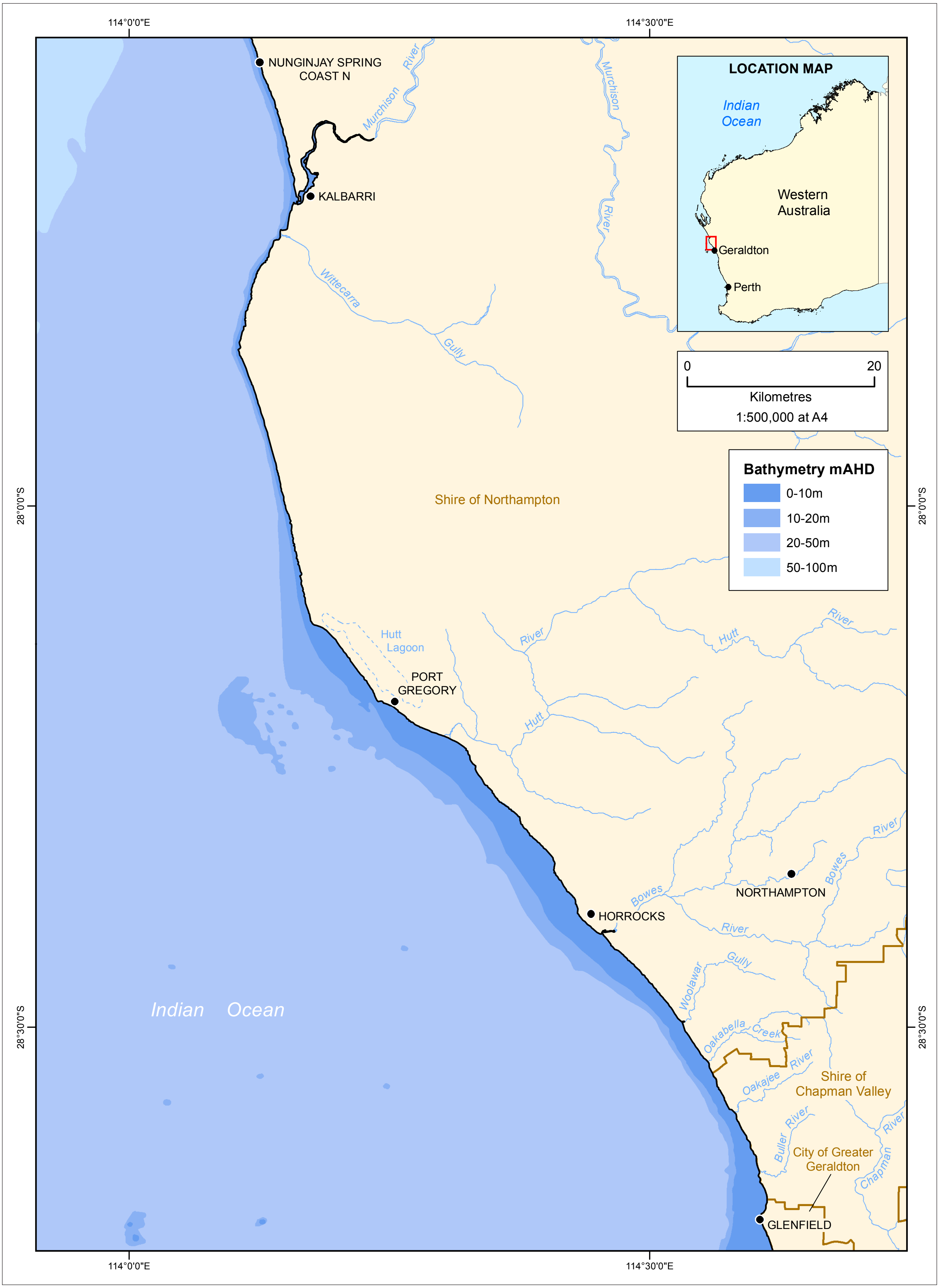


Figure 1: Northampton Region coast from Glenfield to Nunginjay Spring Coast N

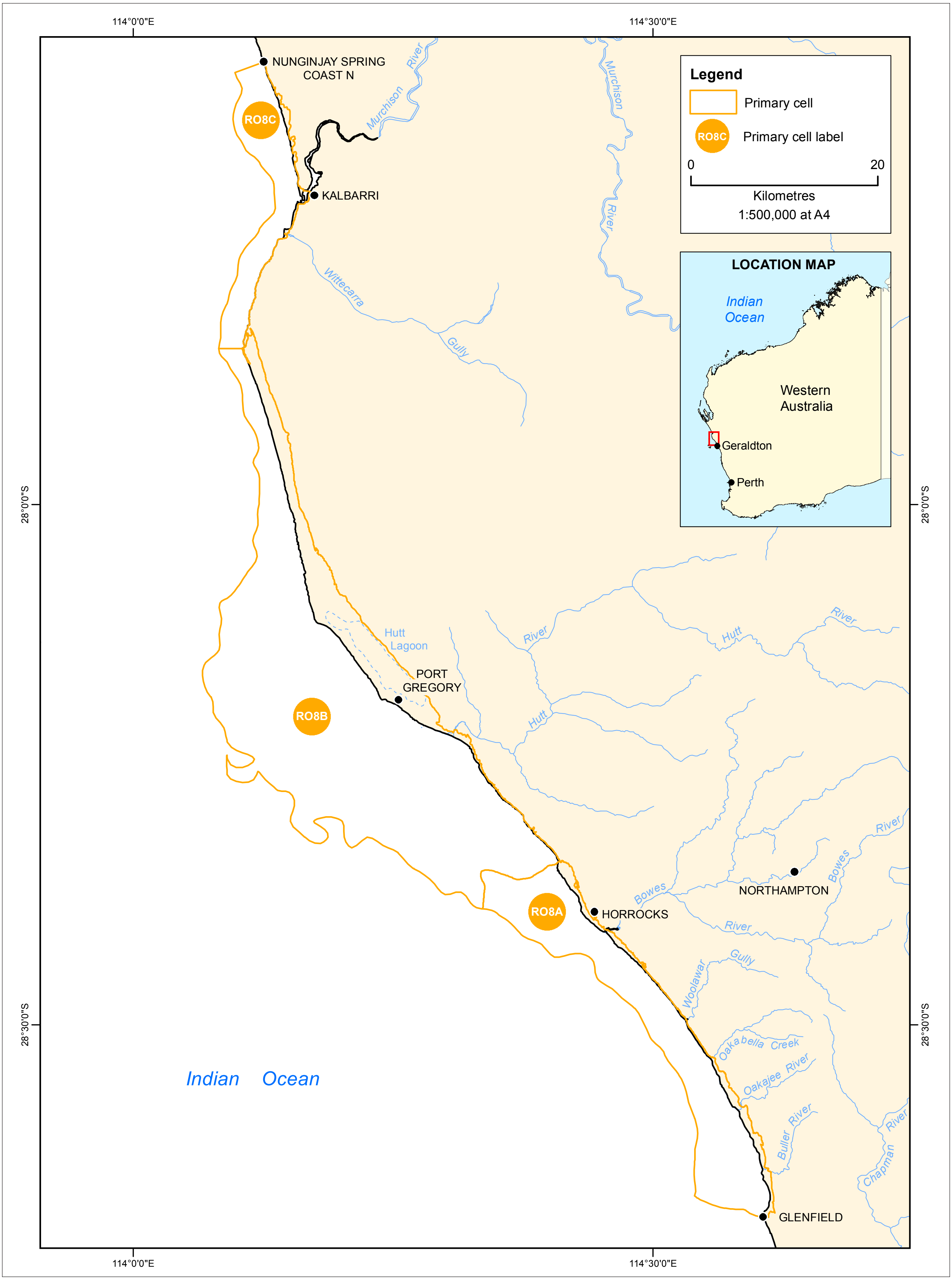


Figure 2: Primary cells of the Northampton Region

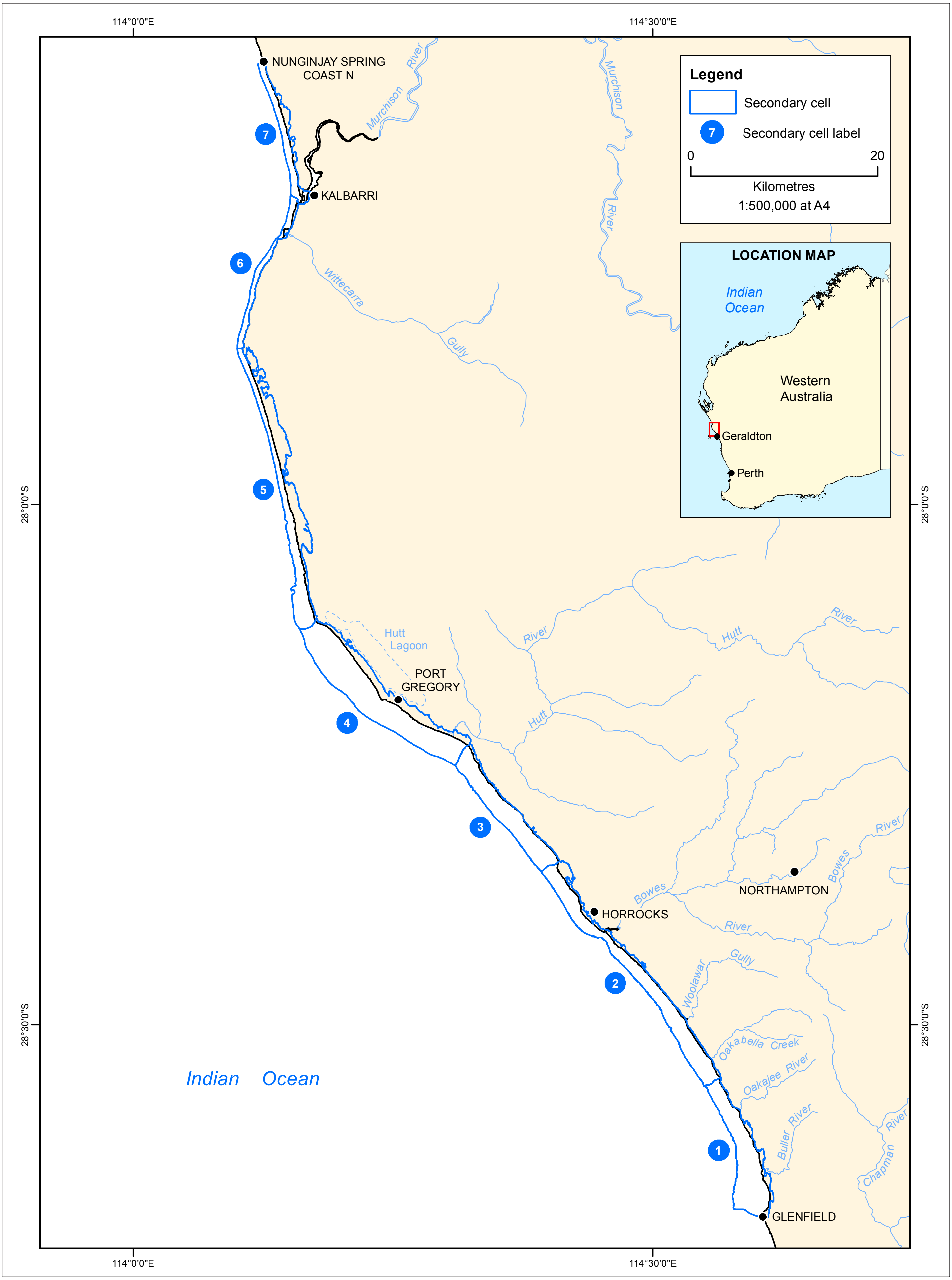


Figure 3: Secondary cells of the Northampton Region

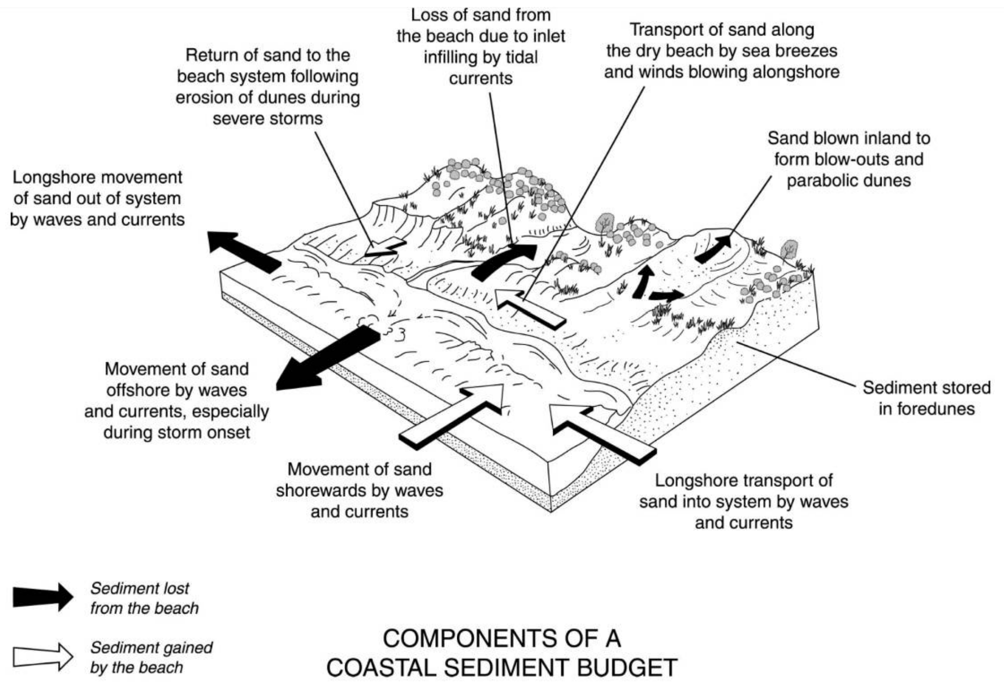


Figure 4A: Components of a coastal sediment cell (WAPC 2003)

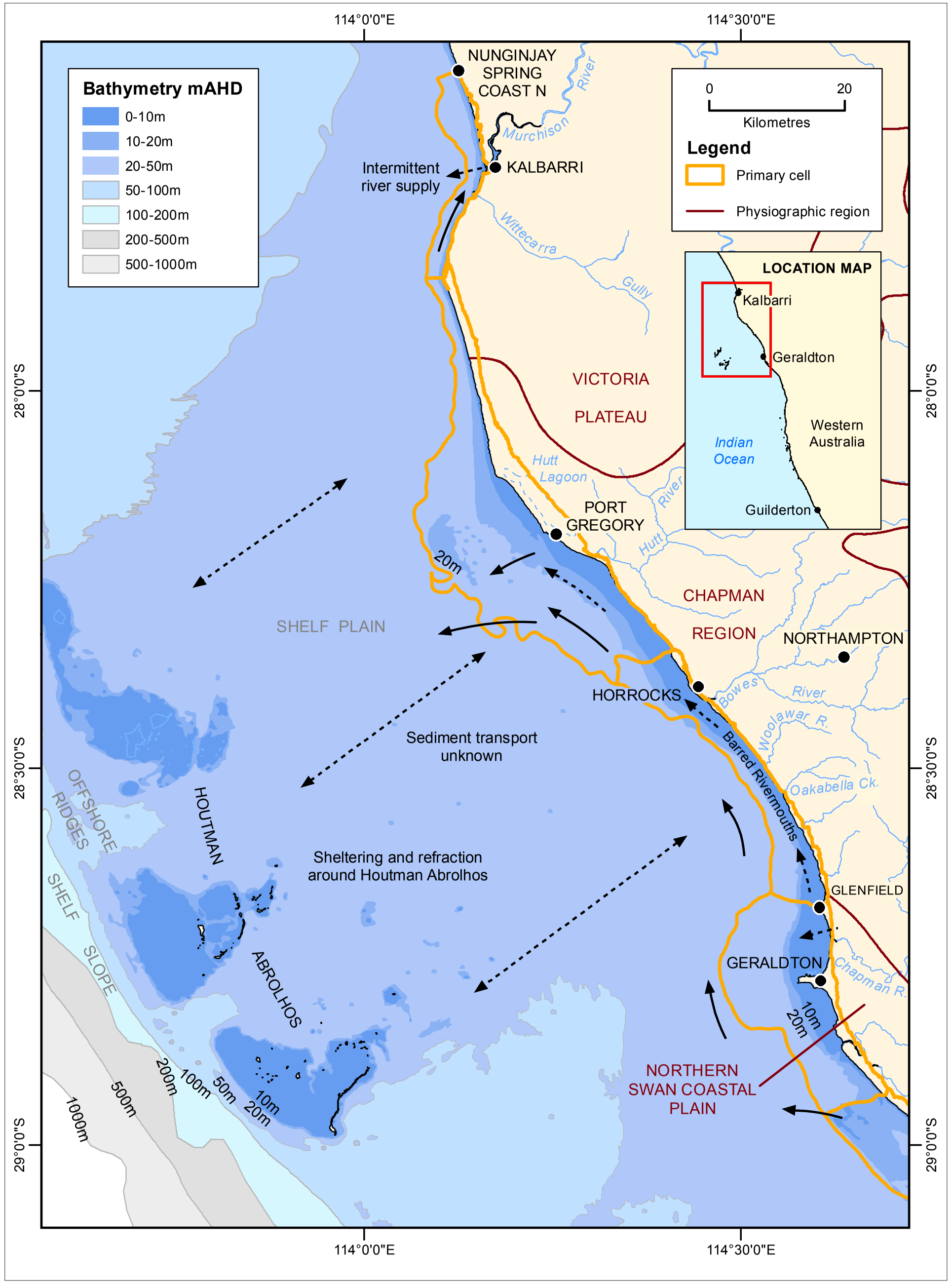


Figure 4B: Example primary cells (R07F to R08C)

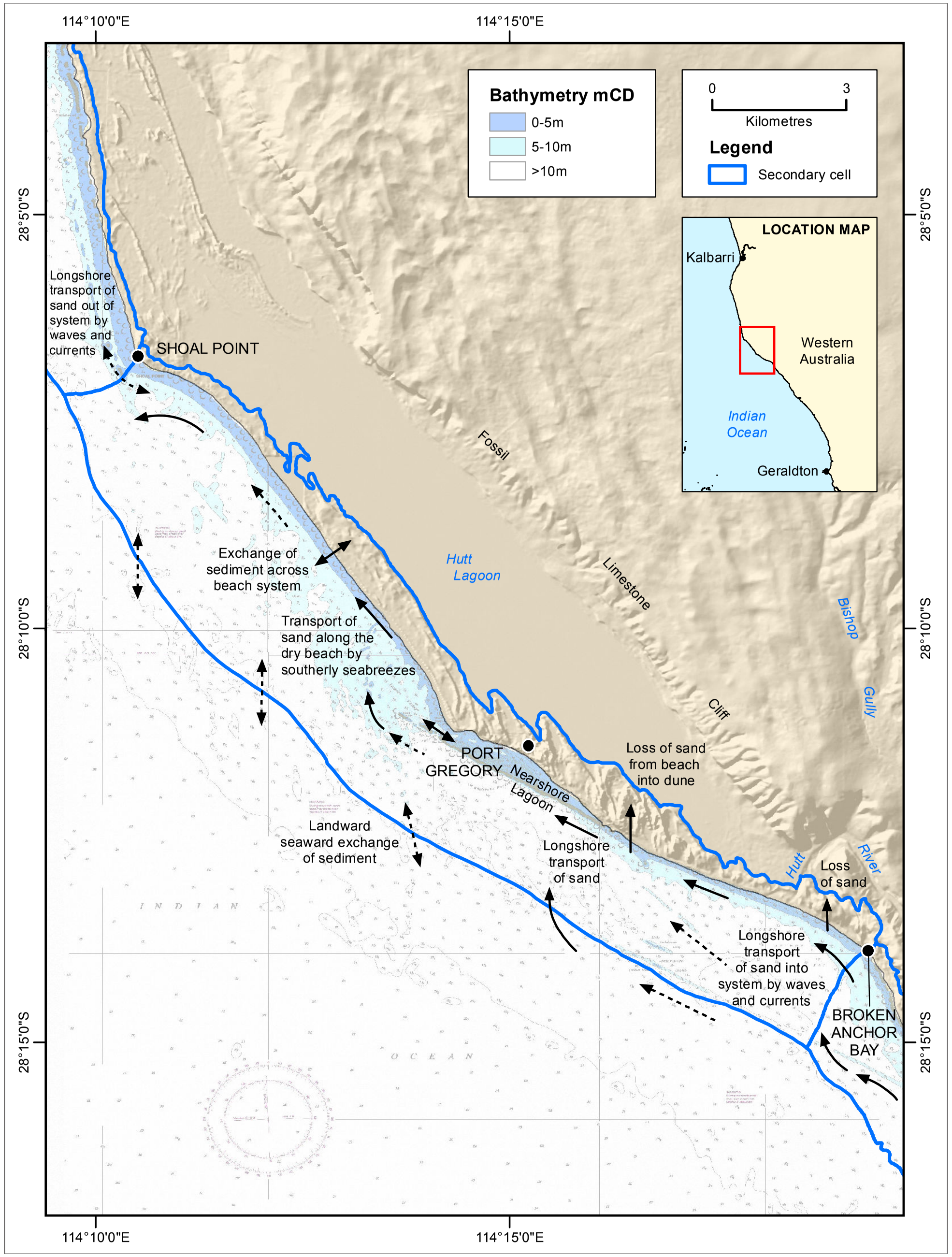


Figure 4C: Example secondary cell (R08B4)

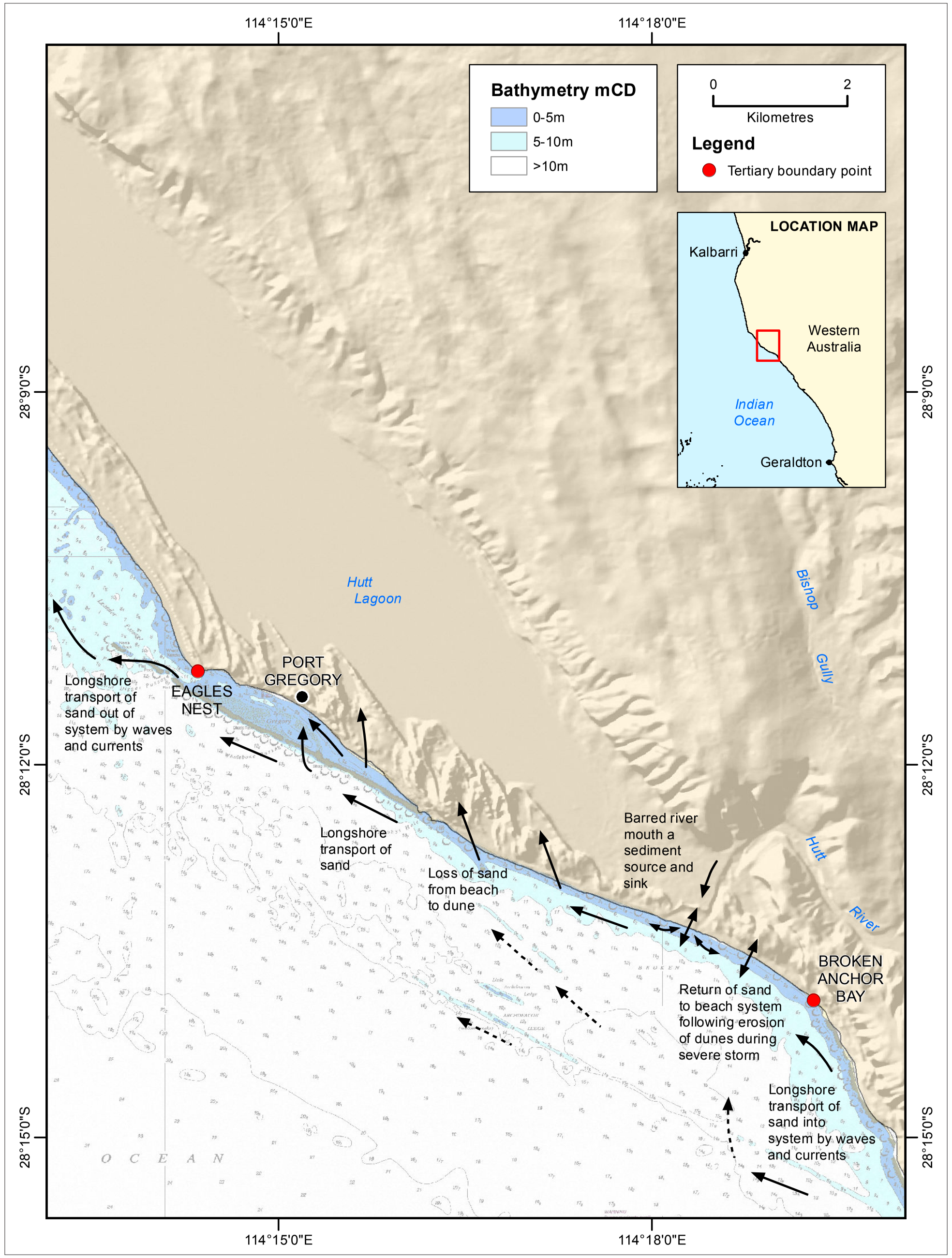


Figure 4D: Example tertiary cell (R08B4a)

The Northampton coast

Coastal landform development on the microtidal Northampton coast, with low present-day supply of sediment, is subject to substantial control by the geologic framework. Control occurs through interaction of the fixed rocky topography, comprising the framework, with coastal processes and available sediments. The framework for the Northampton coast has been described at a variety of scales as part of a series of large-scale coastal compartments identified for the whole Western Australian coast[26].

Modern Holocene sediments and inherited, remnant landforms abut and overlay the geologic framework. Both are reworked by present-day processes, although typically less for remnant landforms. The partly repetitive patterns of reworking define sediment transport behaviour at all scales. Landforms of the Northampton Region include:

1. A broad shelf plain between the Houtman Abrolhos and the shore;
2. A paleodelta associated with avulsion of the Murchison River (Cell R08B) sand flats and sand banks interacting with inshore reefs, rock outcrops and platforms in the inshore waters; and
3. Salients, forelands, barred rivermouths, coastal dune barriers and small dunes along the coast impounding lagoons and abutting cliffs[27].

These landforms provide an indication of the source areas, transport pathways and sinks; although they need to be established in relation to the processes driving coastal change. Additionally, the Murchison River provides localised intermittent sediment supply to the northern Northampton coast. This intermittent supply should be considered in any assessment of coastal sediment budgets, particularly for cells south and north of the river mouth.

The spatial distribution of alongshore sediment supply is affected by the degree of bypassing at rocky coastal features. This varies with shoreline aspect and may therefore be subject to decadal-scale fluctuations. Further offshore there is a broad shelf plain between the coast and the Houtman Abrolhos, with an absence of local reef ridges and inshore reef chains to provide a constraint to onshore sediment movement. It is unknown how sediment transported offshore from the beaches and inshore areas will be distributed on the broad shelf plain, and how available it is for return to the nearshore system. At the shore, the geologic framework in the form of cliffs and bluffs may constrain sediment transport to landward. However, if the onshore sediment supply is sufficiently substantial dunes may climb above the cliffs in areas with large sediment feeds onshore (Cell R08B3).

The geologic framework provides a context for identification and description of sediment cells. However, transition from the fixed-structural, broad-scale geologic framework of the compartments to the functionally highly-variable, fine-scale sediment cells commonly includes a change in the balance of processes affecting the shore. For example, offshore currents driven by tides or winds may be significant to coastal evolution at a broad scale but not at a local scale where waves are likely to be dominant. This implies there is potential for process-landform interactions to generate errors at a broader or finer scale than a specific scale under investigation. The broader scale interactions commonly are apparent as trends whereas finer scale interactions contribute to the variability of the system being investigated.

Further information on geology, geomorphology, landforms, meteorological and oceanographic processes for the Northampton Region is included in a recent vulnerability report[27]. Additional geology and geomorphology information is included in the WACoast[28] database and from a country-scale study of Australian beaches[29]. Information on terminology used in this report is contained in previous reports[27,26,30] and global publications[31]. A glossary relevant to landforms in the Northampton Region is included in Appendix B of the landform vulnerability report[27].

Methods for the definition of sediment cells

Coastal sediment cells and sectors have previously been investigated along large sections of the Northampton Region[32,27,33]. These are commonly identified as points along the coast. They provided a starting point for the cells identified in 2012[27], which are refined in the present report. In the present analysis, established techniques[34], with some modification of terminology, have been applied to map sediment cell boundaries. Notably, some adaptation of the technique used to identify and map sediment cells in the Vlamingh Region34 was required for the Northampton Region, with the expectation that further revision of the criteria used (Figure 5; Table 1; Table 2; Appendix C) will be required for application to other parts of the WA coast or elsewhere.

A threefold hierarchy of cells was defined by the type and shape of landforms present as well as the frequency of coastal processes and potential landform responses relevant to each scale. Each larger primary cell is related to a functional coastal land system, whereas the smaller secondary and tertiary cells identify specific coastal landforms and landform components at increasingly detailed scales. Further offshore, larger cells may extend to a continental shelf feature well offshore with a contemporary link to the coast (e.g. excluding Houtman Abrolhos), whereas a smaller cell may capture seasonal to decadal nearshore processes. At each scale cells are likely to vary in area based on the dimensions of the geologic framework containing the coastal landforms or landform elements being considered, together with meteorologic and oceanographic processes driving coastal change.

Tasks undertaken were based on available data, and involved:

1. Review of available literature to determine prevailing regional and local processes driving geomorphic change[27], including their temporal and spatial attributes;
2. Identification of the geologic framework and environmental context in which processes operate;
3. Establishment of criteria to identify cell boundaries at each level in the hierarchy of spatial scales indicated in Task 1;
4. Application of the criteria along the Northampton coast between Glenfield Beach and Nunginjay Spring Coast N to identify sediment cells;
5. Preparation of digital datasets and maps showing the cells at primary and secondary levels in the hierarchy, and points along the shoreline at the tertiary level; and
6. Comparison of potential differences in the morphodynamic processes active at each level in the cell hierarchy.

Information used to define the cells

Points along the shoreline that separate sediment cells were derived using the existing knowledge base of the coast, remotely sensed datasets and landform digital datasets (Table B.1 in Appendix B). Datasets used were:

1. Landgate Mean High Water Mark (MHWM) shoreline compiled to 2006;
2. Department of Transport nautical charts and isobaths; along with Australian Navy hydrographic charts and isobaths;
3. Onshore geology and geomorphology (including landforms) from Geological Survey of Western Australia[28];
4. A shaded relief model from the Geological Survey of Western Australia;
5. Aerial orthophotography from Landgate; and
6. High-angle oblique aerial photography from Geological Survey of Western Australia[28].

The datasets cover most of the Northampton Region but vary with respect to time, spatial scale of capture and level of resolution. These factors limit use of the project datasets which may be reviewed as more detailed information becomes available. Information from which the secondary cell onshore boundaries were determined also included recent oblique aerial photography, the shaded relief model, 2011 field surveys and landform mapping at various scales using 2006 aerial orthophoto mosaics[28]. Nautical charts, hydrographic charts, isobaths and 2006 aerial orthophoto mosaics were used for delineation of the offshore boundaries and marine sections of the alongshore boundaries at both the primary and secondary cell levels. The coverage of the nautical charts is incomplete (see Appendix A for coverage) restricting our present capacity to define the marine section of the alongshore boundaries.

Additional information, particularly at a local scale, may facilitate refinement of cell boundaries and provide data to map tertiary cell boundaries. In no particular order the extra information could include:

1. Local seismic surveys to determine rock coverage and depth of sediments;
2. Landform mapping of foredunes and frontal dunes for onshore boundaries of tertiary cells;
3. Sediment distributions;
4. Long-term analysis of aerial photographs for dune activity;
5. Benthic habitat information;
6. Collection of LiDAR bathymetry; and
7. Contemporary and projected local variations in water levels, waves, currents and winds.

For example, detailed assessment of sediment characteristics and processes contributing to their distribution is useful for boundary verification[35] (see *Detailed evaluation of coastal behaviour*). An ongoing review process, say every 10 years, may allow the implications of observed coastal change to be incorporated.

Cell boundaries

A threefold hierarchy of cells is considered for the Northampton coast with each cell represented as two-dimensions because sediment transport pathways include both alongshore and cross-shore processes. Each cell may be thought of holistically as a collection of marine and terrestrial landforms, inter-related by sediment exchange between the landforms.

In this study, points along the shoreline separating the cells have first been identified (Table 1), followed by offshore and onshore boundaries (Figure 5; Table 2). Offshore and onshore boundaries are connected by mapping through the beachface points at the shoreline (Table 1). This sequence provides a focus on the alongshore boundary definition at the shoreline, and therefore on beachface processes, while being aware that significantly higher rates of sediment transport occur in this zone. Only points were identified for tertiary cells as available data were inadequate for accurate mapping of the onshore and offshore boundaries.

Alongshore cell boundaries (beachface points) are principally determined by one or several geologic, geomorphic or engineered features at the shoreline (Table 1) Each alongshore boundary has marine and terrestrial sections that connect the offshore and onshore cell boundaries through the beachface point (Figure 5). Distinctions between morphology and processes at each sediment cell scale are incorporated in criteria used to identify the beachface points and cell boundaries. Separate criteria are described for each level in the hierarchy (see *Primary cells, Secondary cells and Tertiary cells*). Sediment cells with cliffed coasts may have alongshore boundaries with no terrestrial section where the beachface point is coincident with the Landgate MHWM to 2006.

A list of features used to determine the alongshore boundary lines for marine and terrestrial sections is included in Table 1. Those identifying the marine section of the alongshore boundaries provide some restriction to sediment transport at varying timescales: from greater than 100 years for primary cells to inter-decadal and higher frequency timescales for tertiary cells. The terrestrial section of alongshore boundaries is the limit of, or discontinuities in, the relative coastal land system or coastal landform between adjacent cells at the scale of interest. Relevant Holocene coastal land systems are used at a primary cell scale, with foredune plains and parabolic dunes at a secondary scale and frontal dunes or foredunes at a tertiary scale. Exceptions occur on engineered coasts and cliffed coasts where there is no terrestrial section of the alongshore boundary. In places where there is no variation in the land system or landform landward of the beachface point, a notional boundary is mapped as a landward extension of the marine boundary line through the beachface point to the onshore boundary along a similar trajectory or orthogonal to the coast (e.g. Glenfield in Figure A.1 in Appendix A).

Points along the shore separating the cells are characterised according to the restriction of sediment transport (open or closed); the extent of the restriction (point or zone) and the potential for migration (fixed or ambulatory). For example the apex of a rocky headland is defined as a fixed point whereas a salient sustained by wave convergence behind a large area of reef is recognised as a fuzzy boundary or zone, although it is geographically fixed. Ambulatory features may be points (e.g. large spits) or zones (e.g. deltas). By definition, an alongshore boundary cannot be ambulatory and closed.

Method overview

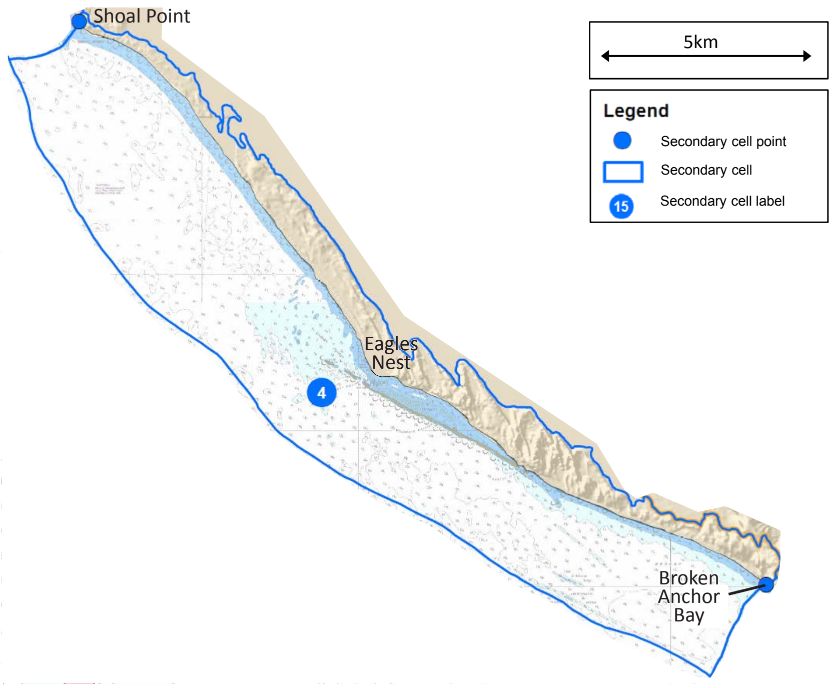
1) Identify points at the beachface.

2) Identify offshore and onshore boundaries.

3) Map alongshore boundaries that connect onshore and offshore boundaries through the beachface point.

Each alongshore boundary has a marine and a terrestrial section.

4) Process is iterative and is checked between cell scales.



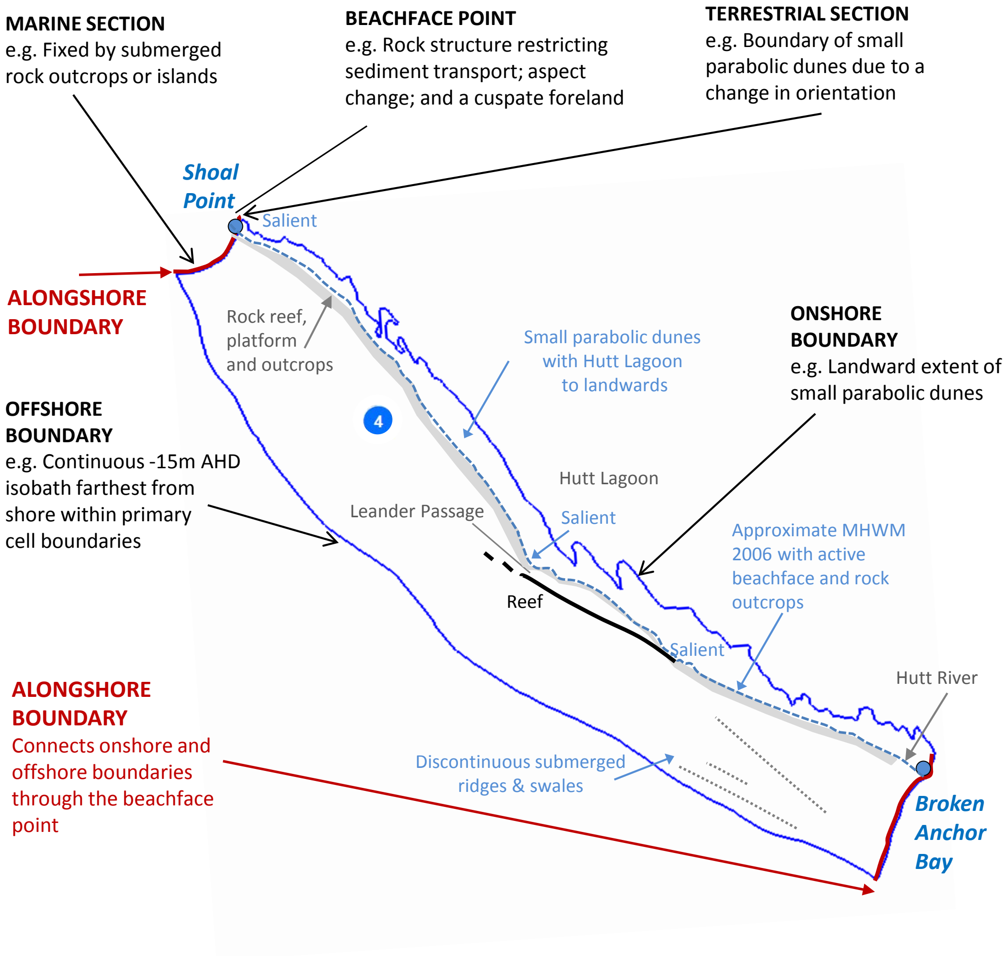


Figure 5: Cell boundaries - example for R08B4

Data Source: Bathymetry by Department of Transport and shaded relief model supplied by Geological Survey of WA, Department of Mines and Petroleum.

Table 1: Criteria for mapping alongshore boundaries in the Northampton Region

Variation of criteria will be required when applied to other coastal regions.

	Primary cell	Secondary cell	Tertiary cell
Alongshore Boundary	**Marine Section** (i) Fixed by a submerged ridge with rock outcrops or islands, then, a marine extension from the edge of the outermost rock outcrop to the offshore boundary (perpendicular to bathymetric contours where possible)[1] (ii) Deepest point of depression or contour reentrant (if depth < -30m AHD)[2] (iii) Broad area of sediment transport convergence (e.g. reefs, banks, change in aspect) (iv) Boundary is drawn orthogonal to coast because of a lack of bathymetric information	**Marine Section** (i) Fixed by submerged rock outcrops or islands (ii) Area of sediment transport convergence on banks or reefs (iii) A marine extension of the beachface point to the offshore boundary (perpendicular to bathymetric contours where possible) (iv) Deepest point of depression or contour reentrant (if depth < -15m AHD)[2]	**Marine Section** (i) Fixed by rock outcrops or islands (ii) Focal point of sediment transport convergence on banks or reefs (iii) Engineered structures or dredged areas (iv) A marine extension of the beachface point to the offshore boundary (perpendicular to bathymetric contours where possible)
	Beachface Point (May be multiple reasons for selection of position) (i) Rock structures restricting sediment transport at a decadal scale (ii) Geomorphic feature (land system or landform) (iii) Adjacent cells have a different shoreline aspect restricting sediment transport at a decadal scale (iv) Engineered structure (e.g. port) or shipping channel	**Beachface Point** (May be multiple reasons for selection of position) (i) Rock structures restricting sediment transport at an annual scale (ii) Geomorphic feature (landform) (iii) Adjacent cells have a different shoreline aspect restricting sediment transport at an annual scale (iv) Engineered structure (e.g. large marina) or dredged channel	**Beachface Point** (May be multiple reasons for selection of position) (i) Rock structures restricting sediment transport at a seasonal scale (ii) Geomorphic feature (landform or landform element) (iii) Adjacent cells have a different shoreline aspect restricting sediment transport at a seasonal scale (iv) Engineered structure (e.g. small harbour) or dredged channel
	Terrestrial Section (i) Boundary of, or discontinuity in, a Holocene land system (ii) An extension of marine section and beachface point directly to the onshore boundary if there is no change in land system between adjacent cells (iii) Centre line of engineered structure or feature (iv) No terrestrial section (e.g. cliffs)	**Terrestrial Section** (i) Boundary of, or discontinuity in, a foredune plain, large mobile dune, narrow dune barrier, small parabolic dune or frontal dune (ii) An extension of marine section and beachface point directly to the onshore boundary if there is no change in foredune plains, parabolic dunes or frontal dunes between adjacent cells (iii) Centreline of engineered structure or feature (iv) No terrestrial section (e.g. cliffs)	**Terrestrial Section** (i) Boundary of, or discontinuity in, the foredune (ii) Boundary of frontal dune if the foredune is eroded or absent (iii) An extension of marine section and beachface point directly to the onshore boundary if there is no change in foredune or frontal dune morphology between adjacent cells (iv) Centreline of engineered structure or feature (v) No terrestrial section (e.g. cliffs)

Note: 1. In some locations the ridge may need connection to the beachface
2. Isobaths were mapped to the vertical datum of Australian Height Datum (AHD).

Table 2: Criteria for mapping onshore and offshore boundaries in the Northampton Region

Variation of criteria will be required when applied to other coastal regions.

	Primary cell	Secondary cell	Tertiary cell
Offshore Boundary	(i) -30m AHD[1] isobath farthest from shore	(i) Continuous -15m AHD[1] isobath farthest from shore within primary cell boundaries	(i) -5m AHD isobath[1] closest to shore
Onshore Boundary	(i) Landward extent of Holocene land system, except for a transgressive dune system overlying older and higher land surfaces (ii) Landward extent of a coast-linked transgressive dune system overlying older and higher land surfaces (iii) Late Holocene dunes abutting rocky topography to landward (e.g. foot slopes, bluffs and cliffs) (iv) Landgate MHWM to 2006 on cliffed coast without dunes	Landward extent of: (i) foredune plain (e.g. Cervantes) (ii) large mobile dune (e.g. Southgate dune) (iii) narrow dune barrier (iv) small parabolic dunes (v) frontal dunes (vi) Landgate MHWM to 2006 on cliffed coast without dunes	(i) Landward extent of foredunes (ii) Landward extent of the frontal dune if the foredune is eroded or absent (e.g. Sunset Beach) (iii) Landgate MHWM to 2006 on cliffed coasts without dunes (iv) Landgate MHWM to 2006 on engineered coasts with shore parallel structures without dunes to landward

Note: 1. Isobaths were mapped to the vertical datum of Australian Height Datum (AHD).

Primary cells evolve over centuries and millennia. They are linked to coastal land systems[36,37,38,39,40,41] and broad marine sectors. Secondary cells are based on large coastal landforms[28] subject to inter-decadal change. Tertiary cells are based on coastal landforms subject to change on an inter-annual scale, as well as beachface features restricting sediment transport at a seasonal scale.

Primary cells: geologic framework and long-term change in morphology

Primary cells (Figure 2) encompass the geologic framework controlling long-term evolution of the coastal land systems, such as coastal barriers, river deltas and broad salients that impound lagoons. Although substantial changes to these large land systems occur at time scales longer than 100 years, the changes are trends when considered over coastal management time scales.

At the shoreline, boundaries of primary cells are mainly defined by one, or a combination of, rocky structures that restrict sediment at a decadal scale and changes in coastal aspect. In the Northampton Region, all alongshore cell boundaries of primary cells are defined by a rock structure. The structures include rock outcrops at Glenfield and Whale Boat Cove (Cells R08A and R08B) and large cliffs at Bluff Point and Nunginjay Springs Coast N (Cells R08B and R08C). There are no alongshore boundaries controlled by an engineered structure at a primary cell level.

Accretionary landforms include a mainland barrier with dunes abutting and overlaying older limestones near Bowes River (Cell R08A), as well as the Hutt Lagoon barrier and lagoon complex which is located on the remnants of a paleo-delta from when the Murchison River joined to the Hutt River (Cell R08B). The beachface point on the alongshore boundary for an accretionary landform is located at the northern extent of the landform to encompass the whole sediment sink.

The offshore boundary of primary cells is the -30m AHD isobath or depth contour. It is located on the shelf plain inshore of the Houtman Abrolhos, and includes the paleo-delta from when the Murchison River joined to the Hutt River. Formation and reworking of these broad landforms is also related to the interaction of reef and rock structures with the coast during the Holocene rise in sea level[42,43,44,45]. Sediment transport across the -30m AHD isobath would occur in the Northampton Region, but at present the sediment dynamics have not been resolved. Further investigation of the sediment transport behaviour is recommended to refine the offshore boundaries of the primary cells and to determine how available offshore sediments are to return to the nearshore system.

The onshore boundary of primary cells is the landward extent of Holocene accretionary land systems, including the foredune plains, transgressive dune systems and dunes abutting rocky topography to landward[28]. Exceptions to this are cliffed coasts without dunes to landward and when broad transgressive dune systems overlay older and higher land surfaces (Table 2). The Landgate MHWM to 2006 has been used for cliffed coasts (Appendix B). All sections of coast with the Landgate MHWM to 2006 as the onshore boundaries require further investigation at a more detailed scale. For example, there may be small pocket beaches or sections with lower elevation rock that have sediment exchange to landward. In the case of broad transgressive dune systems overlying older and higher land surfaces only the dunes with direct link to the coast were included in the primary cell.

Secondary cells: regional-scale processes and morphology

Secondary cells contain the broad patterns of contemporary (inter-annual to decadal) sediment movement on the inner continental shelf (Figure 3).

Most of the beachface points on the alongshore boundaries are fixed, although one is an ambulatory boundary (Table 1; Table 7). Fixed boundaries include rocky outcrops restricting sediment transport at an annual scale such as at Shoal Point (R08B3) and Chinaman's Rock (R08C6). The one ambulatory boundary is associated with an area of convergence of sediment transport which occurs at the northern extent of an accretionary landform; in this case the dune systems at Whale Boat Cove (R08A2). The northern extent of accretionary landforms was selected as the beachface point on the alongshore boundary to encompass the extent of the sediment sink at an inter-decadal scale. No ambulatory boundaries have been stabilised using engineered structures in the Northampton Region.

The offshore boundary of secondary cells follows the continuous -15m AHD isobath farthest from shore and within the offshore boundaries of primary cells. This depth is near the seaward margin of discontinuous shore-parallel limestone ridges close to shore that are present in the southern cells (R08A1, R082) and near Broken Anchor Bay (R08B4). Selecting this depth encompasses contemporary sediment transport by nearshore wave[46] and current processes within the cell, including dispersal of locally derived biogenic material[35,45].

Onshore boundaries of secondary cells include potential landform activity at an inter-decadal scale. The onshore boundary corresponds to the landward extent of the foredune plain, large mobile dune systems (such as the dune north of Drummond Cove in cell R08A1), narrow parabolic dune barriers, small parabolic dunes or frontal dunes. As noted above, an exception to this is cliffed coast without dunes, where the Landgate MHWM to 2006 is used as the onshore boundary (Table 2). Sediment activity could extend beyond the onshore boundaries of secondary cells in some circumstances.

Tertiary cells: local-scale, short-term processes and morphology

Tertiary cells incorporate the reworking and movement of sediment near the shore and associated potential seasonal to inter-annual landform response (Figure A series in Appendix A). Tertiary cells perform similar functions to those of secondary cells, often on a finer scale. Their alongshore boundaries coincide in some places. Beachface points on the alongshore boundaries of tertiary cells (mapped; Table 1), along with onshore and offshore boundaries (not mapped; technique could follow Table 2) are highly subject to change. They may be transgressed by extreme events and modified by low frequency coastal processes.

Tertiary sediment cells were identified for the Northampton coast, excluding islands, and with only the beachface points on the alongshore boundaries mapped.

Beachface points on the alongshore boundaries of tertiary cells restrict sediment transport at a seasonal to inter-annual scale. Fixed boundaries include rocky headlands, such as at Coronation Beach (R08A2a), north of Oakajee River. There are no boundaries fixed by engineered structures. The installation of future engineered structures potentially may change the alongshore boundaries of tertiary cells and lead to development of new cells. Ambulatory boundaries are associated with zones of convergence or divergence associated with local wave refraction and diffraction patterns[19,17]. Ambulatory boundaries at a tertiary cell scale may be located at the tip of accretionary landforms, such as at Whale Boat Cove (R08B3a) or Eagles Nest (R08B4b), as the change in aspect and wave sheltering restrict sediment transport at a seasonal to inter-annual scale.

The offshore boundaries of tertiary cells would have been mapped to the -5m AHD isobath (Table 2). This approximately corresponds with the toe of reef platforms flanking the shore and the margin of large sand shoals flanking the shore. There may be localised areas of the Northampton coast near the Murchison River (R08C) with deeper boundaries due to reduced sheltering from wind-waves and swell.

When mapped, the onshore boundary of tertiary cells should indicate the landward extent of average seasonal processes. Onshore boundaries would be the alongshore swales between the foredunes and the frontal dunes or the landward toe of the frontal dunes if foredunes are eroded or absent (Table 2). Exceptions to the landward extents of landforms as onshore boundaries would be cliffed coasts or engineered coasts with extensive shore parallel structures (e.g. seawalls) without dunes to landward. The onshore boundary of tertiary cells would not be indicative of the landward extent required for engineering, planning and management investigations. It represents the landward extent of average seasonal processes which may be superseded annually. However, it may be used as a marker to establish higher frequency changes at the shore.

Rivers

Onshore boundaries for rivers in the Northampton Region have been represented in datasets and the figures in this report as a truncation between the dune and alluvial landforms on opposite banks of the rivers. In this respect the onshore boundary does not comprehensively represent the onshore extent of estuarine processes within each river. Further investigation of landforms and sediment budgets adjacent to rivers should include:

- All alluvial landforms with connection to the coast;
- The potential for alluvial landforms to become estuarine with changing climatic conditions;
- The capacity for flooding;
- Sediment transport along the river; and
- Sediment transport fluxes associated with opening and closing of sand bars across river mouths.

The main estuarine systems of the area are the Buller River, Oakajee River, Oakabella Creek, Bowes River, Hutt River and the larger Murchison River (Figure 1), all of which have barred mouths that are breached and flow intermittently.

Marine sections of the alongshore cell boundaries may follow submarine paleo-channels or remnant channels of rivers together with their banks. These channels are likely to trap sediment or divert sediment movement. For the Northampton coast the marine section of the secondary cell alongshore boundary at the Murchison River (Kalbarri) follows the submarine paleo-channel bank of the Murchison River (R08C6).

Cell labels

The cell labelling convention follows the direction of prevailing littoral drift according to:

1. Region – increasing order of R01, R02 to R13 from the South Australia border[26]. The Northampton Region is region R08;
2. Primary cell – upper case letter resetting for each region;
3. Secondary cell – number resetting for each region;
4. Tertiary cell – lower case letter resetting for each secondary cell with letters increasing in the direction of littoral drift or clockwise around islands, for example 14a; and
5. Quaternary cell – Roman numeral resetting for each tertiary cell, for example 14ai. Quaternary cells were not applicable in this investigation.

Northampton cells are labelled to the tertiary cell, for example R08A1a, from south to north following the direction of prevailing littoral drift.

Sediment cell results along the Northampton coast

Three primary cells, seven secondary cells and 12 tertiary cells were identified along the Northampton coast between Glenfield Beach and Nunginjay Spring Coast N. The hierarchy of cells is presented as maps, tables and electronic datasets available from the Department of Transport (Table 3).

Table 3: Location of cell results for the Northampton Region

Item	Further information included	Location in report
Beachface points on the alongshore boundaries[1]	Information on the beachface point on alongshore boundaries at all three sediment cell scales. This includes features that define the beachface point, coordinates and character of the boundary	Tables in Appendix E (separate document)
Alongshore boundaries[1]	Information on the features that define the marine and terrestrial sections of the alongshore boundaries for cells at the primary and secondary scales	
Onshore and offshore boundaries[1]	Information on the features that define the onshore and offshore boundaries for cells at the primary and secondary scales	
Cell names	Hierarchy of cell names including cell labels	Table 4
Maps of cells	Primary and secondary cells at 1:1,250,000 scale at A4 size	Figure 2 and Figure 3
	Secondary and tertiary cells at 1:100,000 scale at A4 size	Figures A.1-A.7 in Appendix A
Coincidence of cell boundaries	Boundary names and coincidence at different levels in the hierarchy	Table 5
Comparison to previous study	Comparison with previously defined sediment cell boundaries[27] in landform vulnerability reports.	Table D.1 in Appendix D

Note: 1. Electronic datasets of boundaries and beachface points available from Department of Transport in ESRI shapefile format or as Google Earth KMZ files. The kmz filename is 'R08 Northampton Cells'.kmz'. The shapefile filenames are Primary_Cells.shp and Secondary_Cells.shp and are available upon request from the Department of Transport officers.

Cell boundaries

The alongshore spatial scale of cells in the Northampton Region varies with wave exposure, geologic framework, sediment availability and aspect. Further information on these parameters is provided in the landform vulnerability report[27], but should be updated at an appropriate scale in any analysis of sediment budgets. The mean length of cells was 47km (33-66km), 20km (15-30km) and 12km (1-19km) for primary, secondary and tertiary cells respectively (Table 6). Larger cells in the size ranges are present on coasts with reduced sheltering by reefs, offshore features and large rock outcrops, with smaller cells in the size ranges on coasts with increased geological control, such as coasts with tombolos and large cuspate forelands. Secondary and tertiary cell boundaries may be coincident for coasts that are open or have inherited features.

There is some consistency in scale with littoral cells reported from elsewhere, overseas and on the WA coast. Spatial scales of primary cells (33-66km) are smaller than the littoral cells in England, Wales and Scotland (50 -300km)[13,14] and the Pilbara Region (100-300km)[47], and at a similar scale to cells in the Vlamingh Region (13-87km)[34], Mid-West Region (37-78km)[49], California (10-95km)[20] and Hawkes Bay, New Zealand (20-60km)[48]. The Northampton Region had fewer smaller primary cells than the Vlamingh Region[34] because there is less sheltering, with no large islands within the primary cell boundaries and a discontinuity in, or absence of, offshore ridges. The local primary and secondary cell scales correspond with sub-cell scales in the United Kingdom. The comparison across the hierarchy of cells provides confidence in linking cell dimensions to the geologic framework, sediment availability and different metocean processes driving shoreline change at each scale.

Primary cell boundaries are also secondary and tertiary cell boundaries (Table 5). All eight (100%) secondary cell boundaries are also tertiary cell boundaries, with five (38%) unique tertiary cell boundaries.

The cell hierarchy and boundary character classification (Table 4; Table 7) reveal the complexity of the coastal system of the region which has varied rock control and inherited features. All boundaries are open at all three scales with varying degrees of sediment transport leakage. Notably, sediment flow directions may be reversed with changes in meteorological and oceanographic conditions, with some boundaries effectively closed for one sediment transport direction.

Table 4: Primary, secondary and tertiary sediment cells of the Northampton Region

Region	Primary	Secondary	Tertiary
R09. Shark Bay Region	Beyond Study Area	Beyond Study Area	Beyond Study Area
R08. Northampton Region from Glenfield to Nunginjay Spring Coast N	C. Bluff Point to Nunginjay Spring Coast N	7. Chinaman's Rock to Nunginjay Spring Coast N	b. Oyster Reef to Nunginjay Spring Coast N
			a. Chinaman's Rock to Oyster Reef
		6. Bluff Point to Chinaman's Rock	b. Red Bluff to Chinaman's Rock
			a. Bluff Point to Red Bluff
	B. Whale Boat Cove to Bluff Point	5. Shoal Point to Bluff Point	b. Yanganooka to Bluff Point
			a. Shoal Point to Yanganooka
		4. Broken Anchor Bay to Shoal Point	b. Eagles Nest to Shoal Point
			a. Broken Anchor Bay to Eagles Nest
		3. Whale Boat Cove to Broken Anchor Bay	a. Whale Boat Cove to Broken Anchor Bay
	A. Glenfield to Whale Boat Cove	2. Coronation Beach to Whale Boat Cove	b. Bowes River to Whale Boat Cove
			a. Coronation Beach to Bowes River
		1. Glenfield to Coronation Beach	a. Glenfield to Coronation Beach
R07. Mid-West Region	Beyond Study Area	Beyond Study Area	Beyond Study Area

Table 5: Sediment cell alongshore boundaries of the Northampton Region

Coordinates, alongshore boundary character, onshore and offshore boundaries, along with marine and terrestrial sections of the alongshore boundary are in the KMZ file, shapefile and Appendix E.

Cell alongshore boundary name	Cell boundaries
Nunginjay Spring Coast N	1°, 2°, 3°
Oyster Reef	3°
Chinaman's Rock	2°, 3°
Red Bluff	3°
Bluff Point	1°, 2°, 3°
Yanganooka	3°
Shoal Point	2°, 3°

Cell alongshore boundary name	Cell boundaries
Eagles Nest	3°
Broken Anchor Bay	2°, 3°
Whale Boat Cove	1°, 2°, 3°
Bowes River	3°
Coronation Beach	2°, 3°
Glenfield	1°, 2°, 3°

Table 6: Alongshore length of cells of the Northampton Region

Cell level	Minimum length (km)	Maximum length (km)	Mean length (km)	Median length (km)
1°	33	66	47	44
2°	15	30	20	18
3°	1	19	12	13

Table 7: Alongshore boundary characteristics of cells of the Northampton Region

Alongshore boundary characteristics for each cell are in the KMZ file, shapefile and Appendix E.

	Alongshore boundaries					
	Primary		Secondary		Tertiary	
	Count	%	Count	%	Count	%
Point	3	75%	6	75%	8	62%
Zone	1	25%	2	25%	5	38%
Fixed	3	75%	7	88%	10	77%
Ambulatory	1	25%	1	13%	3	23%
Open	4	100%	8	100%	13	100%
Closed	0	0%	0	0%	0	0%

Boundaries are ambulatory (≈20%) where rock control is on the sub-tidal part of the shoreface and may be defined as a zone where there is limited to no rock control on the beachface. At all scales, 60-75% of all cell boundaries are points and 25-40% are zones with approximately 20% ambulatory boundaries. Landforms adjacent to tertiary cell boundaries are susceptible to variation as a result of both sub-tidal and inter-tidal rock control.

Along coast variation of sediment cells

Geographic differences in geology, sediments and processes cause alongshore variation in the characteristics of sediment cells over both regional and sub-regional scales. These differences change the relative influence of the criteria used to define sediment cells boundaries. They identify which attributes best define the sediment cells and at what scale.

Intra-regional variation in sediment cells of the Northampton Region is described according to primary cells, linked to the seafloor terrain, onshore sedimentary landforms and coastal processes. The Northampton Region comprises an inner shelf that broadens in the area of the Houtman Abrolhos, with local areas of inshore bays and sections of nearshore reef. There are extensive outcrops of coastal limestone at the shoreline, including shore-parallel reefs and cliffs; and the several types of barrier dunes along the shore[27]. The barriers include broad salients, as well as small parabolic dunes impounding lagoons, mainland barriers and dunes abutting and overlying cliffs. The distribution of these landforms changes with distance northward from Glenfield.

Most of the region (Cells R08A and R08B) is characterised by a 100km wide and shallow inner shelf including the Houtman Abrolhos. Changes in the plan form of the reefs and cliffs, their position of outcropping along the shore; the sheltering by the Houtman Abrolhos; and the development of large sedimentary landforms contribute to local variation in coastal aspect and exposure, hence variation in the relative intensity of meteorological and oceanographic processes affecting the coast.

The southern part of the region (Cells R08A) has a 0.5-3km wide nearshore reef (depths <10m) running parallel to the shore. The reef narrows with distance north and changes from a S-N alignment to a SSE-NNW alignment north of the Buller River. Small salients are present where reefs are close to the coast and large dunes adjacent to each of the smaller river mouths. Extensive outcrops of coastal limestone at the shoreline exist as cliffs north of Coronation Beach (Cell R08A2) with dunes abutting the cliffs, and climbing them towards the north of the cell at Whale Boat Cove.

The central part of the region (Cell R08B) is sheltered by the Houtman Abrolhos. It has a substantial accumulation of inherited sediments associated with the Murchison-Hutt paleo-delta when the rivers discharged further south of their present location. There are broad salients, tied to rock outcrops, in the lee of shore-parallel reefs at Eagles Nest and Shoal Point, with narrow parabolic dunes impounding the Hutt Lagoon.

Cliffs outcrop on the coast north of Shoal Point. Further north (Cell R08C), the shelf narrows and extensive outcrops of coastal limestone occur at the shoreline. The outcrops include a shore parallel reef that is the existing shoreline in certain locations, as well as outcrops of coastal cliffs. There are dunes and alluvial landforms in the vicinity of the Murchison River mouth.

Inter-regional variation in sediment cells is summarised by comparing the criteria for mapping cells for the four regions of Vlamingh, Mid-West, Northampton and Pilbara. Criteria for defining sediment cells for the Northampton Region were the same as the Mid-West Region[49], but differ from those used in the Vlamingh and Pilbara Regions[34,50]. Despite the differences, a consistent approach has been used to determine the beachface point on the alongshore boundaries and follows the procedure described in the coastal compartments report[26]. Differences in criteria between the Vlamingh Region and Northampton Region is related to engineering modifications and the presence of near continuous ridges formed by elongate reefs, large islands and basins in the Vlamingh Region (Appendix C). Differences in criteria between the Pilbara Region and Northampton Region is related to a shift in dominant forcing from waves in the southern regions to tidal reworking, extreme waves and increased river activity in the Pilbara (Appendix C).

Differences to landform vulnerability assessments

The cells defined in this report may differ from those described within the recent landform vulnerability report prepared by the same authors[27]. Previous cell descriptions and vulnerability assessments[27] should not be aggregated into the revised cell hierarchy presented here without reassessing the main landforms within each cell appropriate to the scale of interest. The hierarchy of cells presented here should be used in preference to previously defined cells for Glenfield to Nunginjay Spring Coast N[27].

Cells reported in 2012[27] were non-hierarchical, comprising a set of points along the coast. They were used for a landform-based coastal vulnerability assessment and were therefore mapped to a high resolution (small-scale cells). They correspond to tertiary or quaternary cell scales in the present hierarchy. The two-dimensional mapping of cells in this present report captures interactions between marine and terrestrial environments at comparable scales along the coast. It also facilitates interpretation of the interactions between and within scales.

Comparison of the cell hierarchy with previous cell definitions[27] is demonstrated in Table D.1 in Appendix D. The 18 cells of the Shires of Coorow to Northampton report[27] within the Northampton Region are mapped as three primary, seven secondary and 12 tertiary cells (Table D.1 in Appendix D).

Applications

In this report, sediment cells are areas in which there is strong connectivity between marine and terrestrial landforms. Hence, they are natural management units, presented in a simple spatial format. Applications of sediment cells include identification of spatial context for coastal evaluations; a common framework for dialogue about the coast; support to coastal management decision-making and a range of technical uses largely relating to coastal stability assessment. Some uses of sediment cells are listed in Table 8 and briefly described below.

Table 8: Applications of sediment cells

Context	• Identification of area to be evaluated • May be used for problem scaling
Communication	• Cross-jurisdictional co-operation • Spatial basis readily comprehended by non-technical audience • Common framework for discussion between disciplines
Decision-Making	• Screening destabilising actions from high coastal amenity • Recognition of stabilisation trade-offs
Technical Use	• Improved coastal erosion assessment • Sediment budget development • Upscaling and downscaling of coastal information • Identification of key coastal processes • Landform vulnerability assessment

Context

As defined in this report, sediment cells provide an indication of a spatial area within which marine and terrestrial landforms are likely to be connected through processes of sediment exchange. This implies that either natural or imposed changes at any point in the cell may affect any other part, recognising such relationships are strongly bound by proximity. A fundamental use of sediment cells is therefore one of ***context***, to identify an area that should be considered in a coastal study. Specifically, questions that should be considered are:

- How may an imposed action, such as installation of a groyne, affect the wider coast through changes to the sediment budget?
- Have changes to the wider area influenced locally observed response?

Note that this does not mean that sediment cells must be used to define a study area or model area. These are typically smaller due to data or budget limitations.

A qualitative assessment within the sediment cells context is often valuable for problem scaling when dealing with coastal instability. Considering whether an observed issue is prevalent within a cell or adjacent cells may provide guidance on the type of management solutions available, and therefore suggest the form of technical advice most likely to be useful (Figure 6). For example (labelling corresponds to panels in Figure 6):

A. If there is a balance of erosion and accretion within a sediment cell, there is potential opportunity to manage the problem through coastal stabilisation works, which transfer stresses along the coast;
B. For a coastal stability issue that is affecting the majority of a sediment cell, it is appropriate to improve coastal resilience, including techniques that improve the transfer of sand from the nearshore to the beach and dune system;
C. If erosion and accretion occur differently between cells, it is possible that the stress can be more evenly distributed, including artificial interventions such as bypassing. However, limited natural sediment transfer at cell boundaries determine that balancing erosion and accretion requires long-term management;
D. If erosion or accretion is prevalent across multiple cells, the issue is likely to be dominant in the long term. This typically requires a decision about where to focus the problem, such as through identification of sacrificial coastal nodes.

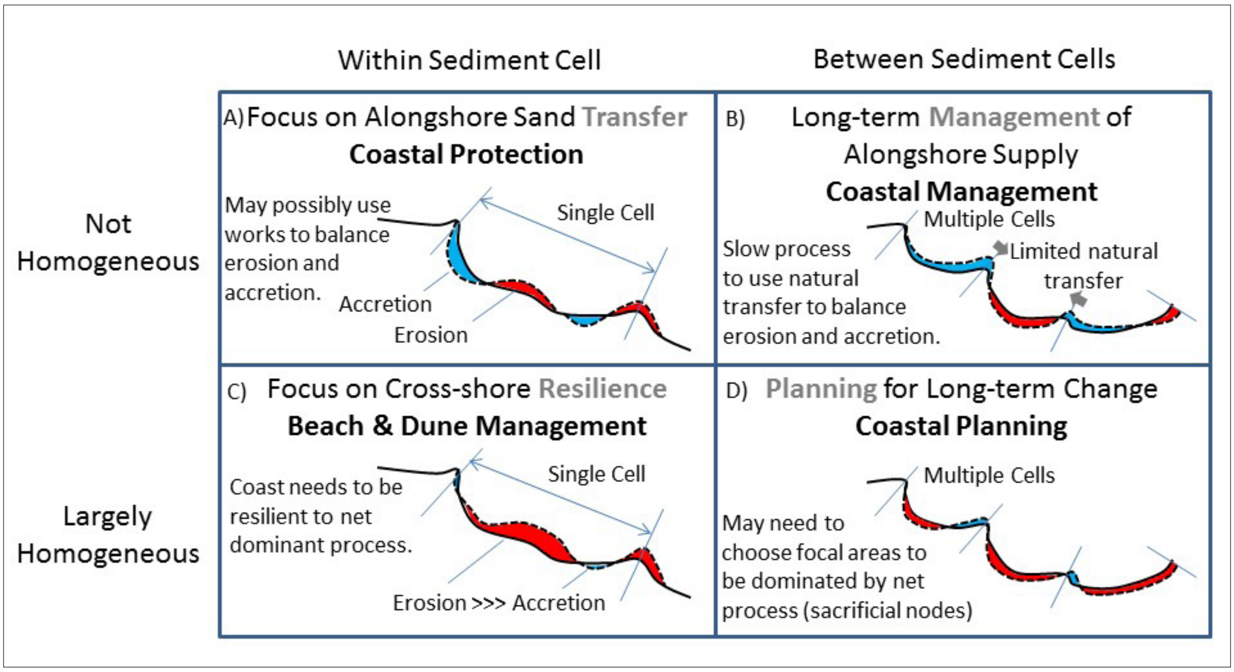


Figure 6: Use of sediment cells for problem scaling

Communication

A key feature of the sediment cell framework is its development from physical attributes rather than a jurisdictional basis. This highlights situations where communication between coastal managers may be necessary, and supports formation of strategic planning groups such as the Peron-Naturaliste Partnership or Cockburn Sound Coastal Alliance in the Vlamingh Region.

The relatively simple spatial representation of sediment cells may be a valuable tool for communication between technical agencies and the general public. Recent application of coastal process connectivity mapping[24] has highlighted the value of simple spatial tools to help explain the basis for coastal management decisions to a non-technical audience.

The value of communicating through a common spatial framework may also enhance dialogue between technical staff involved in different disciplines. The framework of sediment cells and coastal compartments are designed to be of use for coastal management across multiple scales, from engineering through to strategic planning[26]. However, the strong relationship between habitats and morphology[54], includes links between catchments areas and sediment cells. This more broadly suggests that sediment cells may have value as natural management units when considering natural resource management or coastal ecosystem services.

Decision-making

Recognition of the inter-connected nature of marine and terrestrial landforms within a sediment cell may support simplified decision-making by coastal managers, including local and State government agencies.

For agencies managing large areas, sediment cells can be used for low-cost geographic screening, particularly when combined with the direction of net alongshore sediment transport. As the cells provide preliminary guidance regarding the possible extent of development impacts, the cells framework may be used to guide the distribution of infrastructure. For example, destabilising infrastructure may be preferentially excluded from a cell containing sensitive or high amenity coastal areas. Alternately, a largely isolated single cell may be identified as a strategic coastal node, with focused coastal protection works and interventions creating a minimised coastal footprint.

An objective of the sediment cells definition is to focus coastal managers' attention upon the connected nature of marine and terrestrial landforms. This is intended to disrupt expectation that the whole coast under management can be made stable. For every effort toward stabilisation, the consequent trade-off should be clearly identified and understood. This way of thinking reduces the likelihood of tail-chasing through successive coastal stabilisation works.

Technical use

A major technical use for sediment cells is to improve erosion hazard assessments by better integrating regional and local coastal change. Regional changes may include the effects of climate or sea level fluctuations and the consequent variations in sand supply. Local changes include storm responses and coastal interactions with natural and artificial structures. Improved knowledge of how local changes may have broader impact is essential to good coastal planning[20,21,22,52,53,54]. Equally, refined understanding of how regional change influences local response can improve setback assessment[55] and structural design[56].

Sediment cells evaluated for regional processes should be identified based on the relative magnitude of local coastal change and the proximity to cell boundaries. Large-scale engineering works, such as ports and harbours, should be considered over the full hierarchy of primary, secondary and tertiary sediment cells to ensure adequate identification of possible effects. However, most planning and engineering investigations require consideration at a secondary cell scale as this incorporates broad sediment transport processes over inter-decadal timescales. If proposed works are unlikely to restrict sediment transport on an inter-annual scale, assessment may occur at tertiary cell scale. In all cases, proximity to a cell boundary may suggest the need to consider adjacent cells.

Landform information used to develop the sediment cells, including indications of sediment transport pathways and sinks, is equally important to the development of quantitative sediment budgets. Consequently, the sediment cells framework provides a useful spatial basis for the development of sediment budgets[1,2,6]. Detailed application of a sediment budget-based coastal assessment has recently been conducted in the Geraldton area[35] (Cell R07F in the Mid-West Region and Cell R08A in the Northampton Region). The effect of timescale on sediment budget variability is acknowledged along the Northampton coast, with ocean-estuary exchange and pulses of sand supply contributing to these fluctuations.

Definition of sediment cells (and coastal compartments[26]) over multiple spatial scales supports the processes of upscaling and downscaling, where information collected or applicable at one particular scale is made meaningful at another larger or smaller spatial scale. Upscaling involves the aggregation of information from a finer scale, often sparse across the wider area. Downscaling involves interpretation of coarse scale information at a finer scale, usually through the use of additional information. The concepts of upscaling and downscaling are important tools for combining regional and local coastal change assessments, often using a sediment budget approach.

Connectivity of marine and terrestrial landforms is used as a basis for sediment cell definition. The identified landforms and pathways for transport may also suggest the key active coastal process and therefore indicate appropriate conceptual models for coastal dynamics. Mapping of coastal morphology in the Northampton Region has been described as part of the WACoast series[28] and in a landform vulnerability report[27].

Sediment cells have previously been used as a spatial framework for landform-based coastal vulnerability assessment in the Northampton Region[27]. This assessment involved coastal classification based on landform characteristics considering both present-day mobility and the potential sensitivity to disturbance of existing conditions.

Modification of cell boundaries

Although the cell boundaries have been presented as a spatial framework, they are based upon interpretation of geomorphic information. Therefore boundaries may require variation according to either the intended application or due to further relevant information being obtained. Common reasons to update the database describing the cells may include:

- Large-scale change that will affect cell connectivity;
- Coastal change near a cell boundary;
- Modification due to engineering works; or
- More detailed evaluation of active coastal behaviour.

Sediment cell connectivity

Determination of the number and scale of sediment cells used for coastal assessment should involve consideration of the magnitude and timescale of coastal change as well as the relative connectivity between sediment cells. It is appropriate to consider multiple sediment cells when evaluating larger or more sustained coastal change, or when assessing cells with moderate or high connectivity. Cell connectivity is indicated by the nature of the coastal boundary, with higher connectivity occurring where:

- The boundary is open or ambulatory; for example, sediment transfer occurring across boundaries on salients and cuspate forelands;
- Reversal of littoral drift direction is known to occur;
- There is an onshore feed of sediment;
- A boundary is located on a sediment source or sink; or
- Boundaries providing headland control of estuary entrances to coastal lowlands.

Investigation of coastal processes should recognise the potential role of connectivity between cells, including the relative significance of prevailing and extreme events in driving linkage of adjacent cells.

In situations where coastal change is substantial, such as coastal adjustment subsequent to mass deposition from a river system, or the potential impact of sea level rise over the next hundred years, there is potential for change to affect even rock boundaries. Users of the cell framework on mixed rock and sand coasts, such as the Northampton coast, should consider:

1. Sections of coast which have occasional outcrops of rock and are progressively eroding will potentially reach points where either the rock has reduced influence on the coast, or a newly exposed area of rock starts to control the coastal configuration. These changes of coastal state may effectively alter sediment cell boundaries.
2. The influence of rock features that control the coast through sheltering may change with sediment supply. The resulting sandy features, salients or cuspate forelands, may migrate under changing meteorological, oceanographic or sediment supply conditions. This can occur following a loss of offshore reef control, as has been reported for a calcarenite coast[57], or if there is a reduction in sediment supply such as caused by Geraldton Port breakwaters.

Proximity to cell boundaries

As the influence of a local coastal change is strongest in its immediate vicinity, it is possible for the effect of a moderate change to be transferred across a cell boundary. In such a situation, adjacent sediment cells should be assessed simultaneously.

Modification due to engineering works

Engineering works may modify the nature of sediment cell boundaries and in some instances, might create new boundaries. An example of modifying the cell boundary has occurred at Geraldton Port, where the influence of the partly mobile salient has been overtaken by the extensive rock breakwaters.

Detailed evaluation of coastal behaviour

Detailed coastal assessment, including sediment analysis, sediment transport assessment or higher frequency evaluation of coastal configuration may provide better representation of how the sediment cell boundary operates. Cell boundaries may need to be reviewed following such investigations.

Recent work for the Mid-West Region, immediately south of the Northampton Region, provides an example of how sediment analysis may be used to verify and resolve cell boundaries[35]. It is also an example of how previous knowledge of sediment cells can inform and have a bearing on a study of sediment transport. Processes affecting the distribution of sediments and variability in sediment supply from nearshore sources were investigated to help develop sediment budgets for the Tarcoola and Champion Bay embayments, north and south of Point Moore. Study[35] outcomes relevant to the definition of sediment cells included:

- At a primary cell scale the study improved understanding of sediment sources and sinks over a long time scale. The presence of heavy mineral and garnet sands in beach sediments indicates river processes have played a major geologic role in sediment supply north of the Greenough River. This supports the selection of the primary cell Phillips Road Coast to Glenfield (R07F in the Mid-West Region) incorporating the Greenough-Chapman paleo-delta.
- Separation of secondary cells at Point Moore was supported by differences in contemporary sources of sediment north and south of the Point Moore tombolo, with higher biogenic components derived from seagrass meadows to the south and higher components of reworked marine and terrestrial components to the north.

Possible studies to further resolve cell boundaries requires consideration of how the cells are to be applied, the time and space scales and the range of landforms within the domain of interest. For example, when assessing over an extended time scale for climate change adaptation assessment, there may be sensitivity to buried rock. A program of seismic surveys could therefore refine the onshore boundary. A second example is where coastal dunes define the onshore boundary of secondary cells, as the degree of dune mobility and the time scale of change will directly affect the area of interest. In this situation, active dune movement may be identified through aerial photograph interpretation or sediment analysis.

Further work to increase the resolution of cell boundaries may involve:

1. Ensuring the temporal and spatial resolution of data are consistent between datasets and fit for purpose at the scale at which they are being applied;
2. Extension of the criteria used to identify the cell boundaries to include criteria describing sediment characteristics and the limits to their distribution;
3. Identification of the potential for change of ambulatory boundaries at a local scale related to projected variation in climate and ocean processes, along with more detailed information of underlying rock structures;
4. Verification of sediment cells through determination of sediment character, composition, depth and distribution;
5. Determination of the contribution of barred estuaries to cell functions; and
6. Revision of cell boundaries in the event of large-scale engineering works, such as ports or harbours, restrict sediment transport at relevant time and space scales.

In the future, the beachface points identifying the alongshore boundaries of tertiary cells in the Northampton Region should be extended to include their marine and terrestrial sections and link them with onshore and offshore boundaries, according to the recommended criteria in Table 1 and Table 2. This work could be conducted when datasets of sufficient resolution are available, such as LiDAR imagery of the nearshore (see *Information used to define the cells*).

Proposed modification of cell boundaries should be presented to the dataset custodian, the Western Australian Department of Transport. The modifications should be presented in either ESRI Shapefile format or as Google Earth KMZ files with metadata and supporting documentation.

References

[1] Bowen AJ and Inman DL. (1966) *Budget of littoral sands in the vicinity of Point Arguello, California*. United States Army CERC Technical Memorandum No. 19.

[2] Komar PD. (1996) The budget of littoral sediments, concepts and applications. Shore and Beach. 64 (3): 18 – 26.

[3] van Rijn LC. (1998) *Principles of Coastal Morphology*. Aqua Publications, NL.

[4] McGlashan DJ and Duck RW. (2002) The Evolution of Coastal Management Units: Towards the PDMU. *Littoral 2002, The Changing Coast*. 29-33.

[5] Cowell PJ, Stive MJF, Niedoroda AW, de Vriend DJ, Swift DJP, Kaminsky GM and Capobianco M. (2003a) The coastal-tract (Part 1): a conceptual approach to aggregated modeling of low-order coastal change. *Journal of Coastal Research*, 19 (4): 812-827.

[6] Rosati JD. (2005) Concepts in sediment budgets. *Journal of Coastal Research,* 21(2): 307–322.

[7] Cooper NJ & Pontee NI. (2006) Appraisal and evolution of the littoral 'sediment cell' concept in applied coastal management: Experiences from England and Wales. *Ocean and Coastal Management*, 49: 498-510.

[8] Whitehouse R, Balson P, Beech N, Brampton A, Blott S, Burningham H, Cooper N, French J, Guthrie G, Hanson S, Nicholls R, Pearson S, Pye K, Rossington K, Sutherland J and Walkden M. (2009) *Characterisation and prediction of large scale, long-term change of coastal geomorphological behaviours:* Final science report. Science Report SC060074/SR1. Joint DEFRA and Environment Agency Flood and Coastal Erosion Risk Management R & D Programme, Environment Agency and Department for Environment, Food and Rural Affairs, United Kingdom.

[9] Inman DL and Frautschy JD. (1966) Littoral processes and the development of shorelines. *Proceedings of Coastal Engineering Santa Barbara Specialty Conference*, American Society of Civil Engineering, 511–536.

[10] Davies JL. (1974) The coastal sediment compartment. *Australian Geographical Studies*. 12: 139-151.

[11] Searle DJ and Semeniuk V. (1985) The natural sectors of the Rottnest Shelf coast adjoining the Swan Coastal plain. *Journal of the Royal Society of Western Australia,* 67: 116-136.

[12] Griggs GB. (1987) Littoral Cells and Harbour Dredging Along the California Coast. *Environmental, Geological and Water Science*, 10 (1): 7-20.

[13] Motyka JM and Brampton AH. (1993) *Coastal Management: Mapping of Littoral Cells*. Wallingford UK: HR Wallingford. Hydraulics Research Report SR 328.

[14] HR Wallingford. (1997) *Coastal cells in Scotland*. Scottish Natural Heritage. Research, Survey and Monitoring Report 56.

[15] McGlashan DJ and Duck RW. (2000) Undeveloped Coasts: a protocol for the assessment of development potential. *Periodicum Biologorum*, 102(1):329-332. Cited within McGlashan & Duck (2002).

[16] Department for Environment, Food and Rural Affairs: DEFRA. (2006) *Shoreline management plan guidance*. United Kingdom. www.defra.gov.uk

[17] Sanderson PG and Eliot I. (1999) Compartmentalisation of beachface sediments along the southwestern coast of Australia. *Marine Geology,* 162: 145-164.

[18] Stapor FW & May JP. (1983) The cellular nature of littoral drift along the northeast Florida Coast. *Marine Geology*, 51: 217-237.

[19] Carter B. (1988) *Coastal environments: an introduction to the physical, ecological, and cultural systems of coastlines*, Academic Press, New York.

[20] California Coastal Sediment Management Workgroup. (2006) *California Coastal Sediment Master Plan Status Report; Draft for Public Review and Comment.* California Geological Survey, Santa Rosa CA.

[21] MESSINA. (2006) *Integrating the Shoreline into Spatial Policies*. Practical Guide prepared as part of the Managing European Shorelines and Sharing Information on Nearshore Areas (MESSINA). Prepared by IGN France International, Isle of Wight Council, University of Szczecin, Community of Agglomeration for the Thau Basin and Municipality of Rewal. Produced for European Union.

[22] van Rijn LC. (2010) *Coastal erosion control based on the concept of sediment cells.* Prepared for the European Commission, Concepts and Science for Coastal Erosion Management, Conscience.

[23] Eliot M, Stul T & Eliot I. (2013) Revisiting Landforms in Coastal Engineering, *In: Proceedings of Coasts & Ports 2013 Conference*, Manly, Sydney, 11-13 September 2013.

[24] French J and Burningham H. (2009) *Mapping the connectivity of large scale coastal geomorphological systems: Coastal system mapping with Cmap Tools tutorial*. Science Report SC060074/PR2. Joint DEFRA and Environment Agency Flood and Coastal Erosion Risk Management R and D Programme, Environment Agency and Department for Environment, Food and Rural Affairs, United Kingdom.

[25] McLean RF. (2000) Australia's coastal vulnerability assessment studies: recent upscaling or downscaling? *Proceedings of APN/SURVAS/LOICZ Joint Conference on coastal impacts of climate change and adaptation in the Asia-Pacific region*, Kobe, Japan, November 14-16, 2000, 29-33.

[26] Eliot I, Nutt C, Gozzard B, Higgins M, Buckley E and Bowyer J. (2011) *Coastal Compartments of Western Australia: A Physical Framework for Marine and Coastal Planning.* Report 80-02. Damara WA Pty Ltd. Report to the Departments of Environment and Conservation, Planning and Transport. Environmental Protection Authority.

[27] Eliot I, Gozzard B, Eliot M, Stul T and McCormack G. (2012) *The Mid-West Coast, Western Australia: Shires of Coorow to Northampton. Geology, Geomorphology & Vulnerability*. Damara WA Pty Ltd and Geological Survey of Western Australia, Innaloo, Western Australia.

[28] Gozzard JR. (2011b) *WACoast –Lancelin to Kalbarri*. Geological Survey of Western Australia digital dataset.

[29] Short AD. (2005) *Beaches of the Western Australian Coast: Eucla to Roebuck Bay*, Sydney University Press, Sydney.

[30] Western Australian Planning Commission: WAPC. (2003) 'Chapter 2 – Coastal Environments' in *Coastal Planning and Management Manual: A community Guide for Protecting and Conserving The Western Australian Coast.* WAPC, Perth.

[31] Schwartz ML. (2005) *Encyclopedia of Coastal Science.* Encyclopedia of Earth Sciences Series. Springer, The Netherlands.

[32] Landvision and UWA. (2001) *Batavia Coast strategy – final*. For Ministry for Planning. Prepared for and by the Batavia Coast Coastal Planning Group, Landvision and the Institute for Regional Development at the University of Western Australia. Perth, Western Australia.

[33] Chalmers CE. (1983) *Coastal Management Plan: Kalbarri Townsite*, Department of Conservation and the Environment, Coastal Management Co-ordinating Committee of Western Australia and the Shire of Northampton, Department of Conservation and Environment Bulletin 145.

[34] 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 Western Australian Department of Transport, Fremantle.

[35] Tecchiato C and Collins LB. (2012) *Geraldton Embayments Coastal Sediment Budget Study.* Coastal Vulnerability and Risk Assessment Program - Project 2 - Stage 2: Sediment Mapping for Identification of Sediment Sources, Transport Pathways and Sinks for Components of the Batavia Coast, With Special Consideration of the Inshore Waters and Coast between the Greenough River and Buller River. First Year Final Report for the WA Department of Transport, Curtin University, Bentley. Western Australia.

[36] Gozzard JR and Hesp PA. (1983) *Description and Capability of Coastal Lands – Dongara to Green Head.* Geological Survey of Western Australia, Environmental Geology Report EV21.

[37] Dye RA, Van Vreeswyk AM and Moore GA. (1990) *Geraldton rural-residential land capability study*, Land Resources Series No. 4, 1:50,000 soil landscape map and report. Department of Agriculture, Western Australia, 53p.

[38] Rogers LG. (1996) *Geraldton region land resource survey*, Department of Agriculture and Food, Land Resources Survey No. 13, Western Australia, 198p.

[39] Schoknecht NR and Bessell-Browne JA. (1996) *North Coastal Plain land resources survey*, 1:100,000 map and report (unpublished).

[40] Langford, RL. (2000) *Regolith–landform resources of the Geraldton 1:50 000 sheet*. Geological Survey of Western Australia, Record 2000/17, 37p.

[41] Hennig P. (2009) *An inventory and condition survey of the lower Murchison River area, Western Australia*, Department of Agriculture and Food, Technical Bulleting No. 96, Western Australia, 184p.

[42] Collins LB. (1988) Sediments and history of the Rottnest Shelf, southwestern Australia: a swell dominated, non-tropical carbonate margin. *Sedimentary Petrology*, 60: 15–29.

[43] Semeniuk V and Searle DJ. (1986) Variability of Holocene sealevel history along the southwestern coast of Australia – Evidence for the effect of significant local tectonism. *Marine Geology*, 72: 47-58.

[44] Wyrwoll K-H, Zhu ZR, Kendrick GA, Collins LB and Eisenhauser A. (1995) Holocene sea-level events in Western Australia: revisiting old question'. In: CW Finkl (ed.), *Holocene cycles: climate, sea level, and coastal sedimentation*. *Journal of Coastal Research*, Special Issue no. 17: 321–326. Coastal Education and Research Foundation.

[45] James NP, Collins LB, Bone Y and Hallock P. (1999) Subtropical carbonates in a temperate realm: modern sediments on the southwest Australian shelf. *Journal of Sedimentary Research*, 69 (6): 1297-1321.

[46] Hallermeier RJ. (1981) *Seaward Limit of Significant Sand Transport by Waves: An Annual Zonation for Seasonal Profiles*. United States Army Corps of Engineers. Coastal engineering technical aid no. 81-2.

[47] Eliot I, Gozzard B, Eliot M, Stul T and McCormack G. (2013) *Geology, Geomorphology & Vulnerability of the Pilbara Coast, In the Shires of Ashburton, East Pilbara and Roebourne, and the Town of Port Hedland, Western Australia.* Damara WA Pty Ltd and Geological Survey of Western Australia, Innaloo, Western Australia.

[48] Komar PD. (2005) *Hawke's Bay Environmental Change, Shoreline Erosion & Management Issues*. Asset Management Group Technical Report ISSN 1174 3085. Prepared for Napier City Council, Port of Napier Ltd and Hawke's Bay Regional Council.

[49] Stul T, Gozzard JR, Eliot IG and Eliot MJ. (2014a.) *Coastal Sediment Cells for the Mid-West Region between the Moore River and Glenfield Beach, Western Australia.* Report prepared by Seashore Engineering Pty Ltd and Geological Survey of Western Australia for the Western Australian Department of Transport, Fremantle.

[50] Stul T, Gozzard JR, Eliot IG and Eliot MJ. (2014b) *Coastal Sediment Cells for the Pilbara Region between Giralia and Beebingarra Creek, Western Australia.* Report prepared by Seashore Engineering Pty Ltd and Geological Survey of Western Australia for the Western Australian Department of Transport, Fremantle.

[51] Lyne V, Fuller M, Last P, Butler A, Martin M & Scott R. (2006) *Ecosystem characterisation of Australia's North West Shelf. North West Shelf Joint Environmental Management Study*. Technical Report No. 12. CSIRO.

[52] Patsch K and Griggs G. (2006) *Littoral cells, sand budgets and beaches: Understanding California's shoreline*. Institute of Marine Sciences, University of California, Santa Cruz.

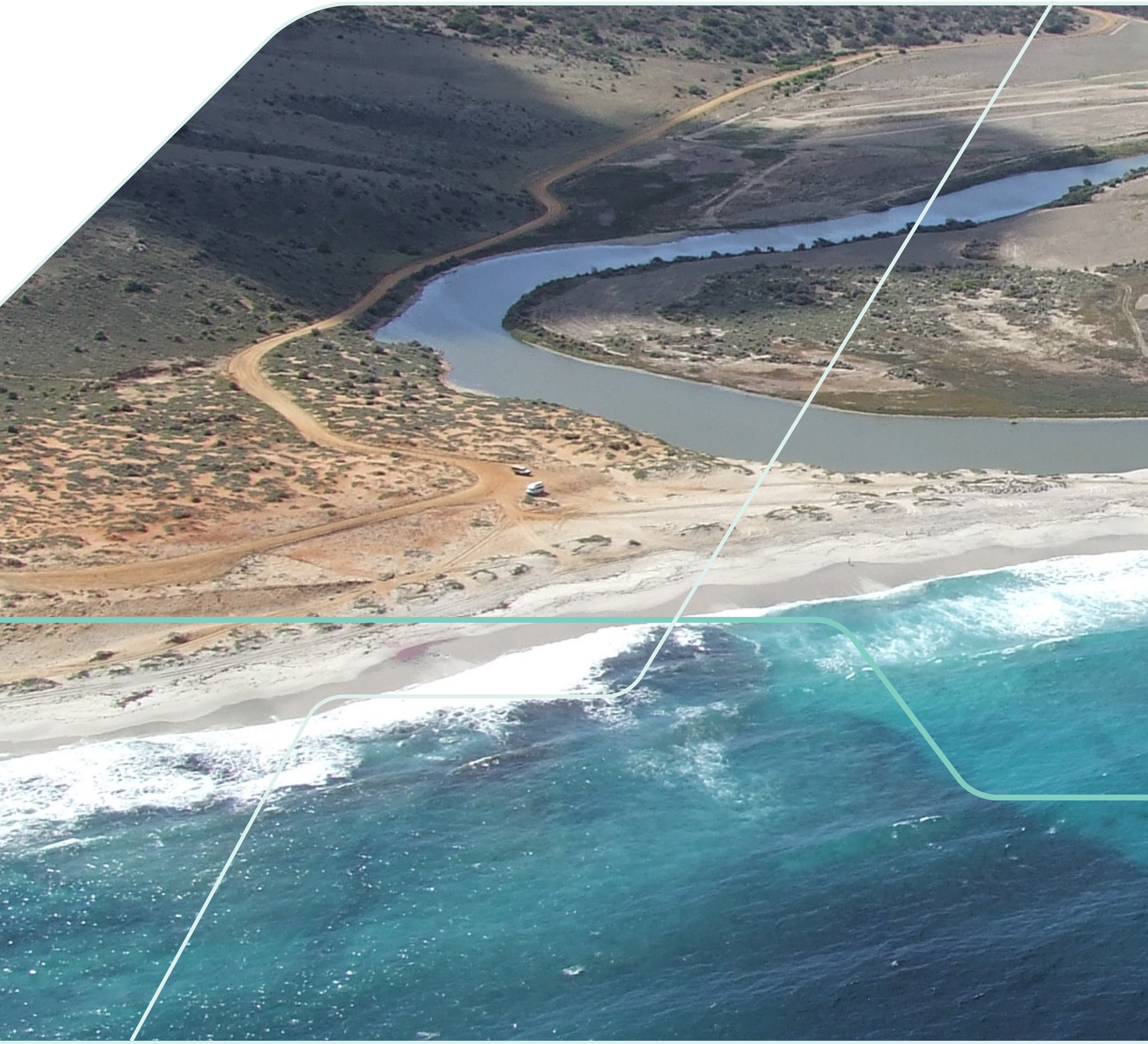
[53] Inman DL and Jenkins SA. (1984) The Nile littoral cell and man's impact on the coastal zone of the southeastern Mediterranean, In: *Proceedings of the 19th Coastal Engineering Conference,* American Society of Civil Engineers, 2: 1600-1617.

[54] Komar PD. (2010) Shoreline Evolution and Management of Hawke's Bay, New Zealand: Tectonics, Coastal Processes and Human Impacts. *Journal of Coastal Research*, 26 (1): 143-156.

[55] Eliot M. (2013) *Application of Geomorphic Frameworks to Sea-Level Rise Impact Assessment*. Prepared for Geoscience Australia by Damara WA Pty Ltd, Report 193-01-Rev0.

[56] Thomson GG, Khalil SM & Tate B. (2005) Sediment budgets as an aid for breakwater design: Raccoon Island case study. *Proceedings of the 14th Biennial Coastal Zone Conference*, New Orleans, Louisiana July 17-21, 2005.

[57] Fotheringham D. (2009) *Shoreline Erosion at Port Office Rock Near Beachport, South Australia*. Coastal Management Branch, Department for Environment and Heritage South Australia, Technical Report 2009/09.



Coastal Sediment Cells for the Northampton Coast

Appendices A to E

Appendix A
Secondary and Tertiary Cells

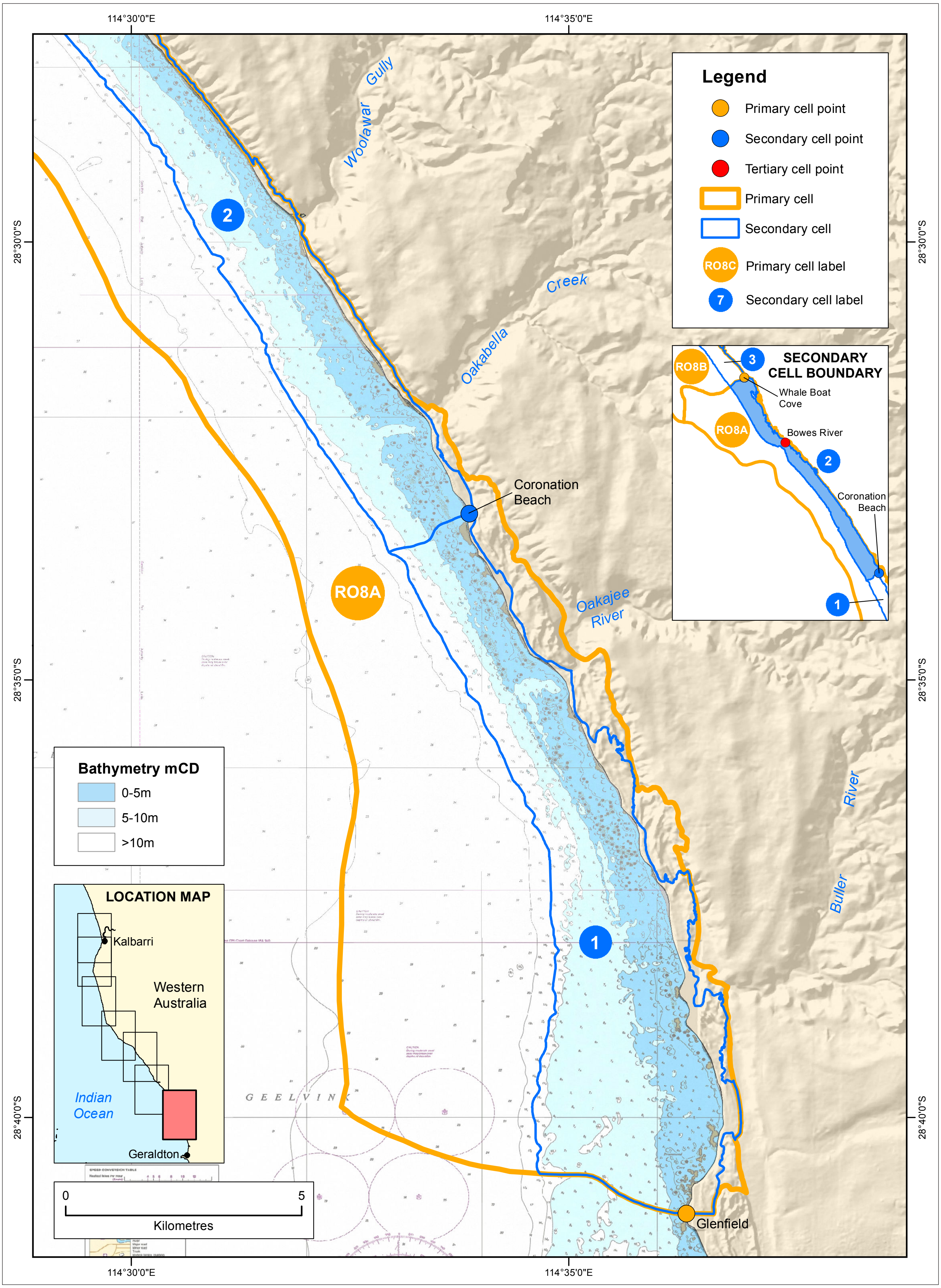


Figure A.1: Secondary cells and tertiary cell points of the Northampton Region

Figure is at scale of 1:100,000 at A4. A primary cell point is also a secondary and tertiary cell point. A secondary cell point is also a tertiary cell point. This map should not be used for navigation purposes. Bathymetry information supplied by Department of Transport. Shaded relief model supplied by Geological Survey of WA, Department of Mines and Petroleum.

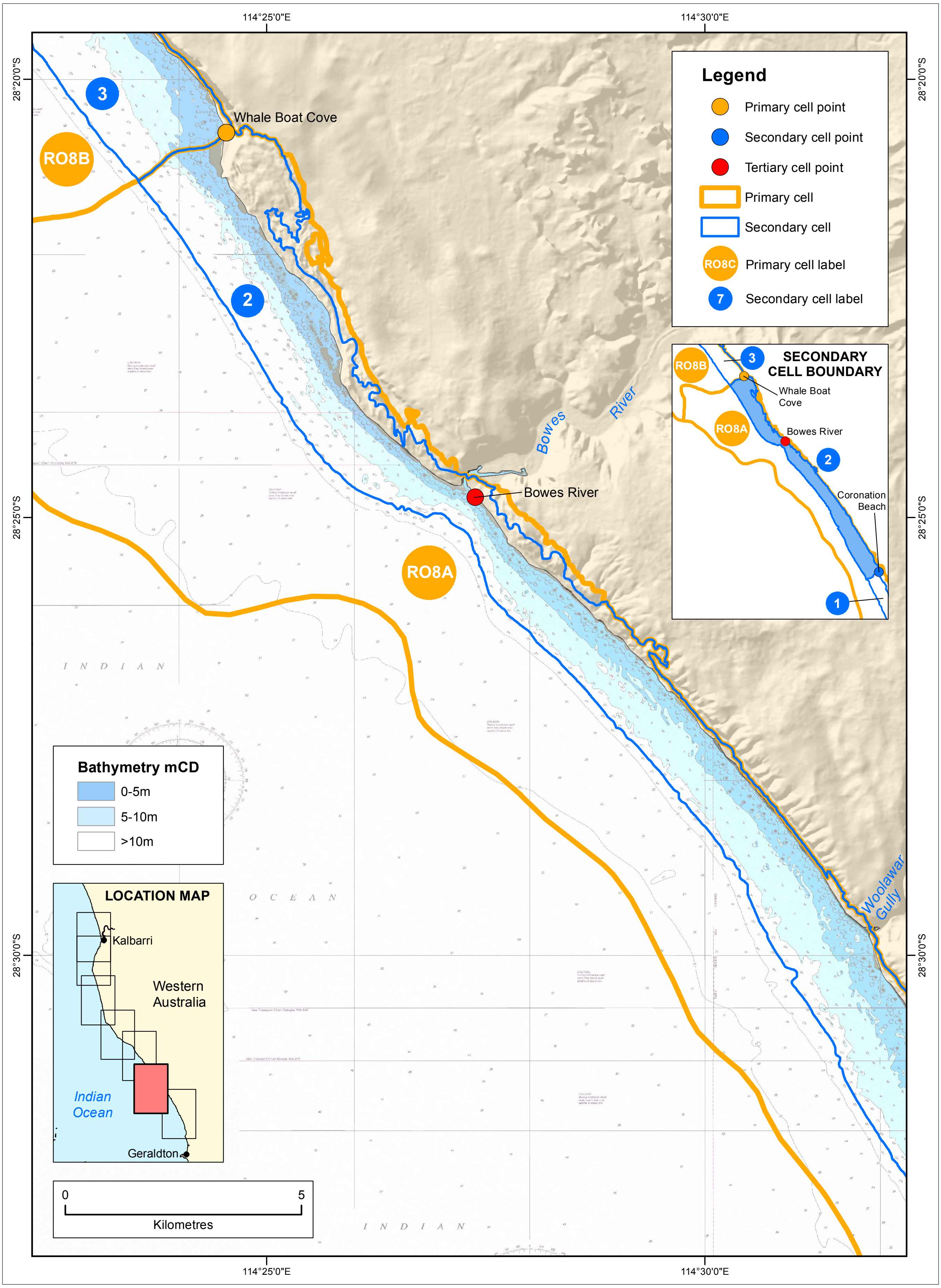


Figure A.2: Secondary cells and tertiary cell points of the Northampton Region

Figure is at scale of 1:100,000 at A4. A primary cell point is also a secondary and tertiary cell point. A secondary cell point is also a tertiary cell point. This map should not be used for navigation purposes. Bathymetry information supplied by Department of Transport. Shaded relief model supplied by Geological Survey of WA, Department of Mines and Petroleum.

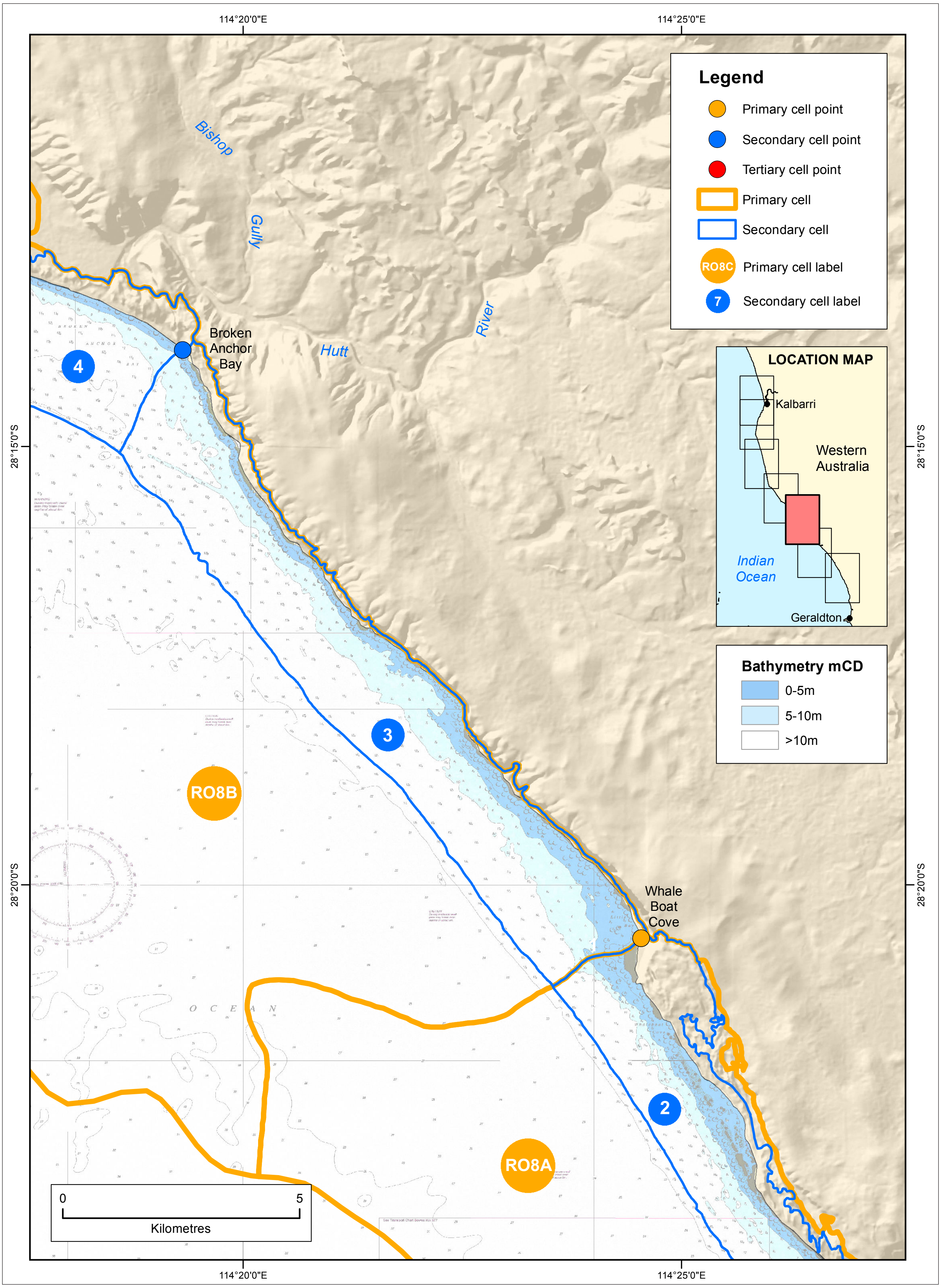


Figure A.3: Secondary cells and tertiary cell points of the Northampton Region

Figure is at scale of 1:100,000 at A4. A primary cell point is also a secondary and tertiary cell point. A secondary cell point is also a tertiary cell point. This map should not be used for navigation purposes. Bathymetry information supplied by Department of Transport. Shaded relief model supplied by Geological Survey of WA, Department of Mines and Petroleum.

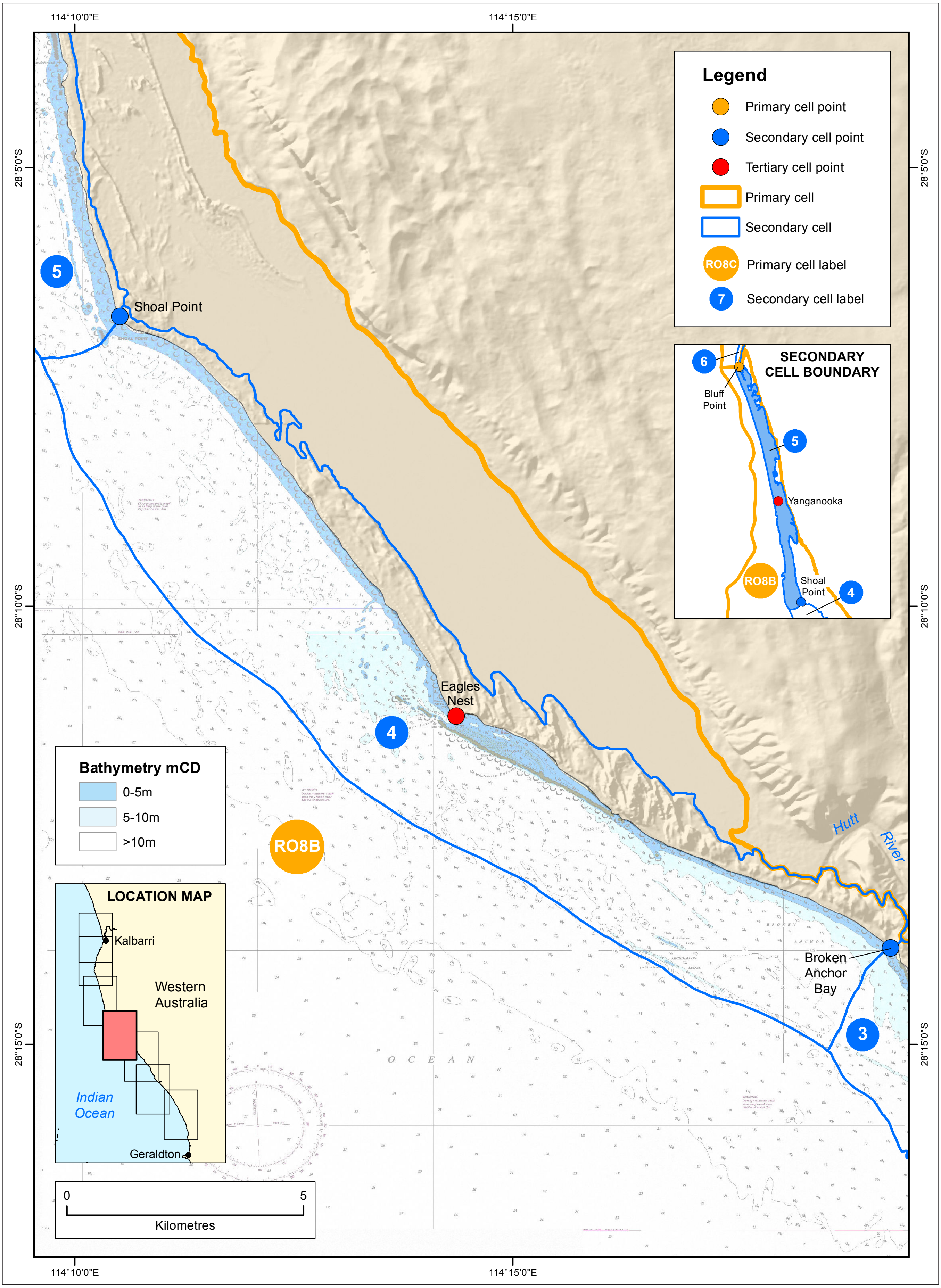


Figure A.4: Secondary cells and tertiary cell points of the Northampton Region

Figure is at scale of 1:100,000 at A4. A primary cell point is also a secondary and tertiary cell point. A secondary cell point is also a tertiary cell point. This map should not be used for navigation purposes. Bathymetry information supplied by Department of Transport. Shaded relief model supplied by Geological Survey of WA, Department of Mines and Petroleum.

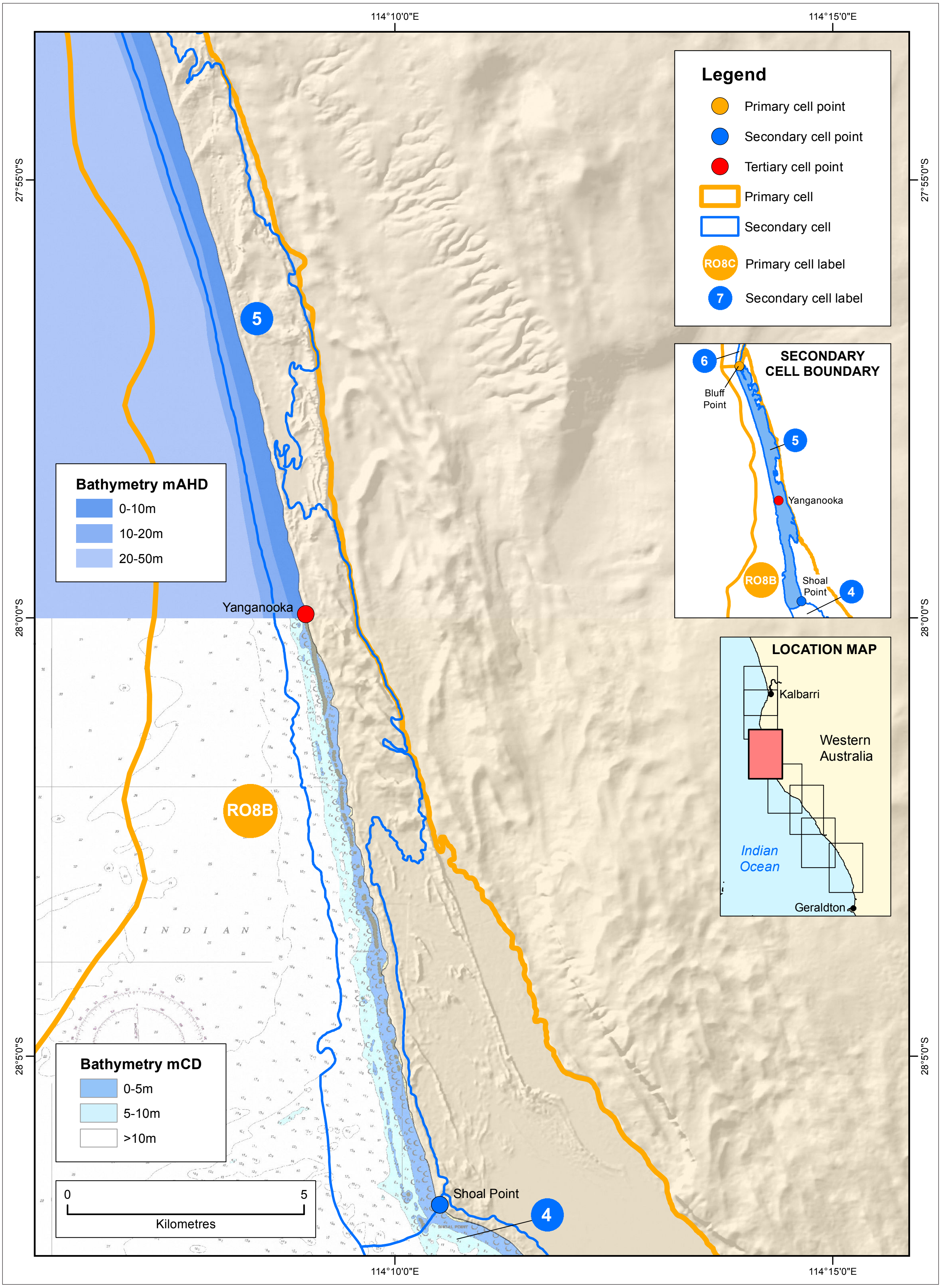


Figure A.5: Secondary cells and tertiary cell points of the Northampton Region

Figure is at scale of 1:100,000 at A4. A primary cell point is also a secondary and tertiary cell point. A secondary cell point is also a tertiary cell point. This map should not be used for navigation purposes. Bathymetry information supplied by Department of Transport. Note the shift in vertical datums between the two bathymetric datasets. Shaded relief model supplied by Geological Survey of WA, Department of Mines and Petroleum.

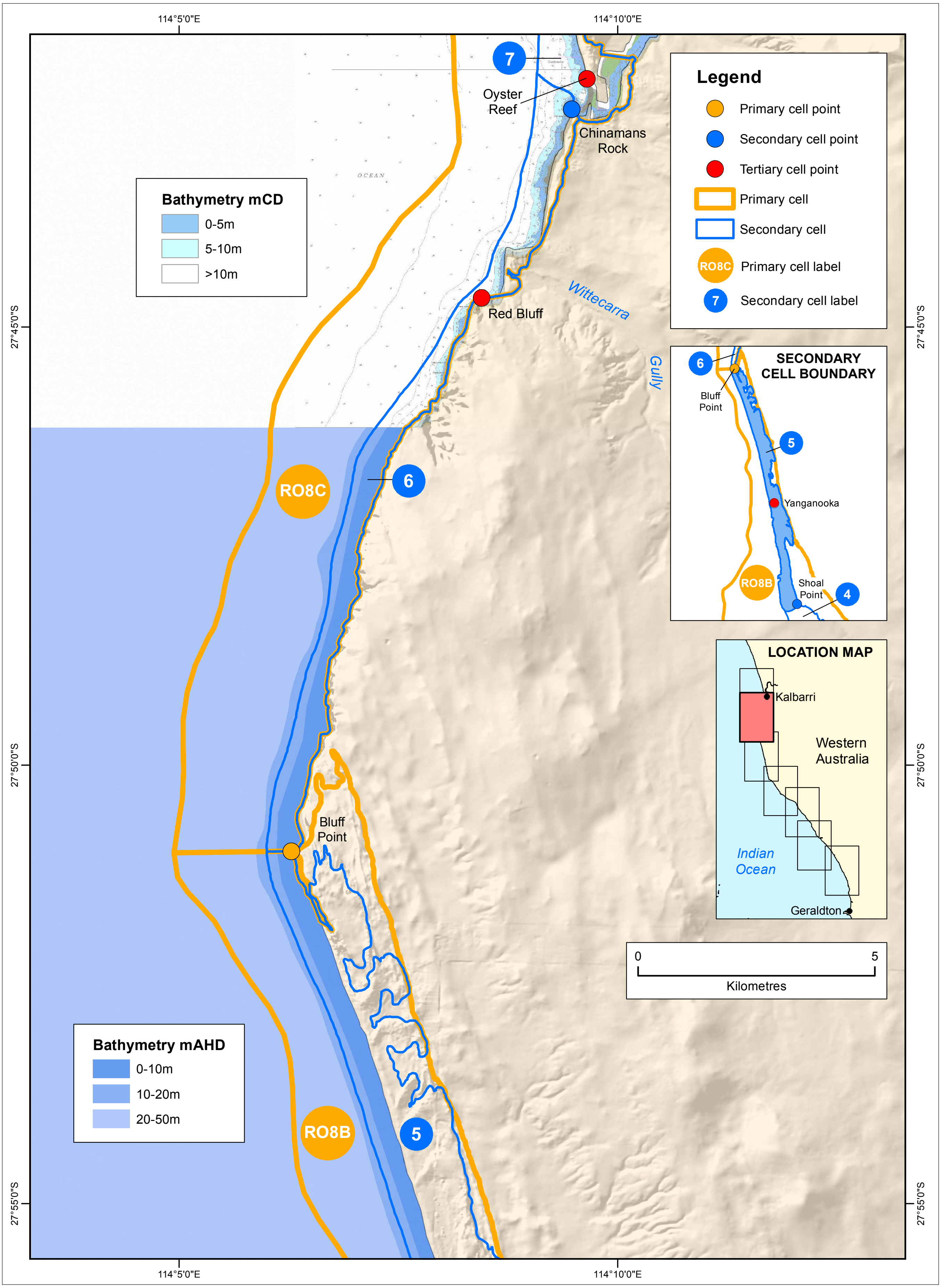


Figure A.6: Secondary cells and tertiary cell points of the Northampton Region

Figure is at scale of 1:100,000 at A4. A primary cell point is also a secondary and tertiary cell point. A secondary cell point is also a tertiary cell point. This map should not be used for navigation purposes. Bathymetry information supplied by Department of Transport. Note the shift in vertical datums between the two bathymetric datasets. Shaded relief model supplied by Geological Survey of WA, Department of Mines and Petroleum.

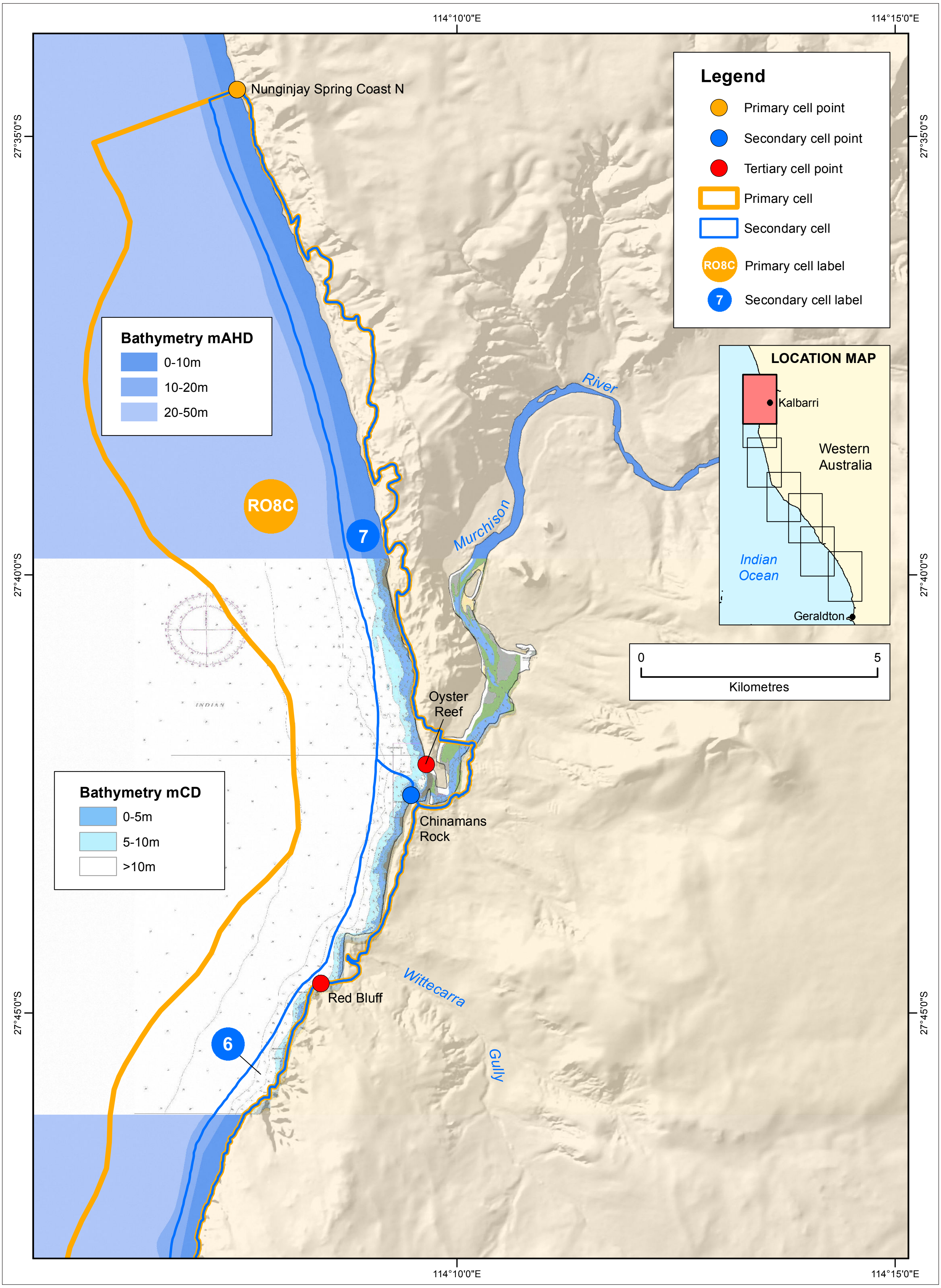


Figure A.7: Secondary cells and tertiary cell points of the Northampton Region

Figure is at scale of 1:100,000 at A4. A primary cell point is also a secondary and tertiary cell point. A secondary cell point is also a tertiary cell point. This map should not be used for navigation purposes. Bathymetry information supplied by Department of Transport. Note the shift in vertical datums between the two bathymetric datasets. Shaded relief model supplied by Geological Survey of WA, Department of Mines and Petroleum.

Appendix B
Data sets

Table B.1: Data Sources used for determining cell boundaries in the Northampton Region

Source	Dataset
Context	• Geological and geomorphological information and photographs contained in the WACoast[1] database.
	• Sediment information, with some examples provided in cited references[2].
Remotely sensed datasets	• *Bathymetry*: The preferred bathymetric data source for mapping sediment cells is nearshore and inshore LiDAR, with none available for this project. Datasets used were the Department of Transport (previously Department of Marine and Harbours) nautical charts and nautical isobaths; and Department of Planning polygons derived from Department of Transport nautical charts. All depths use the vertical datum of Australian Height Datum (AHD). Alternative information could have been used, however it was generally of a larger spatial resolution than needed, with reduced spatial accuracy. These datasets include the Australian Navy hydrographic charts, Geoscience Australia bathymetry, General Bathymetric Chart of the Oceans (GEBCO) bathymetry.
	• *Topography*: Geological Survey of Western Australia shaded relief model derived from the Landgate high-resolution digital elevation model. Alternative sources include Landgate topographic contours and spot heights; and any LiDAR collected in future.
	• *Vertical aerial imagery*: Landgate orthophotography from 1999-2012. Satellite imagery could be an alternative information source, but is generally of reduced spatial resolution and accuracy.
	• *Historic coastal change*: Historic aerial imagery provided context for coastal change, including recent changes identified by the time-series available through NearMap or Google Earth. There were limited Department of Transport shoreline movement plots for this coast, including plan books DPI5, DPI377 and DPI565. *Shoreline*: The shoreline used as the basis for mapping is the Mean High Water Mark (MHWM) to 2006 prepared by Landgate and used by the Department of Environment and Conservation as the basis for the coastal compartment mapping[3]. This dataset is based on a combination of the cadastral and topographic coasts and is updated in areas as required based on government priority. It is unlikely to represent the location of the MHWM in 2006.
	• *Rivers*: 1:1M and 1:250k scale rivers by the Department of Water.
Landform mapping	• Digital dataset of the Holocene dunes and other landforms at 1:20,000 scale to 3km inland of Landgate MHWM to 2006 as part of WACoast datasets[1]. Land system information also in Department of Agriculture and Food Western Australia land resources series map and reports.
	• Heads up digitising (not photogrammetric) of frontal dunes from orthophotographs at various scales.
	• 1:100k geology maps (GSWA) show the Holocene extent for primary cell onshore boundaries.
Naming conventions	• AUSLIG. (1993) Topographic Series, 1:100 000 Map Sheets for Western Australia. Commonwealth Government, Canberra.
	• Geological Survey of Western Australia. (2007) Atlas of 1:250 000 Geological Series Map Images.
	• Department of Transport nautical charts and Australian Navy hydrographic charts.

(Footnotes)

1 Gozzard JR. (2011b) WACoast – *Lancelin to Kalbarri*. Geological Survey of Western Australia digital dataset.

2 James NP, Collins LB, Bone Y and Hallock P. (1999) Subtropical carbonates in a temperate realm: modern sediments on the southwest Australian shelf. *Journal of Sedimentary Research*, 69 (6): 1297-1321.
Richardson L, Mathews E and Heap A. (2005) *Geomorphology and Sedimentology of the South West Planning Area of Australia: Review and synthesis of relevant literature in support of Regional Marine Planning*. Geoscience Australia Report Record 2005/17.
Tecchiato C and Collins LB. (2012) *Geraldton Embayments Coastal Sediment Budget Study*. Coastal Vulnerability and Risk Assessment Program - Project 2 - Stage 2: Sediment Mapping for Identification of Sediment Sources, Transport Pathways and Sinks for Components of the Batavia Coast, With Special Consideration of the Inshore Waters and Coast between the Greenough River and Buller River. First Year Final Report for the WA Department of Transport, Curtin University.

3 Eliot I, Nutt C, Gozzard B, Higgins M, Buckley E and Bowyer J. (2011) *Coastal Compartments of Western Australia: A Physical Framework for Marine and Coastal Planning*. Report 80-02. Damara WA Pty Ltd. Report to the Departments of Environment and Conservation, Planning and Transport. Environmental Protection Authority

Appendix C
Regional variation in criteria

Table C.1: Comparison of cell criteria for the Northampton, Vlamingh and Pilbara Regions

The same criteria apply for Mid-West and Northampton Regions

	Vlamingh Region compared to Northampton Region	Pilbara Region compared to Northampton Region
Beachface point	Same criteria used.	Cells in the Pilbara Region are frequently defined to include areas with likely sediment supply by individual river systems, incorporating whole deltas within broader cells. Rivers in the Northampton discharge smaller volumes of sediment, with cells more frequently defined based on changes in barrier land systems.
Offshore boundaries and marine section of the alongshore boundary	Continuous ridgelines of elongate reefs, large offshore islands within the primary cell offshore boundaries, large sediment banks and basins are prominent features in the Vlamingh Region. The offshore boundaries and the marine section of alongshore boundaries in the Vlamingh Region take into account the presence of these features as well as sheltering of wave energy by the larger islands. *Offshore boundaries* are simplified for the Northampton Region to one criterion per cell level corresponding to a depth of -30m AHD for primary cells, -15m AHD for secondary cells and -5m AHD for tertiary cells.	*Offshore boundaries* of cells in the Pilbara Region are related to tidal reworking of sediment and waves, whereas waves are the primary process for Northampton Region. One consequence of this difference is offshore boundaries generally occur at shallower depths for the Pilbara Region in areas where tidal reworking and extreme waves provide the dominant environmental forcing.
	Marine sections of the alongshore boundaries were mapped as orthogonal to the coast in the Northampton Region where limited bathymetric information was available. Mapping the toe of Holocene sediment banks in the Vlamingh Region is not included for the Northampton Region.	*Marine sections* of the alongshore boundaries cannot be easily resolved due to extensive tidal reworking of sediments from multiple rivers across the broad nearshore area in the Pilbara Region, combined with limited bathymetric information. Marine sections were often not orthogonal to the coast, but were skewed in the direction of the dominant current or wave forcing following high points in the bathymetry or ridge lines of islands.
Onshore boundaries and terrestrial section of the alongshore boundary	The Vlamingh Region is the most densely populated area of the Western Australian coast and the coast has been extensively modified. Hence more criteria for onshore boundaries and the terrestrial section of alongshore boundaries are related to engineering works.	Rivers, creeks and outwash plains are common features of the Pilbara Region, with fluvial breakouts and interactions with marine processes at multiple scales. Due to this interaction of estuarine and alluvial land systems, onshore boundaries at a primary cell scale cannot be represented by the landward extent of Holocene and alluvial land systems because the onshore boundaries would be more than 70km landward of mean sea level.
	Natural *onshore boundaries* of cells in the Vlamingh Region are mainly the landward extent of Holocene land systems. Two exceptions are included for the Northampton Region to ensure exclusion of dunes without a connection to the coast and inclusion of dunes abutting rocky topography to landward, such as colluvial foot slopes and cliffs.	*Onshore boundaries* for primary cells in the Pilbara Region are linked to elevation contours for the extensive systems of outwash plains, where Holocene land systems are used in the Vlamingh Region. Onshore boundaries for secondary and tertiary cell scales relate to the landward extent of supratidal landforms and inter-tidal landforms respectively, excluding the presence of dunes, cliffs and engineered coasts.
	Terrestrial sections of the alongshore boundaries also include discontinuities in large mobile dunes or narrow dune barriers for the Northampton Region.	*Terrestrial sections* of the alongshore boundaries cannot easily be resolved in the Pilbara Region due to extensive marine and fluvial interactions at multiple scales over the low-lying topography. Most frequently the boundary was mapped to ridgelines and connecting high points that separate basins.

Appendix D

Comparison to previously defined cells in the Northampton Region

Table D.1: Northampton Region cells compared to cells in the Landform Vulnerability Report

Comparison between 18 of the cells identified in a previous landform vulnerability study for the Shires of Coorow to Northampton[1] to the revised hierarchy of boundaries in this report. The cell hierarchy presented in this report should be used in coastal studies rather than the cell boundaries used in the 2012 study. Further discussion is included in the Results section of the report.

Cell Hierarchy			Cells from Coorow to Northampton Report[1]	
Primary	Secondary	Tertiary	No. Cells	Old cells per new tertiary cell
R08C. Bluff Point to Nunginjay Spring Coast N	7. Chinaman's Rock to Nunginjay Spring Coast N	b. Oyster Reef to Nunginjay Spring Coast N	2 cells across 3 new ones	Boundaries shifted adjacent to Murchison River. Cells were 63. Red Bluff to Murchison River, 64 Murchison River to Nuningjay Spring Coast North
		a. Chinaman's Rock to Oyster Reef		
	6. Bluff Point to Chinaman's Rock	b. Red Bluff to Chinaman's Rock		
		a. Bluff Point to Red Bluff	2	61. Bluff Point to Pot Alley, 62. Pot Alley to Red Bluff
R08B. Whale Boat Cove to Bluff Point	5. Shoal Point to Bluff Point	b. Yanganooka to Bluff Point	3	58. Yanganooka to Wagoe Well South, 59. Wagoe Well South to Wagoe Well, 60. Wagoe Well to Bluff Point
		a. Shoal Point to Yanganooka	2	56. Shoal Point to Sandlewood Bay, 57. Sandlewood Bay to Yanganooka
	4. Broken Anchor Bay to Shoal Point	b. Eagles Nest to Shoal Point	1	55. Eagles Nest to Shoal Point
		a. Broken Anchor Bay to Eagles Nest	1	54. Broken Anchor Bay to Eagles Nest
	3. Whale Boat Cove to Broken Anchor Bay	a. Whale Boat Cove to Broken Anchor Bay	3	51. Whale Boat Cove to White Cliffs, 52. White Cliffs to Menai Cliffs, 53. Menai Cliffs to Broken Anchor Bay
R08A. Glenfield to Whale Boat Cove	2. Coronation Beach to Whale Boat Cove	b. Bowes River to Whale Boat Cove	1	50. Bowes river to Whale Boat Cove
		a. Coronation Beach to Bowes River	1	49. Coronoation Beach to Bowes River
	1. Glenfield to Coronation Beach	a. Glenfield to Coronation Beach	2	47. Glenfield to Buller, 48. Buller to Coronation Beach

(Footnotes)

1 Eliot I, Gozzard B, Eliot M, Stul T and McCormack G. (2012) *The Mid-West Coast, Western Australia: Shires of Coorow to Northampton. Geology, Geomorphology & Vulnerability*. Damara WA Pty Ltd and Geological Survey of Western Australia, Innaloo, Western Australia.

Appendix E
Beachface points and cell boundary information

Table E.1: Rationale for selection of primary cell beachface points in the Northampton Region
Co-ordinates in Latitude and Longitude rounded to 3 decimal places

Beachface Point Name	Lat.	Long.	Other Boundaries	Alongshore Boundary Character	Beachface Point	Associated Primary Cells
Nunginjay Spring Coast N	-27.574	114.125	2°, 3°	Point, Fixed, Open	Rock structures restricting sediment transport at a decadal scale (southern extent of Zuytdorp cliffs)	R08C, R09A
Bluff Point	-27.850	114.105	2°, 3°	Point, Fixed, Open	Rock structures restricting sediment transport at a decadal scale; Geomorphic feature (northern extent of dune systems); Adjacent cells have a different shoreline aspect restricting sediment transport at a decadal scale (WSW to WNW)	R08B, R08C
Whale Boat Cove	-28.343	114.409	2°, 3°	Zone, Ambulatory, Open	Rock structures restricting sediment transport at a decadal scale (rock outcrop); Geomorphic feature (northern extent of dune systems)	R08A, R08B
Glenfield	-28.685	114.606	2°, 3°	Point, Fixed, Open	Rock structures restricting sediment transport at a decadal scale (rock outcrop); Geomorphic feature (northern limit of Greenough-Chapman paleo-delta)	R07F, R08A

Table E.2: Rationale for selection of primary cell onshore, offshore and alongshore boundaries in the Northampton Region

Primary Cell	Offshore Boundary	Onshore Boundary	"From" Alongshore Boundary			"To" Alongshore Boundary		
			Point	Marine Section	Terrestrial Section	Point	Marine Section	Terrestrial Section
R08C. Bluff Point to Nunginjay Spring Coast N	-30m AHD isobath farthest from shore	Landward extent of Holocene land system, except for a transgressive dune system overlying older and higher land surfaces; Late Holocene dunes abutting rocky topography to landward; Landgate MHWM on cliffed coast without dunes	Bluff Point	Boundary is drawn orthogonal to coast because of a lack of bathymetric information	No terrestrial component (cliff)	Nunginjay Spring Coast N	Boundary is drawn orthogonal to coast because of a lack of bathymetric information	No terrestrial component (cliff)
R08B. Whale Boat Cove to Bluff Point	-30m AHD isobath farthest from shore	Landward extent of Holocene land system, except for a transgressive dune system overlying older and higher land surfaces; Landgate MHWM to 2006 on cliffed coast without dunes	Whale Boat Cove	Fixed by a submerged ridge with rock outcrops or islands, then, a marine extension from the edge of the outermost rock outcrop to the offshore boundary; Deepest point of depression or contour reentrant	An extension of marine section and beachface point directly to the onshore boundary of the cell if there is no change in land system between adjacent cells	Bluff Point	Boundary is drawn orthogonal to coast because of a lack of bathymetric information	No terrestrial component (cliff)
R08A. Glenfield to Whale Boat Cove	-30m AHD isobath farthest from shore	Landward extent of Holocene land system, except for a transgressive dune system overlying older and higher land surfaces; Late Holocene dunes abutting rocky topography to landward	Glenfield	Deepest point of depression or contour reentrant	An extension of marine section and beachface point directly to the onshore boundary if there is no change in land system between adjacent cells; Boundary of, or discontinuity in, a Holocene land system	Whale Boat Cove	Fixed by a submerged ridge with rock outcrops or islands, then, a marine extension from the edge of the outermost rock outcrop to the offshore boundary; Deepest point of depression or contour reentrant	An extension of marine section and beachface point directly to the onshore boundary of the cell if there is no change in land system between adjacent cells

Table E.3: Rationale for selection of secondary cell beachface points in the Northampton Region

Co-ordinates in Latitude and Longitude rounded to 3 decimal places

Beachface Point Name	Lat.	Long.	Other Boundaries	Alongshore Boundary Character	Beachface Point	Associated Secondary Cells
Nunginjay Spring Coast N	-27.574	114.125	1°, 3°	Point, Fixed, Open	Rock structures restricting sediment transport at an annual scale (southern extent of Zuytdorp cliffs)	R08C7, R09A1
Chinaman's Rock	-27.709	114.158	3°	Zone, Fixed, Open	Rock structures restricting sediment transport at an annual scale (Chinaman's Rock); Geomorphic feature (southern bank of the Murchison River mouth); Adjacent cells have a different shoreline aspect restricting sediment transport at an annual scale (WNW to W)	R08C6, R08C7
Bluff Point	-27.850	114.105	1°, 3°	Point, Fixed, Open	Rock structures restricting sediment transport at an annual scale; Geomorphic feature (northern extent of dune systems); Adjacent cells have a different shoreline aspect restricting sediment transport at an annual scale (WSW to WNW)	R08B5, R08C6
Shoal Point	-28.112	114.175	3°	Point, Fixed, Open	Rock structures restricting sediment transport at an annual scale (Shoal Point reef); Geomorphic feature (foreland); Adjacent cells have a different shoreline aspect restricting sediment transport at an annual scale (SW to WSW)	R08B4, R08B5
Broken Anchor Bay	-28.232	114.322	3°	Point, Fixed, Open	Rock structures restricting sediment transport at an annual scale (northern extent of rock outcrops); Geomorphic feature (southern limit of the Hutt-Lagoon barrier and lagoon complex); Adjacent cells have a different shoreline aspect restricting sediment transport at an annual scale (WSW to SSW)	R08B3, R08B4
Whale Boat Cove	-28.343	114.409	1°, 3°	Zone, Ambulatory, Open	Rock structures restricting sediment transport at an annual scale (rock outcrop); Geomorphic feature (northern extent of dune systems)	R08A2, R08B3
Coronation Beach	-28.552	114.564	3°	Point, Fixed, Open	Rock structures restricting sediment transport at an annual scale (southern limit of cliffs at small rocky headland); Geomorphic feature (northern extent of dunes and southern extent of cliffs)	R08A1, R08A2
Glenfield	-28.685	114.606	1°, 3°	Point, Fixed, Open	Rock structures restricting sediment transport at an annual scale (rock outcrop); Geomorphic feature (northern limit of Greenough-Chapman paleo-delta)	R07F15, R08A1

Table E.4: Rationale for selection of secondary cell onshore, offshore and alongshore boundaries in the Northampton Region

Secondary Cell	Offshore Boundary	Onshore Boundary	"From" Alongshore Boundary			"To" Alongshore Boundary		
			Point	Marine Section	Terrestrial Section	Point	Marine Section	Terrestrial Section
R08C7. Chinaman's Rock to Nunginjay Spring Coast N	Continuous -15m AHD isobath farthest from shore within primary cell boundaries	Landgate MHWM to 2006 on cliffed coast without dunes	Chinaman's Rock	Fixed by submerged rock outcrops or islands (rock control and remnant southern bank of Murchison River)	Boundary of, or discontinuity in, a foredune plain, large mobile dune, narrow dune barrier, small parabolic dune or frontal dune (Chinaman's rock and discontinuity in foredune plain)	Nunginjay Spring Coast N	A marine extension of the beachface point to the offshore boundary	No terrestrial component (cliff)
R08C6. Bluff Point to Chinaman's Rock	Continuous -15m AHD isobath farthest from shore within primary cell boundaries	Landgate MHWM to 2006 on cliffed coast without dunes	Bluff Point	A marine extension of the beachface point to the offshore boundary	No terrestrial component (cliff)	Chinaman's Rock	Fixed by submerged rock outcrops or islands (rock control and remnant southern bank of Murchison River)	Boundary of, or discontinuity in, a foredune plain, large mobile dune, narrow dune barrier, small parabolic dune or frontal dune (Chinaman's rock and discontinuity in foredune plain)
R08B5. Shoal Point to Bluff Point	Continuous -15m AHD isobath farthest from shore within primary cell boundaries	Landward extent of small parabolic dunes; Landward extent of frontal dunes	Shoal Point	Fixed by submerged rock outcrops or islands	Boundary of, or discontinuity in, a foredune plain, large mobile dune, narrow dune barrier, small parabolic dune or frontal dune (small parabolic dunes change in orientation)	Bluff Point	A marine extension of the beachface point to the offshore boundary	No terrestrial component (cliff)
R08B4. Broken Anchor Bay to Shoal Point	Continuous -15m AHD isobath farthest from shore within primary cell boundaries	Landward extent of small parabolic dunes	Broken Anchor Bay	A marine extension of the beachface point to the offshore boundary (Ensures remnant lagoon is entirely in cell to the north. May be old lagoon entrance at this location)	Boundary of, or discontinuity in, a foredune plain, large mobile dune, narrow dune barrier, small parabolic dune or frontal dune	Shoal Point	Fixed by submerged rock outcrops or islands	Boundary of, or discontinuity in, a foredune plain, large mobile dune, narrow dune barrier, small parabolic dune or frontal dune (small parabolic dunes change in orientation)

Secondary Cell	Offshore Boundary	Onshore Boundary	"From" Alongshore Boundary			"To" Alongshore Boundary		
			Point	Marine Section	Terrestrial Section	Point	Marine Section	Terrestrial Section
R08B3. Whale Boat Cove to Broken Anchor Bay	Continuous -15m AHD isobath farthest from shore within primary cell boundaries	Landward extent of narrow dune barrier	Whale Boat Cove	Fixed by submerged rock outcrops or islands	An extension of marine section and beachface point directly to the onshore boundary if there is no change in foredune plains, parabolic dunes or frontal dunes between adjacent cells	Broken Anchor Bay	A marine extension of the beachface point to the offshore boundary (Ensures remnant lagoon is entirely in cell to the north. May be old lagoon entrance at this location)	Boundary of, or discontinuity in, a foredune plain, large mobile dune, narrow dune barrier, small parabolic dune or frontal dune
R08A2. Coronation Beach to Whale Boat Cove	Continuous -15m AHD isobath farthest from shore within primary cell boundaries	Landgate MHWM to 2006 on cliffed coast without dunes	Coronation Beach	Fixed by submerged rock outcrops or islands	An extension of marine section and beachface point directly to the onshore boundary if there is no change in foredune plains, parabolic dunes or frontal dunes between adjacent cells	Whale Boat Cove	Fixed by submerged rock outcrops or islands	An extension of marine section and beachface point directly to the onshore boundary if there is no change in foredune plains, parabolic dunes or frontal dunes between adjacent cells
R08A1. Glenfield to Coronation Beach	Continuous -15m AHD isobath farthest from shore within primary cell boundaries	Landward extent of small parabolic dunes	Glenfield	Deepest point of depression or contour reentrant	An extension of marine section and beachface point directly to the onshore boundary if there is no change in foredune plains, parabolic dunes or frontal dunes between adjacent cells	Coronation Beach	Fixed by submerged rock outcrops or islands	An extension of marine section and beachface point directly to the onshore boundary if there is no change in foredune plains, parabolic dunes or frontal dunes between adjacent cells

Table E.5: Rationale for selection of tertiary cell beachface points in the Northampton Region

Co-ordinates in Latitude and Longitude rounded to 3 decimal places
No information was reported for offshore boundaries, onshore boundaries and the marine and terrestrial sections of the alongshore boundaries

Beachface Point Name	Lat.	Long.	Other Boundaries	Alongshore Boundary Character	Beachface Point	Associated Tertiary Cells
Nunginjay Spring Coast N	-27.574	114.125	1°, 2°	Point, Fixed, Open	Rock structures restricting sediment transport at a seasonal scale (southern extent of Zuytdorp cliffs)	R08C7b, R09A1a
Oyster Reef	-27.703	114.161	-	Zone, Ambulatory, Open	Rock structures restricting sediment transport at a seasonal scale (Oyster Reef); Geomorphic feature (northern bank of the Murchison River mouth)	R08C7a, R08C7b
Chinaman's Rock	-27.709	114.158	2°	Zone, Fixed, Open	Rock structures restricting sediment transport at a seasonal scale (Chinaman's Rock); Geomorphic feature (southern bank of the Murchison River mouth); Adjacent cells have a different shoreline aspect restricting sediment transport at a seasonal scale (WNW to W)	R08C6b, R08C7a
Red Bluff	-27.744	114.141	-	Point, Fixed, Open	Rock structures restricting sediment transport at a seasonal scale (rocky headland)	R08C6a, R08C6b
Bluff Point	-27.850	114.105	1°, 2°	Point, Fixed, Open	Rock structures restricting sediment transport at a seasonal scale; Geomorphic feature (northern extent of dune systems); Adjacent cells have a different shoreline aspect restricting sediment transport at a seasonal scale (WSW to WNW)	R08B5c, R08C6a
Yanganooka	-27.999	114.150	-	Point, Fixed, Open	Rock structures restricting sediment transport at a seasonal scale (northern limit of linear platform reef); Geomorphic feature (northern limit of lagoon)	R08B5a, R08B5c
Shoal Point	-28.112	114.175	2°	Point, Fixed, Open	Rock structures restricting sediment transport at a seasonal scale (Shoal Point reef); Geomorphic feature (foreland); Adjacent cells have a different shoreline aspect restricting sediment transport at a seasonal scale (SW to WSW)	R08B4b, R08B5a
Eagles Nest	-28.188	114.239	-	Zone, Ambulatory, Open	Geomorphic feature (reef-controlled salient in the lee of Leander Passage and break in reef at Gold Digger Passage, northern entrance to Hutt lagoon)	R08B4a, R08B4b

Beachface Point Name	Lat.	Long.	Other Boundaries	Alongshore Boundary Character	Beachface Point	Associated Tertiary Cells
Broken Anchor Bay	-28.232	114.322	2°	Point, Fixed, Open	Rock structures restricting sediment transport at a seasonal scale (northern extent of rock outcrops); Geomorphic feature (southern limit of the Hutt-Lagoon barrier and lagoon complex); Adjacent cells have a different shoreline aspect restricting sediment transport at a seasonal scale (WSW to SSW)	R08B3a, R08B4a
Whale Boat Cove	-28.343	114.409	1°, 2°	Zone, Ambulatory, Open	Rock structures restricting sediment transport at a seasonal scale (rock outcrop); Geomorphic feature (northern extent of dune systems)	R08A2b, R08B3a
Bowes River	-28.413	114.456	-	Zone, Fixed, Open	Rock structures restricting sediment transport at a seasonal scale (rock outcrop); Geomorphic feature (southern bank on the mouth of the Bowes River)	R08A2a, R08A2b
Coronation Beach	-28.552	114.564	2°	Point, Fixed, Open	Rock structures restricting sediment transport at a seasonal scale (southern limit of cliffs at small rocky headland); Geomorphic feature (northern extent of dunes and southern extent of cliffs)	R08A1a, R08A2a
Glenfield	-28.685	114.606	1°, 2°	Point, Fixed, Open	Rock structures restricting sediment transport at a seasonal scale (rock outcrop); Geomorphic feature (northern limit of Greenough-Chapman paleo-delta)	R07F15c, R08A1a

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