6.4.1. Geomorphic Processes

Port Hedland geomorphology is characteristic of its high tidal regime, with significant influence of rocky features, both alongshore and offshore. Combined with episodic fluvial and marine influences of tropical cyclones, the resulting coastal morphology is a complex mixture of depositional and erosional features. The area differs from 'typical' Pilbara behaviour (as described by Semeniuk 1996) by having limited fluvial sediment input, although there is some sediment supply through coastal transport. This constraint is a key reason for the formation of Port Hedland Harbour as a naturally large and deep basin.

Port Hedland regional coastal morphology is described by Lyne *et al.* (2006) as a limestone barrier system, which is expressed by the presence of low coastal cliffs along much of Finucane and Downes Islands, with partial exposure along the Port Hedland township shore. These limestone ridges are amongst a series of platforms and discontinuous ridges lying sub-parallel between Cape Thouin and Tabba Tabba Creek, declining in level to the east. The present-day coastal position is staggered relative to these ridges, such that the coast coincides with increasingly landward ridges from west to east. This structure determines that the majority of the shore tends to be stable, with hotspot dynamic areas located where the coast spans between two ridges (Figure 6-46).

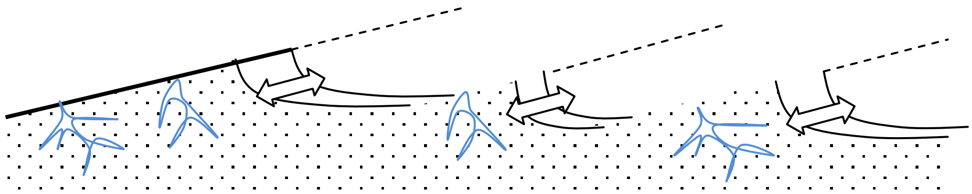

Figure 6-46: Schematic Illustration of Regional Port Hedland Coastal Dynamics

Breaches along the limestone ridges provide physical constraints for fluvial outwash paths, which switch roles during non-flow conditions to act as tidal creeks networks. In the vicinity of Port Hedland, these networks are relatively small, implying localised catchments and a comparatively high retention of sediment on the floodplain, behind the limestone barriers, reworked by tidal channel morphodynamics.

The relatively low availability of sediment in the vicinity of Port Hedland is suggested by the comparatively coarse sandy seabed material present nearshore (Mulhearn & Cerneaz 1994, GEMS 2010a). Sediment sampling and seabed LIDAR analysis has demonstrated that the sediment size and presence of seabed features, including bars and underwater dunes, are strongly linked to the configuration of underlying or adjacent rock features (Figure 6-47). Interpretation of these seabed features has further enhanced knowledge of coastal processes in the Port Hedland area, with the corresponding focal zones of sediment transport matching hotspot areas of sedimentation within Port Hedland navigation channel. The general pattern of transport is a net eastward movement of sediment, with a small onshore drift explaining the accumulation of a sand 'ribbon' along the north side of Finucane Island, which feeds locally higher sedimentation in the mouth of Port Hedland Harbour.

Sedimentation rates measured in Port Hedland shipping channel are highly variable on an inter-annual basis. A general pattern of declining sedimentation over two decades was previously attributed to winnowing (gradual loss of fine material) of the seabed sediments based upon two seabed surveys (Mulhearn & Cerneaz 1994; Harris & O'Brien 1998). However, this interpretation is not wholly consistent with dredging records, which also show that sedimentation rates tend to increase dramatically for 3-5 years following tropical cyclone impact (GEMS 2010a). This is arguably caused by stirring up of sub-surface seabed sediments, and movement of sediment out of 'stable' ambient positions due to the potential for unusual wave and current conditions during the cyclone.

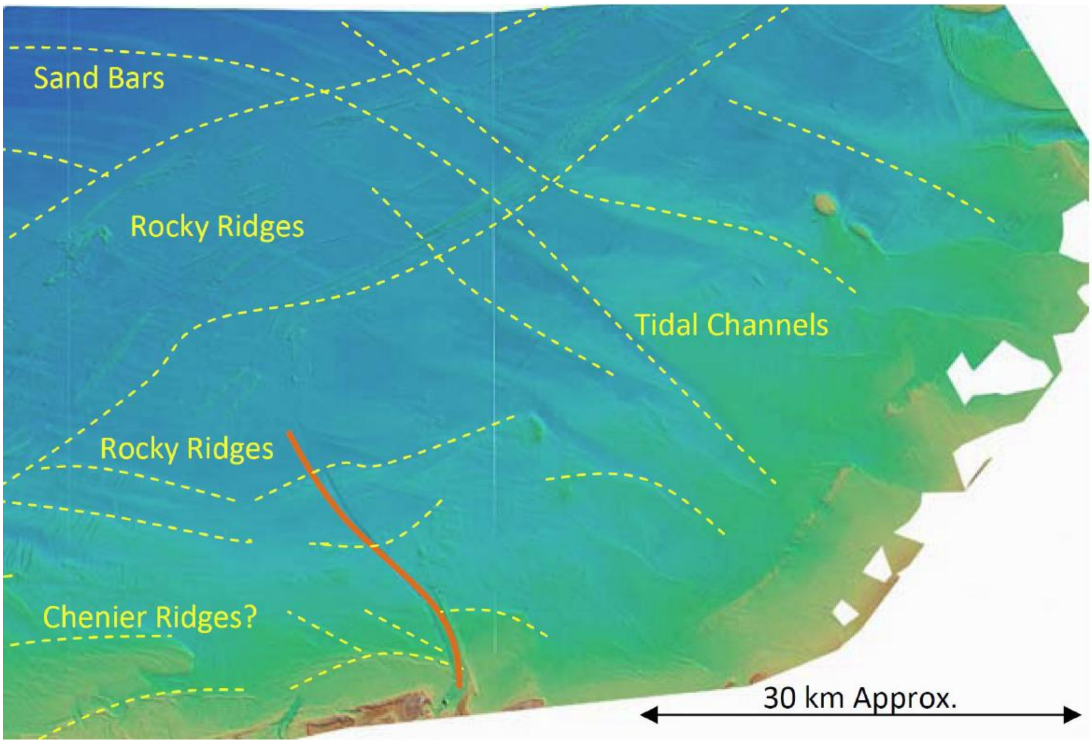

Figure 6-47: Regional Bathmetry
Source: GEMS (2010a)

The tendency for sediment drift to vary offshore is illustrated by the seabed features and the relative behaviour of previously dumped dredged spoil. Modelling has indicated that this is consistent with tidal current zonation (GEMS 2010b) including onshore movement near to shore, alongshore transport at the outer limit of the Spoil Bank and relative seabed stability at the more recent spoil disposal area, further offshore. The significance of the tidal flows is also suggested by the presence of enormous sand bar structures which extend more than 60km from the de Grey delta, crossing the offshore rocky ridges.

The natural seabed structure has been highly modified in the vicinity of Port Hedland shipping channel through dredging and spoil disposal. Sidecasting of sediment adjacent to the channel formed an extensive ridge (Figure 6-48), which has subsequently evolved gradually in response to the tidal current transport. Offshore, current flow over the ridge caused alongshore transport, spreading material eastward, which now exists are a large sand splay north of Port Hedland townsite. Closer to shore, the material was placed as an island, with the onshore sediment drift causing it to evolve landward, connecting to the shore several years after initial placement. The Spoil Bank has continued to evolve, with the alongshore and onshore drift causing the ridge to progressively fold back east and landwards. This sequence is displayed dramatically through a series of historical aerial imagery (Cardno 2011).

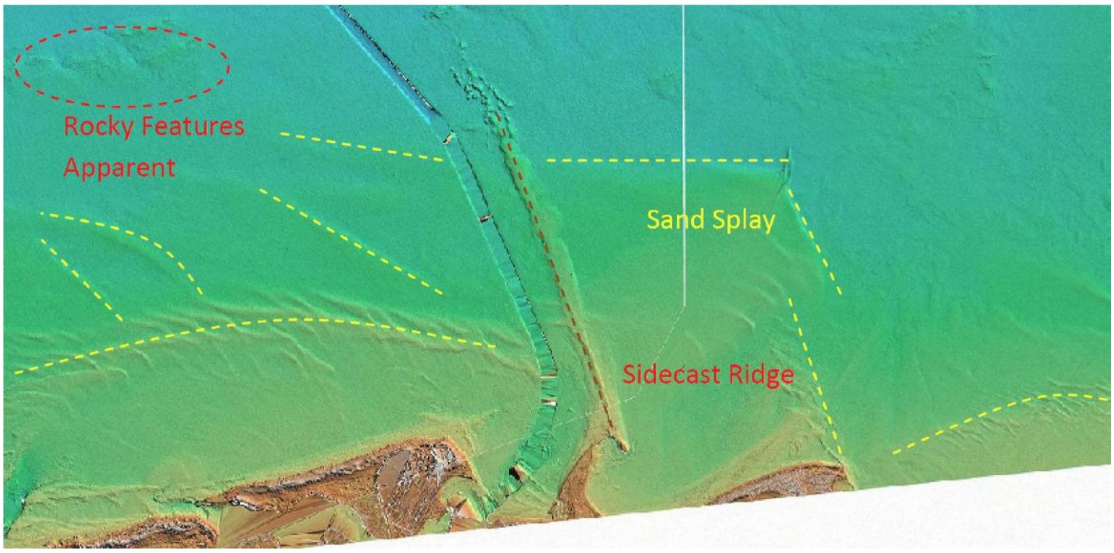

Figure 6-48: Intermediate Scale Seabed Features adjacent to Cells 19-21
Source: GEMS (2010a)

The effect of the Spoil Bank was locally significant upon the Port Hedland coast to Cooke Point, due to modification of currents and waves. This has previously been interpreted as a local reversal in the net direction of prevailing sediment transport (Paul 1980).

6.4.2. Planning Context

Prior to European settlement the Port Hedland area was a gathering place for the Nyamal (or Ajamal) and the Kariyarra Aboriginal peoples (DPUD 1992; WAPC 2003b; Town of Port Hedland 2011). A Native Title Agreement has been signed for South Hedland (August 2011) with discussions progressing for Port Hedland townsite, with separate agreements required for mining groups.

European settlement in the Pilbara first established a pastoral industry in the region, with a series of informal settlements located along the main river channels. Construction of landing facilities near the mouths of the de Grey, Harding and Ashburton Rivers led to more formal gazettal of town sites, with Condon Landing (Town of Shellborough) being established near the mouth of the de Grey. Subsequent to damage from tropical cyclones (Hardie 2001) and with increased demand during a short-lived gold rush, the need for a deepwater port was identified.

The Port Hedland site had previously been identified as an ideal natural harbour, named Mangrove Harbour in 1863, but its distance from a major river system restricted its value for pastoral use. Development of port facilities commenced in 1895, with Port Hedland established as a town in 1896, supporting a port and rail hub to service the pastoral and mining industries. The initial jetty was completed in 1898 for tin and gold exports, with the goldfields railway jetty completed in 1909 (Le Page 1986).

Port Hedland has subsequently grown through a series of resource booms and large-scale development projects, continuing to act as a port and rail hub for widespread operations across the Pilbara. Each port or industrial expansion also necessitated further transport routes, reclamation for land-backed port facilities and land for industrial and residential purposes. From 1957-1960, port expansion was associated with the manganese ore boom associated with the Korean War (Le Page 1986).

A major phase of rapid expansion at Port Hedland occurred after the lifting of a trade embargo on iron ore exports in 1966. This led to establishment of South Hedland, 14km south of Port Hedland for residential expansion (WAPC 2003b). Railway and port facilities were constructed on Finucane Island from 1967-1974, with dredging of the harbour entrance channel. Leslie Salt salt pond levees (now Rio Tinto Dampier Salt) were also initially constructed in 1966, later expanded in the 1990s (Le Page 1986; EPA 1991b). Further capital dredging for the navigation channel, basin deepening and widening occurred in 1975-1976, 1984-1986 and 2007 to accommodate larger ships (Le Page 1986; MJ Paul & Associates 2003; GHD 2008). Much of the material generated from capital and maintenance dredging works was sidecast on to the Port Hedland Spoil Bank up to 2001. Subsequent townsite and industrial expansion was associated with the BHP Hot Briquette Plant in 1996 and the release of land in the Boodarie Strategic Industrial estate (PHAPS WAPC 1998 draft).

A recent mineral resources boom, associated mainly with iron ore, occurred through 2004 to 2011 with a peak in 2008-2009. The high commodity prices facilitated 'rapid growth' and capacity expansion projects for the established BHP facilities, but also enabled mid-size and junior miners to establish port and rail infrastructure. A list of recently completed and proposed projects includes:

- FMG port facility at Anderson Point, commenced in 2008 (EPA 2008b);
- BHPBIO expansion at Utah Point, commenced in 2010 (EPA 2009b);
- BHPBIO Inner Harbour expansion, commenced in 2012 (EPA 2008d, 2009b & 2009d);
- Rio Tinto salt pond expansion, proposed;
- Roy Hill port-rail facility at South West Creek, proposed for 2014 (EPA 2010c);
- North West Infrastructure port-rail facility at South West Creek (EPA 2011b);
- BHPBIO Outer Harbour project, presently on hold (EPA2012b).

These projects include extensive capital dredging and land reclamation, with associated construction of road, railway and drainage infrastructure. A road upgrade of the Great Northern Highway is presently proposed between Port Hedland and South Hedland (Main Roads 2007; WAPC 2009).

The progressive expansion of port and rail facilities has also required increased availability of industrial and residential land, with an associated increase of recreational pressure. A major constraint to land development has been caused by inundation hazard, either through runoff of coastal flooding, with limited elevated land in the vicinity of the port. An early solution to provide suitably safe residential development was the foundation of South Hedland in 1966, 14km south of Port Hedland. Later smaller expansions in the 1970s and 1980s occupied the higher coastal land available at Cooke Point and Pretty Pool. Industrial estates were developed at Wedgefield and Redbank, with cut-to-fill used to set a minimum development level as a means of flood mitigation. Subsequently, constraints on available elevated land have restricted cut-to-fill, with imported or reclaimed fill being used to provide a minimum development level.

Recreation pressures affecting land-use planning in Port Hedland include boat launching facilities, recreational boat harbours, 4WD tracks and informal camping (DPUD 1992; Ecoscape 2005; Davies & Campbell 2009; WAPC 2003b, 2009). Existing boat launching facilities include ramps at Oyster Point on Finucane Island (upgraded in 2009), Richardson Street (Captain Bert Madigan Boat Ramp), Port Hedland Yacht Club, on the south side of Pretty Pool and an informal ramp at Six Mile Creek, with a small craft jetty at the Port. A marina is proposed for the western Spoil Bank incorporating the existing Port Hedland Yacht Club. There is increased pressure for short-term tourist accommodation with new camping grounds and caravan parks proposed.

Coastal Planning, Management and Governance

As a port town, coastal planning and management has been fundamental to each phase of Port Hedland's development, with a major focus upon providing suitable access to port facilities. Over the 116 years of town history, this has resulted in significant changes to development pressures within the town, including a progressively reducing area of undeveloped land and increasing population. A consequence is that planning and infrastructure have occurred as a sequence of layers, each reflecting the changing scale and values of the time.

The most recent coastal plans for the management of Port Hedland coast was developed in 2005 (Ecoscape 2005), which represented an update of the previous coastal plan (DPUD 1992). The recent plan identified that a number of works recommended in 1992 had not been implemented by 2004. Works to be completed from 2004-2009 were identified, with revised priorities subsequently recommended (Ecoscape 2007). Recommendations relate to foreshore access, track rehabilitation, landscape and recreation plans, coastal parking, construction platforms and boardwalks along top of dunes.

The wider planning context is provided by the *Port Hedland Area Planning Study* (WAPC 2003b) and the planning scheme for the Town of Port Hedland (DoP 2011b). These two documents were prepared in 1998 and 2001 respectively, with 57 proposed or approved amendments to the planning scheme by December 2012 (ToPH website). A number of more recent documents have been prepared to facilitate the growth of Port Hedland with recent iron ore port construction and expansion projects (PHLUMP Steering Committee *et al.* 2007; RPS *et al.* 2008; Town of Port Hedland 2010a, 2010b, 2011a; RPS 2011; WAPC 2009, 2010b, 2011, 2012). A brief summary of planning documents prior to 2011 is summarised in Appendix A of *Pilbara's Port City Growth Plan* (ToPH 2011a). The relevant maps, policies and report sections are listed in Table 6-15 for recreational areas, port facilities, Wedgefield industrial area, residential area expansions, the Spoil Bank precinct, the Pretty Pool precinct and Rio Tinto salt pond expansions.

The *Port Hedland Land Area Plan* (RPS 2011) is the most recent strategic planning document that supports detailed structure plans in preparation for key precincts at Pretty Pool, the

Spoil Bank and infill development in the Wastewater Treatment Plant buffer zone. Rezoning of land will be required for areas shown in *Port Hedland Regional Hotspots Land Supply Update* (WAPC 2011) and the *Port Hedland Land Area Plan* (RPS 2011 Appendix 1 and Appendix 2). The uncertainty surrounding potential impacts of coastal hazards, specifically in the context of potential high scenarios for projected sea level rise, has prompted reanalysis of coastal flooding extent and erosion (Cardno 2011) which is intended to refine previous advice and be used in the preparation of detailed structure plans.

The layered nature of development in Port Hedland has also included changes to coastal governance, resulting in apparent jurisdictional inconsistencies and overlaps. These add to the constraints to effective coastal planning and management affecting Port Hedland. Sections of the coast are vested with Town of Port Hedland, Port Hedland Port Authority, BHPBIO and Rio Tinto with varying degrees of overlap. For example, the municipal boundary for the Town of Port Hedland extends to low mater mark and the Port Hedland Port Authority reaches up to high water mark (in a 10 nautical mile radius from the Hunt Point Beacon). The large tidal range further complicates definition of the coastal zone. Some of the issues arising from the complexity of coastal governance have previously been described (DPUD 1992 pp. 20-21; WAPC 2003b p.73).

Planning for Coastal Hazards

The long history of development in Port Hedland and the mixture of industrial and residential land use have provided varied approaches towards the planning and management of coastal hazards. Coastal flooding is acknowledged as the most significant widespread hazard to Port Hedland, with erosion and sedimentation requiring consideration typically in more focused areas.

Coastal flooding risk has been mitigated through development occurring on areas of generally higher ground, with cut-to-fill used to provide ground levels above a defined minimum. Development across low-lying areas, such as port access and laydown areas, have also typically defined a minimum level, met by using imported fill or reclamation using dredged material. Identification of suitable minimum levels has varied according to the nature of the development and the potential coincidence of multiple factors, such as wave-storm surge or runoff flooding-storm surge. In general terms, residential premises have been required to be above the effects of a ‘100 year’ event, whilst higher risk levels have been tolerated for industrial or transport infrastructure. More than 12 studies have been conducted to identify flood levels at either facility of town-site scale.

Table 6-15: Planning Documents for Sites within the Port Hedland Area

Cell	Coastal Townsite/Area	TPS Section & Map (DoP 2011b) Gazetted 2001	Other Planning Documents
N/A	15km and 23km west of Port Hedland town ('Horseshoe' and 'Bus Stop')	Map 1; Clause 6.16	ToPH (2010a) p.22 *Coastal Access and Managed Camping Project*; Cardno (2011) Figure 1.2, Figure D.2.7
19	Finucane Island recreation area and boat ramp	Maps 3 and 4; Clause 6.16	Sector 1 of DPUD (1992) and Ecoscape (2005, 2007).
19	Port Hedland Outer Harbour – Presently on hold	Maps 3 and 4; Clause 6.16	DoT (2010b); BHP Billiton (2011) Figure ES.1 EPA (2012b)
20	Port Hedland Inner Harbour expansions (PHPA, BHP, FMG, Roy Hill, NWI) Extension of land-based port facilities	Maps 3 and 4; Clause 6.16	WAPC (2003b) Map 12; WAPC (2009a) berths to increase to 21 from 9; ToPH (2011a) Precinct 3; ToPH (2011b); EPA (2008b, 2008c, 2008d, 2009b, 2009d, 2010c, 2011b)
20	Wedgefield Industrial Area expansion	Maps 3 and 7; Clause 6.16; Clause 7.2 (Boodarie Industrial Area buffer); Clause 7.5 (Wedgefield Special Control Area);	WAPC (2003b) Map 12; PHLUMP (2007); WAPC (2009a) Map 21; JDA (2010a); Cardno (2011); RPS (2011) Appendix 4; ToPH (2011a) Precinct 6; WAPC (2012) Map 6; WAPC (2012) Map 9
20	South Hedland expansion	Maps 3 and 9; Clause 5.3.5 (South Hedland precinct); Clause 6.16; Clause 7.2 (Boodarie Industrial Area buffer); Clause 7.3 (Gas power station buffer); Clause 7.4 (WWTP buffer)	WAPC (2003b) Map 12; PHLUMP (2007); RPS *et al.* (2008); WAPC (2009a) Map 21; GHD (2011); Cardno (2011); RPS (2011) Appendices 2 and 4; ToPH (2011a) Precincts 9 – 13; WAPC (2012) Map 6; WAPC (2012) Maps 9 and 10.
20	West End/Town Beach	Map 4; Clause 6.16; Clause 7.4 (WWTP buffer)	Sector 2 of DPUD (1992) and Ecoscape (2005, 2007); WAPC (2003b) Map 12; PHLUMP (2007); WAPC (2009a) Map 20; Cardno (2011); EPA (2011b); RPS (2011) Appendix 1; ToPH (2011a) Precinct 1; WAPC (2012) Map 5; WAPC (2012) Map 8

Cell	Coastal Townsite/Area	TPS Section & Map (DoP 2011b) Gazetted 2001	Other Planning Documents
21	Spoil Bank, including marina	Map 4; Clause 6.16	Sector 3 of DPUD (1992) and Ecoscape (2005, 2007); WAPC (2003b) Map 12; PHLUMP (2007); WAPC (2009a) Map 20; Cardno (2011); RPS (2011) Appendix 1; ToPH (2009); ToPH (2010a) p12-13; ToPH (2011a) Precinct 1; WAPC (2012) Map 5; WAPC (2012) Map 8
21	Cemetery and Sutherland Beaches; Cooke Point	Maps 4 and 5; Clause 6.16; Clause 7.4 (WWTP buffer)	Sectors 4-6 of of DPUD (1992) and Ecoscape (2005, 2007); WAPC (2003b) Map 12; PHLUMP (2007); WAPC (2009a) Map 20; Cardno (2011); RPS (2011) Appendix 1; ToPH (2011a) Precinct 2; WAPC (2012) Map 5; WAPC (2012) Map 8
22	Pretty Pool and WWTP removal	Map 5; Clause 5.3.3 (Pretty Pool Precinct); Clause 6.16; Clause 7.4 (WWTP buffer); Appendix 10 (Pretty Pool Requirements)	DOLA (1985); Sector 7 of of DPUD (1992) and Ecoscape (2005, 2007); WAPC (2003b) Map 12; MP Rogers & Associates (2006); PHLUMP (2007); EPA (2009c); WAPC (2009a) Map 20; Cardno (2011); RPS (2011) Appendix 1; ToPH (2009); ToPH (2010a) p.16-17; ToPH (2011a) Precinct 2; WAPC (2012) Map 5; WAPC (2012) Map 8
22	Four and Six Mile Creeks, possible salt pond expansion	Maps 3 and 5; Clause 6.16	Sector 8 of of DPUD (1992) and Ecoscape (2005, 2007); Davies & Cammell (2009); RPS (2011); ToPH (2011a) Precinct 2 and Precinct 5; ToPH (2011b)
N/A	Shellborough, 85km east of Port Hedland. Also referred to as Condon.	Map 1; Clause 6.16	Hardie (2001) Figure 5; ToPH (2010a) p.22 *Coastal Access and Managed Camping Project*; Cardno (2011) Figure 1.3, Figure D.2.8; ToPH (2011a) Precinct 16

Since the 1970s, there have been at least three acknowledged planning approaches towards flooding mitigation:

- In the 1970s the 'Kelly Line' for Port Hedland was defined as 10 feet above the Highest Astornomical Tide level;
- Port Hedland Coastal Plan (DPUD 1992) acknowledged spatial variation of wave conditions, recommending different minimum levels near the coast, behind the coastal ridge and at Wedgefield;
- A risk-based approach towards defining levels has been followed since 2000, making allowance for the discrepancy between residential and industrial flood impacts.

This most recent approach is incorporated within the *Town of Port Hedland Town Planning Scheme No. 5* (DoP 2011b; Table 6-15), with a 100 year flood level providing demarcation whether a risk-assessment is required for each development site. Identification of an appropriate risk level is deferred to relevant public authorities, allowing up-to-date information to be incorporated. The Town of Port Hedland risk demarcation is below the level proposed in the SPP 2.6 (WAPC 2013), which recommends consideration of impacts for a 500 year flood event, defined as the peak steady water level plus wave run-up.

The potential for hazard mitigation works to transfer flood risk to adjacent areas was identified in the *Greater Port Hedland Storm Surge Study* (GEMS 2000b), particularly impoundment by extended curvilinear features such as roads and rail embankments. This outcome has required greater consideration as the floodplain has been progressively infilled.

Inundation Assessments

Port Hedland has a comparatively high exposure to both coastal and fluvial flooding which provides constraints to industrial, residential and commercial development. This susceptibility has also led to a series of detailed coastal flooding risk assessments within the Port Hedland area (Table 6-16).

Changes in the estimates of extreme water level over time reflect the development of knowledge databases and modelling methodologies. Early estimates provided very low levels due to the absence of intense tropical cyclones within the Bureau of Meteorology records, or during the period for which tide gauge measurement was available. The occurrence of several extreme events, notably 950 hPa TC Connie (1987) and 905 hPa TC Orson (1989), prompted significant improvement of local modelling capacity and information gathering. Surge generated by TC Connie was recorded 2.0m above predicted tide at Port Hedland, with the peak surge generated by TC Orson modelled to be 5.0m (Hanstrum & Holland 1992), but fortunately not impacting on any town sites.

Subsequent modelling up to 2010 in the Port Hedland has generally applied a single numerical modelling approach (Hubbert *et al*. 1991) but has changed progressively through the adaptation of overland flooding and the methods in which tide and surge are integrated. The result has been a general lowering of the levels associated with the estimated 100-year ARI coastal flooding level (Table 6-16). Review of models from 1991 to 1995 suggested that some of the methodological changes were non-conservative, and may potentially underestimate the likelihood of extreme water levels (CMPS&F Pty Ltd 1999; Damara WA 2010b).

Table 6-16: Previous Water Level Assessments at Port Hedland

Study	Description	Recommendation or Hazard
1970s (described in JDA *et al.* 2011a)	Kelly Line. A simple minimum level as 10 feet (3.05m) above Highest Astronomical Tide of +3.5mAHD at Port Hedland.	+6.55mAHD
Hopley & Harvey (1976)	Observations derived from Port Hedland tide gauge, with Jelesnianski modelling. Early TC database underestimated cyclone intensity.	100 yr ARI: +4.4mAHD
Silvester & Mitchell (1977)	Parametric storm surge estimation. Also used early form of BoM TC database (see comment above)	'extreme' WL: +4.3mAHD
BoM (1991)	Derived from 'fixed wall' surge model plus tidal distribution	100 yr ARI: +6.2mAHD PLUS 1.2m wave setup
BoM (1993)	Derived from 'fixed wall' surge model plus tidal distribution	100 yr ARI: +6.2mAHD PLUS 0.8m wave setup
BoM *et al*. (1994)	Inundation surge model. At Six Mile Creek: At Catfish Creek	100 yr ARI: +6.1mAHD + 2.6m setup & runup 100 yr ARI: +6.8mAHD +2.3m setup & runup
BoMSSU & GEMS (1995b)	Report for BHP DRI Plant. Output from coast:	100 yr ARI: +5.4mAHD PLUS 0.8m wave setup
CMPS&F (1999)	Derived from Port Hedland tide gauge. Identified that that BoMSSU & GEMS (1995b) underestimated the frequency of extreme water levels. Derived lower limit from 1988-1998 observed water levels, as no nearby TC during this period.	100 yr ARI: +4.6mAHD (lower limit)
GEMS (2000b)	Monte carlo modelling, with coverage over wider area of Port Hedland	100 yr ARI: avg. +6.0mAHD
MP Rogers & Associates (2006)	Study for Pretty Pool, applying WAPC (2003a) scenario. Applied a category 5 cyclone upon MHWS tide level	500 yr ARI: +7.4mAHD
Damara WA (2009b)	Surge variation with shift in tropical cyclone intensity and frequency	100 yr ARI surge (existing): 5.3m
Damara WA (2010b)	Used Jelesnianski (1972) method for Port Hedland Access Corridor incorporating coastal water level, 0.2m SLR, coastal wave setup, local wind & wave setup.	100 yr ARI PSWL: +6.6mAHD (+8.3mAHD excluding runup)
Cardno (2011)	Monte carlo modelling for100-yr ARI and longer periods. Includes open coast wave setup and peak steady water level. Shellborough site: 100 yr ARI PSWL of +5.9mAHD PLUS 0.9m wave setup 500 yr ARI PSWL of +6.6mAHD PLUS 1.0m wave setup	100 yr ARI PSWL: +4.9 to +5.1mAHD PLUS 0.7 to 0.8m wave setup. 500 yr ARI PSWL: +5.1 to +5.6mAHD PLUS 1.2m wave setup

The role of methodological bias to affect estimation of extreme water levels at Port Hedland is significant (see Section 6.1.6), including systematic biases introduced by exclusion of processes such as wave runup or runoff-surge interaction. In particular, the relative absence of extreme water level events limits the capacity for modellers to validate extreme water level processes. Whilst it is not reasonable or possible to interpret bias without a more thorough evaluation, stark contrasts are evident between the events used for validation by the GEMS (2000b) and Cardno (2011) studies. In this context, no available estimates of extreme water level frequency should be considered wholly reliable. This implies that flood risk management should have sufficient scope to adapt to different conditions, and in keeping with good engineering practice, should consider the implications of events exceeding a design threshold. The alternate practice to use deliberately conservative methods (e.g. Damara WA 2010b) should equally be used with care as it potentially overstates requirements for hazard mitigation.

Coastal flooding levels are relevant to runoff flooding estimates as they define the downstream conditions. The approach used for coincidence of runoff and coastal flooding has varied between studies, depending upon study budget and the focal area of interest. A simplified approach, which is to assume a high downstream water level, normally with a corresponding event ARI, is acknowledged to produce conservatively high level results, particularly in near-coast channel reaches. Correspondingly, ignoring coastal water levels is likely to result in an underestimate of flood levels in the coastal fringe. Attempts to define a statistical relationship between runoff and coastal flooding have been undertaken (GEMS 2000b; Cardno 2011) although both these studies have indicated that their approach is not definitive.

6.4.3. Landforms and Sediment Cells

Landform mapping has been completed for the wider Port Hedland area by the Geological Survey of Western Australia (Figure 6-50 with key in Figure 6-49), which reflects the complex interaction of marine and fluvial processes overlying a geological framework. Simply described, there are three zones moving landward: a limestone coastal barrier, marine-dominated floodplain and terrestrial floodplain. Land system behaviour (aggregated behaviour of a collection of landforms), shows distinct differences in the Pilbara region according to the continuity of the coastal barrier, which was used to define the regional sediment cell classification (Section 2.1). Apparent land systems were further confirmed based upon observed coastal dynamics and seabed structure.

Four sediment cells are suggested by the landform analysis:

Islands: Tertiary Cell 19 from Downes Island to Finucane.
The limestone coastal barrier is almost continuous along Downes and Finucane Islands, allowing retention of relict sand features perched on top of and behind rock features. Discontinuities in limestone formations, particularly parallel to the coast, provide a structurally-influenced tidal channel network and a broad marine floodplain.

Hedland Harbour: Tertiary Cell 20 from Finucane to Spoil Bank W, includes Harbour margins. A large breach in the coastal barrier, combined with low fluvial sediment supply has enabled formation of a large and deep relict (i.e. non-tidal) basin. Tidal constraint apparently occurs near the harbour entrance, and the harbour ‘arms’ have characteristic tidal channel structure.

Old Hedland: Tertiary Cell 21 from Spoil Bank W to Cooke Point.
The coast is dominated by a sandy dune barrier, which is variably connected to underlying and adjacent rock features. A sub-tidal limestone ridge that runs approximately 10^o to the shore is expressed as inter-tidal rock near Cemetery Beach, and apparently forms the shore further west (in Tertiary Cell 20). This section of coast has been highly modified through construction of the Spoil Bank.

Beebingarra: Tertiary Cell 22 from Cooke Point to Petermarer Creek.

The shoreline is coincident with a highly discontinuous limestone coastal barrier, producing a series of extended beach segments, with isolated rock headland controls. Tidal creek systems occur individually for most of these segments, with a number connected through to mid-sized fluvial catchments. The limited protection from the barrier has enabled formation of a marine floodplain, at present-day tide levels. Consequently, this section of coast has a wide area of marine floodplain mudflats, which have been opportunistically used

The major features, when described at this scale are outlined in Table 6-17.

The most apparent coastal changes in the Port Hedland area are attributable to historic port works. The largest of these is the Spoil Bank, created by depositing dredged sediment offshore, which has progressively moved landward. Following its connection to shore, alongshore sediment transport from the Spoil Bank to Cooke Point apparently reversed its prevailing direction. Other major changes include formation of salt works ponds and construction of port infrastructure, including laydown areas, roads and rail lines.

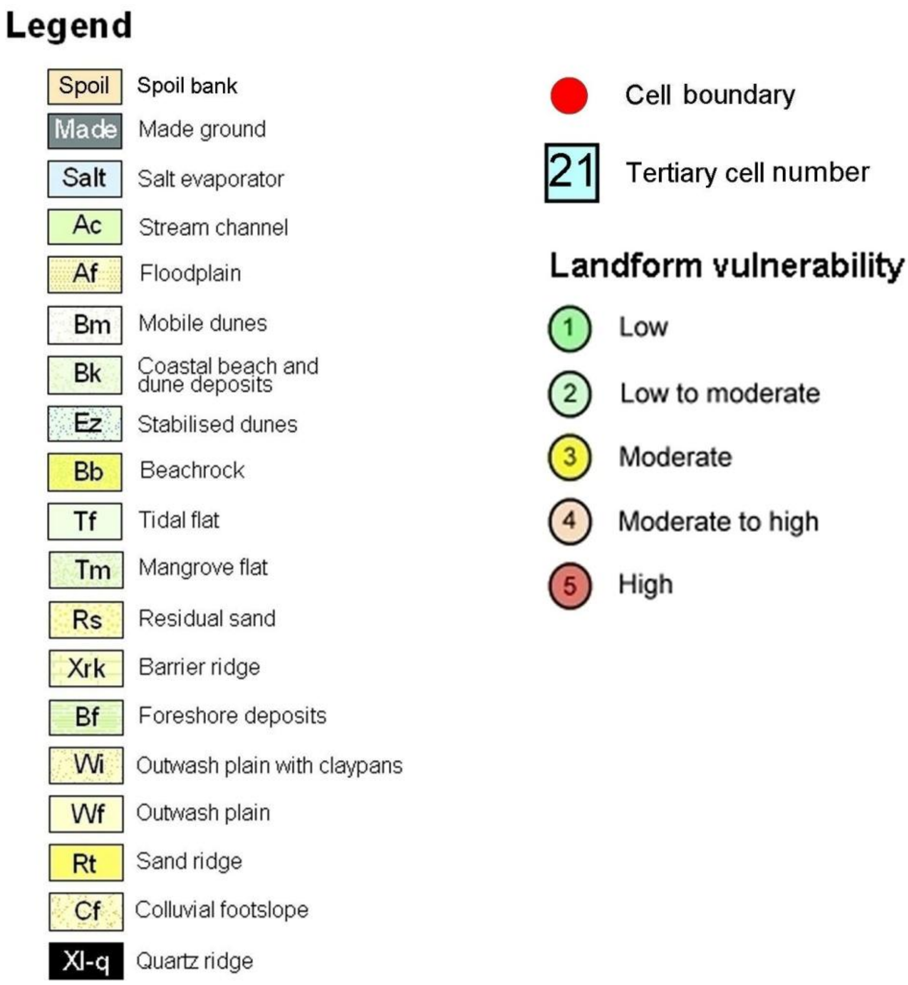

Figure 6-49: Port Hedland Landform and Vulnerability Map Legend

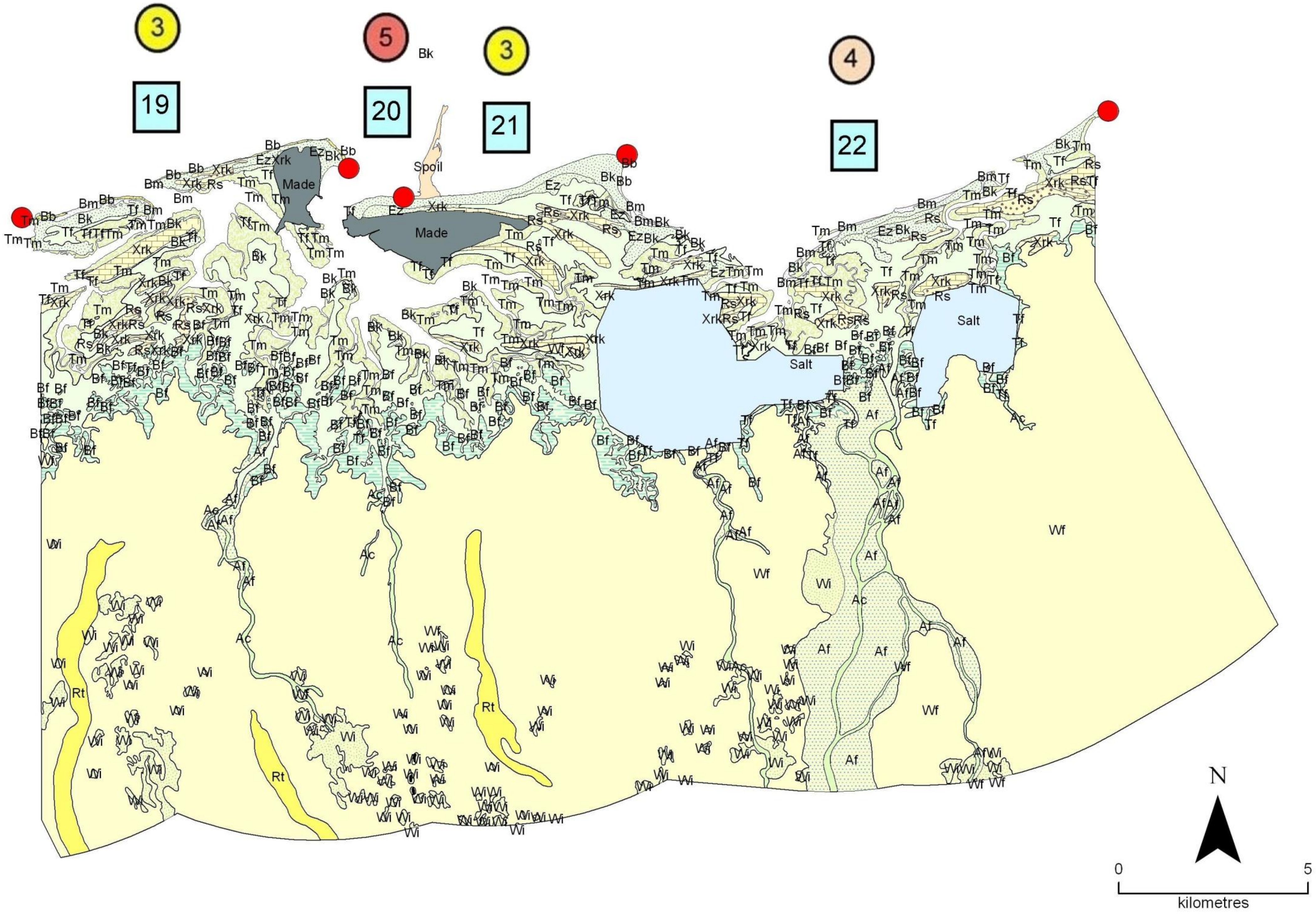

Figure 6-50: Port Hedland Area Vulnerability and Landforms
Legend in Figure 6-49

Table 6-17: Port Hedland Area Tertiary Sediment Cell Description

Tertiary Cell	Compartment Inner-Shelf Morphology	Subtidal Shoreface	Intertidal Shore	Backshore Landforms
22. Cooke Point to Petermarer Creek	The sediment cell includes part of two compartments: the eastern part of Downes Island to Beebingarra Creek and the western 2km of Beebingarra Creek to Wattle Well. The inner-shelf is wide. Water depth is <10m approximately 14km from shore; and 20m approximately 47km from shore. Three islands are located in State Waters.	The markedly dissected shore constitutes a large zeta-form embayment extending eastwards from Cooke Point to a mouth of a tidal inlet draining seaward of Petermarer Creek. The inshore waters include tidal channels, subtidal reef platforms and rock outcrops. Between 25 and 50% of the subtidal shoreface includes subtidal platforms and rock outcrops. Extensive sandy tidal flats, up to 3.5km wide, are common particularly near the mouths of tidal creeks. Water depth is <5m for approximately 8km from shore.	The zeta form of the shore is apparent as three lithified chenier ridges with outcrops of low bluff and rock platform. Sandy beaches are perched on rock outcrops as well as on spits connected to the chenier ridges. Along the coast the high ridges are separated by tidal creeks and sand flats. The widest break between cheniers occurs immediately east of a rocky headland at 4 Mile Creek. There are approximately four tidal creeks per 10km along the irregular shore. The cheniers are connected to the hinterland by extensive mudflats and outwash plains. Mangroves line the tidal creek networks.	Partially vegetated perched dunes occur along the seaward margin of the cheniers. These include bare sand surfaces and narrow foredune ridges. Tidal creeks and mudflats occur between lithified chenier ridges and an outwash plain drained by small creeks. Several streams including Beebingarra and Petermarer Creeks, drain onto mudflats and intermittently connect with tidal creeks. Salt ponds and urban infrastructure have modified some of the streams and tidal creeks. The coastal cheniers may be separated from the mainland during extreme water level events when the mudflats are inundated.
21. Spoil Bank (W) to Cooke Point	The sediment cell is located in the Downes Island to Beebingarra Creek Compartment. The inner-shelf is wide. Water depth is <10m approximately 14km from shore; and 20m approximately 47km from shore. Three islands are located in State Waters.	Water depth is <5m for approximately 8km from shore. The inshore waters include 50-75% subtidal reef platforms and rock outcrops. The subtidal platforms support an irregular veneer of sediment with ridges and banks. Sediment supply and transport is affected by the Spoil Bank which is perpendicular to the shore and is shedding sediment.	The Spoil Bank is a major source of sediment to the sandy shore, but also causes localised erosion. The sandy shore overlies near continuous beachrock and tempestites abutting Pleistocene dunes.	The beach is backed by a high chenier ridge comprised of old coastal dunes. The Old Port Hedland to Cooke Point chenier is one of several ridges within the cell which are separated by low-lying mudflats and tidal creeks. Further landward these features merge with mudflats modified for industrial purposes and with outwash plains.

Tertiary Cell	Compartment Inner-Shelf Morphology	Subtidal Shoreface	Intertidal Shore	Backshore Landforms
20. Finucane to Spoil Bank (W)	The sediment cell is located in the Downes Island to Beebingarra Creek Compartment. The inner-shelf is wide. Water depth is <10m approximately 14km from shore; and 20m approximately 47km from shore. Three islands are located in State Waters.	The inshore waters include the main NE facing channel of Port Hedland Harbour. The channel is between Finucane Island and Old Port Hedland. It opens into a network of tidal creeks, which include South Creek and Stingray Creek. To seaward the channel borders tidal flats perched on subtidal rock pavement along the Spoil Bank, a bank of material dumped during channel dredging. The subtidal and intertidal sand veneer covers 50-75% reef or pavement.	On the open coast the intertidal coast includes perched sandy beaches at the eastern extent of Finucane Island as well as in the vicinity of Old Port Hedland and along the Spoil Bank. The shoreline and channel of Port Hedland Harbour have been extensively modified for harbour construction. Further landward, the major part of the irregular shore is comprised of extensive mudflats, fringing mangroves and numerous tidal creeks.	Tidal creeks and mudflats occur on an outwash plain of the Turner River, which is intermittently connected with the tidal creeks. In places, the supratidal margins of the mudflats have been substantially modified by construction of urban and port infrastructure with concomitant modification of the drainage flows. Elsewhere in the supratidal mudflats surface runoff has resulted in the formation of residual islands and palaeochannels.
19. Downes Island to Finucane	The sediment cell is the western part of the Downes Island to Beebingarra Creek Compartment. The inner-shelf is wide. Water depth is <10m approximately 14km from shore; and 20m approximately 47km from shore. Three islands are located in State Waters.	The cell is comprised of numerous lithified islands in a much dissected mudflat basin with extensive tidal creek networks. Away from the tidal channels separating the islands the nearshore waters of Finucane and Downes Islands are <5m deep for approximately 8km from shore. The inshore waters include tidal channels, subtidal rock pavements and rock outcrops. There is >75% reef or pavement.	Downes and Finucane Islands have extensive intertidal rock platforms and moderately high (5-10m) cliffs along their northern shores. Mangrove communities line the sheltered southern shores of the islands and the numerous tidal creeks. More than eight tidal creeks form a drainage network in the lee of the irregular shore and its complex of islands.	The islands have a calcarenite core that is exposed along the northern shore and on the high ridge of each island. In places, sandy storm bars are perched on the seaward side of the ridge. Sandy spits are present at the ends of each island. Landward of the islands is a dissected mudflat with residual mounds, palaeochannels and tidal creeks. The mudflats are part of extensive deltaic plains associated with the distributary channels of the Turner River.

Coastal change has been evaluated for each of the sediment cells through the comparison of historic and modern aerial imagery. Dominant changes are almost exclusively associated with the significant impacts of port works and their associated consequences.

Aerial imagery for **Islands** (Figure 6-52) shows the shoreline has historically been relatively stable and is controlled by underlying, alongshore and supratidal rock features including cliffs; described in DPUD (1992) and GEMS (2010a). Limited change that has been observed on the perched dunes is mainly attributed to 4WD tracks on western Finucane Island and aeolian transport on eastern Finucane Island, although some erosion was observed during high wave conditions from TC Vance in March 1999. Engineered modifications include the Oyster Point boat ramp and car park, the BHPBIO facilities and the interruption of West Creek with the Finucane Road Bridge. The presence of a 'ribbon' of sand along the base of Finucane Island cliffs suggests that transport is strongly limited by sand availability (Figure 6-51.)

Figure 6-51: Nearshore Bed Features Adjacent to Cell 19
Source: GEMS (2010a)

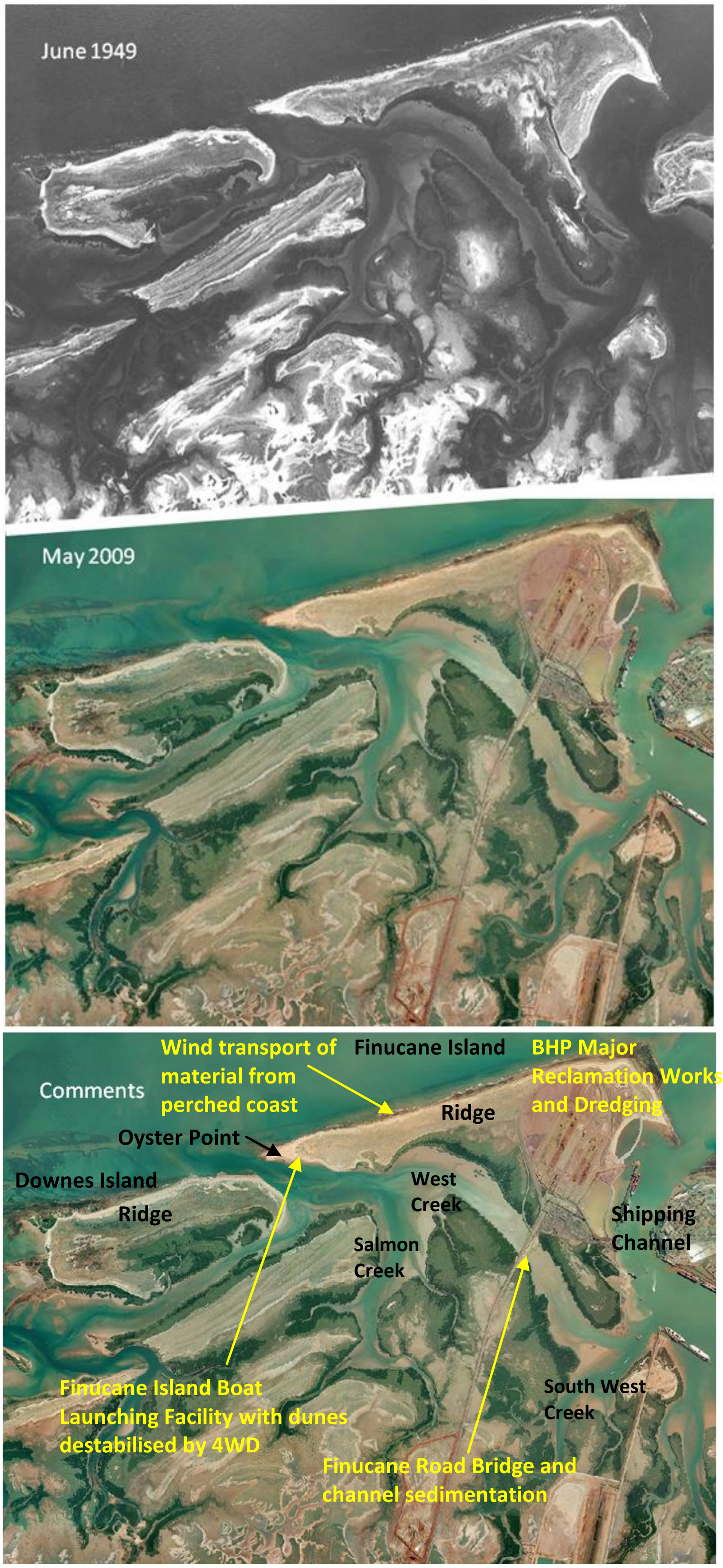

Figure 6-52: Aerial Photography for the Islands (1949-2009)

Imagery for the **Hedland Harbour** (Figure 6-53) shows that coastal change is dominated by human interventions through dredging, disposal of dredged material, reclamation for land-backed port facilities and the interruption of sediment transport pathways. These works have altered the tidal prism of the main entrance channel, hardened reclaimed coasts and have entirely filled tidal creek arms on eastern Finucane Island, at Mangrove Point and East Creek. South Creek and South West Creek are presently undergoing significant modification with further work likely to proceed in South East and Stingray Creeks (EPA 2008b, c, d, 2009b, d, 2010c, 2011b). The distributive nature of the Port Hedland tidal flats determines that changes resulting from these works may be difficult to detect from aerial photography, occurring through subtle adjustments of the tidal flats and channel networks. Corresponding changes at the heads of the tidal creeks, which usually provide an indication of dynamics, are obscured by other works, particularly roads and rail lines.

The coast between Airey Point and the Spoil Bank has also been altered by engineering modifications including the Spoil Bank and excavation through rock for the Richardson Street boat launching facility and yacht club. The spoil bank is a large feature developed since 1966, which has effectively created a new boundary to coastal sediment transport. The progression of the spoil bank is shown in Figure D.2.6 of the Cardno (2011) study, demonstrating large amounts of local sediment reworking that occur on the artificial spit. Channel sedimentation records for the navigation channel suggest that there has been some transport from the Spoil Bank westward, although this has principally occurred where the bank is submerged by tidal action (Cooke 1979; MJ Paul & Associates 2001) The coast west of the bank is a low-bluffed rock platform with a perched dune barrier to landward with private residential property atop the barrier. Initial change following connection of the Spoil Bank to shore included narrowing of the perched beach, with more recent behaviour involving widening at the eastern end of the cell.

Figure 6-53 : Aerial Photography for Hedland Harbour (1949-2009)

Old Hedland has a predominantly sandy shore, which is highly influenced by controlling rock features and locally affected by unmanaged runoff. A high (+10m AHD) dune barrier is perched on rock features including rock platforms, sub-tidal ridges, 3-5m high bluffs and tempestites (cobble-boulder ramparts) with nearshore areas covered by a thin veneer of sand. Alongshore variability of rock features causes local dune and coastal changes, which are otherwise dominated by the formation of the Spoil Bank (Figure 6-54; Figure 6-55) and the associated change in prevailing wave and current conditions (Paul 1980). Some historic changes to the coast have been described in DPUD (1992), GEMS (2010a) and Cardno (2011 Appendix D). Limited coastal movement is apparent in areas with supratidal rock control, such as the low cliffs east near Webster Street and the tempestite rampart up to Cooke Point.

Comparatively large shore realignments have occurred between Webster and Wodgina Streets, including significant infilling of a shallow arcuate embayment that occurred shortly after the Spoil Bank connected to shore. In recent years, this area has experienced hotspot erosion, with a similar pattern to the earlier structure. This focal area occurs due to the change in shore alignment and the relative width of the intertidal rock platform.

Figure 6-54: Nearshore Bed Features Adjacent to Cell 21
Source: GEMS (2010a)

Figure 6-55 : Aerial Photography for Old Hedland (1949-2009)

In its broadest sense, the **Beebingarra** coast has an arcuate shape, providing the transition between two almost parallel limestone ridges (one continuous, one relict) that define almost linear coast in front of Old Hedland and the tidal creek systems east of Four Mile Creek. This formation is also reflected in the inter-tidal terrace, giving the narrowest terrace in the vicinity of Cooke Point. At a finer scale, the coast is comprised of a series of beaches, each partially constrained by small sections of emergent limestone features. The rock partly restricts coastal mobility, and helps to anchor the position of tidal creeks. In contrast, uncontrolled sedimentary features, which are present across the inter-tidal terrace are highly dynamic. The complexity of these features, which illustrates the dominance of different processes and suggests the influence of rock features, is shown by Figure 6-56. Spit structure and formation, with fingers extending eastward, suggests a net eastward sediment transport, through pulsational sediment supply, with a cyclic pattern of erosion and accretion.

During the modern history of the Beebingarra area, as demonstrated by aerial imagery (Figure 6-57), change has included onshore migration of sandbars and significant erosion (600m) of a previously extensive tidal entrance spit at Four Mile Creek. The sequence for individual features is irregular and includes migratory behaviour. The general pattern suggests a relative reduction in sediment availability. Whilst this may arguably have been enhanced by the changes to the updrift sediment supply from the Old Hedland area, the time scale of the natural cycle (or trend) of landform features on this coast has not been established. For a similar reason, it is difficult to isolate the influence of extensive modifications to the tidal creek networks, which have included construction of salt ponds levees, provision of roads and drainage pathways.

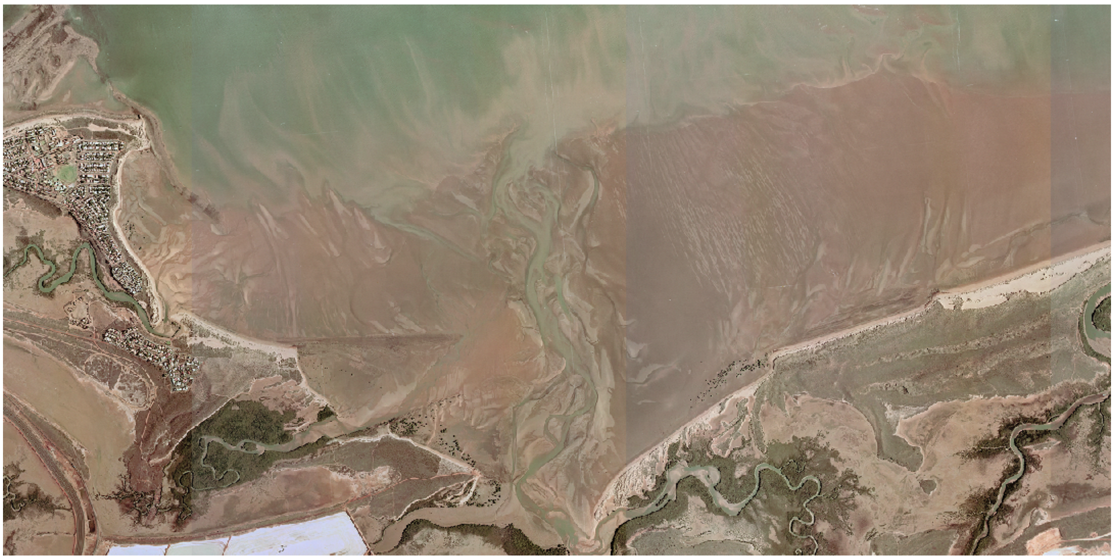

Figure 6-56: Complexity of Tidal Channel Networks across Beebingarra (2009)

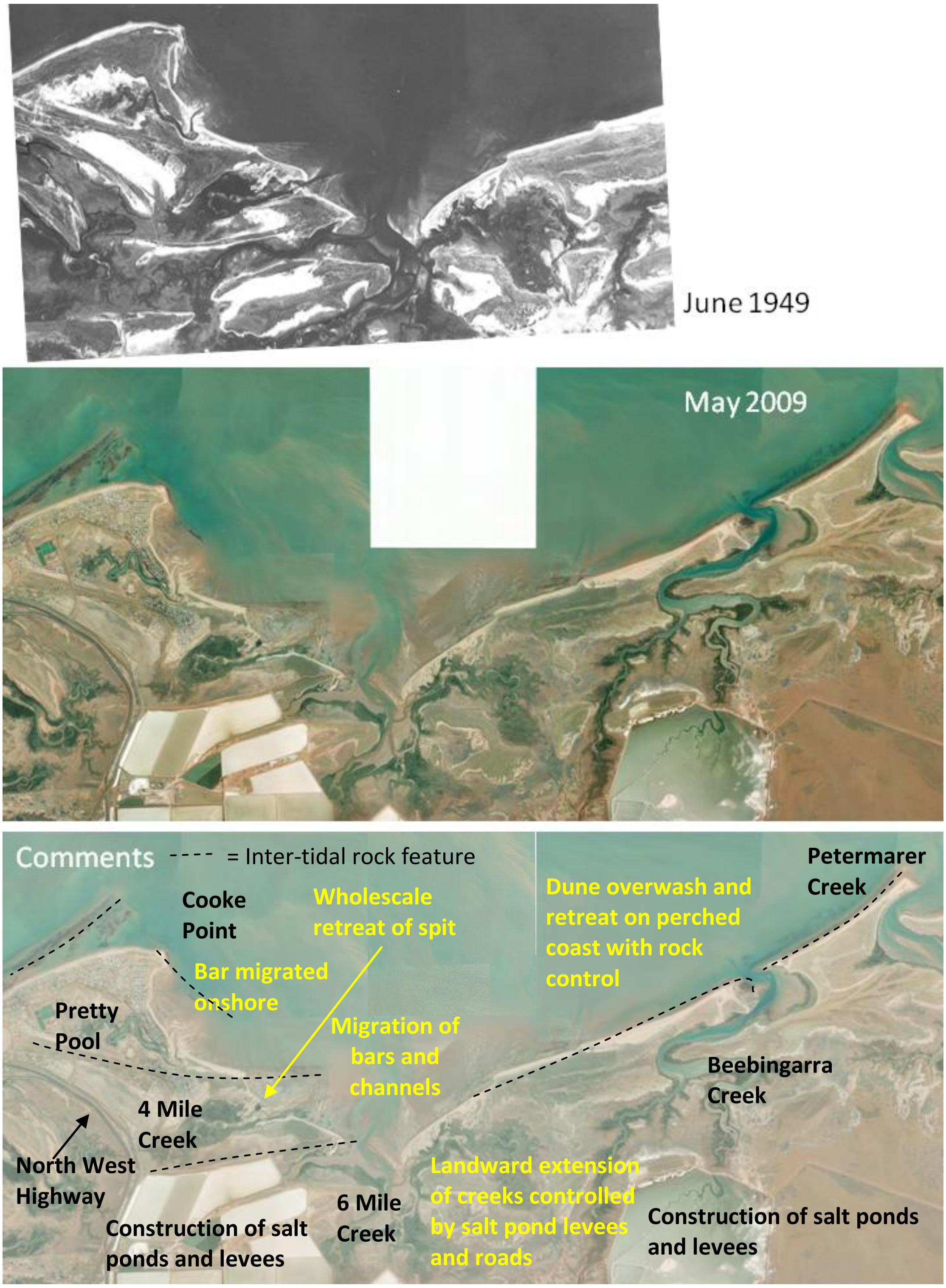

Figure 6-57 : Aerial Photography for Beebingarra (1949-2009)

6.4.4. Coastal Susceptibility, Instability and Vulnerability

Coastal landform vulnerability has been assessed at a sediment cell scale for Port Hedland using the combination of instability and vulnerability described in Section 2 (see classifications in Table 2-7, Table 2-11, Table 2-12 and Figure 2-20).

Coastal instability has been indicated at three scales: (i) at the sediment cell scale noted above (Section 5); (ii) through interpretation of landform classification (Table 6-17; Table 6-18; Figure 6-58); and (iii) combined with observations of coastal change from modern aerial imagery (Section 6.4.3). The distribution of different landform types suggests a general landward trend of increased stability (Figure 6-58), with the observed coastal change indicating that there are local hotspots of coastal variability, primarily determined by the configuration and presence of rock features. The extensive area of unstable coastal landforms is mainly a consequence of their low relief across the coastal floodplain and within broad alluvial channels. Patterns of change have also been strongly affected by significant human interventions. The largest of these impacts was caused by construction of the Spoil Bank, which affected an extended length of coast that had a previous history of stability.

Variation of coastal instability over the three spatial scales reflects different time scales, with hotspot, landform and sediment cell instability indicating potential behaviour over short, medium and longer time frames. Equivalently, these scales also indicate differences between realised, expected (future) and possible (future) coastal change. The extensive response to the Spoil Bank construction highlights the relative coastal instability, which is not otherwise apparent in the historic record.

The distribution of controlling rock formations affects the behaviour of sedimentary coastal features. Strongly controlled features, such as the perched dunes along *Old Hedland* coast, are affected by 'perturbing' conditions, particularly due to tropical cyclones, but recover quickly provided that sediment is locally available. For fringing and loosely controlled features present along the exposed Port Hedland coast (i.e. excluding Hedland Harbour), reduced sediment supply results in increased influence of rock control. Consequently, the coastal configuration varies with sediment supply. For the *Islands*, the width of the foreshore 'sand ribbon' varies with supply. For *Beebingarra* coast, the segments between rock controls vary in the embayment curvature. In both cases, the relationship between the sediment volume and the alongshore transport rate determines that coastal change is transferred downdrift, with potential for lagged response on the Beebingarra coast. Arguably, the Beebingarra coast may also have been affected by the Spoil Bank formation, as the apparent change in prevailing net transport direction has reduced the incidence of eastward sand transport bypassing Cooke Point and causing spit formation in thevicinity of Pretty Pool.

Table 6-18: Landforms of the Port Hedland Area and their Relative Instability (After: Gozzard 2012a). See Table 2-7B for Explanation of Colour Codes

Landform	Description	Relative Instability
Spoil bank	Spoil bank	High (Unstable)
Made ground (Made)	Made ground	Low (Stable)
Salt evaporator (Salt)	Salt evaporator	High (Unstable)
Stream channel (Ac)	Silt and silty sand in smaller watercourses and sands and gravels with subangular to subrounded pebbles of Precambrian rocks in larger watercourses	Moderate
Floodplain (Af)	Reddish brown to yellowish brown, fine-grained very silty sand and sandy silt with some development of 'gilgai'	Moderate
Mobile dunes (Bm)	Low, unvegetated coastal dunes and banks comprising pinkish grey shelly sands	High (Unstable)
Coastal beach and dune deposits (Bk)	Generally low, rounded dunes of pale yellowish brown to pinkish brown, fine- to medium-grained comminuted shell debris (up to 70%) with quartz; whole Anadara granosa and other molluscs are common and massive corals occur on the beaches	High (Unstable)
Stabilised dunes (Ez)	Rounded, low-lying to almost flat-lying dunes composed of pale yellowish brown, fine- to medium-grained sand with comminuted shell debris, whole shells are scarce and shell fragments are small and pitted	High (Unstable)
Beachrock (Bb)	Angular to subrounded shells, corals, sponges, pebbles of Precambrian rocks and quartz grains set in a hard, yellowish brown calcareous matrix; low-angle cross-bedding is evident at some locations	Low (Stable)
Tidal flat (Tf)	Intertidal and supratidal halophyte mudflats of brown, black and grey muds and silts with grey, brown and red, mottled clayey and silty sands all heavily salt-impregnated	High (Unstable)
Mangrove flat (Tm)	Flat to gently inclined surface vegetated by dense thickets of *Avicennia marina* up to 4 m high on an organic-rich muddy substrate	High (Unstable)
Residual sand (Rs)	Slightly to moderately silty, pale yellowish brown to reddish brown non-calcareous sand formed by the weathering (decalcification) of the underlying calcarenite	Moderate
Barrier ridge (Xrk)	Shore-parallel, rounded limestone ridges developed in a correlative of the Tamala Limestone; pale yellowish brown lithified calcareous sand with some oolitic layers; cross-bedding is common as is a surface caprock up to 0.5 m thick with root casts	Low (Stable)
Foreshore deposits (Bf)	Reddish brown to yellowish brown, fine to coarse quartz sand with common fragmented and whole shells of Anadara granosa with other broken molluscs; silt content is variable and predominates near the mouth of Beebingarra Creek; Holocene in age	High (Unstable)
Outwash plain with claypans (Wi)	Reddish brown to yellowish brown, very silty sands and sandy clays, locally with expansive clay or 'gilgai' between claypans; Pleistocene in age	Moderate
Outwash plain (Wf)	Reddish brown to yellowish brown unsorted silty sands with minor amounts of feldspar and rock fragments; highly variable silt content; greyish nodular calcrete is present in the subsurface; Pleistocene in age	Moderate
Sand ridge (Rt)	North-trending ridges generally 5-10 m above the surrounding plain comprising reddish brown, fine- to coarse-grained, poorly sorted sand with a low silt content; represents the remnants of an earlier (?pre-Pleistocene) coastal plain	Moderate
Colluvial footslope (Cf)	Quartz scree with small amounts of reddish brown sand and silt in the White Hill area	Moderate
Quartz ridge (Xl-q)	Sporadic outcrops, as north-south trending ridges of milky grey to white, massive quartz with patchy iron oxide staining	Low (Stable)

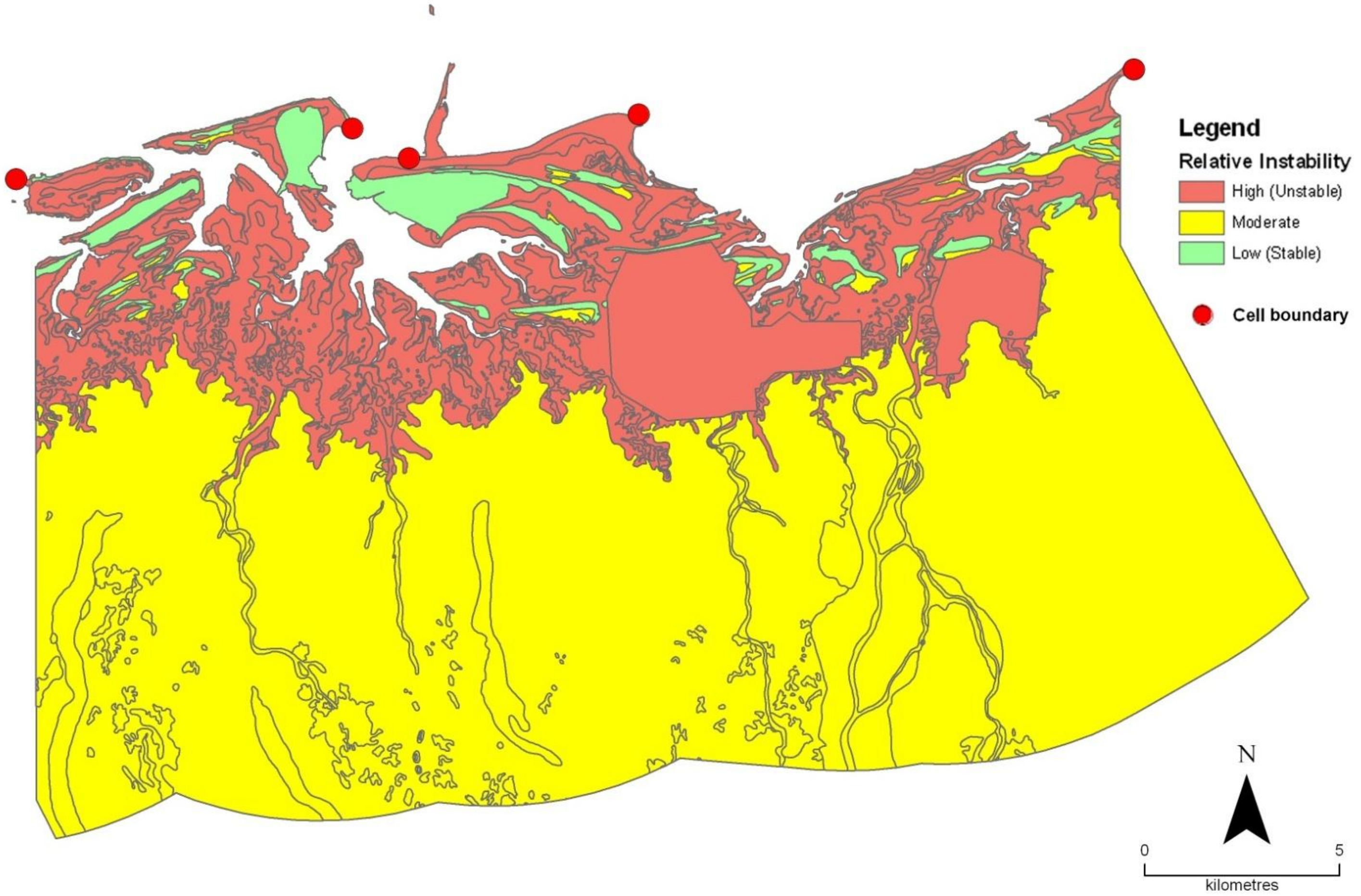

Figure 6-58: Port Hedland Area Landform Instability

In comparison with many other parts of the Pilbara, Port Hedland is relatively isolated from large river systems and consequently has limited fluvial sediment supply. Coastal sediment supply, including onshore drift from the adjacent shelf region, is limited due to coastal configuration and the presence of extensive rock ridges. Sediment supply is further constrained at a local scale within Hedland Harbour, with with only a small volume of material entering the basin and repeated dredging. The lack of sediment supply enhances instability, as it slows recovery after erosion events.

Susceptibility of the Port Hedland coast reflects variation of the geologic framework. Sedimentary coastal features along the Islands and Old Hedland coasts are largely fringing almost continuous limestone ridges, which are variable in elevation and experession. Rock features through Hedland Harbour and along Beebingarra coast are significantly less extensive, providing comparatively higher susceptibility at a sediment cell scale. Locally, these rock features are highly significant for the position of tidal channel structures.

At the cell scale, susceptibility, instability and vulnerability varies from moderate to high dependent on the level of rock control, sediment availability, exposure to extreme events and interaction between tidal and fluvial dynamics on the low-relief coastal floodplain landforms (Table 6-19 and Table 6-20; Figure 6-50). Cells with high vulnerability have extensive low-lying coast with floodplains and tidal creeks; with moderate vulnerability for cells with a higher-elevation coast with extensive rock control.

Table 6-19: Port Hedland Area Tertiary Sediment Vulnerability Rankings

Sediment Cell	Cell Boundaries	Inner Shelf Morphology	Subtidal Shoreface Structure	Intertidal Shore	Onshore Structures	Susceptibility Score	Susceptibility Ranking	Inshore Substrate	Rivers or Tidal Creeks	Frontal Dune Complex or Tidal Flats (Shoreline)	Hinterland Topography or Supratidal Mudflats	Instability Score	Instability Ranking	MATRIX SCORE	Vulnerability
22	Beebingarra: Cooke Point to Petermarer Creek	3	4	4	4	15	H	3	4	4	3	14	M	4	M-H
21	Old Hedland: Spoil Bank (W) to Cooke Point	3	3	3	4	13	M	2	2	1	5	10	M	3	M
20	Hedland Harbour: Finucane to Spoil Bank (W)	3	5	4	4	16	H	2	5	5	5	17	H	5	H
19	Islands: Downes Island to Finucane	3	2	2	4	11	M	1	5	1	5	12	M	3	M

Table 6-20: Port Hedland Area Tertiary Sediment Cell Vulnerability Implications
Susceptibility and Instability Rankings should not be used independently.

Area	No.	Cell	From Lat.	From Long.	To Lat.	To Long.	Susceptibility		Instability		Vulnerability		
							Rank	Implications	Rank	Implications	Rank	Risk	Rationale
Beebingarra	22	Cooke Point to Petermarer Creek	118.64023	-20.298541	118.75449	-20.288235	H	Natural structural features are extensively unsound. Major engineering works are likely to be required.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay).	M-H	Coastal risk is likely to be a significant constraint for coastal management.	The site has significant constraints due to a combination of low integrity of natural structures, poor natural resilience and/or moderate-high ongoing management requirements.
Old Hedland	21	Spoil Bank (W) to Cooke Point	118.58727	-20.308667	118.64023	-20.298541	M	Some natural structural features are unsound hence the area may require further investigation and environmental planning advice prior to management. Detailed assessment of coastal hazards and risks is advised.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay).	M	Coastal risk may present a moderate constraint for coastal management.	The site has constraints due to a combination of low-to-moderate integrity of natural structures, limited natural resilience and/or ongoing management requirements.
Hedland Harbour	20	Finucane to Spoil Bank (W)	118.57423	-20.301824	118.58727	-20.308667	H	Natural structural features are extensively unsound. Major engineering works are likely to be required.	H	Management responses require repeated installation or repair of major stabilisation works (eg. Port Geographe, Mandurah & Geraldton).	H	Coastal risk is a major constraint for coastal management.	The site has major constraints due to low integrity of natural structures, little natural resilience and high ongoing management requirements.
Islands	19	Downes Island to Finucane	118.49665	-20.313521	118.57423	-20.301824	M	Some natural structural features are unsound hence the area may require further investigation and environmental planning advice prior to management. Detailed assessment of coastal hazards and risks is advised.	M	Management responses are required to accommodate occasional major events, regular moderate events or frequent minor events. Responses may involve stabilisation work (eg. Cottesloe, Floreat & Broun Bay).	M	Coastal risk may present a moderate constraint for coastal management.	The site has constraints due to a combination of low-to-moderate integrity of natural structures, limited natural resilience and/or ongoing management requirements.

The high ranking of coastal landform vulnerability across the low-lying cells indicates that any coastal development is subject to significant management constraints that should be addressed with caution. In particular, treatment of storm surge and runoff flooding hazards requires careful consideration, as management of one threat may exacerbate the other hazard. This may be particularly significant for areas adjacent to tidal channel networks, which are highly dynamic and may episodically switch between expansion or contraction.

Tidal creek systems along the Port Hedland coast have been highly modified by human interventions, including infilling, closure (Finucane Island causeway), reclamation works, salt pond construction and interruption by roads, where culverts replace the natural channels. Arguably, these systems can be highly sensitive to such changes, transferring any loss of tidal exchange through the channel network (Perillo & Piccolo 2011; Woodroffe & Davies 2011). However, in comparison with other locations in the Pilbara (e.g. Onslow, Karratha), the tidal channels in Port Hedland have undergone relatively small response to imposed changes. This is potentially due to the limited availability of sediment supply from either marine or fluvial sources, but it is also likely that the relict (i.e. non-equilibrium) structure of Port Hedland Harbour contributes this apparently reduced sensitivity.

Visual comparison of aerial photography from 1949 to 2012 suggests that the majority of Port Hedland tidal channels have experienced minor expansion. Exceptions are provided where creek arms have been deliberately closed, either through reclamation infilling or construction of barriers, including Fincuane Island causeway and Rio Tinto salt ponds. Tidal channel dynamics are not typically problematic unless the channel interacts with nearby infrastructure. The most common forms of interaction are via drainage networks, with potentially complex response at culverts if they switch from fluvial to tidal conditions (Figure 6-59).

A key reason for considering the dynamics of tidal creek systems is that they demarcate the spatial extent of tidal activity, therefore indicating the likely area to change in response to sea level rise. The relative volume of available sediment suggests whether these areas may keep pace with sea level rise, or will respnd through drowning or profile adjustment (Semeniuk 1994). In some cases, modern creek dynamics provide a basic indicator of the likely pathway of future coastal evolution.

Local Coastal Sensitivities

For the open coast, the coastal sensitivity to mild variations of sediment supply (seasonal or inter-annual) and sea level rise vary with the level of rock control and landform type. The high rock control on Finucane Island, at Cooke Point and sections from Airey Point to Cooke Point results in the shoreline being relatively insensitive to weather systems and environmental change. Vulnerability increases for artificial or modified coasts, including ports and modified or flattened dunes, and dunes with lower-level rock control with reduced sediment supply. This includes the dunes landward of the spoil bank, from Crawford Street to Wodgina Street and the Goode Street dunes. Coastal response in these areas may include bed level lowering to underlying rock platforms, profile adjustment, rapid dune retreat and limited capacity for recovery after erosion events. Sections of low-lying coast adjacent to tidal creeks with low-level rock control features are suceptible to sea level rise if the rock control is reduced. This change is reflected in the ephemeral and migratory behaviour of spits and sandbars on the broad rock platforms, such as for sections of coast east of Cooke Point (Figure 6-58).

Figure 6-59: Culvert and Drain Interaction with Tidal Creek Channels (Source: Nearmap. November 2011)

Development of the spoil bank precinct and marina is vulnerable to sedimentation and storm surge. The pursuit of a marina in this location is legacy from the initial excavation works conducted in 1978 prior to the onshore migration of the spoil bank (Figure 6-60). The low-lying site is vulnerable to storm surge with anticipated wave runup and overwash during extreme events. The operability of the marina is vulnerable to sedimentation of the marina and entrance channel with high ongoing maintenance costs required. Navigation hazards will occur from sediment accumulation in the marina entrance channel with formation of flood tide bars and shoals inside the marina and migratory bars seaward. Sediment will impound on the northern breakwaters and structure of the marina and be transported into the marina basin via marine sediment transport and through wind drift over the structures. Significant basin infill may occur during a tropical cyclone event.

Figure 6-60: Initial Construction of the Port Hedland Yacht Club 1978
(Source: State Library of Western Australia. 24 August 1978)

Proposed concepts for the Pretty Pool precinct include a canal estate, a weir option with a road connecting Cooke Point to Pretty Pool or partial infill of the tidal flats. Council approved the weir concept in March 2010, with increased vulnerability to scour and poor water quality. The creek bed either side of the weir is vulnerable to scour in extreme events and to seaward during prevailing tidal behaviour. Modification of the tidal creek mouth will have implications for the adjacent coast and existing Goode Street and Pretty Pool developments.

Development has been permitted on small areas of higher vulnerability on sections of the sandy coast where sediment supply has been interrupted by the spoil bank. More vulnerable sections include those with lower elevation rock control and change in alignment of nearshore rock control, with modified dunes (DPUD 1992), reclaimed land, dunes with washover features and blowouts, and where drains discharge adjacent to higher rock platforms. Two locations with retreating dunes adjacent to infrastructure are near Wodgina Street (≈5-10m width to path and road) and Goode Street (≈15-20m width to a house). There is insufficient capacity for both dunes to withstand storm events without damage to infrastructure, with modelled retreat of ≈10m by a single event of TC John or TC Connie and 19-25m for a 500 year design event (Cardno 2011). The stability of the dune between the broader Steven Street and Pretty Pool, and infrastructure atop the dunes, is vulnerable to the reduction in sediment supply attributed to the Spoil Bank. Infrastructure located atop dunes is also vulnerable to increased overwash with sea level rise.

Structures located in the intertidal zone, such as boat ramps, are vulnerable to scour and sedimentation. Integrating boat ramps with rock platforms could reduce the scour of the toe by littoral and tidal currents. For example, scour is already occurring on the fixed concrete boat ramp recently installed inside Pretty Pool creek. Key recreation facilities located inside tidal creek mouths are further vulnerable to sedimentation and shoaling of the mouth.

Aeolian (wind-blown) sediment transport can accumulate on structures and properties. For residential and commercial properties this is a concern for impoundment, smothering, infill and sediment transport into ceilings with potential ceiling collapse. This is most likely to occur during extreme events, for example Tropical Cyclone Joan (1975) impounded sand on properties up to 2m vertically (DPUD 1992). A sufficient vegetation buffer to reduce wind transport is not available in the developed areas of Port Hedland.

Response to Sea Level Rise

The Port Hedland coast is strongly influenced by the underlying geologic framework, with surface expression in some locations. As a consequence, adjustment to sea level rise will not be uniform along the coast, invalidating the Bruun approach to estimating coastal change. Some of the likely responses are suggested by the present-day coastal dynamics:

- The seabed structure offshore from the Islands and Old Hedland is characteristic of a limited amount of sediment, held in place by rocky features. Offshore sediment accumulation is unlikely to "keep pace" with sea level rise;
- Coastal features held in place by high-relief rock are likely to have limited change, including perched dunes along Finucane Island and Old Hedland;
- Enhanced coastal change is likely to occur for those coastal sections which are presently influenced by sub-tidal rock features, such as between Webster and Wodgina Streets;
- Any regional reduction of sediment availability will be most strongly experienced in areas with limited sediment, such as is presently evident between Cooke Point and Pretty Pool;
- The main basin of Hedland Harbour is expected to have limited response to sea level change, as its formation does not reflect sediment flux equilibrium (through tidal exchange). However, the connected tidal creeks are more likely to be dynamic, with head-cutting and channel deepening anticipated;
- The Beebingarra coast has an extensive intertidal terrace, which is not strongly constrained by rock features, and therefore may potentially rise with sea level. Sediment demand by the terrace is likely to cause enhanced local coastal retreat, in the form of embayment deepening, between the existing dispersed rock controls.

Sea level rise will increase the incidence and extent of coastal flooding, dune overwash and risk of isolation. In present day conditions, sections of western Port Hedland, Redbank, the spoil bank precinct, pretty pool precinct, the Tjalkuwara (Tjalka Wara) Aboriginal Community (GEMS 2000b), the Finucane Island causeway and the main artery into Port Hedland from the North West Highway (Wilson Road) may be affected by water levels above +5mAHD (excluding setup and wave runup). This level is estimated to be the 100 year recurrence interval (Cardno 2011), which becomes the 25 year recurrence interval for a 0.9m sea level rise. Similarly, Wilson Road is impassable for large sections at the existing 500 year recurrence level, ≈6mAHD, which is equivalent to a 100 year recurrence interval in 2110 (Cardno 2011). This represents an increase in the likelihood of coastal flooding, requiring adaptation planning with regard to emergency management. Safe evacuation could only occur when water levels are <0.3m above the road, assuming Wilson road was not breached from flow through 4 Mile Creek.

Expanded development of recreation and camping facilities in areas prone to inundation, such as Bus Stop and Condon Landing (Cardno 2011), increases the number of areas requiring emergency management procedures.

Some utilities and key infrastructure are vulnerable to the increased coastal flooding, and exposure to wave forcing, with sea level rise. This includes:

- The potential inundation or scour damage of roads including Wilson Street, Styles Road (to Pretty Pool) and the Finucane Island causeway;
- Abutments for rail lines and port facilities, including the abutment for the railway line adjacent to Stingray Creek;
- Moving the existing wastewater treatment plant to South Hedland reduces the coastal flooding hazard, but increases the fluvial flooding hazard as it is located adjacent to South Creek on flood prone land;
- Salt pond levees; and
- The main power supply to town is located adjacent to Wilson Road and may be destabilised by scour or additional wave loading not accounted for in the pole designs.

Adaptation planning would be useful to mitigate risk by coastal inundation or breaching of this infrastructure, including strengthening or raising structures at low or weak points.

Local low points in dunes and roads may provide pathways for inundation waters. Cardno (2011) identified the Stevens Street area, including the recently extended Port Hedland Community Park and cemetery as potentially inundated in the 2110 scenario. Raising the land locally is unlikely to signficiantly reduce the inundation hazard to landward as inundation will occur via the low-lying areas of the old townsite and via Pretty Pool.

Runoff Flooding and Drainage Management

Large areas of Port Hedland are vulnerable to fluvial flooding as described and mapped most recently by GEMS (2000), GHD (2010), JDA (2010) and Cardno (2011). This includes sections of Wedgefield, South Hedland, port facilities and the Tjalka Wara aboriginal community. Local flood risk may be enhanced by the cumulative impact of downstream engineering modifications, such as reclamation and causeways, which has not necessarily been incorporated into these studies. These assessments have limited discussion on the potential widening, migration or avulsion of fluvial channels with no consideration of impacts of sand mining occurring in Beebinagarra Creek. Areas vulnerable to movement or widening of fluvial channels include road abutments and culverts, Riddle Street in Wedgefield, large areas of South Hedland including the extension of the wastewater treatment plant, and the salt pond levees adjacent to Beebingarra Creek.

Runoff and managed stormwater contributes to dune scour, destabilisation and retreat in the high rainfall environment. Rainfall from paved areas such as paths and carparks without formal drainage accumulates at low points and flows onto the dune, causing local dune scour and potentially undermining coastal infrastructure (DPUD 1992). Discharge of drains onto the beach, dune base or tidal flats causes local scour and bed lowering, contributing to enhanced coastal retreat over a broader area. Retreat may be further enhanced when drains are located immediately adjacent to sections of coast with rock controls at higher elevations, such as Wodgina Street (Cemetery Beach) and Barker Court (Goode Street Dunes). Dune scour and deflation may occur from burst pipes and overflowing pools. Prior erosion mitigation techniques of headwalls, rock piles and infilling of gullies with clay fill lined with rock rubble have exacerbated the response (DPUD 1992). The coastal plan (DPUD 1992) suggested allowing free movement of waves around a drain, without recommending active sediment management on the sediment starved coast.

6.4.5. Advice

Hazard assessment and risk mitigation for the Port Hedland area should follow the risk framework in Section 6.1, including separate considerations for erosion and inundation. Detailed information on erosion risk management has not been included in Section 6.1.

Various parts of the Port Hedland area are subject to coastal flooding, runoff flooding or a combination of the two. Any approach used for hazard mitigation should be cognisant of the potential transfer of risk to adjacent sites or other processes. This may include drainage focusing or deflection of floodwaters. An example of transfer between processes is where raising ground levels to reduce the risk of coastal flooding acts to constrain a runoff floodway and cause increased flood levels upstream of the restriction. A parallel issue may occur on coastal floodplains where barrier construction prevents landward propagation of surge waters, enhancing coastal runup and allowing more rapid development of coastal surge components that may enable higher total water levels. Any planning or potential mitigation works for areas prone to flooding should incorporate the requirements within the Better Water Management Plan (WAPC 2008b) at the relevant scale. This includes the planning of any new roads, such as the Port Hedland Access Corridor and Great Northern Highway Realignment (MainRoads 2007; WAPC 2009; Damara 2010). Flood hazard mitigation advice should be sought from the Department of Water with additional advice from the Department of Transport coastal engineers for works with a coastal component.

As a general guide, construction should be avoided within any floodways or the active coastal margin. This approach accommodates the large morphodynamics which occur in these locations without causing infrastructure damage. This general principle is consistent with the Coastal Zone Policy (WAPC 2001). Any construction within the active coastal margin would require preparation of a Coastal Hazard Risk Management and Adaptation Plan (WAPC 2013), with consideration of risk transferral through raising land and limited placement of culverts.

The recent coastal vulnerability study (Cardno 2011) found there is a shortage of available land in Port Hedland without coastal risk. The principal technique for making further land available in Port Hedland has been raising the land level which is expensive (ToPH 2011a). Considering the use of finished floor levels as a technique to manage inundation hazard on an eroding coast should also incorporate costs for erosion mitigation structures.

Application of emergency management principles should apply to flood hazard mitigation, considering isolation of aboriginal communities and residential properties in the main area of Port Hedland, Wedgefield and South Hedland, ensuring key facilities are located in areas of lowest practical risk and providing a suitable evacuation plan. Emergency management principles are necessary for any planning of tourist facilities or residential developments for Shellborough (Condon Landing), the Bus Stop and Six Mile Creek due to the inundation hazard. Emergency management requires effective warning systems, provision of cyclone shelters and evactuation plans that consider hazard along evacuation routes. The single access road for many areas of Port Hedland, such as Pretty Pool, and surrounds may be subject to flooding or erosion at relatively moderate levels, potentially providing a major constraint for emergency management. Adaptation funding, or allowance for ongoing maintenance should be secured for roads potentially vulnerable to washout due to migration of tidal creeks or inundation.

Adaptation to future conditions may require maintenance or fortification of both natural and artificial existing barriers to ensure they have sufficient structural capacity to minimise erosion and inundation hazards. It is advisable not to excavate, lower or mine natural barriers to inundation or wave action. Improved stabilisation of existing near-coast infrastructure, particularly footpaths and roads atop dunes, is likely to be required in coastal areas which actively respond to sea level rise if sediment management is not conducted.

It is important to note that definition of setback allowances may have little resemblance to prediction of likely coastal change. This most significant difference is caused through the use of a constant coastal response to sea level rise, which is extremely unlikely to occur in Port Hedland due to the highly variable presence of rock features.

Sediment transport on the inner continental shelf is highly dynamic, and may dramatically switch from prevailing tide-dominant conditions to transitory extreme responses to tropical cyclones. These changes may allow large changes in landform structure, which in turn modifies the nature of transport. Sediment transport under a broad range of environmental conditions may require consideration for coastal developments, particularly where the reliability of sediment supply may affect sedimentation or post-erosion recovery rates. This is particularly evident along the perched dune systems, such as occur on Cemetery Beach and Goode Street dunes, where both erosion and recovery mechanisms are outside ambient conditions. Factors to consider for sediment supply for rock controlled shores of the Pilbara include the:

- floodplain response;
- sub-tidal terrace response;
- influence of the rock framework, including reduced capture capacity of control features with varied mean sea level;
- variation in proximity to sediment supply within a sediment cell;
- modification of sediment supply and transport due to the spoil bank;
- feature capture and rebuild behaviour; and
- variation in sediment supply from rivers, tidal creeks and offshore with associated landform response.

The relative supply of sediment to the floodplains and the flats of Port Hedland and likely evolutionary pathways have not been established. The connectivity of alongshore transport within sediment cells requires consideration for any coastal development. Any facility or coastal works in the Port Hedland area should be designed or managed to minimise downdrift impacts.

The dynamics of sediment transport is of particular relevance in assessment of coastal development impacts on post-event recovery processes and pathways, including:

- Any **structure on beaches, perched beaches or spits** should be designed to minimise downdrift impacts, potential sediment accumulation and sand-drift issues. In this context, sand drift management may be required at the proposed spoil bank marina and the Oyster Point boat ramp;
- Plans to dispose of large amounts of **dredged material** (e.g. any future capital or maintenance works) should consider mechanisms for return of material to the dredged channel or onshore transfer as per the GEMS (2010) investigation. This study considered the stability of a number of disposal locations in Port Hedland. The impacts of prior dredged material disposal on long-term sediment transport pathways should be carefully evaluated for future management of the spoil bank and the adjacent coast;
- Any **structure extending onto tidal flats** should be designed or managed to minimise impacts on tidal flows and sediment movement under cyclonic conditions;
- Any works incorporating **excavation of inter-tidal rock and terraces** should be designed to minimise offshore loss of material through the excavated area;
- **Cumulative impacts** of prior engineered modifications should be considered for any works;
- Any **structure on dune crests or overwash features** should be designed to allow for overwash, erosion, sand drift and stormwater runoff with allocation of sufficient maintence funding. The structures may include the Staircase to the moon carpark, Cooke Point caravan park, footpaths, viewing platforms and boardwalks (DPUD 1992; Ecoscape 20054, 2007);
- Any **emergency dune stabilisation works** should avoid placing rocks at the toe of the dunes; and
- Any **stormwater discharge** to the coast should consider scour capacity, rock control and implications for the adjacent coast.

Stormwater discharge to the coast should be managed to reduce sediment scour and associated dune retreat and undermining of infrastructure. Present planning documents for stormwater management in Port Hedland (DoW 2007; WAPC 2008; ToPH Information Sheet 5 Stormwater Drainage) have limited consideration of coastal response to stormwater discharge or the need for drainage management from all paved areas in high rainfall environments. The Town of Port Hedland information sheet could be updated with advice for:

- siting of new drains;
- incorporating drainage management for any paved areas on or adjacent to the beach or dunes;

- reducing impact of discharge from local drains from car parks and paved areas through scour management and shifting of outlets from base of dunes;
- reducing impact of discharge to tidal flats, especially adjacent to fill areas; and
- emergency dune management due to drainage scour with an explanation of how dumping of rock fill may exacerbate erosion.

An adaptation study could be conducted for the management and possible relocation of the two large drains at Wodinga Street (Cemetery Beach) and Barker Court (Goode Street Dunes) including life-cycle costing.

Road modification and salt pond expansion projects should consider drainage management and culvert design in relation to the existing tidal creek network and anticipated change with sea level rise. The studies could incorporate:

- Restriction of flow through runoff channels (inadequate culverts);
- Increased flow speeds due to head build up behind culvert;
- Increased channel structure through focus through drain/culvert; and
- Impact of modification of tidal prism of the main creek channel.

Active coastal management may be required in the sections of sandy coast without high-level rock control. Required management includes previous recommendations for consolidating and managing beach access, reducing 4WD use on the coast, reconstruction of dunes in the Crawford Street to Wodgina Street area to remove clays and replace with sediment conducive to revegetation and dune management (DPUD 1992; Ecoscape 2004, 2007). Dune management should be a combination of revegetation techniques and providing a sediment source for the dunes on retreating coasts. The spoil bank material impounding on the yacht club structures could be investigated as a source for active sediment management east of the spoil bank and between Cooke Point and Pretty Pool. Any management option, or recreation facility, should be considered using life-cycle costing incorporating maintenance following tropical cyclone events and due to ongoing coastal retreat. Life-cycle costing of recreation facilties, sediment supply and dune stability should be incorporated into landscape and recreation plans for each coastal sector (Ecoscape 2004, 2007).

Active coastal management for remediating wind drift of sediment should incorporate the cause of any dune instability. Revegetation may reduce the amount of wind drift in areas of small dune blowouts or destabilisation due to uncontrolled access. Revegetation may also be useful for a non-eroding duneface that only becomes active in extreme events with rapid post-event recovery. Treatment of the cause of erosion is required in areas with chronic erosion of the dunes, with intermittent activities to minimise wind drift likely to be short-lived in effectiveness. Short-term measures such as dumping of rock fill is likely to exacerbate the problem.

The Spoil Bank is a migratory feature presently collapsing against the shore. Historically, sediment accumulation has occurred in the entrance channel and the harbour basin. The Spoil Bank precinct requires a detailed investigation of coastal hazards and risk mitigation prior to preparation of structure plans including surge risk, potential sedimentation, uncertainty of future sediment supply and emergency management. The feasibility of marina operability should be assessed in the context of requirements of ongoing dredging and active sediment management, along with all associated costs.

The Pretty Pool precinct, including land made available from the relocation of the wastewater treatment plant, also requires a detailed investigation of coastal hazards and risk mitigation. A preliminary feasibility study for the council-approved weir option should consider cost-benefit analysis along with environmental impacts, modification of the adjacent coast and emergency management requirements. Costs should consider total construction and maintenance costs, and funding to manage poor water quality due to creation of a salt pond, management of scour adjacent to structures, and implications of modifying the tidal creek mouth on the adjacent coast and the existing developments. Further costs are likely to be required for emergency management and post-event clean up as the plans may increase the number of people in a high surge hazard environment. Preliminary concepts suggest the Cooke Point Caravan Park would be replaced by high density hotels and development. Temporary sites, such as Caravan Parks, are development with an accepted level of risk which is likely to be unacceptable for such high capital developments.

There is potential significant environmental risk for collapse or breach of any seaward levees of the Rio Tinto salt ponds to the east of the Port Hedland. However, these facilities are third-party owned and managed, which provides a constraint upon risk management for the Town of Port Hedland Shire, who are not responsible for levee upkeep and adaptation. Any future expansion of the salt ponds should incorporate increased risk with potential sea level rise and the cumulative impact of the salt ponds on sediment supply to the Beebingarra sediment cell.

Expanded wastewater treatment facilities are commencing in South Hedland. A hazard and risk mitigation investigation should be prepared for the proposed eastward expansion as it encroaches into flood-prone land. If future expansions incorporate any sewage outfalls to the ocean, Source-Receptor-Pathway investigations are required for managing environmental and health risk given the broad shallow nearshore and tidal flats.

6.4.6. Further Studies

The following projects have been identified as being useful to the management of the Port Hedland coast:

- *Flood Hazard Building Criteria*. One-off identification of building design requirements in flood affected areas, with ongoing education and auditing programs to assist land owners.
- *Post-event surveys*. Ongoing program of post-flood surveys to assess influence of local processes. This information should be used for post-validation of inundation assessments.
- *Tidal Creek Baseline Assessment*. Identification of sites with values at risk, monitoring, triggers and possible management actions.
- *Evaluation of Runoff-Surge Coincidence*. Assessment of the potential for flood runoff and cyclonic storm surge to be coincidental, to facilitate floodplain hazard modelling and mitigation.

- *Aggregation of Stakeholder Data*. Formation of database identifying available information collected by government organisations and resource companies that is directly relevant to coastal planning and management.
- *Inundation Review*. Confirmation of previously modelled synoptic climate and comparison of model performance against tide gauge records for low-level flooding every 5-10 years. Post-event flood surveys on an opportunistic basis.
- *Use of the Spoil Bank Material*. A one-off study considering the feasibility of using the spoil bank material for active sediment management or infill.
- *Coastal Change Evaluation*. Collation of geotechnical information, evaluation of sediment availability and foreshore beach survey analysis, every 3-5 years if new information has been collected as part of other projects.
- *Coastal System and Barrier Stability Assessment*. Geophysical and geotechnical assessment of the existing barriers that provide primary protection for infrastructure and residential areas in Port Hedland. Identification of monitoring, triggers and opportunities for strengthening. The assessment of the broader system includes one-off identification of key coastal change indicators relative to baseline assessment of coastal barrier dune and tidal creek systems.
- *Coastal Adaptation and Flood Hazard Adaptation Study*. One-off study to outline possible risk mitigation measures, monitoring and triggers. The flood study would also identify exclusion zones that may allow cost-effective flood mitigation.

These studies are outlined in more detail below.

The Port Hedland area has a complex topography, comprising many low-lying areas of extensive floodplains, rivers and drainage channels which flood events likely to affect a large number of residential and commercial properties. It is difficult to continue raising fill for new development areas to limit inundation risk. Within flood hazard areas, the potential for economic loss associated with flooding may be dramatically reduced through consideration of suitable design principles (ABCB 2012) and flood preparedness (EMA 2009a). Substantial additional guidance regarding building design and retrofitting is available from US Flood and Emergency Management Agency (FEMA 2005, 2009, 2011). This information should be made available to landowners, requiring an appropriate communication and education strategy. Following from the findings of wind-related damage after TC Yasi, a program of auditing is required to maximise the effectiveness of building design principles as a risk mitigation tool. It is recognised that this will require capacity building for the auditing agency.

Existing inundation models are largely unvalidated, with only a few well-recorded historic examples of tropical cyclone extreme impacts and limited representation of local processes within the models. Hence, future events may provide an opportunity for both further model verification and identification of sub-scale variability of flood hazard. At the coast, local processes include wave setup and overtopping, with similar factors along streams for bend-effects, hydraulic jumps and changes to channel morphology. Post-flood surveys enable the relative importance of these local processes to be assessed on-ground, which facilitates more refined scaling of setbacks and design of any adaptation works. Whilst the survey extent will vary according to the spatial signature of each event, the program should evaluate flooding in close proximity to development areas, and capture the variations with different landform types. Landform maps described in Section 6.4.3 (Figure 6-50 and Figure 6-58), along with LiDAR collected for LandCorp and the hillshade DEM within *WACoast* (Gozzard 2012a), may assist selection of survey coverage.

Historic observations suggest that coastal change in the Port Hedland area occurs focally, with potential for significant advance and expansion of tidal creek networks, particularly under projected sea level rise scenarios and in response to engineering works. Creek movement is likely to require active management given the proximity of creeks to coastal development, including pressure for reclamation at the margins of coastal lagoons. Aerial imagery analysis provides a preliminary means of historic assessment, but provides only limited guidance for future behaviour. The actual imagery should be viewed, rather than solely relying on plotted shorelines, to provide indication of response to events and determining when human interventions are modifying geomorphic response. It is also recommended that a tidal creek baseline assessment be undertaken within an adaptive management framework. The assessment should identify sites with values at risk, along with defining a monitoring program, triggers and possible management actions. Monitoring and management may be tied to the environmental approvals process, in limited situations, for large scale and industrial developments.

A single feasibility assessment could be conducted to determine if the spoil bank material could be used within Port Hedland. The spoil bank is starving the coast to the east of a sediment supply and the capacity for reversal of sediment transport. Other locations where projects interrupt sediment transport such as Dawesville, Mandurah and new project Wheatstone require sediment bypassing and active sediment management. Bypassing of spoil bank material could reintroduce sediment the sediment starved coast between Cemetery Beach and Pretty Pool. Investigation is needed into effective techniques for transferring the sediment, cost and environmental impacts. Another option is to use material for complete infilling of the Pretty Pool creek area for residential development.

Considerable development in Port Hedland occurs within the coastal floodplain, where there is potential for coincidence of flood runoff with cyclonic storm surge. This has been incorporated in Cardno (2011) through consideration of a 100 year surge coincident with a 30 year runoff event, or a 10 year surge with a 100 year runoff event. For non-cyclonic regions this is discussed in *Interaction of Coastal Processes and Severe Weather Events* (Westra 2012), which acknowledges the relationship of runoff-surge coincidence to catchment and coastal lagoon scales, with smaller areas more likely to have joint occurrence. Evaluating the flood hazard more accurately in Port Hedland may require assessment of high frequency pluviograph and radar datasets, combined with tide gauge and flood measurements. A major advantage of refining the flood hazard assessment is to more accurately assess potential benefits of hazard mitigation.

Runoff and coastal flooding hazards are evaluated on the basis of limited available historical flood and rainfall records, requiring periodic review to confirm the modelled synoptic climate and compare model performance against observed floods. Recent comparisons of rainfall and flood gauge records for Port Hedland or the wider Pilbara suggest that early estimates have generally under-represented the potential for runoff flooding (JDA 2009).The scheduled revision of *Australian Rainfall & Runoff – A Guide to Flood Estimation* (Pilgram *ed.* 1987), due for completion in 2012, should be evaluated to determine if previous flood hazard assessments require reconsideration. The most recent studies of coastal flooding for Port Hedland (Cardno 2011) use relatively up-to-date synoptic data, and therefore may be adequate for the immediate future, although it was identified that the events used for model validation were all low.

Ongoing review of inundation hazard levels is appropriate, which may include identification of mean sea level trend from tide gauge records or altimetry (e.g. Australian Baseline Sea Level Monitoring Program); confirmation of previously modelled synoptic climate (e.g. as identified by Harper 2009) and post-event validation of tropical cyclone flooding, such as the wrack-line surveys reported by Nott & Hubbert (2005).

Extensive coastal data and model output is collected by government organisations and resource companies in Port Hedland. Information has been collected for the following organisations or their predecessors: Town of Port Hedland, Port Hedland Port Authority, Western Australian Planning Commission, Public Works Department, LandCorp, BHP, FMG, Roy Hill, NWI and Dampier Salt. Although access to this information is potentially commercially restricted, an information-base identifying what exists may provide an invaluable resource for coastal planning and management. Ideally the information-base should be accessible through a portal system similar to the *Australian Ocean Data Network*, developed for publically accessible data and model outputs from Western Australian Integrated Marine Observation Systems (WAIMOS), Bluelink and Western Australian Marine Science Institute (WAMSI) coastal node projects.

The existing evaluation of coastal change is based upon a simplified evaluation of potential coastal erosion, based upon mapping from historical aerial imagery and SBEACH modelling (MP Rogers & Associates 2006; Cardno 2011 Appendix D). This does not sufficiently consider the presence of rock, the relative availability of sediment supply from the nearshore, impact of the spoil bank to the east, the dune barrier capacity, overtopping and landform connectivity. Refined erosion risk assessment for sites in Port Hedland may involve collection of information collected by field survey or geotechnical investigations, and visual assessment of landform response from old aerial photography prior to residential developments.

Construction of road embankments and residential areas on the coastal dune barrier at Port Hedland results in increasing the erosion risk east of the Spoil Bank. Simple evaluation of sea level rise and extreme tropical cyclone impacts suggested that the barriers may be eroded or inundated in the future (Cardno 2011 Appendix D), although the presence of high-level rock within the barrier may significantly ameliorate the threat. A detailed stability assessment for the coastal barrier is recommended when considering site specific projects, incorporating geophysical and geotechnical measurement of the dunes. A further consideration is the potential for drastic modification of the dune and tidal creek landforms east of the spoil bank due to modifications in sediment supply and transport processes, particularly in the face of potential climate change. Due to the high level of uncertainty associated with projected change, the stability assessment should identify a monitoring program, triggers for management relative to a baseline assessment and opportunities for strengthening the dunes or active sediment management programs.

Existing coastal studies for Port Hedland include inundation and erosion assessments. These provide a basic measure of "worst-case" events that may affect Port Hedland and are arguably focused towards "100 year events", with restricted ability to describe less extreme variations in water level or coastal change, with limited consideration of landform response. This limitation is important in the context for providing risk-based coastal management and planning adaptation (Section 6.1), as Port Hedland is already affected by less-severe events, with active risk mitigation measures including an evacuation warning system and large reclamation structures. Some areas of the existing town site are strongly challenged by projected sea level rise, such as the Spoil Bank and Pretty Pool, with limited ability to use 'Avoid' or 'Retreat' management pathways in the Avoid-Retreat-Accommodate-Manage risk mitigation hierarchy. This places greater importance on assessment of risk likelihood and the associated economic consequences of risk accommodation or acceptance. A coastal adaptation study that identifies possible adaptive measures for risk mitigation, with associated monitoring and triggers would facilitate planning for Port Hedland and its facilities.

Further coastal studies could include:

- Coastal response to reduced sediment supply and altered coastal processes east of the spoil bank;
- Coordinated adaptation and management, including drainage management, for the narrow dunes at Sutherland Street near Wodgina Street and at Goode Street;
- Investigation of the cumulative coastal impacts of the Spoil Bank marina and Pretty Pool precincts, along with management requirements; and
- Implications of roads, railways, fill levels and salt bunds on tidal creek expansion and response.

The pressure for industrial and residential growth in Port Hedland is such that development is pushing the limit of the planning envelope, which for much of the town is defined by runoff flooding zones. This situation creates reduced capacity for adjustment to changes in flood hazard, which may occur due to channel dynamics, climate variability or occupation of the flood fringe. Consequently, following the principles of the *Better Urban Water Management Plan* (WAPC 2008b) it is recommended that development planning within Port Hedland is supported by a flood hazard adaptation study (Section 6.1.6). The study rationale should consider economic value, identifying where carefully selected development exclusion zones may allow cost-effective flood hazard mitigation rather than intensive engineering solutions.