Wetlands of the northwestern Great Sandy Desert in the LaGrange hydrological sub-basin

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GREAT SANDY DESERT
OCTOBER 1999

KALJI

RED SAND

September 2000

Wetlands of the northwestern Great Sandy Desert

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Executive Summary

1. The objectives of this study were to identify wetland types in the northwestern Great Sandy Desert, preliminary identify wetlands of significance, and determine the hydrological mechanisms maintaining them.

2. A major part of the work was a desk study, but field surveys were undertaken to verify aerial photograph patterns, collect information not currently available, and upgrade information where resources were not available in enough detail.

3. Three classifications for inland wetlands were used, each serving a different purpose: 1. a practical genetic one designed for this study that assigns wetlands to hydrological maintenance (*e.g.*, "oases" as windows to a water table, "pans" as perched water basins, and "springs" as wetlands fed by upwelling water or seepage); 2. terms used by the local communities (*e.g.*, "jila"); and 3. a scientific classification (*e.g.*, lakes and sumplands as permanently and seasonally inundated basins, and peat mounds as self-emergent mounds of peat). A correlation between the three is provided. Marine coastal wetlands were classed as tidal mud flats, tidal sand flats, tidal creeks, and beaches.

4. Wetlands are also classed as to their inter-relatedness ("consanguineous suites"), in that they may have similarity because they occur in similar geomorphic, geologic, and hydrologic setting, and/or because they have formed by similar underlying processes. Recognition of inter-related suites is important for comparative, for management, and representative conservation purposes. Nine consanguineous suites are identified:

Geomorphic setting	Name of consanguineous unit
linear desert dune fields	Kidson Track Suite
sand plain developed on sandstone plains	Dampier Downs Suite
rocky ranges and tablelands	Geegully Creek Suite
straight chains of playas	Salt Creek Suite
meandering chains of playas	Lake Auld Suite
clusters of playas	Dragon Tree Soak Suite
coastal plain/ribbon	La Grange Bay Suite Mandora Suite Injudinah Suite

5. Wetlands are assessed as to their "value" and "function", "value" referring to the importance, merit, or worth of a wetland after evaluation, and "function" referring to the role a wetland performs in its natural setting (*e.g.*, it may be a local water source for fauna, local food source for fauna, drought refuge for avifauna, breeding ground for avifauna, hydrological discharge zone, collection point for a range of ephemeral drainage lines, and habitat for biota.

6. From a regional perspective, the northwestern Great Sandy Desert area, located in tropical northwestern Australia, is one of the driest regions of Western Australia. It contains desert of linear dune fields, rocky deserts, and coastal plains, the latter containing a range of smaller scale landform units such as relict/stranded coastal flats, mangrove coasts, tidal flats, coastal dunes, and rocky shores, amongst others. The Study area is underlain by the Broome Sandstone, lateritized (ferricreted) sandstone, red dune sand, local fluvial deposits, and coastal deposits.

7. The flora in the wetlands can be categorized into several common assemblage types that occur in specific habitat settings; these are:

Habitat type	Description of vegetation and main species
Inland wetlands	
Lakes, playas, sumplands, and damplands	*Acacia ampliceps, Byblis liniflora, Centipeda minima, Dactyloctenium radulans, Fimbristylis ferruginea, Ipomea polymorpha, Pluchea rubelliflora, Schoenoplectus subulatus, Sesbania cannabina, Sesbania formosa , Sporobolus virginicus, Stylidium desertorum, Typha domingensis*
Creeks and wadis	*Acacia ampliceps, Acacia spondylophylla, Acaica farnesiana, Bulbostylis barbata, Byblis liniflora, Centipeda minima, Cyper bulbosus, Cyperus difformis, Cyperus ixiocarpus, Cyperus rigidellus, Cyperus squarrosus, Cyperus vaginatus, Rhadinosta* ssp *rhadinostachya, Eucalyptus camaldulensis, Fimbristylis ferruginea, Fimbristylis littoralis, Lipocarpha microcephala, Melaleuca glomerata, Pluchea rubelliflora, Schoenoplectus subulatus, Sesbania formosa , Sphaeranthus indicus, Trichodes zeylanicum, Triglochin centrocarpum, Typha domingensis*

Floodplains and barlkarras	*Bulbostylis barbata, Cyperus blakeanus, Cyperus bulbosus, Cy rigidellus, Cyperus rigidellus, Dactyloctenium radulans, Dysph glomulifera, Dysphania plantaginella, Eucalyptus victrix, Lipocarpha microcephala, Melaleuca glomerata, Pluchea rubelliflora, Pluchea tetranthera, Sporobolus australasicus, Streptoglossa odora, Trichodesma zeylanicum*
Peat mounds and p basins	*Acacia ampliceps, Avicennia marina, Byblis liniflora, Fimbristy ferruginea, Paspalum* sp., *Schoenoplectus subulatus, Sesbania formosa , Sporobolus virginicus, Typha domingensis*
Coastal Plain and Marine wetlands	
mid-tidal to high ti mud flats	zoned mangrove formations: mainly *Avicennia marina, Rhizoph stylosa, Ceriops tagal, Bruguiera exaristata, Camptostemon schultzii, Excoecaria agallocha* (see Semeniuk *et al.* 1978; Semeniuk 1983, 1993)
high-tidal mud flat	saltmarsh (samphires): *Halosarcia* spp, *Threkeldia, Batis agric*
contact between tic mud flats and freshwater seepage zone	saltmarsh (samphires): *Halosarcia* spp, *Threkeldia, Batis agric*

8. In terms of fauna, information on avifauna and general fauna was compiled by Australasian Ecological Services with information up to June 1999. The wetlands viewed as significant from this perspective of avifauna include the Eighty Mile Beach Wetland System, the Mandora Wetland System (= Salt Creek playa chain), the Roebuck Bay Wetland System, and the Roebuck Plains Wetland System.

9. The hydrology of the Great Sandy Desert can be divided into 3 zones: 1. a northern section, north of the Salt Creek playa chain where mainly fresh groundwater resides at depth within the Broome Sandstone, with the water table located in excess of 10 m below the ground surface; a southern section, along the Salt Creek chain wherein fresh, brackish to saline groundwater is shallow, located beneath a calcrete and limestone sheet; a coastal section, where fresh to saline groundwater is located in coastal aquifers.

10. In relation to these hydrologic settings, wetlands in the region are maintained by: 1. surface water flows from the drainage lines; 2. water table rise in the unconfined surficial aquifer; 3. ponding/perching of meteoric water by the near-surface hardpans; and 4. by upward leakage from formational waters. Discharge of groundwater relevant to this study occurs along the coastal zone, and in a zone where the Salt Creek drainage line is present; the former is the interface between the groundwater of the inland regions discharging along the shore zone under the regional hydraulic head; the latter is an interface of discharge formed by the incision of a former ancient (Cenozoic) river system.

11. The stratigraphy of the region is important to the hydrological functioning of the wetlands. The main and important stratigraphic contexts are: 1. the Mesozoic Broome Sandstone aquifer, with its internal depositional sedimentary stratigraphy; 2. the Cenozoic dune sand aquifer; 3. the interaction between Quaternary coastal mud deposits and the sandy inland aquifers (Broome Sandstone and dune sand); and 4. local clay lenses. The coastal mud deposits are referred to as "kalji".

12. The Broome Sandstone is a large sheet-like body of sedimentary rock that is ***not internally homogeneous in terms of rock types and cementation.***

13. In terms of rock types, and interlayering, within the Broome Sandstone there are changes in sedimentary rock types that reflect basin-wide changes in sedimentary depositional regime. The Broome Sandstone, as exposed in outcrop, was deposited in a variety of environments, ranging from medium gradient fluvial (sand dominated) to low-gradient fluvial (sand and some mud sheets) to coastal tidal flat (sand with more abundant mud sheets). The change from fluvial sand dominated to sand-and-mud tidal flat dominated is from the Pilbara Craton and the Kimberley Block (to the south and to the north, respectively), and from east to west towards the ancient "Indian Ocean". These sedimentary transitions have major implications on the hydraulic properties and across-aquifer transmissivity of the Sandstone, in that there will be local to subregional groundwater confinement.

14. In terms of cementation, the Broome Sandstone, is variably cemented to wholly uncemented. There are two patterns: the Sandstone is cemented in a relatively thin upper zone forming a sheet parallel to the present land surface, and is also differentially cemented in mosaics in the subsurface. With the former, the cementation is an iron oxide and silica, related to weathering and dust impregnation. With the latter, the cementation is silica, and probably a groundwater-related phenomenon. These cementation styles also have implications on the hydraulic properties of the Broome Sandstone.

15. There are eight situations, mechanisms, or processes that can maintain wetlands hydrologically: these are: 1. window to a water table, 2. surface perching of meteoric water, 3. subsurface perching of meteoric water and run-off, 4. run-off recharged, 5. groundwater upwelling (springs) inland, 6. groundwater upwelling (springs) coastal, 7. impedance to coastal zone discharge by coastal muds, and 8. seawater recharge,

16. Wetland types and their hydrologic maintenance are described firstly in terms of their geographic and geologic setting, viz., coastal wetlands, inland wetlands, and those developed along the Salt Creek Line.

17. For coastal wetlands, the interaction of coastal mud and the discharge of groundwater from the inland aquifers is very important. There are five wetland settings along the coastal zones, with their distinctive stratigraphic setting hydrologic setting, and their resulting wetlands.

18. In the first case of coastal wetlands, where there is a large discharge of freshwater into the coastal zone, relict early Holocene "kalji" (~ 7000 years old) impedes the freshwater forming small to large clusters of lake-like wetlands. In a second setting, where there is low discharge of freshwater into the coastal zone, relict early Holocene "kalji" (~ 7000 years old) impedes the freshwater forming damp terrain. In the third case, where there is a large discharge of freshwater into the coastal zone, appropriate conduits and pathways in the Broome Sandstone result in springs forming along the upper shore zone. In the fourth case, where there is a discharge of freshwater into the coastal zone, appropriate conduits and pathways in the Broome Sandstone result in springs forming on the low tidal zone. Fifthly, marine water recharges and maintains tidal flat and mangrove systems, and there is an interplay between marine versus freshwater maintenance. The resultant wetlands are marine wetlands.

19. For inland wetlands, the situations of the main groundwater system, any local perching of meteoric water and local upwelling of groundwater are important to the development of wetlands. There are five wetland settings within the inland systems, each with distinctive stratigraphic setting hydrologic setting, and their resulting wetlands.

20. In the first case, there are large to small "oases" or playas, developed along drainage lines where there is a large fluvial discharge. These situations are channels that are windows to the regional water table, and as such there is large evaporation of the groundwater, with the result that these wetlands are salty. In the second case, pans/playas are developed along the same currently dominant drainage lines, but with overflow from the fluvial discharge, there is local ponding of water to form clay-lined pans. In the third situation, there are small pans, or playas, developed along relict drainage lines where there is a large discharge along buried channels, with local expression of ponding due to muddy surface layers. The resultant wetlands are clay or muddy sand floored playas. The fourth situation are pans developed along low relief drainage lines where there is small fluvial discharge. The fifth setting are springs where there is significant freshwater upwelling, and the resultant wetlands are peat mounds.

21. The Salt Creek Line is a significant discharge zone, but it is complicated, because although it functions to discharge groundwater along the ancient riverine incision, it also is plugged with "kalji" mud accumulated at least since the Quaternary (perhaps 2 millions years ago to the present). It has an east-west change in sediment types, from fluvially dominated in the east along the drainage line, to estuarine and fluvial interlayering in the middle tract sections, to estuarine-marine dominated in western tract sections. Wetlands along the Salt Creek drainage line are of four types. The first results from the ponding effect of the "kalji" mud. The second is due to the upwelling of groundwater along the discharge line to from local springs. The third is the local ponding along the fluvial tract.

22. A range of field case studies of the coastal and inland wetlands was undertaken during this project: those wetlands in coastal settings, those in inland settings, and those located along the former estuary (Salt Creek Line). In addition, patterns of vegetation were assessed in the field and from aerial photographs and remote sensing techniques to determine the extent of phreatophytes (groundwater dependent vegetation). The various field study sites, themes within these settings, and their implications are listed below.

Coastal wetland sites	
La Grange Bay tidal muds and mangroves	illustrates maintenance of mangroves and tidal fla marine water recharge
Freshwater discharge and beachrock	illustrates the importance of freshwater seepage in the shore zone through sandy coastal sections
The "kalji" seepage model	illustrates seepage of freshwater into the muddy u shore zone by interaction of hinterland groundwat and "kalji"
Tidal zone freshwater seepage	illustrates seepage of freshwater into the tidal zon preferred pathways and conduits
La Grange subterranean freshw "streams"	illustrates seepage of freshwater into the upper sh zone by preferred pathways and conduits
Roebuck Plains pattern	illustrates seepage of freshwater into the muddy u shore zone by interaction of hinterland groundwat and "kalji"

Inland wetland sites	
Munro Springs playa model	illustrates wetland formed as terrain intersects the water table; playa is salinized
Munro Springs perched pan mc	illustrates ponding of fluvial overflow water to maintain wetland
Munro Springs peat mound mo	illustrates upwelling of groundwater to levels abo the regional water table to maintain wetland and develop a peat mound
perched pan inland from Bidyadanga	illustrates ponding of meteoric water to maintain wetland
perched pan inland from Bidyadanga	illustrates development of wetland at surface abov buried fluvial channel, and hence subterranean perching of fluvial water

Former estuary sites	
Salt Creek drainage line dynan	illustrates the interaction of the Salt Creek incisio with a range of sedimentary fill along the incision develop a range of wetlands through marine water intrusion, meteoric recharge and ponding, regiona groundwater discharge along the incision line, flu water overflow and baseflow
The 7000 year Mandora draina lines	illustrates the extent of the 7000 year sealevel highstand, and the resulting sedimentary fill
The former coastal estuary	illustrates development of wetland and perching o meteoric water by the sedimentary fill within the former coastal estuary to as far back possibly as th Cenozoic
Salt Creek peat mounds	illustrates upwelling of groundwater to levels abo the regional water table to maintain wetland and develop a peat mound

23. Analysis of aerial photographs and remote sensing images provided little evidence of extensive and regionally detectable groundwater dependent (phreatophytic) vegetation. The obvious vegetation patterns were related to creek lines, valley tracts and basins, and these patterns were relatively easy to extrapolate with the available techniques.

24. Evaluation of wetlands in the region was undertaken, and this required an understanding of the particular wetland, (through field data inventory and monitoring), an understanding of its context in a regional setting, and an understanding of the range of wetland functions. The study area contains a large number of wetlands, many of which are inaccessible, and therefore, what has been undertaken, is a preliminary analysis based on the current available knowledge of wetland attributes and values. The following criteria were used in evaluation: representativeness of a consanguineous suite, scarcity of wetland type, habitat diversity, geomorphic/landscape values and geoheritage, faunal values, linkage of systems, condition of wetland. Three types of assessments were carried out these wetlands: that of the Australian Heritage Commission, that used in Water Resources Council (1988) & Semeniuk (1985), that used by Hill *et al.* (1996), and expanded by C A Semeniuk (1998).

25. On-site inspections/assessments for wetland evaluation in the Study Area involved these procedures: assessment of wetland vegetation status, recognition of vegetation diversity (*e.g.,* structural diversity, presence of restricted community types), recognition of unusual physiognomy (potential indicators of changes to wetland hydrology), recognition of dynamic biological responses as an indicator of habitat alteration (evident in floral community changes), assessment of possible anthropogenic alteration to hydrology, assessment of degradation. This resulted in identification of wetlands of *outstanding significance* (with values recognised as being of Statewide, National or International significance). Wetlands of outstanding environmental significance generally satisfied more than one criterion.

26. Wetlands assessed as being of significance are:

    Cape Bossut embayment
    Munro Springs Wetland System
    Eighty Mile Beach Wetland System, including Anna Plains wetlands, and coastal wetlands of the Mandora Coastal wetland suite
    Injudinah Swamp and associated wetlands along regional seepage lines
    La Grange Bay
    Mandora Wetland System (= Salt Creek playa chain)
    Munro Spring wetland system
    Roebuck Bay Wetland System
    Roebuck Plains Wetland System
    Salt Creek System

27. The conclusions emanating from this study are:

- the wetlands in the region are varied and complex in origin and maintenance
- many of the wetlands are significant in terms of biota and geoheritage values
- it cannot be assumed that the Broome Sandstone regionally is a simple unconfined aquifer with a simple water table situated metres below the ground surface and that wetlands in the region located at the surface are unrelated to this groundwater body
- further, given the preferred pathways and springs that appear along the coastal zones and those that appear in inland settings, it would be prudent to investigate in detail the groundwater dynamics that maintain such wetland systems and not to assume that abstracting water from the Broome Sandstone will not affect the wetlands in the region.

Wetlands of the northwestern Great Sandy Desert

Introduction

Water & Rivers Commission (WR&C) invited the V & C Semeniuk Research Group (VCSRG) to undertake a study to identify the wetland types in the northwestern Great Sandy Desert (Figure 1), provide a preliminary identification of the wetlands of significance in this region, and determine the hydrological mechanisms that maintain them. Though it is an arid region, the Great Sandy Desert, in fact, contains a range of arid zone wetlands, and has a varied assemblage of consanguineous suites. It is the objective of this document to provide a preliminary report on these wetlands. In this context, this report is structured as follows:

- outline of Scope and Methods of this study
- description of the Terminology/Classification of the wetlands
- brief summary of previous work
- Regional Setting in terms of the climate, geology and geomorphology, hydrology, consanguineous wetland suites, and fauna/flora
- wetland hydrological mechanisms
- results pertaining to coastal wetlands
- results pertaining to inland coastal wetlands
- results pertaining to case studies and their extrapolation
- summary of the studies into fauna and flora of the region
- criteria for selection of significant wetlands
- preliminary delineation of significant wetlands
- summary, conclusions, recommendations

While the northwestern Great Sandy Desert region contains nine wetland types (playas, lakes, sumplands, damplands, creeks, wadis, floodplains, barlkarras, and peat mounds, though only four are commonly occurring) hosted on basins, channels and flats, and seven consanguineous suites, the Swan Coastal Plain, in contrast, has seven common wetland types also hosted on basins, flats and channels, and 22 types of consanguineous wetland suites, excluding estuaries, and southern coastal areas of Western Australia, in the wettest part of the State, where more landforms have been captured there are nine types of wetlands, with some 26 consanguineous suites, again excluding estuaries.

Acknowledgments

This study could not have taken place without the support of the Bidyadanga Community located at La Grange, and their regional associates. Several individuals were key in assisting in field work by locating wetlands, explaining wetlands from their perspective, and providing on-site assistance in accommodation: Donald Grey, Edna Hopiga, Stephen Possum, John Nankiriny, Norman Munro, John Hopiga, Cecelia Bennett, Rene Hopiga, Mervyn Mulardy Snr, Susie Gilbert, Louisa Grey, Malat, Rosie Munro.

Thanks are extended to Sarah Yu, an anthropologist at Broome, for assisting in a number of ways in this project: organizing the Bidyadanga Community to accompany VCSRG personnel in the field and explain the wetlands; locating wetlands with the Bidyadanga Community; mediating between the Bidyadanga Community and VCSRG; and explaining wetlands from the perspective of the Bidyadanga Community. Without her help this survey would not have been possible.

WR&C personnel, and in particular Roy Stone, assisted with information and advice whenever required. This assistance is gratefully acknowledged.

A large portion of the data and regional concepts on stratigraphy, hydrology, and coastal systems, used in this report, derive from R&D information from VCSRG obtained over 20 years.

Appreciation is also extended to Western Agricultural Industries (WAI) for the use of local stratigraphic and hydrologic data deriving from their studies in this region.

Scope & Methods, this study

The major part of the study was undertaken as a desk study, using resources such as topographic maps, aerial photographs, orthophotographs, published and unpublished reports, inventories, and scientific literature, and in-house VCSRG R&D data . However, field surveys were conducted in order to verify aerial photographic interpretation, collect information not currently available through existing resources, and to upgrade information where resources were not available in enough detail. In detail, this study was undertaken in four stages, as follows:

1. review of literature and VCSRG R&D data
2. literature review of wetlands, and collation of information on biota
3. field study of wetlands during October 1999
4. data reduction and assessment of conservation status.

Stage 1: available literature was accessed to determine its relevance to this study at the scale that this study was being undertaken. This involved desk study of climate, geology, hydrology, geomorphology, and any relevant wetland work, as well as topographic maps and aerial photographs.

VCSRG in-house R&D data involved some 20 years of coastal plain and mangrove information for the Canning Coast between Pardoo and Broome (some of which has been published in Semeniuk 1983 and Semeniuk 1993), and information on the northern Great Sandy Desert adjoining the Fitzroy River valley tract (cf. Semeniuk 1996). Within this Stage, the wetlands were designated to their consanguineous suite setting by relating them to the physiographic units in which they occur. The physiographic/geomorphic information was used as a basis for preliminary identification of consanguineous suites on the following criteria: geomorphic setting; similar phototone; proximity; similarity in wetland size and shape; recurring pattern of wetland forms or alternatively; heterogeneous pattern representing a spectral range of inter-related wetland forms.

Stage 2: In this stage, literature review of wetlands, and collation of information on biota was undertaken to develop a preliminary model of ecosystem function of the wetlands within a consanguineous suite. This was based on an analysis and integration of baseline natural history information on flora, invertebrate fauna, and vertebrate fauna such as waterfowl. Functions of wetlands were categorized as ecological, social, and cultural. In this study, the emphasis was on ecological functions. Again, the sources were field work (see next section), and some literature review. Literature also was reviewed in relationship to developing criteria for assessment of significance of wetlands.

Stage 3: Field study of the wetlands during October 1999 included visiting wetlands in their geologic/ geomorphic setting to determine their origin, the nature of the hydrologic mechanisms maintaining them, drilling/augering wetland to determine the nature of the sedimentary fill, and sampling water to determine its salinity. Areas of interest, specific transects, road traverses, and study sites visited in the northwestern Great Sandy Desert upon which this report is based are shown in Figure 2. In the field, the following information on the natural features for each suite of wetlands was obtained:

- geomorphic and stratigraphic setting
- hydrologic setting and water salinity
- hydrological dynamics if readily discernible
- wetland vegetation

Stage 4: This involved data reduction from field work, and an evaluation of wetland suites based on status or condition, regional significance, representativeness, scarcity, diversity, and functions, culminating in identifying selected wetland suites or parts of suites, for conservation. The rationale for selection was the information on natural features, ecological functions and evaluation. It also involved determining the feasibility of detecting the occurrence of water-dependent vegetation using aerial photography and remote sensing.

Wetland classification and terminology

Three wetland classifications are employed in this report, and each serves a different purpose; they are:

- the practical genetic assignment of wetlands to hydrological maintenance
- the technical classifications published in the scientific literature
- the terminology employed by the local Aboriginal communities

The first classification is useful for this study in that is addresses the issue of water source that is fundamental to the management of any potential water abstraction. The second provides a technical classification useful for assessing diversity and hence for assigning conservation significance. The third relates the first two to the long-term traditional nomenclature that also in part is based on origin and maintenance of the wetlands. In the final analysis, a correlation between the three will be provided.

The practical classification, devised for this study

In the first case, in regard to the practical wetland classification, in preliminary stages of this study, in the context that dewatering of an area may occur through the lowering of the regional water-table via water abstraction, three categories of basin wetlands were *informally* designated, viz., oases, pans, and springs. These categories were designated essentially to capture within a basin setting the three important mechanisms that maintain wetlands:

- windows to a water table
- perching of meteoric water
- upwelling of water in a spring

This correlation between the informal basin wetland category and their hydrologic setting is as follows (Figure 3):

Nomenclature	Hydrological Mechanism	Comments
oasis	windows to a water table	depression in the landscape that intersects the water-table; generally, oases are freshwater bodies, but where there is long term excessive evaporation, they may be naturally salinized
pan	perching of meteoric water	low depression. often lined by clay, that acts to pond rain water, resulting in perching of water after the "wet season"
spring	upwelling of water in a spring	artesian to subartesian up-welling of water to the land surface to create a local wetland body

This nomenclature is informally followed in this report, in that it address the fundamentally different three setting of basin wetlands that would be affected different ways by any proposed water abstraction in the region.

Wetlands in the region are also creek and wadi forms, but these are surface water flows involving run-off, and are not so affected by water table draw-down.

In regard to the second type of classification, involving the technical aspects of wetland classification, the terminology of Semeniuk & Semeniuk (1997) is employed here. This treats wetlands in terms of their landform setting and hydroperiod in order to differentiate the various types, which will be the basis of assessing their diversity and significance. Therefore, some explanation of terms for wetland classification, description and evaluation used in the report is required before proceeding.

Generally, in the first instance, wetlands are classified as to being inland, estuarine, or coastal marine. In this study area, the main wetland types are inland and coastal marine. The classifications and terms utilized in this study for inland coastal marine wetlands are briefly outlined as follows:

- geomorphic classification for inland wetlands
- coastal marine wetlands
- vegetation classification
- water classification
- general terms

Geomorphic classification for inland wetlands

For a technical classification of wetlands, a geomorphic approach for *inland wetlands* is used here, based on their host landform and hydroperiod (Semeniuk & Semeniuk 1997). In the first instance, wetlands are classified as to whether they are self-emergent or non-emergent, i.e., whether they form positive emerging structures through accumulation of sediment, precipitates, or peat accumulation, or whether they conform to, or fill a landform (Semeniuk & Semeniuk 1997). The latter wetlands are then classified as to their landform settings.

Subdivision on emergence or non-emergence	**Further subdivision**
self-emergent	peat mounds springs mounds sinter mounds
non-emergent	further subdivided on landform setting and hydroperiod

Landforms of wetlands include: basins, channels, flats, slopes and hills/highlands. Hydroperiod includes: permanent, seasonal or intermittent inundation, and seasonal waterlogging. Combining landform with hydroperiod, for wetlands, globally, thirteen primary types of common wetlands are recognized:

1. permanently inundated basin = lake;
2. seasonally inundated basin = sumpland;
3. seasonally waterlogged basin = dampland;
4. intermittently flooded basin = playa
5. permanently inundated channel = river;
6. seasonally inundated channel = creek;
7. seasonally waterlogged channel = trough
8. intermittently flooded channel = wadi
9. seasonally inundated flat = floodplain;
10. seasonally waterlogged flat = palusplain;
11. intermittently flooded flat = barlkarra
12. seasonally waterlogged slope = paluslope.
13. seasonally waterlogged hill = palusmont.

Of these, the main wetland types in this region are:

1. intermittently flooded basin = playa
2. (seasonally) waterlogged basin = dampland
3. permanently inundated basin = lake
4. seasonally inundated basin = sumpland
5. seasonally inundated channel = creek
6. intermittently flooded channel = wadi
7. seasonally inundated flat = floodplain
8. intermittently inundated flat = barlkarra
9. self emergent peaty wetlands = peat mounds

Wetlands may be further categorized according to scale. For basins and flats, the categories of geomorphic scale for wetlands developed therein are (after C A Semeniuk 1987):

- Megascale : Very large scale wetlands larger than a frame of reference 10 km x 10 km;
- Macroscale: Large scale wetlands encompassed by a frame of reference 1000m x 1000m to 10 km x 10 km;
- Mesoscale : Medium scale wetlands encompassed by a frame of reference 500m x 500m to 1000m x 1000m;
- Microscale: Small scale wetlands encompassed by a frame of reference 100m x 100m to 500m x 500m;
- Leptoscale: Very small scale wetlands encompassed by a frame of reference < 100m x 100m

For channels, a definitive width to length relationship is used to separate size of channel wetlands:

- Macroscale: Large scale channels 1 km and greater wide, by several to tens of kilometres long;
- Mesoscale : Medium scale channels hundreds of metres wide, by thousands of metres long;
- Microscale: Small scale wetlands tens of metres wide, hundreds of metres long;
- Leptoscale: Fine scale channels several metres wide, tens of metres long.

Coastal plain and marine wetlands

The Ramsar Bureau (International Convention for the protection of wetlands especially as a waterfowl habitat) identifies marine coastal systems as types of wetlands. For purposes of this report, this procedure is followed here, in that tidally exposed coastal zones are noted as a type of wetland. In this context, there are several types of marine coastal systems that function as "wetland", though it should be noted that there are emergent dry parts of these coastal systems that are not wet or tidally inundated. The term "marine coastal wetland" will be used to denote those parts of the shore that are exposed at low tide, and hence are the "marine wetted" part of the continent. Barrier dunes, and emergent sandy spits, islands surrounded by tidal zones, and rocky cliffs and headlands are not part of this assignment. The main coastal marine "wetlands" are:

- tidal mud flats
- tidal sand flats
- tidal creek complexes
- beaches

The tidal mud flats may be vegetation-free (*e.g.,* low tidal mud flats, or high tidal salt flats), or vegetated by mangroves or samphires. Tidal sand flats are usually broad low gradient low tidal flats. Tidal creek networks are permanently tidally inundated to low-tidally exposed channel systems. Beaches are usually steep gradient sandy shore surfaces.

Wetland vegetation classification

Wetland vegetation is classified on the areal extent and pattern of distribution of vegetation cover over the wetland and the internal organization of that vegetation in plan (Semeniuk *et al.,* 1990). Vegetation cover is divided into 3 intergradational classes: peripheral, mosaic and complete. Complexity of wetland vegetation is divided into 3 classes: homogeneous, zoned and heterogeneous. The combination of cover and internal organization results in the recognition of 9 basic wetland vegetation categories: periform, paniform, latiform, zoniform, gradiform, concentriform, bacataform, heteroform, and maculiform.

Water classification

Water in a wetland may be described in terms of salinity and consistency of salinity. Salinity terms are (Hammer 1986):

- fresh : <1000 ppm salinity
- subhaline : 1000-3000 ppm salinity
- hyposaline : 3000-20000 ppm salinity
- mesosaline : 20000-50000 ppm salinity
- hypersaline : 50000-100000 ppm salinity
- brine : >100000

Wetlands that are seasonally variable in salinity are categorized by the salinity state in which the wetland exists for the major part of each year. Water salinity that is consistent throughout the year, remaining totally within a given salinity field, is termed stasohaline. Water quality that markedly fluctuates throughout the year is termed poikilohaline.

Consanguinity: The concept and its usefulness

Consanguineous wetlands are inter-related wetlands. As defined by Semeniuk (1988), they may have a similarity because they occur in the same geomorphic, geologic, and hydrologic setting, or because they have been formed by the same underlying process. The notion of consanguineous suites essentially recognizes that there are different types of wetlands residing in different settings. Recognition of these differences is important for comparative, for management, and for representative conservation purposes. Thus the identification of consanguineous suites is a powerful first step to comparing similar or "like" wetlands for evaluation and assessment procedures

In general, seven criteria used to establish wetland consanguinity (Semeniuk 1988):

1. *Wetlands should occur in reasonable proximity*
2. *Wetlands should be similar in size and shape*
3. *A recurring pattern of similar wetland forms or a spectral range of inter-related wetland forms resulting from a dynamic process*
4. *Wetlands should have a similar stratigraphy*
5. *Wetlands should have similar water salinity regimes*
6. *Wetlands should have similar hydrological dynamics*
7. *Wetlands should have similar origin*

Limited data were obtained from in-house drill core data and field investigations. However, in this project, due to constraints of time and budget, information obtained from the literature was used to apply some of the criteria, in lieu of more extensive field investigations. One of the criteria, pertaining to water salinity, was not applied, because of the incomplete data set.

The extent to which the criteria were applied, and the sources of data, are explained below.

1. *Wetlands should occur in reasonable proximity*
   Fully applied.

2. *Wetlands should be similar in size and shape*
   Fully applied.

3. *There should be a recurring pattern of similar wetland forms or a spectral range of inter-related wetland forms resulting from a dynamic process*
   Fully applied. Information was obtained from geomorphic setting.

4. *Wetlands should have a similar stratigraphy*
   Information was obtained from the following sources: published geology and soils maps, some in-house data, and field investigations.

5. *Wetlands should have similar water salinity regimes*
   No information was accessed for application.

6. *Wetlands should have similar hydrological dynamics*
   Limited data was obtained from geomorphic setting, field investigations of selected wetlands and in-house data.

7. *Wetlands should have similar origin*
   Limited data were obtained from in-house drill core and field investigations.

General terms

Holocene and Pleistocene are terms for time periods within the Quaternary Epoch. Holocene refers to that period of geological time scale within the Quaternary between 10,000 years and the present. Pleistocene refers to that period of geological time within Quaternary between 2,00,000 years and 10,000 years ago. Other geological terms are defined in Bates & Jackson (1980).

The terms "function" and "value" are used as follows. "Value" refers to the importance, merit, or worth of a wetland after evaluation (this results from assessing the importance of a range of attributes a wetland possesses and functions it performs; to illustrate: if the wetland provides a regional drought refuge for avifauna, and for trans-equatorial migrators, then it has a high value). "Function" refers to the role that a wetland performs in its natural setting. Thus a wetland may perform the following functions, amongst others:

- local water source for fauna
- local food source for fauna
- drought refuge for avifauna,
- breeding ground for avifauna,
- hydrological discharge zone,
- collection point for a range of ephemeral drainage lines,
- habitat for biota.

Terminology employed by local Aboriginal communities

Aboriginal Communities employ various terms to categorize water bodies (Yu 1999), separating "on top" water from "bottom" water (viz., surface waters and shallow groundwater from deeper ground water. "On top" water is of interest here. The types of shallow groundwater and surface water are described below (after Yu 1999), with comments in italics, relating to the VCSRG classification:

Water type	**Description**
lirri	Soaks, in which water is dug up for drinking. Some are permanent (*lakes*), others are dug up in the hot time (*sumplands and damplands*)
jila	Permanent water sources. In some cases jila have visible surface water (*lakes and peat mounds*), *e.g.*, Pikarangu (Joanna Springs), but many require digging. A jila may be marked by a small depression in the ground. Scrubby t-trees may surround the water. Jila occur in clayey soil from which white mud (kalji) is found
pajalpi	Ecosystems surrounding springs, as permanent water sources (*lakes*) found on fringes of coastal mudflats, or inland areas
wawajangka	Fresh water seepages found in mudflats in the intertidal zone and only accessible at low tides
pirapi	claypans (*sumplands*) that fill with water after rain, and usually dry up after the rain or as the hot time approaches

The relationship between the practical classification, the technical classification, and that employed by the Aboriginal Communities is presented below.

Practical classification	**Technical classification**	**Terms employed by the Aboriginal Communities**
oasis	lakes, sumplands, playas	jila, some pajalpi
pan	sumplands, damplands, playas	lirri, pirapi
spring	peat mounds	pajalpi

Previous work

A summary of previous work in this region germane to this study is provided in Table 1 below, listing author and type of information in relationship to the following subjects:

1. Geology
2. Hydrology
3. Wetlands
4. Vegetation
5. Fauna
6. Conservation

Summary of Literature review (preliminary)

Author, year, title	Main content of work	Relevance to this study
Beard 1965	Inland mangroves	Identifies significant mangrove occurrence along Salt Creek
Beard 1979	Vegetation of the northern Great Sandy Desert	Identifies the major vegetation in the region, in a geologic, geomorphic and climatic setting
Beard & Webb 1974.	Vegetation of the central and middle Great Sandy Desert	Identifies the major vegetation in the region, in a geologic, geomorphic and climatic setting
Burbidge & McKenzie 1983	Describes wildlife of the Great Sandy Desert	Deals with wildlife in the alluvial flats and lake deposits
Handley 1996	Describes wetlands in the Great sandy Desert	Describes wetlands on the Register of the National Estate
Lane & Lynch 1996	Description of significant wetlands in the Great Sandy Desert	Identifies significant wetlands in the Great Sandy Desert
Laws 1990	Describes groundwater in the Canning Basin	Provides hydrologic setting
Veevers & Wells 1961	Geological description	provides geological and geomorphologic framework
Young 1981	Describes Dragon Tree Soak	Provides description of wetland oasis in the region
Watkins *et al.*, 1997	Describes Ramsar sites in the region	Provides information on Eighty Mile Beach and the Mandora Marshes
Wyrwoll *et al.*, 1986	Describes age of peat in the wetland	Shows Quaternary age of the deposits
Wyrwoll *et al.*, 1992	Describes age of alluvial deposits in the Northern Great Sandy Desert	Shows Quaternary age of the deposits

Regional Setting I: Physical Setting

The Study Area in this project, the northwestern Great Sandy Desert, is located in tropical northwestern Australia, and comprising one of the driest regions of Western Australia. The Study Area stretches from the Salt Creek complex to the south, to the valley tract of the Fitzroy River to the north, and borders the Indian Ocean to the west. It contains megascale landform units of desert linear dune fields, rocky deserts, and coastal plains, the latter containing a range of smaller scale landform units such as relict/stranded coastal flats, mangrove coasts, tidal flats, coastal dunes, and rocky shores, amongst others.

For purposes of this project, the following areas are excluded from definition of the study area:

- to the north, the area north of Broome along the Dampier Peninsula;
- to the east, the area outside the limit of outcrop of the Broome Sandstone.
- to the south, the area south of the Salt Creek - Sandfire Flats complex

In the Study Area of this project, there are a range of regional physical features and patterns which are important to understanding the development of wetland types and their distribution; they are:

- climate
- geology
- geomorphology

In addition to the features mentioned above, there also are key terrain features such as drainage patterns and aeolian landforms.

Climate

Climate also affects the development of wetlands, and determines the style of development/characteristics of wetland regions through its affect on landform, hydrology, water salinity, and vegetation. Key features of the regional climate in development of landforms, hydrology, and wetlands are: rainfall, evaporation, and wind.

Rainfall influences the development of landforms and wetlands through run-off and erosion, in recharging the groundwater aquifers, and in maintaining wetland hydrology. Evaporation influences wetland formation through development of increasing salinity, and through salt-weathering. Wind influences evolution of landform and wetlands though development of aeolian landforms (e.g., linear dunes), development of deflation flats, and in the formation of beachridges and lunettes that fringe and/or isolate wetlands.

The Study Area may be subdivided into four climatic regions; these are:

- the northern coastal zone
- the southern coastal zone
- the central inland area

Climatic zone	**Characteristics** (Gentilli 1972; Bur. Meteor. 1973, 1975)
northern coastal zone	semi-arid, tropical, 600-800 mm rainfall annually, 3200 mm of annual evaporation
southern coastal zone, to the area of Salt Creek	arid, tropical, 500-600 mm rainfall annually, 3200 mm of annual evaporation
central inland area	semi-arid, tropical, 600 mm rainfall annually, 3600 mm of annual evaporation

The coastal zone of the Study area represents the most humid climate for this region. The rainfall c. 500-800 mm/yr, evaporation is 3200 mm/yr, and the winds are strongly influenced by the landbreeze and seabreeze systems. Wind in the coastal zone is important in developing marine and coastal landforms such as coastal dunes, and their associated distinctive wetlands.

Geology

Through lithology and structure, geology controls how geomorphology evolves, and this determines the setting for development of landforms that are host to wetlands. Geology through its expression of varied rock types, formational aquifer properties, plan geometry of formations and hence geometry of landforms, and in structures such as faults, joints, also influences hydrology in development of aquifers, seepage points, discharge zones, perching patterns, drainage patterns, etc.

The stratigraphy of the region is important to the hydrological functioning of the wetlands. The main and important stratigraphic contexts are: 1. the Mesozoic Broome Sandstone aquifer, with its internal depositional sedimentary stratigraphy; 2. the Cenozoic dune sand aquifer; 3. the interaction between Quaternary coastal mud deposits and the sandy inland aquifers (Broome Sandstone and dune sand); and 4. local clay lenses. The coastal mud deposits are referred to as "kalji".

Over most of the Study Area, the surface is underlain by Cenozoic dune deposits, that overlie Mesozoic sandstone (the Broome Sandstone). The Broome Sandstone crops out throughout the region intermittently, locally forming ranges, or isolated tablelands, mesas, and buttes (Geological Survey of Western Australia 1990).

Stratigraphically the Study Area is underlain by a range of Mesozoic, to Tertiary to Quaternary units. These are described in the Table below, and summarised diagramatically in Figure 4.

Stratigraphic units in the area

Unit	**Age**	**Thickness** (metres)	**Relationship to adjoining units**
Quaternary dune sand	Holocene (<7000 yrs)	3-10 m	overlies other Quaternary units, Tertiary units, and locally Broome Sandstone
Quaternary beach sand and beachrock	Holocene (<7000 yrs)	1-10 m	interfingers with other Holocene units
Quaternary wetland sediment	Holocene (<7000 yrs)	lens-like <1m-4m	fills hollows in other Quaternary units
Quaternary coastal mud (termed "Kalji" by local aboriginal communities	Holocene (<7000 yrs)	wedge-like <1m-15m; mostly 5-10m thick	interfingers with other Holocene units; overlies other Quaternary and Tertiary units, and locally Broome Sandstone
Quaternary limestone (Holocene)	Holocene (<7000 yrs)	1-10 m	interfingers with other Holocene units; overlies other Quaternary and Tertiary units, and locally Broome Sandstone

Quaternary limestone (Pleistocene)	Pleistocene >10000 yrs to $2x10^6$ yrs	1-10 m	overlies Tertiary units, and locally Broome Sandstone
Quaternary red sand, and red muddy sand (Pleistocene)	Pleistocene >10000 to $2x10^6$ yrs	1-6 m	overlies Tertiary units, and locally Broome Sandstone
Quaternary to Tertiary valley fills (Holocene to Tertiary)	Holocene to Tertiary < 10000 to >$2x10^6$ yrs	1 to > 4 m	overlies Tertiary ironstone units, and locally Broome Sandstone
Tertiary ironstone and breccia	Tertiary (>$2x10^6$ yrs	1-6 m	overlies Broome Sandstone
Mesozoic Broome Sandstone	Early Cretaceous	150-300m	underlies all Cenozoic units with unconformity; conformable on Jeriemai Siltstone
Mesozoic Jeriemai Siltstone	Late Jurassic	160 m	underlies Broome Sandstone with conformity, overlies Alexander Formation with conformity
Mesozoic Alexander Formation	Late Jurassic	50 m	underlies Jeriemai Siltstone with conformity, overlies Wallal Sandstone conformity
Mesozoic Wallal Sandstone	Early to Late Jurassic	>100 m	underlies Alexander Formation with conformity, overlies Permian formations with unconformity

These formations, and their function as aquifers, can have influence on groundwater in the region, either as aquifers directly providing waters to wetlands, or indirectly through conduits (see later).

A description of these formations follows:

Description of stratigraphic units in the area

Unit	Description
Quaternary dune sand	fine grained white coastal dune sand, perched on older units, or interfingering with other Holocene units
Quaternary beach sand and beachrock	ribbon of medium, coarse, and fine sand and shelly sand, locally cemented into beachrock perched on older units, or interfingering with other Holocene units
Quaternary wetland sediment	lenses of carbonate mud and peat within hollows of other Quaternary units
Quaternary coastal mud (termed "Kalji")	wedge of cream to grey carbonate mud formed in the tidal to shallow intertidal zone
Quaternary limestone (Holocene)	ribbons and shoestrings of Holocene cemented dune sand
Quaternary limestone (Pleistocene)	ribbons and shoestrings of Pleistocene cemented dune sand (includes oolitic limestone, and other skeletal limestone)
Quaternary red sand, and red muddy sand (Pleistocene)	sheets of red sand and muddy sand, blanketing the Tertiary landscape
Quaternary to Tertiary valley fills (Holocene to Tertiary)	ribbons of sand, muddy sand, to mud filling valley tracts, and valley-tract-aligned playas
Tertiary ironstone and breccia	ironstone: iron-oxide-cemented colluvial breccia, river gravel, and cemented sand of Tertiary age
Mesozoic Broome Sandstone	fine to coarse sand and sandstone, with minor beds of conglomerate, grey siltstone and claystone
Mesozoic Jeriemai Siltstone	light to dark grey siltstone and claystone, with minor sandstone and sandy siltstone
Mesozoic Alexander Formation	grey to white to variegated fine to coarse sandstone with interbedded grey, white brown siltstone, and minor black shale to mudstone
Mesozoic Wallal Sandstone	light grey, fine to coarse grained sandstone interbedded with thin beds of siltstone, some conglomerate, and lignite

A description of the Broome Sandstone, in terms of its more detailed lithology and sedimentary structures, follows, because this has bearing on its aquifer properties and regional hydrology.

The Broome Sandstone is comprised mainly of sand and sandstone, that is medium to coarse in grainsize and with some fine sand locally. The bulk of the sand/sandstone is cross-laminated and cross-bedded, with cross bed sets indicating strong enough current flow during deposition to generate megaripple or sand waves of 10 cm to 30 cm amplitude. The predominantly unidirectional nature of cross-beds indicate currents were mostly unidirectional, though some bi-directionality suggest alternating current directions. Pebbles, as lags, indicate periodic current winnowing in "flood episodes" Local channelling along the base of coarser sand/sandstone bodies indicated fluvial channel systems were operating at time of deposition. The nature of the geometry and internal structures of the sand/sandstone bodies suggests a fluvial environment to tidal estuarine environment for deposition.

Some of the finer-grained sand/sandstone, which is usually interlayered with the clay beds, show small scale features such as ripples and flaser structure, both indicating a coastal environment of deposition.

The clay beds in the Broome Sandstone exhibit a range of features that are important to interpreting the environments of deposition of the formation, and hence the basin setting of the formation, which in turn has implications for the regional hydrologic setting. The clay show the following features:

- thin (1-2 cm) sheet geometry: indicating deposition over extensive areas
- channel-cutting of the mud sheets by cross-bedded sand: indicating fluvial erosion and channel migration
- mud cracks, in the claystone, as polygonal to sigmoidal forms, indicating that the mud sheet terrain was wetted then dried, and that the Broome Sandstone sequence cannot be submarine - the likely environments of deposition are fluvial coastal plain to tidal
- reworking of cracked mud sheets into an overlying sand/sandstone layer, indicating periodic floods that demobilized the cracked mud sheets: indicating that the mud cracks were sufficiently dried to be reworked - the likely environment of deposition was fluvial coastal plain
- small vertical burrow in the clay beds, localized often within mud cracks: indicating tidal flat environments, or clay pans on a fluvial coastal plain.

It is likely that the Broome Sandstone represents a fluvial coastal environment to a tidal environment. It does not represent a submarine shelf system. There are stratigraphic implications that flow from this conclusion. The north to central, and south to central part of the Broome Sandstone body will exhibit facies changes in a north to central Basin transition, and in a south to central Basin transition, as the Kimberley Block and the Pilbara Block to north and south, respectively, represent hinterland massifs that constituted the bordering uplands. These massifs would have been the loci of high-gradient, high-discharge braided river style systems, which become more fluvially mud dominated with the amelioration of landscape gradients down-slope towards the palaeo-coast, and then merging with the marine system. The central zone of the Broome Sandstone in response to facies changes will therefore tend to be more muddy in its central axis, i.e., there will tend to be more mud layers in a central axial zone within the Canning Basin. If the Broome Sandstone were deposited on a submarine shelf, then it may be expected to be more lithologically homogeneous regionally. The fluvial to tidal nature of the environments imply that there will be a change in hydrologic properties from marginal-basin to central axial basinal settings.

In terms of cementation, the Broome Sandstone, is variably cemented to wholly uncemented. There are two patterns: the Sandstone is cemented in a relatively thin upper zone forming a sheet parallel to the present land surface, and it is also differentially cemented in mosaics in the subsurface. In regard to the former, the cementation is an iron oxide and silica cementation, related to weathering and dust impregnation. In regard to the latter, the cementation is silica cementation probably a groundwater-related phenomenon. These cementation styles also have implications on the hydraulic properties of the Broome Sandstone.

The important feature about the Broome Sandstone, hydrologically, is that it is a large sheet-like body of sedimentary rock that is ***not internally homogeneous in terms of rock types and cementation***.

Geomorphology

The main regional scale geomorphic units in the area are the linear desert dune fields, the sand plain on sandstone plains, rocky ranges, the straight to meandering chains of playas, the clusters of playas, the coastal plain/ribbon. A brief description of each of these geomorphic units and their relevant wetlands is outlined below:

Regional scale geomorphic units	Description of unit
linear desert dune fields	red sand linear parallel dunes, 5-10 m high, separated by spinifex (*Triodia*) covered interdune sand plains 200-1000 m wide
sand plain on sandstone plains	red muddy sand plain and low degraded linear dunes 5-15 m thick, forming a sheet on a plain or plateau of Broome Sandstone; vegetated by Pindan scrub
rocky ranges and tablelands	tablelands, mesas and buttes of sandstone; capped by ferruginite capped; forming landforms < 10m to tens of metres above the surrounding plain surface
straight chains of playas	chains of oval to linear mud-floored playas, each 100s of metres wide, and kilometers long; samphire and *Melaleuca*-vegetated; bordered by dune and pindan
meandering chains of playas	chains of playas (salt crusted, mud floored) forming meandering networks; bare central zone, with samphire margins; bordered by linear sand dunes
clusters of playas	oval to linear mud-floored playas, each 100s of meters wide, and kilometers long; samphire and *Melaleuca*-vegetated; bordered by sand dune and pindan terrain
coastal plain/ribbon	coastal embayments, mangrove and samphire vegetated, and bordered by dunes, limestone, or Broome Sandstone

Regional Setting II: Consanguineous Wetland Suites

Previous work in this region (VCSRG 1999) identified some seven regions or settings of consanguineous suites were identified in the study area; these are:

1. linear desert dune fields,
2. pindan sand plain developed on sandstone plains,
3. rocky ranges,
4. straight chains of playas,
5. meandering chains of playas,
6. clusters of playas,
7. coastal plain/ribbon.

Within these settings, nine consanguineous suites are identified and named in the Table below, and some key locations or typical locations of which are located in Figure 5.

Geomorphic setting	**Name of consanguineous unit**
linear desert dune fields	Kidson Track Suite
sand plain developed on sandstone plains	Dampier Downs Suite
rocky ranges and tablelands	Geegully Creek Suite
straight chains of playas	Salt Creek Suite
meandering chains of playas	Lake Auld Suite
clusters of playas	Dragon Tree Soak Suite
coastal plain/ribbon	La Grange Bay Suite Mandora Suite Injudinah Suite

Description of the suites follows, in the following structure:

- regional geomorphic setting
- proposed new name of the identified suite
- small scale geomorphology and geomorphic processes
- wetland types
- water parameters - levels, quality, hydrological mechanisms
- stratigraphy
- vegetation - pattern, structure, composition

The Kidson Track Suite comprises linear swales between linear dunes. The wetlands are formed in two ways: as basin floors proximal to water table, or as perched water basins through accumulation of clays on interdunal swale floors that act to pond and perch meteoric water. Overall, the wetlands are oval to elongate-rounded, and tens of metres to 100s of metres wide and up to a kilometre long. Technically, the wetlands are mainly microscale to mesoscale playas, but those that are windows to the water table are microscale to mesoscale damplands. Water is mostly fresh. The wetlands are maintained by water table rise, or by ponding/perching in interdunal swales. Stratigraphically, the wetlands are underlain by clays. In terms of vegetation, the wetlands may have a vegetation-free central zone, and are ringed by concentric zones of samphires. Damplands may be vegetated by concentric zones of samphires. There are a limited number of such wetlands in this Study Area.

The Dampier Downs Suite comprises wetlands on the sand plain developed on sandstone plain. The wetlands are rounded microscale lakes, sumplands, and playas. The wetlands are formed in two ways: as seepage zones from springs, or as perched water basins through accumulation of clays on the undulating dune surfaces that act to pond and perch meteoric water. Water is mostly fresh. Stratigraphically, the wetlands are underlain by clays. In terms of vegetation, the lakes and sumplands are vegetated by sedges, rushes and *Melaleuca*; the playas are vegetated by an outer ring of *Melaleuca* and by grasses. Most of the Study Area is located in this suite.

The Geegully Creek suite is developed in the terrain of rocky ranges and tablelands and hence wetlands are channels, plains, and basins. The channels are floored by sand, and are mesoscale to microscale creeks and wadis, that are vegetated by eucalypts and *Melaleuca*; these channels drain the upland terrain of rocky ranges and sand dunes (Semeniuk 1996). The plains are located between drainage channels, and are ribbon systems several kilometers long and 1-2 km wide, and underlain by mud. Plains are vegetated by grasses. Locally, on the plains, there are mesoscale basins, are seasonally to intermittently flooded. They are usually bare or grass-covered, and underlain by mud. The northern to northeastern part of the Study Area is located in this suite.

The Salt Creek Suite comprises straight chains of linear playas located along swales between linear dunes. The wetlands are macroscale to mesoscale playas, dampland, and sumplands. At the large scale, the wetland chain is a sediment filled estuary and river complex, with the wide estuarine channel located at the western end of the complex, and the riverine system located at the eastern end. The estuarine complex is filled by carbonate muds, and the riverine end has muds and peat. At the smaller scale, the wetlands are formed in three ways: as basin floors proximal to a water table; as perched water basins with meteoric water perched on carbonate clays; and as basins and peat mounds fed by springs. Overall, the wetlands are oval to elongate-rounded, and tens of metres to 100s of metres wide and up to a kilometre long. Water is mostly saline, but locally fresh. In terms of vegetation, the wetlands may have a vegetation-free central zone, and are ringed by concentric zones of samphires, or may be vegetated by paperbarks. Damplands may be vegetated by concentric zones of samphires. The southern margin of the Study Area is bordered and encompasses this suite.

The Lake Auld Suite comprises meandering chains of playas. The wetlands are macroscale to mesoscale playas, dampland, and sumplands. At the large scale, the series of wetlands forming a meandering chain is a sediment filled river complex. Locally, the basins are rock floored systems formed by laterally expanding salt weathering surfaces. The wetlands in the chains are now largely disconnected. The riverine complex of this Suite is filled by sand, mud, gypsum and salt. At the smaller scale, the wetlands are maintained in two ways: as basin floors proximal to a water table; as perched water basins with meteoric water perched on mud. Overall, the wetlands are linear, elongate, varying to oval and elongate-rounded, and kilometres wide and tens of kilometres long. While the main channel-tract consists of the large playas, the linear dune terrain surrounding the main chain may contain smaller playas and sumplands. These are similar to the main chain wetlands in terms of sediment fill and vegetation, but are more rounded, and mostly mesoscale to microscale systems.. Water in the basins is mostly saline, but locally there is freshwater upwelling within the margins or floors of the basins. In terms of vegetation, the wetland basins may have a vegetation-free central zone, and are ringed by concentric zones of samphires, or may be vegetated by paperbarks. Damplands may be vegetated by concentric zones of samphires. Some wetlands in the Study Area belong to this suite.

The Dragon Tree Soak Suite comprises clusters of playas, in relative close proximity to each other. They are mostly macroscale, mesoscale to microscale rounded linear to rounded to irregular playas, lakes, sumplands, peat mounds, and damplands located along swales between linear dunes, tens of metres to 100s of metres wide and up to a kilometre long. The wetlands are filled with peat, or with mud. The wetlands are maintained in three ways: as basin floors proximal to a water table; as perched water basins with meteoric water perched on muds; and as spring fed basins and peat mounds. Depending on water source and maintenance, the water in the wetlands is saline to fresh. In terms of vegetation, in response to water quality, the wetlands may have a vegetation-free central zone, and are ringed by concentric zones of samphires, or may be vegetated by paperbarks. Some wetlands in the Study Area belong to this suite.

The coastal plain/ribbon contains three types of coastal marine wetland suites: a system of tidal embayments vegetated in the mid to upper part by mangroves (the La Grange Bay Suite), a system of barrier dunes and tidal swales (the Mandora Suite), and a system of wetland chains fed by freshwater seepage and springs (the Injudinah Suite). The La Grange Bay Suite is the system of carbonate mud and sand filled coastal embayments located within limestone and sandstone headlands. The mid to upper tidal parts are vegetated by zoned mangroves and samphire and saltmarsh. The salinity of the groundwater water is zoned mesosaline to hypersaline. Locally, there are freshwater seepage onto the tidal flats. Mangrove coasts are described in Semeniuk (1983, 1993). Many wetlands in the Study Area belong to this suite. The Mandora Suite, on the other hand, is the system of quartz/carbonate sandy shore-parallel barrier dunes, with elongate carbonate mud filled with-tidal to low supratidal swales vegetated by samphire. The salinity of the groundwater water is hypersaline. Locally, there are freshwater seepage onto the swales. Many wetlands in the Study Area belong to this suite. Finally, the Injudinah Suite is a system of wetlands developed as a chain along the contact of the Pindan sand plain and the coastal mud deposits. The flow of freshwater from groundwater aquifers fed in the more interior desert regions, and that would normally discharge to the coast is perturbated and retarded by coastally-deposited muds. This results in local development of seepage zones and springs along the zone of contact between coastal mud-filled embayments and the Pindan terrain. Generally, the seepage zone results in a belt of *Melaleuca* thickets bordering the Pindan. Locally, the seepage is marked enough to develop freshwater lakes and sumplands. Many wetlands in the Study Area belong to this suite.

Regional Setting III: Regional Flora

A compilation of specimens occurring in the Great Sandy Desert held at the WA Herbarium (FloraBase 1998) and records from Jessop (1981), Buckley (1982) and Wheeler *et al.* (1992) are presented below. The species are listed as to family, and described as to habitat occurrence.

Species Name	**Habitat notes**
MAGNOLIOPSIDA (Angiosperms)	
Amaranthaceae	
Amaranthus pallidiflorus	creek beds and sand along creeks
Asteraceae	
Centipeda minima	margins of lakes, streams
Pluchea rubelliflora	seasonally wet swamps, claypans, rivers
Pluchea tetranthera	near seasonally wet claypans
Sphaeranthus indicus	seasonally flooded creeks
Streptoglossa odora	near claypans
Boraginaceae	
Trichodesma zeylanicum	watercourses, floodplains
Byblidaceae	
Byblis liniflora	in swamps and along watercourses, sand, muddy sand skeletal soils over sandstone pavements
Chenopodiaceae	
Dysphania glomulifera ssp *eremaea*	alluvial flats, river/creek banks
Dysphania plantaginella	coastal and alluvial flats
D. rhadinostachya ssp *rhadinostachya*	drainage lines
Convolvulaceae	
Ipomea polymorpha	creeklines and moist depressions

Cyperaceae	
Baumea articulata	no habitat information available
Bulbostylis barbata	watercourses, low lying flats
Bulbostylis burbidgeae	cliff bases, granite
Cyperus bifax	creek banks, floodplains
Cyperus blakeanus	claypans, creek floodplains, alluvial fans
Cyperus bulbosus	mudflats, creek banks
Cyperus difformis	watercourses
Cyperus ixiocarpus	sandy creeks
Cyperus rigidellus	watercourses, claypans, floodplains
Cyperus squarrosus	drainage lines, claypans
Cyperus vaginatus	pools, rivers
Fimbristylis dichotoma	creek banks, claypans
Fimbristylis ferruginea	watercourses, springs, swamps
Fimbristylis littoralis	watercourses, springs, swamps
Lipocarpha microcephala	watercourses, rock holes, claypans
Schoenoplectus subulatus	pools swamps streams
Droseraceae	
Drosera burmannii	near creeks, swamps and seepages
Drosera indica	damp areas besides creeks, swamps and seepages
Drosera petiolaris	damp areas
Elatinaceae	
Bergia pedicellaris	clay soils usually near watercourses
Bergia trimera	damp soil
Juncaginaceae	
Triglochin centrocarpum	watercourses
Lythraceae	
Rotala diandra	edges of creeks and rivers, sometimes submerged in pools
Menispermaceae	
Tinospora smilacina	riverine flats

Mimosaceae	
Acacia ampliceps	around watercourses, salt flats
Acaica farnesiana	river/creek lines
Acacia spondylophylla	drainage lines, rocky ground around watercourses
Molluginaceae	
Glinus oppositifolius	watercourses
Glinus orygioides	claypans
Myrtaceae	
Eucalyptus camaldulensis	watercourses
Eucalyptus victrix	floodplains, flats
Melaleuca glomerata	rocky river beds, low lying areas
Melaleuca lasiandra	creek lines
Melaleuca linophylla	creek lines
Papilionaceae	
Sesbania cannabina	areas subject to seasonal waterlogging
Sesbania formosa	creeks, rivers, margins of swamps
Poaceae	
Dactyloctenium radulans	marshes, seasonal swamps, floodplains
Sporobolus australasicus	floodplains , coastal flats
Sporobolus virginicus	salt marshes
Scrophulariaceae	
Lindernia chrysoplectra	seasonally wet sites
M. gracilis	claypans wet areas
Stylidiaceae	
Stylidium desertorum	seasonal wetlands
Typhaceae	
Typha domingensis	freshwater swamps, creeks, rivers

The main or conspicuous species that characterize the wetland vegetation are presented in the Table below:

Species Name	**Habitat notes**
Amaranthus pallidiflorus	creek beds and sand along creeks
Asteraceae	
Centipeda minima	margins of lakes, streams
Pluchea rubelliflora	seasonally wet swamps, claypans, rivers
Pluchea tetranthera	near seasonally wet claypans
Sphaeranthus indicus	seasonally flooded creeks
Streptoglossa odora	near claypans
Boraginaceae	
Trichodesma zeylanicum	watercourses, floodplains
Byblidaceae	
Byblis liniflora	in swamps and along watercourses
Chenopodiaceae	
Dysphania glomulifera ssp *eremaea*	alluvial flats, river/creek banks
Dysphania plantaginella	alluvial flats
D. rhadinostachya ssp *rhadinostachya*	drainage lines
Convolvulaceae	
Ipomea polymorpha	creeklines and moist depressions
Bulbostylis barbata	watercourses, low lying flats
Bulbostylis burbidgeae	cliff bases, granite
Cyperus bifax	creek banks, floodplains
Cyperus blakeanus	claypans, creek floodplains, alluvial fans
Cyperus bulbosus	mudflats, creek banks
Cyperus difformis	watercourses
Cyperus ixiocarpus	sandy creeks
Cyperus rigidellus	watercourses, claypans, floodplains
Cyperus squarrosus	drainage lines, claypans
Cyperus vaginatus	pools, rivers

Fimbristylis dichotoma	creek banks claypans
Fimbristylis ferruginea	watercourses springs, swamps
Fimbristylis littoralis	as above
Lipocarpha microcephala	watercourses, rock holes, claypans
Schoenoplectus subulatus	pools swamps streams
Juncaginaceae	
Triglochin centrocarpum	watercourses
Mimosaceae	
Acacia ampliceps	around watercourses, salt flats
Acaica farnesiana	river/creek lines
Acacia spondylophylla	drainage lines, rocky ground around watercourses
Myrtaceae	
Eucalyptus camaldulensis	watercourses
Eucalyptus victrix	floodplains, flats
Melaleuca glomerata	rocky river beds, low lying areas
Melaleuca lasiandra	creek lines
Melaleuca linophylla	creek lines
Papilionaceae	
Sesbania cannabina	areas subject to seasonal waterlogging
Sesbania formosa	creeks, rivers, margins of swamps
Poaceae	
Dactyloctenium radulans	marshes seasonal swamps, floodplains
Sporobolus australasicus	Floodplains , coastal flats
Sporobolus virginicus	salt marshes
Stylidiaceae	
Stylidium desertorum	seasonal wetlands
Typhaceae	
Typha domingensis	freshwater swamps, creeks, rivers

These species are presented in relation to the main habitat types in the region in the Table below:

river/creek banks	*Dysphania glomulifera*
creek banks claypans	*Fimbristylis dichotoma*
creek banks	*Cyperus bifax*
creek beds	*Amaranthus pallidiflorus*
creek lines	*Melaleuca lasiandra*
creek lines	*Melaleuca linophylla*
creeks, rivers	*Sesbania formosa*
watercourses	*Acacia ampliceps*
watercourses	*Fimbristylis littoralis*
creeks, rivers	*Sesbania formosa*
drainage lines	*D. rhadinostachya* ssp *rhadinostachya*
drainage lines, claypans	*Cyperus squarrosus*
drainage lines, rocky ground around watercourses	*Acacia spondylophylla*
creeks, rivers	*Typha domingensis*
watercourses	*Byblis liniflora*
watercourses	*Bulbostylis barbata*
watercourses	*Cyperus rigidellus*
creek banks	*Cyperus bulbosus*
margins of lakes, streams	*Centipeda minima*
streams	*Schoenoplectus subulatus*
pools, rivers	*Cyperus vaginatus*
river/creek lines	*Acaica farnesiana*
rocky river beds	*Melaleuca glomerata*
sandy creeks	*Cyperus ixiocarpus*
seasonally flooded creeks	*Sphaeranthus indicus*
rivers	*Pluchea rubelliflora*
watercourses	*Cyperus difformis*
watercourses	*Triglochin centrocarpum*
watercourses	*Eucalyptus camaldulensis*
watercourses	*Fimbristylis ferruginea*
watercourses	*Trichodesma zeylanicum*
watercourses, rock holes	*Lipocarpha microcephala*
floodplains	*Sporobolus australasicus*

floodplains, flats	*Eucalyptus victrix*
floodplains	*Cyperus rigidellus*
floodplains	*Dactyloctenium radulans*
floodplains	*Trichodesma zeylanicum*
mudflats	*Cyperus bulbosus*
claypans	*Streptoglossa odora*
claypans	*Lipocarpha microcephala*
claypans	*Pluchea rubelliflora*
claypans	*Cyperus blakeanus*
claypans	*Cyperus rigidellus*
seasonally wet claypans	*Pluchea tetranthera*
low lying areas	*Melaleuca glomerata*
low lying flats	*Bulbostylis barbata*
alluvial flats	*Dysphania plantaginella*
alluvial flats	*Dysphania glomulifera*
areas of seasonal waterlogging	*Sesbania cannabina*
moist depressions	*Ipomea polymorpha*
margins of swamps	*Sesbania formosa*
freshwater swamps	*Typha domingensis*
swamps	*Byblis liniflora*
swamps	*Schoenoplectus subulatus*
swamps	*Fimbristylis ferruginea*
seasonally wet swamps	*Pluchea rubelliflora*
seasonal swamps	*Dactyloctenium radulans*
margins of lakes	*Centipeda minima*
salt marshes	*Sporobolus virginicus*
seasonal wetland	*Stylidium desertorum*
salt flats	*Acacia ampliceps*
salt flats	*Fimbristylis littoralis*
springs	*Fimbristylis ferruginea*
marshes	*Dactyloctenium radulans*

The flora can be categorized into several common assemblage types that occur in specific habitat settings; these are:

Habitat type	**Description of vegetation and main species**
Inland wetlands	
Lakes, playas, sumplands, and damplands	*Acacia ampliceps, Byblis liniflora, Centipeda minima, Dactyloctenium radulans, Fimbristylis ferruginea, Ipomea polymorpha, Pluchea rubelliflora, Schoenoplectus subulatus, Sesbania cannabina, Sesbania formosa , Sporobolus virginicus, Stylidium desertorum, Typha domingensis*
Creeks and wadis	*Acacia ampliceps, Acacia spondylophylla, Acaica farnesiana, Bulbostylis barbata, Byblis liniflora, Centipeda minima, Cyperus bulbosus, Cyperus difformis, Cyperus ixiocarpus, Cyperus rigidellus, Cyperus squarrosus, Cyperus vaginatus, Rhadinostachya* ssp *rhadinostachya, Eucalyptus camaldulensis, Fimbristylis ferruginea, Fimbristylis littoralis, Lipocarpha microcephala, Melaleuca glomerata, Pluchea rubelliflora, Schoenoplectus subulatus, Sesbania formosa , Sphaeranthus indicus, Trichodesma zeylanicum, Triglochin centrocarpum, Typha domingensis*
Floodplains and barlkarras	*Bulbostylis barbata, Cyperus blakeanus, Cyperus bulbosus, Cyperus rigidellus, Cyperus rigidellus, Dactyloctenium radulans, Dysphania glomulifera, Dysphania plantaginella, Eucalyptus victrix, Lipocarpha microcephala, Melaleuca glomerata, Pluchea rubelliflora, Pluchea tetranthera, Sporobolus australasicus, Streptoglossa odora, Trichodesma zeylanicum*
Peat mounds and peat basins	*Acacia ampliceps, Avicennia marina, Byblis liniflora, Fimbristylis ferruginea, Paspalum* sp., *Schoenoplectus subulatus, Sesbania formosa , Sporobolus virginicus, Typha domingensis*

Coastal Plain and Marine wetlands	
mid-tidal to high tidal mud flats	zoned mangrove formations: mainly *Avicennia marina*, *Rhizophora stylosa*, *Ceriops tagal*, *Bruguiera exaristata*, *Camptostemon schultzii*, *Excoecaria agallocha* (see Semeniuk *et al.*, 1978; Semeniuk 1983, 1993)
high-tidal mud flats	saltmarsh (samphires): *Halosarcia* spp, *Threkeldia*, *Batis agricola*
contact between tidal mud flats and freshwater seepage zone	saltmarsh (samphires): *Halosarcia* spp, *Threkeldia*, *Batis agricola*

Regional Setting IV: Regional Fauna

The information on avifauna and general fauna was compiled by Australasian Ecological Services with information up to June 1999. The text below is largely an extract from their study. Note that for the wetlands assessed as significant in this study, there is not always information on their biota.

Waterbird and other fauna data are sparse for arid zone wetlands due to their remoteness, the episodic filling of the wetlands and general lack of survey effort. In particular, little effort has been made to assess breeding in many surveys. Despite this, many arid zone wetlands are known to be both nationally and internationally important for waterbirds (*e.g.*, Watkins 1993, Kingsford and Halse 1998). Many wetlands require considerably more survey work over a range of seasons to assess their fauna values, particularly with respect to non-waterbird data and breeding. Only wetlands with notable values are reported here. However, further, well-timed survey work will no doubt highlight the importance of many other wetland areas.

This compilation comprises the findings of Lane & Lynch (1996) on vertebrate fauna and a current analysis of Birds Australia and Australasian Ecological Services data bases on waterbirds (1981-1999) with some additional information from the Register of the National Estate Data Base, Watkins (1993), Jaensch and Vervest (1990), Halse *et al.* (1998), Kingsford and Halse (1998), Coate *et al.* (1998) Garnett (1992) and Mettam *et al.* (unpub.). The compilation also incorporates a selection of personal communications and unpublished data. As few waterbird data exist for wetlands in northern Western Australia and the arid zone generally, it is difficult to compare and understand the relative importance of wetlands in these areas. Where possible, comparisons are made within arid zone wetlands in NW Australia. In some cases, to help provide some perspective, these wetlands are also compared with wetlands evaluated for waterbird usage in southern Western Australia by Raines *et al.* (unpub.). However, only limited parameters are used, including species richness, variety of breeding species, numbers or variety of species listed under international migratory bird agreements and total numbers of individual waterbirds.

A wetland is considered to be of international importance if it supports more than 1% of the population of a given waterbird species in the Asian-Australasian Flyway and of national importance if it supports more than 1% of the Australian population, according to the criteria developed by Watkins (1993).

The main wetlands of note in this region from the point of view of fauna usage as described below.

Eighty Mile Beach Wetland System
(including intertidal mud flats and coastal plain)
This wetland system is a coastal marine system that comprises the Eighty Mile Beach coastal strip between Cape Missiessy and Cape Keraudren, adjoining tidal mudflats (20,000 ha) and coastal plain (20,000 ha) immediately inland of the beach with distinct swamps mainly near Anna Plains Homestead (the plains include Anna Plains which is located at the northern end of this system). It lies 142 km SSW of Broome to 130 km ENE of Port Hedland. The grid references are 19° 03'S - 19° 58'S, 119° 46'E - 121° 31'E (Lane & Lynch 1996). This site excludes Mandora Salt Marshes (= Salt Creek playa chain) which is listed separately. As mentioned above, in the literature and databases, the Anna Plains area is generally incorporated with information from Eighty Mile Beach in the Directory of Important Wetlands, and this usage is followed here in that it is part of the general coastal plain with shore-normal channel-fill wetlands.

In terms of numbers of individual birds this wetland area is the most important migration stop-over area for shorebirds in Australia, and hence it has important Conservation Values. As the wetland supports more than 1% of the populations of 15 species in the Asian-International Flyway, it is of national and international significance for those species. It also supports more than 1% of the Australian populations of 19 species (nationally significant). The maximum count of 336,000 individual shorebirds for the site was one of the highest counts in the Asian - Australasian Flyway. The plains and swamp areas alone have supported at least 75,000 birds including many ducks and shorebirds (Watkins 1993, Lane & Lynch 1996).

To help put these data in some perspective, the Eighty Mile Beach Wetland System, would rank in the top 5% of wetlands of importance in Western Australia for species richness (65 species) compared to wetlands evaluated in southern Western Australia . The beach area alone would rank in the top 5% (40 species) and similarly for the plains and swamps alone (37 species). This wetland would also rank in the top 5% of sampled wetlands in Western Australia for richness of species listed under international treaties (33 species). (Watkins 1993, Raines unpub.).

The Wetland System is also an important site for the White-winged Black Tern in northern Western Australia (R.A.O.U. and A.E.S. data bases).

In terms of Geoheritage Value, the Eighty Mile Beach Wetland System is an outstanding example of a major beach with associated inter-tidal mud flats and coastal floodplain located in the arid tropics (Lane & Lynch 1996).

In regard to Special Listing, the beach and tidal area only is listed under the Ramsar Convention on Wetlands of International Importance Especially as Waterfowl Habitat. The wetland system is listed in the Directory of Important Wetlands and is on the Register of the National Estate Data Base (status Indicative) (Lane & Lynch; Register of the National Estate Data Base).

Information is also provided below specifically for the Anna Plains area because it has some attributes that make it distinct within the Eighty Mile Beach Wetland system. The Anna Plains wetlands comprise a large area comprising winter wet flats and swamps adjacent to the northern part of the Eighty Mile Beach 19° 04'S – 19° 42'S, 121° 05'E – 121° 42'E. In terms of Conservation Values, the wetlands in the Anna Plains area are of national and international importance as a migration stop-over for at least two species of shorebird, viz., the Sharp-tailed Sandpiper and Little Curlew. It also supports nationally and internationally significant numbers of Black-winged Stilt. It supports more than 1% of the populations of each of these species in the Asian-Australasian Flyway (Watkins 1993).

In terms of numbers of individual waterbirds, the Anna Plains Wetland System is also an important area in northern Western Australia for six other waterbird species, for example the Whiskered Tern and the Brolga (R.A.O.U. and A.E.S. data bases). As part of the Eighty Mile area regionally, it has already been nominated as part of the Eighty Mile Beach System in the Directory of Important Wetlands, and is listed for nomination on the Register of the National Estate Data Base (status Indicative) along with the Eighty Mile Beach (Lane & Lynch; Register of the National Estate Data Base).

Mandora Wetland System (= Salt Creek playa chain)
This is a generally linear wetland complex of some 80 000 ha in area including western claypan (8000 ha), eastern claypan and soak/spring swamps each less than 1-2 ha. The system includes Mandora Soak, South of Salt Creek, Eil Eil Springs, and Grant Springs. The springs and creek are permanent. The wetland system is 45 km ENE of Shay Gap and 25 km E of Mandora Homestead and is immediately N and E of Sandfire Roadhouse (Great Northern Highway), 19° 40'S - 19° 55'S, 12 ° 07'E - 121° 08'E (Lane & Lynch 1996).

The system is important from the point of view of Conservation in that it supports 48 species of waterbird of which 15 are listed under international migratory bird agreements. Up to 20,500 waterbirds have been counted there and it supports breeding in 10 species. To help put these data into some perspective, the system would rank in the top 5% of wetlands of importance for species richness, for the variety of species listed under international migratory bird agreements, for richness of breeding species and for numbers of individuals counted in any one survey, if compared to wetlands evaluated in southern Western Australia (R.A.O.U. and A.E.S. data bases; Raines unpub.).

The Marshes are an important site in northern Western Australia for eight species of waterbird including the Australian Pelican, Whiskered Tern and Red-kneed Dotterel (R.A.O.U. and A.E.S. data bases).

The permanent springs and creek in the Mandora Wetland System (= Salt Creek playa chain) provide an important dry season refuge for fauna (Chris Hassell (R.A.O.U.) pers. comm.).

Mandora Salt Marshes (= Salt Creek playa chain) contain good examples of raised peat bogs and permanent stream and palaeo-drainage systems located in a tropical desert. Mangrove stands constitute the most inland occurrence in Western Australia and the soak/swamp vegetation is confined to isolated small sites in the northern Great Sandy Desert (Lane & Lynch 1996).

In terms of Geoheritage Significance, the wetland is also a stranded former estuary, illustrating accumulation under conditions of higher sealevel, wetter climate, and further marine ingress into the continent than exists at present.

In regard to Special Listing, Mandora Salt Marsh is listed under the Convention on Wetlands of International Importance Especially as Waterfowl Habitat (Ramsar Convention) with the Eighty Mile Beach System. It is within a proposed Mandora Nature Reserve, but the owner of the land will not sell it. The wetland is listed in the Directory of Important Wetlands and on the Register of the National Estate Data Base (status Indicative) (Lane & Lynch; Register of the National Estate Data Base).

Roebuck Bay Wetland System

This wetland system is the mid to low tidal to shallow subtidal coastal marine part of the Roebuck Bay and Roebuck Plains system. The Roebuck Bay system is immediately east and south of Broome, 17° 55'S - 18° 20'S, 122° 05'E - 122° 26'E. It includes the marine bay from Entrance Point (north west) to Cape Villaret (south west), mud flats near Fall Point, Bush Point and Sandy Points, Dampier Creek, Crab Creek, Yardoogarra Creek and associated coastal flats (Lane & Lynch 1996).

In terms of Conservation Values, the Roebuck Bay Wetland System is one of the most important migration stop-over areas for migratory shorebirds (26 species) in Australia and internationally. Large proportions of the Australian migratory bird populations pass through this site. The number of birds using the system may exceed 300,000 individuals annually. Even during winter it can support about 10,000 individual waterbirds. This wetland is of national and international significance for 20 species of shorebirds because it supports more than 1% of each of the populations in the Asian-Australasian Flyway. The wetland is also of national importance for two other species, the Broad-billed Sandpiper and Common Sandpiper, supporting at least 1% of the Australian populations of these species (Watkins 1993; Lane & Lynch 1996).

The wetland system supports at least 65 species of waterbird, of which 34 are listed on international migratory bird agreements. To put these data into perspective, Roebuck Bay would rank in the top 5% of wetlands of importance to waterbirds for species richness, variety of species listed on international migratory bird agreements and numbers of individual waterbirds in any one survey, if compared to wetlands evaluated in southern Western Australia (Lane & Lynch 1996; R.A.O.U. and A.E.S. data base Raines unpub). Furthermore Roebuck Bay is an important site in northern Western Australia for the Asian Dowitcher and the Gull-billed, Little, Common and Lesser Crested Terns (R.A.O.U. and A.E.S. data bases).

The Roebuck Bay area supports a significant population of Dugong that is classified internationally as vulnerable (World Conservation Union IUCN Red List of Threatened Species, 1996) and as a Specially Protected Species in Western Australia (Wildlife Conservation Act, 1950) (Mettam *et al.* unpub.).

Roebuck Bay is a major nursery area for marine fishes and crustaceans (Lane & Lynch 1996).

Roebuck Bay is also an outstanding example of a tropical marine embayment, with sandy beaches and extensive tidal mud flats (Lane & Lynch 1996), and as such it has significant Geoheritage value.

In regard to Special Listing, The Roebuck Bay Wetland System is noted under the Convention on Wetlands of International Importance Especially as Waterfowl Habitat (Ramsar Convention). It will be placed in a marine park covering the entire tidal area except for the north-west (near Broome). A portion of Roebuck Plains will be included at the landward side of the park. The Roebuck Bay Wetland System is listed in the Directory of Important Wetlands and is on the Register of the National Estate (status Registered) (Lane & Lynch; Register of the National Estate Data Base).

Roebuck Plains Wetland System

This wetland system is the upper tidal to low supratidal coastal marine part of the Roebuck Bay system. The system is 11 km east of Broome, 17° 50'S - 18° 07'S, 122° 21'E - 122° 43'E. It includes north west clay pans (100 ha), Lake Eda, Lake Campion, Taylors Lagoon and Ungani Lakes (Lane & Lynch 1996). The Lakes and Lagoons are semi-permanent and have been permanent for the last three years, from at least 1997 to 1999 (Chris Hassell, R.A.O.U., pers. comm.).

In terms of Conservation Values, the Roebuck Plains Wetland System ranks highly in that it is a migration stop-over for 14 species of migrant shorebirds and is used by more than 100,000 shorebirds at times. This wetland is of national and international importance as a stop-over area for two species of shorebird; the Oriental Pratincole and the Little Curlew. The wetland supports more than 1% of the populations in the Asian-Australasian Flyway (Watkins 1993; Lane & Lynch 1996).

The wetland system supports at least 78 species of waterbird of which 15 species breed. Twenty nine of these species are listed under international migratory bird agreements. To help put these data in some perspective, the Roebuck Plains Wetland System would rank it in the top 5% of wetlands of importance to waterbirds for species richness and for variety of species listed under international migratory bird agreements, and in the top 10% of wetlands for breeding species, if it were compared to wetlands evaluated in southern Western Australia (R.A.O.U. and A.E.S. data bases; Raines unpub.)

In addition the Roebuck Plains Wetland System is an important site in northern Western Australia for at least 10 other species of waterbird including the Magpie Goose, Whiskered Tern, and White-winged Black Tern (R.A.O.U. and A.E.S. data bases).

Lake Eda alone supports 72 species of waterbird, 11 breeding species and 28 species listed on international migratory bird agreements. These data place it in the top 5% of wetlands of importance, for all these parameters, if compared with wetlands evaluated in southern Western Australia. It is an important site in northern Western Australia for the Masked Lapwing, Little Curlew, Whiskered Tern, Swamp Harrier, Little Egret and Hoary-headed Grebe (R.A.O.U. and A.E.S. data bases).

Lake Campion alone supports 21 species of waterbird, placing it in the top 5% of wetlands of importance for species richness, if compared with wetlands evaluated in southern Western Australia. It is an important site in northern Western Australia for the Little Curlew, Marsh Sandpiper and Green Pygmy Goose (R.A.O.U. and A.E.S. data bases).

Many of the lakes and lagoons on the plain are semi-permanent, but maintain a supply of water throughout the year on many occasions, providing an important dry season refuge for many waterbirds and other fauna (Lane & Lynch 1996).

The Roebuck Plains Wetland System is a good example of a major freshwater floodplain in the Dampierland bioregion, lacking major substantial riverine inflow (Lane & Lynch 1996).

Roebuck Plains also is an outstanding example of a tropical marine prograded carbonate complex, and as such it is of international significance as a Geoheritage Site.

In regard to Special Listing, this wetland complex is noted in the Directory of Important Wetlands and is on the Register of the National Estate Data Base as Status Indicative (Lane & Lynch; Register of the National Estate Data Base).

General comments on other wetlands
Information avifauna and other fauna of the remaining wetlands in the northwestern Great Sandy Desert region is sparse or absent.

Regional Setting V: Regional hydrology

In terms of hydrology, the inland parts of Study Area is mainly driven by groundwater systems, through there is some perching of water in the area, and along the coast, the system is driven by coastal aquifer systems, marine systems, and the interaction between marine and freshwater systems.

The main inland groundwater system comprises the Broome Sandstone, a porous sandstone and sand body that contains freshwater. Generally, the groundwater in the Broome Sandstone lies with the aquifer at depth as an unconfined body, with a water table metres to tens of metres below the ground surface. In coastal areas there is a complex of aquifers and hydrologic interactions. The various stratigraphic units, described earlier, are re-described below in relation to their hydrologic function. The deeper aquifers are also described because they hold potential to supply water to shallow systems through artesian upwelling or leakage through appropriate conduits.

Description of aquifers in the area

Aquifer	Description
Quaternary dune sand	locally stores freshwater from meteoric input and discharges it along the coastal zone
Quaternary beach sand and beachrock	stores marine water, and interacts with freshwater to form beachrock
Quaternary wetland sediment	locally stores freshwater from meteoric input and receives water from deeper formations
Quaternary coastal mud ("Kalji")	stores marine water, and interacts/perturbs the regional freshwater flows to form local wetlands
Quaternary limestone (Holocene)	locally stores freshwater from meteoric input and discharges it along the coastal zone
Quaternary limestone (Pleistocene)	locally stores freshwater from meteoric input and discharges it along the coastal zone
Quaternary red sand, and red muddy sand (Pleistocene)	sandy parts locally store freshwater from meteoric input and discharges it along the coastal zone; upper pedogenic zone acts as a aquatard; muddy parts act as aquatard
Quaternary to Tertiary valley fills (Holocene to Tertiary)	locally stores freshwater from meteoric input and run-off and discharges downwards and along valley tract

Tertiary ironstone and breccia	locally stores freshwater from meteoric input and run-off and discharges downwards and along valley tract; base of body may act as aquatard
Mesozoic Broome Sandstone	stores freshwater mainly from meteoric input; discharges it along coastal zone, along Salt Creek line, and in local artesian upwellings
Mesozoic Jeriemai Siltstone	acts as aquatard between Broome Sandstone and underlying formations
Mesozoic Alexander Formation	stores freshwater
Mesozoic Wallal Sandstone	stores freshwater to brackish water; potentially a source of water in areas of local artesian upwelling

The various aquifers are recharged differently, and have differing discharge mechanisms, in response to their location and aquifer properties, and as a consequence, bores in the aquifers show varying hydroperiods. Water quality, expressed mainly as salinity also varies in response to recharge, discharge, location, salinity of recharging water, and aquifer properties. This information, with respect to the main aquifers from the surface to the Broome Sandstone is summarised in the Table below.

Description of hydroperiod and water quality of aquifers

Aquifer	Hydroperiod and salinity
Quaternary dune sand	seasonal rise and fall of water table in response to meteoric recharge, with a superimposed dampened tidal fluctuation at margins of aquifer with tidal flats; discharge is lateral, locally vertical into underlying aquifers, and through transpiration; groundwater is fresh to brackish
Quaternary beach sand and beachrock	tidal fluctuation; groundwater is mainly marine graded to hypersaline since recharge is marine, and discharge is lateral seepage and evaporation
Quaternary wetland sediment	seasonal rise and fall of water table in response to meteoric recharge; where perched, discharge is via evapo-transpiration, and where not perched it is vertical into underlying aquifers and via evapo-transpiration; groundwater is mainly fresh, locally brackish, and with extreme evaporation, hypersaline

Quaternary coastal mud ("Kalji")	tidal fluctuation; groundwater is mainly marine graded to hypersaline since recharge is marine, and discharge is lateral seepage and via evaporation; in mangrove zones, some discharge is transpiration
Quaternary limestone (Holocene)	seasonal rise and fall of water table in response to meteoric recharge; on margins of aquifer with tidal flat, there is a superimposed but dampened tidal fluctuation; discharge is lateral, locally vertical into underlying aquifers, and through transpiration; groundwater is mainly fresh, but locally brackish
Quaternary limestone (Pleistocene)	seasonal rise and fall of water table in response to meteoric recharge; on margins of aquifer with tidal flat, there is a superimposed but dampened tidal fluctuation; discharge is lateral, locally vertical into underlying aquifers, and through transpiration; groundwater is mainly fresh, but locally brackish
Quaternary red sand, and red muddy sand (Pleistocene)	seasonal rise and fall of water table in response to meteoric recharge; on margins of aquifer with tidal flat, there is a superimposed but dampened tidal fluctuation; discharge is lateral, locally vertical into underlying aquifers, and through transpiration; groundwater is mainly fresh, but locally brackish
Quaternary to Tertiary valley fills (Holocene to Tertiary)	seasonal rise and fall of water table in response to meteoric recharge; discharge is lateral, and along valley tract, vertically into underlying aquifers, and through transpiration; groundwater is mainly fresh, but where water table is near the surface subject to extreme evaporation, groundwater is hypersaline
Tertiary ironstone and breccia	rapid seasonal rise and fall of water table in response to meteoric recharge; discharge is lateral, and along valley tract; groundwater is mainly fresh
Mesozoic Broome Sandstone	rapid seasonal rise and fall of water table in response to seasonal meteoric recharge; discharge is lateral towards the coast, locally upwelling to the surface; detailed daily hydrograph measurements and weekly suggest tidal fluctuations that implicate *earth tides*, and hence the effect of local intra-formation confinement

For purposes of a study of wetlands in the region, the hydrology of the Great Sandy Desert can be divided into three zones (Figure 6):

- a northern section, north of the Salt Creek playa chain wherein mainly fresh groundwater resides at depth within the Broome Sandstone aquifer, and the water table is located in excess of 10 m below the ground surface;
- a southern section, along the Salt Creek playa chain wherein fresh, brackish to saline groundwater is shallow, located beneath a calcrete and limestone sheet;
- a coastal section, where fresh to saline groundwater is located in coastal aquifers.

In relation to these hydrologic settings, wetlands in the region are maintained by: 1. surface water flows from drainage lines; 2. from water table rise in the unconfined surficial aquifer; 3. from ponding/perching of meteoric water by near-surface hardpans; and 4. by upward leakage from formational waters.

Wetland hydrological mechanisms

In this region, there are eight situations, mechanisms, or processes that can maintain wetlands hydrologically. These situations and/or mechanisms are (Figure 7):

1. window to a water table
2. surface perching of meteoric water
3. subsurface perching of meteoric water and run-off
4. run-off recharged
5. groundwater upwelling (springs) inland
6. groundwater upwelling (springs) coastal
7. impedance to coastal zone discharge by coastal muds
8. seawater recharge

A description of these situations/mechanisms, their field evidence, and how they maintain wetlands is provided in the Table below.

Situation/mechanism	**Description**	**Example**
window to the water table	water table is near the surface, and the landscape intersects this water table forming a wetlands; as a result of the long term exposure of the water table, solar radiation/ evaporation concentrates salt, and these wetlands tend to be salty	large interconnected playas in Munro Springs area
surface perching of meteoric water	rainwater ponds on the surface of a clay-lined basin, forming a temporary wetland	some small playas and sumplands in the Munro Springs area, and small playas in the Pindan terrain northeast of La Grange
subsurface perching of meteoric water and run-off	rainwater and surface run-off down a channel-way infiltrates the terrain but is ponded in the subsurface by a buried hardpan or clay lens along the cannel axis, and hence the water is ponded; the rising water table of the perched groundwater may reach the surface, or may approach the surface sufficiently to result in wetland soils	some small playas in the subdued drainage terrain west of Munro Springs area, and small playas in the Pindan terrain northeast of La Grange
run-off recharged	surface run-off flows into and recharges a basin wetlands; where the basin is clay floored, the inflow is ponded to form a perched water body	some small playas in the subdued drainage terrain west of Munro Springs area, and small playas in the Pindan terrain northeast of La Grange

groundwater upwelling (springs) inland	upwelling groundwater in inland area, probably percolating through rock fractures, reaches the terrain surface and results in the development of wetlands	Munro Springs; small springs in the Salt Creek area
groundwater upwelling (springs) coastal	groundwater discharging regionally from upland/inland aquifers into the coastal zone locally is upwelling to form freshwater springs in saline coastal zone	numerous examples in the La Grange Bay area
impedance to coastal zone discharge by coastal muds	groundwater discharging regionally from upland/inland aquifers into the coastal zone locally is impeded by the coastal muds resulting in local upwelling to form freshwater springs and freshwater-filled basins in and near the saline coastal zone	numerous examples in the La Grange Bay area and Roebuck Plains area
seawater recharge	daily, fortnightly or twice-yearly recharge of tidal zone aquifers by marine tidal waters	the tidal zone comprised of sand deposits and mud deposits

In relation to these hydrologic settings, wetlands in the region are maintained by: 1. surface water flows from the drainage lines; 2. from water table rise in the unconfined surficial aquifer; 3. from ponding/perching of meteoric water by the near-surface hardpans; and 4. by upward leakage from formational waters. Discharge of groundwater relevant to this study occurs along the coastal zone, and in a zone where the Salt Creek drainage line is present. The former is the interface between the groundwater of the inland regions discharging along the shore zone under the regional hydraulic head. The latter is an interface of discharge formed by the incision of a former ancient (Cenozoic) river system.

Results I: Coastal wetland types and their maintenance

The coastal zone is one of freshwater discharge from regional groundwater sources and local freshwater sources, and interactions of freshwater and marine water.

In regard to the former, i.e., freshwater discharge from regional groundwater sources, the Broome Sandstone aquifer adjoins, interacts with, and discharges freshwater along the marine interface along the coast, with perturbations and complications to the discharge pattern due to local coastal aquifers, local coastal aquatards, extent of induration of the Broome Sandstone, and style of coast geomorphology and stratigraphy. In regard to the latter, local sand dunes and limestone bodies, for example, store and discharge freshwater into the marine environment.

For coastal wetlands, the interaction of coastal mud and the discharge of groundwater from the inland aquifers is very important. There are five wetland settings along the coastal zones, with their distinctive stratigraphic setting hydrologic setting, and their resulting wetlands.

In general, in summary, for the first case of coastal wetlands, where there is a large discharge of freshwater into the coastal zone, relict early Holocene "kalji" (~ 7000 years old) impedes the freshwater forming small to large clusters of lake-like wetlands. In a second setting, where there is low discharge of freshwater into the coastal zone, relict early Holocene "kalji" (~ 7000 years old) impedes the freshwater forming damp terrain. In the third case, where there is discharge of freshwater into the coastal zone, appropriate conduits and pathways in the Broome Sandstone result in springs forming along the upper shore zone. In the fourth case, where there is a discharge of freshwater into the coastal zone, appropriate conduits and pathways in the Broome Sandstone result in springs forming on the low tidal zone. In the third case, where there is discharge of freshwater into the coastal zone, there may be a broad zone of seepage, resulting in a band of *Melaleuca* thickets at the zone of contact between the two water bodies. In the fourth case, where there is a discharge of freshwater into the coastal zone, appropriate conduits and pathways in the Broome Sandstone result in springs forming in the coastal zone and on the low tidal zone. Fifthly, marine water recharges and maintains tidal flat and mangrove systems, and there is an interplay between marine versus freshwater maintenance. The resultant wetlands are marine wetlands.

This section describes the types of coastal wetlands in terms of their stratigraphic setting, hydrologic setting, and their resulting wetlands. The five wetland settings along the coastal zones are as follows:

1. Kalji impedes the freshwater in a large discharge setting
2. Kalji impedes the freshwater in a low discharge setting
3. Tidal flats, *Melaleuca* and mangroves
4. Springs in a large, or local in a medium discharge setting
5. Marine wetlands

Kalji impedes the freshwater in a large discharge setting
Along the coast local areas of relict carbonate tidal mud deposits, currently situated above the level of their extant formation and deposition, formed some 7000 years ago when MSL was higher, located in the path of the regional or local freshwater discharges into the coastal zone perturbate the discharge of freshwater to generate permanent upwellings and the creation of very localized freshwater lakes. These form small to large clusters along the contact between pindan and the carbonate mud deposits. There is sufficient freshwater discharge to maintain flow into the lakes. Various stratigraphic/ hydrologic situations for these types of areas are described in Figures 8 & 9.

Kalji impedes the freshwater in a low discharge setting
In stratigraphically similar situations, relict carbonate tidal mud in the path of the low regional or local freshwater discharge perturbates the freshwater flow to generate moderate to minor upwellings and hence freshwater sumplands, or damplands, or wetland areas (though not lakes). These freshwater upwellings form wetlands occurring as small to large clusters, or interfaces, along the contact between pindan and the carbonate mud deposits. Generally such perturbations are very localized. Various stratigraphic/hydrologic situations for these types of areas are described in Figure 10.

Tidal flats, *Melaleuca*, and mangroves
As above, with perturbation of freshwater discharge into tidal zones from upland aquifers (red sand dunes and Broome) by the carbonate mud, there are linear seepage zones between marine derived tidal water and freshwater. This broad interface of seepage is marked by a band of *Melaleuca* thickets. Elsewhere locally, freshwater seepage into tidal flats maintains high-tidal mangroves (Semeniuk 1983). A stratigraphic/ hydrologic situation for this type of area is described in Figure 11.

Springs in a large, medium and local discharge setting
While there may be a general seepage and creation of wetlands due to the perturbation of the regional to local freshwater flow into the tidal zone, this process may be amplified where there are appropriate conduits and pathways in the Broome Sandstone. This results in localized springs forming in the coastal zone and on the low tidal zone. The most pronounced effects are where such freshwater discharges occur on the tidal zone, because here freshwater of ~ 1000 ppm salinity emerges as an upwelling spring on tidal flats with groundwater of ~ 40,000 ppm salinity.

Marine wetlands
Marine water recharges and maintains tidal flat groundwater systems. Marine water of salinity 35,000-40,000 ppm recharges the tidal flat groundwater on a daily to fortnightly basis. Evaporation and transpiration concentrates the salinity of the groundwater up to values of 120,000 ppm. This marine water maintains the mangrove formations (and samphires) on the tidal flats. In response to the gradient of increasing salinity across the tidal flat, there is a zonation of mangrove. At a salinity of ~90,000 ppm, mangroves are eliminated by excessive salinity, and samphires and salt flats remain. Along the interface with the hinterland, where there is freshwater seepage, as described above, there is an interface of brackish to freshwater, and the occurrence of *Melaleuca*.

Results II: Inland wetland types and their maintenance

For inland wetlands, the situations of the main groundwater system, any local perching of meteoric water and local upwelling of groundwater are important to the development of wetlands. There are five wetland settings within the inland systems, each with distinctive stratigraphic setting hydrologic setting, and their resulting wetlands.

In summary, there are large to small "oases" or playas, developed along drainage lines where there is a large fluvial discharge. These situations are channels that are windows to the regional water table, and as such there is large evaporation of the groundwater, with the result that these wetlands are salty. Secondly, pans/playas are developed along the same currently dominant drainage lines, but with overflow from the fluvial discharge, there is local ponding of water to form clay-lined pans. In a third situation, there are small pans, or playas, developed along relict drainage lines where there is a large discharge along buried channels, with local expression of ponding due to muddy surface layers. The resultant wetlands are clay or muddy sand floored playas. A fourth situation are pans developed along low relief drainage lines where there is small fluvial discharge. A fifth setting are springs where there is significant freshwater upwelling, and the resultant wetlands are peat mounds.

The Salt Creek Line is a significant discharge zone, but it is complicated, because although it functions to discharge groundwater along the ancient riverine incision, it also is plugged with "kalji" mud accumulated at least since the Quaternary (perhaps 2 millions years ago to the present). It has an east-west change in sediment types, from fluvially dominated in the east along the drainage line, to estuarine and fluvial interlayering in the middle tract sections, to estuarine-marine dominated in western tract sections. Wetlands along the Salt Creek drainage line are of four types. The first results from the ponding effect of the "kalji" mud. The second is due to the upwelling of groundwater along the discharge line to from local springs. The third is the local ponding along the fluvial tract.

This section describes in more detail the types of inland wetlands in terms of their stratigraphic setting hydrologic setting, and their resulting wetlands. There are five such wetland settings along the inland zones, as follows:

1. playas ("oases") along drainage lines with large surface discharges
2. playas ("pans") along drainage lines with large surface discharge
3. playas ("pans") along low relief drainage with small surface discharge
4. springs where there is significant discharge
5. the Salt-Creek discharge zone

Playas ("oases") along drainage lines with large surface discharges

Playas as "oases" are developed along fluvial tracts where there is a large run-off discharge (Figure 12). An example of this occurs in the Munro Springs area. Here, the landscape is broadly incised by a valley tract, and the terrain containing the playas is low-lying. The terrain consists of hills of Broome Sandstone, with valley fills of interlayered sand and muddy sand and mud. Along the valley there is the occurrence of inter-connected playas, and pans (see later). Topographic and stratigraphic considerations indicate the valley to be incised into the regional water table. The valley tract in this area floods periodically, and the last recorded flooding was within the past two years. The salinity of the playa is variable from hypersaline at shallow depths, to brackish/freshwater where water is locally ponded.

The playa in the Munro Springs area illustrates the following:

- development of wetland chains along a valley tract
- wetland type as a playa (or "oasis") that is a window to the water table
- salinisation of groundwater where it is subject to extreme evaporation, and without the throughflow of freshwater
- the stratification of water bodies: fresher water overlying salinized water.

Playas ("pans") along drainage lines with large surface discharge

In the same setting as the playa types described above, there are subsidiary basins developed along fluvial tracts. These are mostly inter-dunal depressions that flood only on the higher than normal flood levels and have consequently in time partly filled with clay. The resulting clay-floored basins then act as "pans" to perch water. Sources of water are rainfall, overland fluvial flooding, and locally, overland flow from springs. The water level of the pans in the Munro Springs area is 1-2 m above the main regional water table as exhibited in the nearby playas ("oases") described above. Water in the pans is fresh. Various stratigraphic/ hydrologic situations for these type of wetlands are described in Figure 12

The pans in the Munro Springs area illustrate the following:

- development of clusters and chains of wetlands along a valley tract
- wetland type as a playa (or "pan") that is perched above the main water table
- the water is mainly fresh, but begins to salinize towards the end of its drying out phase
- the stratification of water bodies: fresher water in the "pans" overlying salinized water of the main groundwater system.

Playas ("pans") along low relief drainage with small surface discharge
Inland, east of the La Grange Bay area, there are low relief drainage lines along which are developed local playas. The playas are within developed intra-valley-tract lowlands, and essentially are subsidiary basins along fluvial tracts. The basins appear to fill with water annually. The basins are clay-floored basins, and thus act as "pans" to perch water. Sources of water are rainfall, and overland fluvial flooding. Their geomorphic setting suggests that they are not in the path of major flow lines, and are more generally part of tributary systems, hence they are within a system of low relief drainage with small surface discharge. Stratigraphic studies indicate that these pans are underlain by lateritised Broome Sandstone, and that the valley-tract itself is cut into a ferruginized Broome sandstone, and that the valley tract locally has, now-buried, steep walls. Sediments filling the valley tract are in excess of 5 m, appear to be sandy in lower sections, and grade to be muddier in upper sections. On site studies in two locations showed one of the pans to be a perched system where meteorically recharged water is perched on clay floors of the basin, and the other to be comprised of a perched freshwater system (ponded by the clayey floor of the basin) with a deeper, but still perched, groundwater system related to base flow of the valley tract. This latter, deeper, perched groundwater is perched above the groundwater residing in the Broome Sandstone. Water in all these pans is fresh. Various stratigraphic/ hydrologic situations for these wetlands are described in Figure 13

The pans in these situations described above illustrate the following:

- development of clusters wetlands along a valley tract
- wetland as a playa (or "pan") that is perched above the main water table
- the water is fresh, but begins to salinize near the end of a drying out phase.

Springs where there is significant discharge
Two areas of inland springs were studied in this project: one located at Munro Springs, the other along the valley tract of Salt Creek. The area of Munro Springs is an important wetland system in that it provides information and insight into the mechanisms of hydrologic maintenance of some of the wetlands in the region.

In the Munro Springs area, as described above for the playas ("oases" and "pans"), the geomorphic setting is a landscape broadly incised by a valley tract, with the terrain containing the playas being low-lying. The terrain surrounding the playa network consists of hills of Broome Sandstone. The springs in the Munro Springs area occur on hill-side and slopes, away from the lowlands (Figure 14). Topographic surveying at the large scale (i.e., ~ 1 km) shows the water levels within the springs to be 1-2 m above the regional (saline) water table under the main playa, and while the playa groundwater is saline, the water of the springs is fresh, and flow through the whole year. Furthermore , the perched "pans" along the valley tract, while they also are fresh, dry out during the end of the dry season, while, again, the springs flow through the whole year. Clearly, the source and dynamics of the water in the springs is separate from that maintaining the "oases" and "pans" of the valley tract playas.

At the smaller scale, hydrologic investigations of the Munro Springs show small mounds and fingers of fresh water rising and discharging to the surface in very narrow conduits. Stratigraphically, the wetland of the springs is carbonate mud (3-4 m thick) filling a basin, with central plugs of peat forming peat mounds(also 3-4 m thick). The thickness of the peat, and its radiocarbon age indicates that these freshwater discharge areas are long term features of this part of the Great Sandy Desert. Vegetation inhabiting these springs consist of Dragon Trees, *Acacia*, rushes, bullrushes, and paperbark.

In the region of the Salt Creek valley tract, there are a number of springs such as those near the Eil Eil Spring system. The geomorphic setting is a landscape broadly incised by the Salt Creek valley tract, a valley tract filled (plugged) with Pleistocene to Tertiary carbonate mud, and surrounded by linear desert dunes. Here, the springs occur on the lowlands of the valley tract. Their relationship to the regional groundwater is unknown.

At the smaller scale, hydrologic investigations of these springs along the Salt Creek valley tract, again, show small mounds and fingers of fresh water rising and discharging to the surface in very narrow conduits. Similar to the Munro Springs, stratigraphically, the wetlands of the springs along the Salt Creek valley are filled with carbonate mud (3-4 m thick) filling a basin, with central plugs of peat forming peat mounds (also 3-4 m thick). The thickness of the peat indicates that these freshwater discharge areas are long term features of this part of the Great Sandy Desert. Vegetation inhabiting these springs consist of Dragon Trees, *Acacia*, the mangrove *Avicennia*, rushes, bullrushes, and paperbark (Figure 15)

The springs at Munro Springs and Salt Creek illustrate the following:

- development of isolated wetlands as carbonate basin fills and peat mounds
- the isolated nature of freshwater delivery to these wetlands from springs - the water appear to recharge the wetlands as fingers, following conduits
- the water table in the springs is not linked to the main water table, and can be several metres above the main water table
- the water is fresh, remaining fresh through the whole year, and flows all year, indicating that there is sufficient throughflow counter salinisation, and that the flow is not linked to rainfall.

Salt-Creek discharge zone

The Salt-Creek valley tract is an east-west aligned sediment filled ancient wide valley tract system, some 10-20 km wide. Consideration of stratigraphic and geomorphic information, regionally, and information obtained by radar penetration of the surface (CSIRO) suggest that the valley tract was cut as a steep sided valley (or gorge) into the Broome Sandstone. As such, the Salt Creek valley tract, though now largely filled with sediment, potentially stands as a major discharge line for groundwater from the Broome Sandstone. The valley tract has been filled with sediments of various ages and various origins, and thus, bearing such antiquity from at least the Tertiary, it carries a complex history. From a perspective of the nature of the sedimentary fill, which will have bearing on the hydrologic mechanisms that interact with the wetlands developed along the valley tract.

The Salt-Creek valley tract can be divided into three zones. From east to west, these are: 1. the eastern tract, where fluvial processes are/were dominant, and the valley tract is filled with sand, muddy sand, and mud, and wetlands have contracted to playas in inter-dunal depressions; 2. a mid tract where Tertiary and Pleistocene seas made inland incursions along the valley forming palaeo-seaways and estuaries, resulting in filling of the tract with marine sediment, the upper layers of which are carbonate mud (some mud is now indurated to limestone); and 3. a western tract filled with Pleistocene to Holocene carbonate mud (> 10,000 years old, to 2 x 10^6 years old and < 7000 years old, respectively), with the Holocene deposits dominating the more western parts of the tract. Each of these tracts, being filled with a different type of sedimentary deposit, interact with the Broome Sandstone hydrology in their own unique way. In this report, emphasis was placed on the mid- and western tracts of the system, as the eastern tract is outside the Study Area. These tracts are described in terms of their wetlands.

The mid tract region of the Salt Creek system is dominated by a narrow channel cut into Tertiary/Pleistocene limestone. The limestone forms a valley fill ribbon some 20 km wide, and its upper surface is located some 4-5 m above the level of the regional water table. The channel system is bordered by linear dunes. Water in the channel is saline. The mangrove *Avicennia* fringes the channel banks (Beard 1965).

The western tract of the Salt Creek system is more complex. As noted above, it is valley filled with Pleistocene to Holocene carbonate mud deposits and limestone. As such, the surface of the valley tract is a broad flat plain (the Sandfire Flats), covered in saltbush and samphires, or bare due to salt. Locally in the area, cutting through the limestone plain, there are small springs of peat mounds and carbonate-mud-filled basins (described above). The ground water of the western part of the valley tract system is shallow and saline. The extreme western part is still somewhat recharged by marine water, but generally elsewhere, the shallowness of the water table means that it is subject to evaporation, and hence there is a build-up of salinity to hypersaline levels. Since the sedimentary fill is carbonate mud, it is an effective agent for perching surface water - thus rainwater commonly perches on the mud, and rests above the deeper saline groundwater. In June 1999, on one of the surveys by VCSRG to the Great sandy Desert, the entire surface of the western tract (Sandfire Flats), as a result of a cyclone, was inundated with freshwater (and extensively opportunistically utilized by birds).

Various stratigraphic/ hydrologic situations for these situations are described in Figure 16.

The wetlands of the Salt Creek valley tract illustrate the following:

- maintenance of wetlands within the valley tract by fluvial input (eastern region), marine input (extreme western region), salinisation through evaporation (all regions of the tract), groundwater discharge/seepage into the valley tract (all regions of the tract), and ponding of water from meteoric and fluvial run-off sources
- the development, along the mid regions of the valley tract, a long, linear, mangrove fringed channel wetland tens of kilometres inland from the coast, in a desert environment
- the development along the mid-tract regions of saline wetland plains on carbonate muds and limestone due to a shallow water table
- development along the western regions of the tract of samphire-vegetated coastal saline wetland plains within the valley tract
- freshwater that perches on a saline groundwater; the system is fresh, remaining fresh through the whole year, flowing subterraneously all year, and indicating that firstly there is sufficient throughflow to counter salinisation, and secondly the subterraneous flow is not linked to rainfall.

Results III: Patterns of vegetation

One of the objectives of this study was to determine patterns of vegetation occurrence in order to detect phreatophytic vegetation using remote sensing techniques and aerial photography, it potentially could have been possible to provide an indication of groundwater-dependent vegetation that might be affect by any water-table drawdown associated with water abstraction. Identification of wetlands, through vegetation, i.e., by phototone of vegetation (paperbarks swamps, dragon tree swamps, mangrove swamps, and eucalypt-lined water courses, as well as meadow, rush, or sedge vegetated wetlands), was relatively simple. However, vegetation patterns indicating wet conditions clearly occur in areas of lowlands such as drainage lines, basin lowlands, and low plains. In theory, it should be possible to extrapolate such vegetation into areas of non-wetlands, if the vegetation was groundwater dependent.

Water-dependent vegetation in the field was noted during the surveys, and their phototone patterns were assessed back in the Perth Office with aerial photographs and remote sensing techniques. However, for the obvious water dependent vegetation, analysis of aerial photographs and remote sensing images provided little evidence of extensive and regionally detectable groundwater dependent (phreatophytic) vegetation. The obvious vegetation patterns were related to creek lines, valley tracts and basins, and these patterns were relatively easy to extrapolate with the available techniques.

The identification of phreatophytes outside of wetlands, i.e., vegetation on the pindan plain, or lower areas of the pindan, but dependent on groundwater by tap roots, was problematic. Short of excavating a range of plant species to determine their relationship to phreatic or vadose water, it was not possible to define fully what constituted phreatophytic vegetation in the region. The obvious known phreatophytes (such as paperbarks, and the dragon trees, *Eucalyptus camaldulensis*), are related to wetlands, and do not occur to a major extent outside of wetlands (except for one species of paperbark which indicates a shallow water table, but where such areas were identified from field work, the signature of the species was not evident from aerial photography or remote sensing - moreover, in such settings, the dominant vegetation often was spinifex vegetation, a species indicative of dry conditions). In summary, detection of phototones of phreatophyte or groundwater dependent vegetation by aerial photography or remote sensing remained elusive.

Criteria for selection of significant wetlands

Evaluation of any wetland is a process which requires 1) an understanding of the particular wetland, (through field data inventory and monitoring), 2) an understanding of its context in a regional setting, and 3) an understanding of the range of wetland functions. Given the complexity of wetlands, it is an ongoing process. Added to this, the study area contains a large number of wetlands, many of which are inaccessible. Therefore, what has been undertaken, is a preliminary analysis based on the current available knowledge of wetland attributes and values. The analysis was applied to the consanguineous suites described above, and the following criteria were used:

- representativeness of a consanguineous suite
- scarcity of wetland type
- habitat diversity
- geomorphic/landscape values
- faunal values
- linkage of systems
- condition of wetland

Representativeness is assessed on the range of wetland types present in each suite as well as the characteristics of each suite. Scarcity relates to the size, distribution and duplication of wetland suites. Representativeness must be based on comparisons wholly within a given consanguineous suite.

Habitat diversity refers to the variability present in each suite as well as the presence/absence of restricted habitat types.

Geomorphic/landscape values and faunal values refer to specific features present in the wetlands, or documented use of wetlands by specific fauna, and the importance of the wetland in maintaining populations.

Linkage of systems refers to hydrological links such as creeks flowing into or from basins, creeks on flats, and to ecological links such as a series of basins ranging from permanent open water to seasonally waterlogged vegetated damplands surrounded by upland.

Condition of wetland includes assessment of the landform and stratigraphy, hydrology such as hydroperiod, water levels, water quality, and maintenance mechanisms, and vegetation in the wetland and the buffer zone. In most of the wetlands considered here, this feature was not an issue.

Information on habitat diversity and geomorphic/landscape values were obtained from field surveys conducted during this study. In some suites the information available is depauperate, and should not be considered at this stage as representative of the value of the wetland suite. Criteria important to the assessment of each suite, are listed at the beginning of the description.

Three types of assessments were carried out these wetlands:

- that of the Australian Heritage Commission,
- that used in Water Resources Council (1988) & Semeniuk (1985)
- that used by Hill *et al.* (1996), and expanded by C A Semeniuk (1998).

Following description of these evaluation systems, discussion is provided of the concept of Geoheritage, and the Philosophy of Approach undertaken to assess the significance of wetlands in this Study Area.

Australian Heritage Commission Criteria

The criteria for selection of area for Register on the National Estate by the Australian Heritage Commission are listed as 4 main types (Australian Heritage Commission 1990):

1. Criterion A: Importance of an area or site in the course, or pattern, of Australia's natural or cultural history

2. Criterion B: Possession of uncommon, rare or endangered aspects of Australia's natural or cultural history

3. Criterion C: Potential of an area or site to yield information that will contribute to an understanding of Australia's natural or cultural history

4. Criterion D: Importance of an area or site in demonstrating the principle characteristics of (i) a class of Australia's natural or cultural place; or (ii) a class of Australia's natural or cultural environments

These are amplified below, according to the guidelines of the Australian Heritage Commission (AHC), with examples from this study.

Criterion A: Importance of an area or site in the course, or pattern, of Australia's natural history:

A.1 Importance in the evolution of Australian geology, fauna, flora, landscapes or climate. According to the AHC guidelines, this would include:

1. geological evolution: *e.g.,* the evolution of the Mandora,
2. *Melaleuca* thickets fringing freshwater seepage zone,
3. sites significant for climate history: *e.g.,* pollen record at Dragon Tree Soak;

A.2 Importance in maintaining existing processes or natural systems at the regional or national scale. According to the AHC guidelines, this would include:

1. coastal processes and wetland processes (examples include the maintenance of mangrove systems, and the maintenance of wetland vegetation in the inland systems);

A.3 Importance in exhibiting unusual richness or diversity of flora, fauna, landscapes or cultural features. According to the AHC guidelines, this would include:

1. biological or geological diversity. *e.g.,* the vegetation of the springs and soaks along the Mandora Marshes, or the coastal forms at La Grange
2. landform or geomorphic diversity: coastal forms along the tract between La Grange and Roebuck Bay

Criterion B: Possession of uncommon, rare or endangered aspects of Australia's natural history:

B.1 Importance for rare, endangered natural landscapes or phenomena, or as a wilderness. According to the AHC guidelines, this would include:

1.. areas or sites with uncommon or rare landform or geomorphology with vegetation (*e.g.*, the mangrove occurrence along Salt Creek)

Criterion C: Potential of an area or site to yield information that will contribute to an understanding of Australia's natural history:

C.1 Importance for information contributing to a wider understanding of Australian natural history, by virtue of its use as a research site, teaching site, type locality, reference or benchmark site. According to the AHC guidelines, this would include: research areas, reference and benchmark areas, and educational areas (such as the mangrove coast, and the wetlands of Dragon Tree Soak).

Criterion D: Importance of an area or site in demonstrating the principle characteristics of (i) a class of Australia's natural place; or (ii) a class of Australia's natural environments:

D.1 Importance in demonstrating the principal characteristics of the range of landscapes, environments or ecosystems, the attributes of which identify them as being characteristic of their class. According to the AHC guidelines, this would include: places demonstrating the principal characteristics of the range of landscape and ecological classes: examples of which would be the wetlands in relationship to linear dunes, the wetlands in relationship to relationship to groundwater seepage zone, and wetlands in relationship to coastal evolution; some of these are of global significance, *e.g.*, the linear sand dunes and the wetlands, and the relationship of the salt lake systems to palaeo-drainage.

In this context. many of the wetlands of the Great Sandy Desert qualify for inclusion on the Register of the National Estate, as will be discussed below.

Note that Criterion E is not applied in this study.

Water Resources Council (1988) & Semeniuk (1985)

The most comprehensive evaluation of wetlands was the system of the Water Resources Council (1988), based on Semeniuk (1985). It was based on identifying some 15 criteria, and providing a weighting or score to each based on the level of significance of each of the criteria (5 = international, 4 = national, 3 = State-wide, 2 = regional, 1 = local), with a team of professional wetland scientists visiting the wetland in the field. The evaluation system was developed by Semeniuk (1985) for coastal wetlands and modified to account for inland wetlands, and was published in the proceedings of an international workshop.

Hill *et al.* (1996) and C A Semeniuk (1998)

The evaluation system described by Hill *et al.* (1996) was based on previous systems extant in Southwestern Australia, together with a review and assessment of the International Literature. While designed for the Swan Coastal Plain, in southwestern Australia, its principles are nonetheless applicable to this present Study Area in the northwestern Great Sandy Desert.

According to the scheme of Hill *et al.* (1996), the evaluation of wetlands results in their categorization into three management classes, following (Hill *et al.*, 1996); the classes are:

1. Conservation
2. Resource Enhancement
3. Multiple Use

The Conservation Category was understood to mean that the priority would be to manage the wetland as a reserve and to protect the attributes and functions which were of high value. Alteration to the wetland would be strongly discouraged and mechanisms would be put in place to protect the wetland from any man-induced deterioration.

The Resource Enhancement category was understood to mean that the priority would be to maintain the wetland, its attributes and functions, and wherever possible enhance the ecological status of the wetland by such activities as improving water quality or re-vegetating cleared areas with endemic site-appropriate species

The Multiple Use category was understood to mean that the priority would be to maintain multiple uses of the wetland including ecological functions. This would necessitate maintaining the geomorphic integrity of the wetland. It excludes destruction of the wetland through processes such as infilling, excavation, mining, or erection of urban structures.

In the context of the Great Sandy Desert, the Conservation Category is the most important, and will the only one dealt with here.

Although evaluation of wetlands has taken place elsewhere in other regions in Western Australia, in Australia generally, and globally, much debate and confusion surrounds the issue, and it was the intention of Hill *et al.* (1996) to present clear and comprehensive criteria for each of the various management categories with respect to natural or ecological attributes, and hence reduced the number of management categories to simplify the assessment process.

Evaluation demands a logical and systematic approach to exhaustively capture all recognised natural wetland values, therefore, criteria are needed to be designed to assess the following attributes of wetlands. C. A. Semeniuk (1998; *in* VCSRG 1998) developed criteria to assign wetlands to the conservation category, as follows:

- wetland type
- wetland processes maintaining the system
- wetland habitats
- wetland functions
- biodiversity
- scientific value

Criteria are listed below and explained for the category of *Conservation*. The list is organised in the same sequence as the list of wetland attributes above. This order does not imply priority. The evaluation criteria aim to be comprehensive.

Wetland type: A wetland may be classed as Conservation *if it satisfies one or more of the following criteria*

1. it is an anthropogenically unaltered wetland type (i.e., river, creek, floodplain, lake, sumpland, dampland)
2. it is a scarce wetland type
3. it is a representative wetland type (i.e., representative of its consanguineous suite)

Wetland processes: A wetland may be classed as Conservation *if it satisfies one or more of the following criteria*

1. the wetland is subject to anthropogenically unaltered wetland processes (i.e., recharge and discharge mechanisms, hydroperiod, sedimentary processes,)
2. the wetland exhibits unusual wetland processes
3. the wetland exhibits representative wetland processes (i.e., representative of its consanguineous suite and geomorphic setting)

Wetland habitats: A wetland may be classed as Conservation *if it satisfies one or more of the following criteria*

1. the wetland is a habitat for rare & endangered fauna
2. the wetland is a habitat for rare & endangered flora
3. the wetland exhibits a high diversity of habitats

Wetland functions: A wetland may be classed as Conservation *if it satisfies one or more of the following criteria*

1. the wetland is necessary for maintenance of large faunal populations
2. the wetland is a refuge for resident fauna
3. the wetland is an important breeding, feeding or watering site for migratory populations (local and international)
4. the wetland is a significant regional component of the hydrological cycle (has an important hydrological storage, recharge or discharge function; or an hydrochemical function)

Biodiversity: A wetland may be classed as Conservation *if it satisfies one or more of the following criteria*

1. the wetland exhibits unaltered wetland vegetation and fauna
2. the wetland has a scarce vegetation association or faunal association
3. the wetland has a highly diverse wetland flora or fauna

Scientific value: A wetland may be classed as Conservation *if it satisfies one or more of the following criteria*

1. the wetland contains scientifically significant pollen records
2. the wetland is underlain by unusual wetland sediments (indicators of wetland history)
3. the wetland has unusual geomorphology (i.e., it is situated in an unusual geomorphic setting or contains unusual geomorphic features within it)

Concept of Geoheritage

Conservation, globally, to date, has been based on the preservation of plant and animal species, and in particular, preservation of rare and endangered species. Recently, there has been a shift to the recognition and preservation of communities or assemblages (Wyatt & Moss 1990; Blandin 1992), and hence the recognition of biodiversity and geoheritage as a basis to conservation (IUCN, 1992; Ledec, 1988; Wyatt & Moss, 1990). Thus, conservation is more than just the preservation of single rare species, or assemblages of species. It should also encompass a gamut of natural history features that should include:

1. purely biological phenomena of scientific and heritage value, ranging from preservation of rare and endangered species at one extreme, to preservation of representative assemblages of species (Soule, 1986), to preservation of "biodiversity" (McNeely et al, 1990).

2. features that combine biological and geological, geomorphological, pedological and hydrological attributes, essentially linking biodiversity with "geodiversity" (Hopkins, 1994), and

3. purely physical (i.e., non-biological) phenomena of scientific and heritage value, such as unusual rock or landscape formations, many of which may be termed "geoconservation", or where there is diversity, "geodiversity" (Duff, 1994; Creaser, 1994; Markovics, 1994).

Where the terrain, or a geological formation, or the physical feature in a given area is of outstanding importance, conservation of geologic or geomorphic systems is straightforward. At the National level, examples are the geological formation known as "The Breadknife" in the Warrambungals, Uluru (Ayers Rock in Central Australia, the "Twelve Apostles" along coastal Victoria, or a classic exposure of dinosaur footprints. Not so clear to the general public, and decision-making non-scientists, is the case for "geoheritage", unless it been made more acceptable where geological diversity, or unusual geological features, or a unique geological setting results in the occurrence of unusual or rare biota.

The term "geoheritage", in the Australian setting, is used here as follows:

> *State-wide to Nationally important features of geology, including igneous, metamorphic, sedimentary, structural, geochemical, palaeontologic, geomorphic, pedologic, hydrologic attributes that offer important information or insights into the formation or evolution of the continent; or that can be used for research, teaching, or reference sites.*

Philosophy of approach, this study

As a basis to understanding the approach used in evaluating the wetlands, some discussion of the philosophy underlying the methods are provided here. Most but not all of these were directly applicable to the Study Area, but all are described and discussed because they provide a context of debate for the conservation of wetlands generally, and to illustrate that wetlands in good condition in the Study Area are outstanding in comparison to wetlands normally afforded conservation status elsewhere.

In terms of obtaining information to apply the criteria for the four evaluation schemes, there were three general methods used in this study:

- aerial photographic assessment,
- review of published information and
- field site inspection.

More specific details on methods in relationship to delineation of consanguineous suites and for implementing the criteria for evaluation are described in appropriate later sections.

The photographic analysis of a given wetland included:

1. assessment of the presence and amount of natural vegetation
2. assessment of the presence and type of a buffer zone
3. assessment of the geomorphic integrity of the wetland
4. investigation of unusual geomorphic features or setting
5. assessment of the nature of local catchment
6. assessment of hydrological linkages, and
7. assessment of possible wetland hydrological functions

The literature and database searches were undertaken to obtain information on specific functions of wetlands such as faunal usage or habitat attributes. The following databases were accessed:

- contact with CALM on rare and endangered fauna
- Birds Australia database on waterfowl use of wetlands

Literature and published maps were used to access information on unusual geological, landform or soil formations, pollen sites and fossil sites. Publications were also a supplementary source of information on values of specific wetlands *e.g.,* National Directory of Important wetlands, Lane & Lynch (1996).

On-site inspections/assessments for the evaluation of wetlands in the Study Area included the following procedure:

1. an assessment of wetland vegetation status
2. recognition of wetland vegetation diversity (*e.g.*, structural diversity, presence of restricted community types)
3. recognition of unusual vegetation physiognomy (potential indicators of changes to wetland hydrology)
4. recognition of dynamic biological responses as an indicator of habitat alteration (evident in floral community changes)
5. assessment of possible anthropogenic alteration to hydrology
6. assessment of degradation

The procedures outlined above were used, and the philosophy of assessing the extent of degradation was the basis for a general evaluation of wetlands in response to the primary objective. There was a second objective to this study, i.e., identification of wetlands of *outstanding significance*. This translated to identification of wetlands with values that are recognised as being of Statewide, National or even International significance. The following criteria were used to select wetlands in this class:

- wetlands that have outstanding values as a faunal habitat or refuge,
- wetlands that have value as a habitat for significant flora,
- wetlands that have high habitat diversity,
- wetlands that have value as a rare wetland type,
- wetlands that are an outstanding example of a particular type of wetland and wetland processes (geoheritage)
- wetlands that have value as a scientific resource
- wetlands that in association typify a geomorphic setting (geoheritage)

The wetlands in this category of outstanding environmental significance generally satisfied more than one criterion.

Significant wetlands in the northwestern Great Sandy Desert

Wetlands assessed as being of significance in the Study Area are listed below, and then noted as to the criteria that are satisfied.

The wetlands of significance determined in this study in alphabetical order, are (Figure 17):

1. Cape Bossut embayment
2. Eighty Mile Beach Wetland System, including Anna Plains wetlands, and coastal wetlands of Mandora Coastal wetland suite
3. Injudinah Swamp and associated wetlands along regional seepage lines
4. La Grange Bay
5. Mandora Wetland System (= Salt Creek playa chain)
6. Munro Spring wetland system
7. Roebuck Bay Wetland System
8. Roebuck Plains Wetland System
9. Salt Creek System

Table showing which assessment criteria are satisfied by the various wetlands:

(*) Categories of assessment are dealt with in the report earlier in the section on Australian Heritage Commission criteria. The notation A1, A2, etc., denotes which criteria are satisfied by the given location.

(**) Categories of assessment for the WRC assessment: there are 5 categories, I = international significance, I = international significance, N = national significance, S = State-wide significance, R = regional significance, and L = local significance;

(***) Categories of assessment for the WR&C assessment: there is only one category "C" - if the wetland qualifies to be considered of Conservation significance, then it is assigned "C", if not, there is no "C" in the column.

Wetland	**Criteria of this report**	**AHC Criteria (*)**	**WRC criteria (**)**	**W&RC criteria (***)**	**Rationale and comments: (the information in this column summarizes information in the descriptions above, hence there is some repetition)**
Cape Bossut embayment	representativeness habitat diversity geomorphic values	A1, D1	I	C	This is a small mangrove-fringed tidal embayments, with the most southern occurrence of *Sonneratia* (Semeniuk 1983). The system is a globally significant example of mangrove embayments and barriers set in an arid coast. In terms of conservation values, this system has importance as a coastal mangrove habitat area. As yet the system as not been listed
Eighty Mile Beach Wetland System	representativeness geomorphic values faunal values linkage of systems	A1, A2., A3, B1, C1, D1	I	C	This system has conservation value as a coastal and near coastal plain of stranded former interdunal lagoons, and shore-normal carbonate-filled former estuarine channel systems. It supports a samphire complex in the swales. In terms of numbers of individual birds this wetland area is the most important migration stop-over area for shorebirds in Australia, and hence it has important Conservation Values. As the wetland supports more than 1% of the populations of 15 species in the Asian-International Flyway, it is of national and international significance for those species. It also supports more than 1% of the Australian populations of 19 species (nationally significant). The Wetland System is also an important site for the White-winged Black Tern in northern Western Australia.

					In terms of Geoheritage Value, the Eighty Mile Beach Wetland System is an outstanding example of a major beach with associated inter-tidal mud flats and coastal floodplain located in the arid tropics In regard to Special Listing, the beach and tidal area only is listed under the Ramsar Convention as internationally important. The wetland system is listed in the Directory of Important Wetlands and is on the Register of the National Estate Data Base.
Anna Plains Wetlands (as part of northern Eight Mile Beach System	representativeness geomorphic values faunal values linkage of systems	A1	I	C	In terms of Conservation Values, this wetland system is of national and international importance as a migration stop-over for at least two species of shorebird, viz., the Sharp-tailed Sandpiper and Little Curlew. It also supports nationally and internationally significant numbers of Black-winged Stilt. It supports more than 1% of the populations of each of these species in the Asian-Australasian Flyway. In terms of Special Listings, Anna Plains has been listed in the Directory of Important Wetlands and on the Register of the National Estate Data Base along with the Eighty Mile Beach
Injudinah Swamp and associated wetlands along regional seepage line	representativeness geomorphic values biota values linkage of systems	A1, A3, C1, D1	I, and locally N	C	A small lake situated along the contact of the Pindan and the tidal marshes of La Grange Bay. The lake is developed by seepage of freshwater from the regional aquifers interfacing with the muds of the tidal zone. Freshwater biota include Dragon Trees and the native Bull-rush. The area is a haven for wetland birds. This is an excellent example of a seepage wetland developed in an arid zone setting along the margin of a tidal flat.
La Grange Bay	representativeness geomorphic values	A1, D1	I	C	This is a system of mangrove-fringed tidal embayments that occur along the coast between Cape Bossut and False Cape Bossut. The system is a globally significant example of mangrove embayments and barriers set in an arid coast. In terms of conservation values, this system has importance as a coastal mangrove habitat area and a coastal type.

Mandora Wetland System (= Salt Creek playa chain)	representativeness geomorphic values faunal values linkage of systems	A1, A2, A3, B1, D1	I and locally N	C	The system is important from the point of view of Conservation in that it supports 48 species of waterbird of which 15 are listed under international migratory bird agreements. Up to 20,500 waterbirds have been counted there and it supports breeding in 10 species. The permanent springs and creek in the Mandora Wetland System (= Salt Creek playa chain) provide an important dry season refuge for fauna. Mandora Salt Marshes (= Salt Creek playa chain) is a good example of a raised peat bog, permanent stream and palaeo-drainage system located in a tropical desert. The mangrove communities constitute the most inland occurrence in Western Australia and the soak/swamp vegetation is confined to isolated small sites in the north of the Great Sandy Desert. In terms of Geoheritage Significance, the wetland is also a stranded former estuary, illustrating accumulation under conditions of higher sealevel, wetter climate, and further marine ingress into the continent than exists at present. In regard to Special Listing, Mandora Salt Marsh (= Salt Creek playa chain) is listed under the Convention on Wetlands of International Importance Especially as Waterfowl Habitat (Ramsar Convention) with the Eighty Mile Beach System. It is within a proposed Mandora Nature Reserve, but the owner of the land will not sell it. The wetland is listed in the Directory of Important Wetlands and on the Register of the National Estate Data Base
Munro Spring wetland system	representativeness geomorphic values faunal values linkage of systems	A1, A2, A3, B1, D1	I	C	This is an important system in that it illustrates wetlands in an setting of the Great Sandy Desert. Munro Spring itself is a spring/soak, vegetated by Dragon Trees, saltwater Couch, native Bull-rush, and Paspalum. The spring/soak produces a peat mound. Nearby is a playa that is a window to the water table. Also nearby are overflow basins that are perched wetlands

Roebuck Bay Wetland System	representativeness geomorphic values faunal values linkage of systems	A1, A2, A3, B1, D1	I	C	In terms of Conservation Values, the Roebuck Bay Wetland System is one of the most important migration stop-over areas for migratory shorebirds (26 species) in Australia and internationally. Large proportions of the Australian migratory bird populations pass through this site. The number of birds using the system may exceed 300,000 individuals annually. Even during winter it can support about 10,000 individual waterbirds. This wetland is of national and international significance for 20 species of shorebirds because it supports more than 1% of each of the populations in the Asian-Australasian Flyway. The wetland is also of national importance for two other species, the Broad-billed Sandpiper and Common Sandpiper, supporting at least 1% of the Australian populations of these. Furthermore Roebuck Bay is an important site in northern Western Australia for the Asian Dowitcher and the Gull-billed, Little, Common and Lesser Crested Terns. The Roebuck Bay area supports a significant population of Dugong that is classified internationally as vulnerable (World Conservation Union IUCN Red List of Threatened Species, 1996) and as a Specially Protected Species in Western Australia Roebuck Bay is a major nursery area for marine fishes and crustaceans. Roebuck Bay is also an outstanding example of a tropical marine embayment, with sandy beaches and extensive tidal mud flats, and as such it has significant Geoheritage value. In regard to Special Listing, The Roebuck Bay Wetland System is noted under the Ramsar Convention on Wetlands of International Importance. It will be placed in a marine park covering the entire tidal area except for the north-west (near Broome). A portion of Roebuck Plains will be included at the landward side of the park. Roebuck Bay Wetland System is listed in Directory of Important Wetlands, and on the Register of the National Estate

Roebuck Plains Wetland System (the entire plain to its contact with Pindan)	representativeness scarcity of wetland type habitat diversity geomorphic/landscape values faunal values linkage of systems condition of wetland	A1, A2, A3, B1, D1	I	C	In terms of Conservation Values, the Roebuck Plains Wetland System ranks highly in that it is a migration stop-over for 14 species of migrant shorebirds and is used by more than 100,000 shorebirds at times. This wetland is of national and international importance as a stop-over area for two species of shorebird; the Oriental Pratincole and the Little Curlew. The wetland supports more than 1% of the populations in the Asian-Australasian Flyway. In addition the Roebuck Plains Wetland System is an important site in northern Western Australia for at least 10 other species of waterbird including the Magpie Goose, Whiskered Tern, and White-winged Black Tern (R.A.O.U. and A.E.S. data bases). Many of the lakes and lagoons on the plain are semi-permanent, but maintain a supply of water throughout the year on many occasions, providing an important dry season refuge for many waterbirds and other fauna. The Roebuck Plains Wetland System is a good example of a major freshwater floodplain in the Dampierland bioregion, lacking major substantial riverine inflow. Roebuck Plains also is an outstanding example of a tropical marine prograded carbonate complex, and as such it is of international significance as a Geoheritage Site. In regard to Special Listing, this wetland complex is noted in the Directory of Important Wetlands and is on the Register of the National Estate Data Base
Salt Creek System	representativeness geomorphic values faunal values linkage of systems	A1, A2, A3, B1, D1	I	C	This system has conservation value as a near coastal former estuary with relict mangrove occurrence. The area is listed as part of the Mandora Marshes

Conclusions and Discussion

The key points of this study are summarised and discussed below following the structure of the report. From a regional perspective, the Great Sandy Desert, in tropical northwestern Australia, is one of the driest areas of Western Australia, and as such any wetlands therein *a priori* potentially assume significance as wetland types that occur in desert regions. While the Great Sandy contains features of deserts elsewhere globally and in Australia, i.e., linear dune fields, rocky deserts, and local creeks, it is globally unique for the style of coast developed along the coastal fringe. Accordingly, the Great Sandy Desert and its coastal plain should be viewed as a significant natural history resource. Assessments of the wetlands in terms of their fauna, flora, geoheritage values, and Aboriginal cultural values support this view.

To facilitate scientific description, communication with Community Groups, and to relate the terminology of the Aboriginal Communities, three wetland classifications for inland wetlands were used for this study, each in essence serving a different purpose: 1. a practical genetic classification assigning wetlands to hydrological maintenance (*e.g.*, "oases" as windows to a water table, "pans" as perched water basins, and "springs" as wetlands fed by upwelling water or seepage); 2. a terminology employed by the local communities (*e.g.*, "jila"); and 3. a technical classification (*e.g.*, lakes as permanently inundated basins, sumplands as seasonally inundated basins, and so on). Marine coastal wetlands are separately classified as tidal mud flats, tidal sand flats, tidal creeks, and beaches. The various wetland types, inland and coastal, essentially reflect different origins and maintenance mechanism.

For the purposes of comparative work, assessment, conservation, and potential management, wetlands were also classified at another scale as "groups of wetlands" and their inter-relatedness ("consanguineous wetlands"), as occurring in the same geomorphic, geologic, and hydrologic setting, or because they have been formed by similar process. There are nine suites in this region: Kidson Track Suite (in linear desert dunes), Dampier Downs Suite (in sand plain on sandstone plains), Geegully Creek Suite (in rocky ranges and tablelands), Salt Creek Suite (in straight chains of playas), Lake Auld Suite (in meandering chains of playas), Dragon Tree Soak Suite (in clusters of playas), and the La Grange Bay Suite, Mandora Suite and Injudinah Suite (all along the coastal plain).

Flora and fauna of the wetlands were largely described from the literature, while additional information was obtained on flora in the site-specific studies. Wetland flora was categorized according to habitat settings. For inland wetlands, these were species in lakes, playas, sumplands, and damplands; those in creeks and wadis; those on floodplains and barlkarras; and species on peat mounds and peat basins. For coastal wetlands, these were species on mid-tidal to high tidal mud flats, on high-tidal mud flats, and along the contact between tidal mud flats and zones of freshwater seepage zone. In terms of fauna, wetlands viewed as significant from the perspective of avifauna include the Eighty Mile Beach Wetland System, the Mandora Wetland System (= Salt Creek playa chain), the Roebuck Bay Wetland System, and the Roebuck Plains Wetland System.

The hydrology of the northwestern Great Sandy Desert was divided into three zones, essentially representing major zones of processes and function: a northern section, north of the Salt Creek playa chain wherein mainly fresh groundwater resides at depth within the Broome Sandstone aquifer, and the water table is located in excess of 10 m below the ground surface; a southern section, along the Salt Creek playa chain wherein there is more hydrologic complexity, and fresh, brackish to saline groundwater is shallow, located beneath a calcrete and limestone sheet; a coastal section, where there also is hydrologic complexity, and fresh to saline groundwater is located in coastal aquifers.

How wetlands are maintained hydrologically is an important aspect of wetland management in this region. For instance, it is necessary to know whether wetlands are windows to the water table, or perched, or maintained by upwelling of groundwater through springs, and in this context, there was an emphasis on determining through stratigraphy and hydrologic processes at the site-specific level the hydrologic mechanism or process that maintained a given wetland. In relation to the three regional hydrologic settings, mentioned above, wetlands in the region are maintained by: 1. surface water flows from the drainage lines; 2. from water table rise in the unconfined surficial aquifer; 3. from ponding/perching of meteoric water by the near-surface hardpans; and 4. by upward leakage from formational waters. Discharge of groundwater relevant to this study occurs along the coastal zone, and in a zone where the Salt Creek drainage line is present. The former is the interface between the groundwater of the inland regions discharging along the shore zone under the regional hydraulic head. The latter is an interface of discharge formed by the incision of a former ancient (Cenozoic) river system.

The main, important aquifers and stratigraphic/hydrologic contexts in the region are: 1. the Mesozoic Broome Sandstone aquifer, with its internal stratigraphy; 2. the Cenozoic dune sand aquifer; 3. the interaction between Quaternary coastal mud deposits ("Kalji") and the sandy inland aquifers (Broome Sandstone and dune sand); 4. upwards leakage of freshwater to develop springs; 5. the effect regionally of the Salt Creek drainage line; 6. local clay lenses along valley tracts; and 7. the complex array of sediment and sedimentary rock in the coastal zone.

Understanding the hydrologic aspects of the Broome Sandstone is important, both in terms of its local properties, and its relationship to systems marginal to the aquifer regionally (*e.g.*, the coastal deposits) because the Sandstone is the target aquifer for any proposed groundwater abstraction in the region. The Broome Sandstone is a large sheet-like body of sedimentary rock, and contrary to perhaps a prevailing view, it is not internally homogeneous in terms of rock types and cementation, and hence at this stage should not be viewed as an isotropic aquifer at the local scale . As described in this report, within the formation there are changes in sedimentary rock types reflecting basin-wide changes in depositional regime, and variation in cementation. Sedimentary structures and sedimentary rock types indicate that the Broome Sandstone was deposited in a variety of environments, ranging from medium gradient fluvial environments (sand dominated) to low-gradient fluvial environments (sand and some mud sheets) to coastal tidal flat environments (sand with more abundant mud sheets). The change from fluvial sand dominated to sand and mud tidal flat dominated appears to be from the uplands of the Pilbara Craton and the Kimberley Block (to the south and to the north, respectively), and from east to west towards the ancient "Indian Ocean". This sedimentary transitions have major implications on the hydraulic properties and across-aquifer transmissivity of the Broome Sandstone at the regional scale, and will also have effects at the local scale.

The Broome Sandstone is variably cemented to wholly uncemented. The sedimentary formation is cemented by iron oxide in a relatively thin upper zone forming a sheet parallel to the present land surface; the cementation is an iron oxide and silica cementation, related to weathering and dust impregnation. It is also differentially cemented in mosaics by silica in the subsurface. These cementation styles also have implications on the hydraulic properties of the Broome Sandstone in producing heterogeneity to any presumed isotropic groundwater movement at the local scale.

There are eight situations, mechanisms, or processes that can maintain wetlands hydrologically in this region: 1. wetlands are windows to a water table, 2. wetlands are the result of surface perching of meteoric water, 3. wetlands are the result of subsurface perching of meteoric water and run-off, 4. wetlands are the result of run-off recharge, 5. wetlands are the result of groundwater upwelling (springs) inland, 6. wetlands are the result of groundwater upwelling (springs) coastal, 7. wetlands are the result of impedance to coastal zone discharge by coastal muds, and 8. wetlands are the result of seawater recharge, on tidal flats.

For coastal wetlands, the interaction of coastal mud and the discharge of groundwater from the inland aquifers is very important. There are five wetland settings along the coastal zones, with their distinctive stratigraphic setting hydrologic setting, and their resulting wetlands. Where there is a large discharge of freshwater into the coastal zone, relict early Holocene "kalji" (~ 7000 years old) impedes the freshwater forming small to large clusters of lake-like wetlands. Where there is low discharge of freshwater into the coastal zone, relict early Holocene "kalji" (~ 7000 years old) impedes the freshwater forming damp terrain. Where there is a discharge of freshwater into the coastal zone, the occurrence of appropriate conduits and pathways in the Broome Sandstone may result in springs forming along the upper shore zone, or in springs forming on the low tidal zone. Finally, marine water recharges and maintains tidal flat and mangrove systems, and there is an interplay between marine versus freshwater maintenance, with the development of marine wetlands.

For inland wetlands, the situations important to the development of wetlands are exposures of (or windows to) the main groundwater system, any local perching of meteoric water, and local upwelling of groundwater. There are five wetland settings within the inland systems, each with distinctive stratigraphic setting hydrologic setting. For instance, there may be large to small "oases" or playas, developed along drainage lines where there is a large fluvial discharge. These situations involve fluvial channels incised deep enough in the landscape to expose the local water table (i.e., they are windows to the regional water table). As such, there is evaporation of the groundwater, and consequently these wetlands tend to be salty. Pans/playas also are developed along the same currently dominant drainage lines, but with overflow from the fluvial discharge during flood periods, there is local ponding of water to form clay-lined pans. There also may be small pans, or playas, developed along relict drainage lines where there is a large discharge along buried channels, with local expression of ponding due to muddy surface layers. Pans may also be developed along low relief drainage lines where there is small fluvial discharge. Finally, there are springs with significant freshwater upwelling, and the resultant wetlands are peat mounds.

The Salt Creek Line along the southern border of the Study Area is a significant discharge zone, but it is complicated, because although it functions to discharge groundwater along the ancient riverine incision, it also is plugged with "kalji" mud accumulated at least since the Quaternary. It has an east-west change in sediment types, from fluvially dominated in the east along the drainage line, to estuarine and fluvial interlayering in the middle tract sections, to estuarine-marine dominated in western tract sections. These various types of valley tracts have implications for the style of hydrologic functioning in the region in terms of properties of the local aquifer (i.e., "kalji" mud and limestone mud dominated at one extreme, to interlayered mud and sand in a fluvial context, at the other), and in terms of types of source water (i.e., marine water, that sourced from the Broome Sandstone, and fluvial run-off and baseflow). Wetlands along the Salt Creek drainage line are of four types. The first results from the ponding effect of the "kalji" mud. The second is due to the upwelling of groundwater along the discharge line to from local springs. The third is the local ponding on clay beds and lenses along the fluvial tract.

The various wetlands sites studied in the field in this region illustrate different types and mechanisms of wetlands maintenance and hydrology. A range of site-specific areas were selected to investigate a full range as possible of the variety of wetlands and the hydrologic mechanisms maintaining them. In the coastal zone, emphasis was placed on the model of La Grange Bay tidal muds and mangroves, the freshwater discharge and beachrock, the "kalji" seepage model, the tidal zone freshwater seepage, the La Grange subterranean freshwater "streams", and the pattern of wetlands and hydrology on the Roebuck Plains pattern. These showed the importance of "kalji" in perturbating freshwater flow, and the heterogeneous movement of groundwater along 'streams" and conduits. In this region, it appears that the coastal carbonate muds play an crucial part in the perturbation of coast directed groundwater flow to the extent that important long term wetlands are developed along the zone of interaction between the coastal groundwater and that discharging from the Broome Sandstone.

Along Salt Creek, emphasis was placed on the Salt Creek drainage line dynamics, the 7000 year Mandora drainage lines, and the location of the former coastal estuary. The results again showed the importance of "kalji" in perturbation of the freshwater flow, and the heterogeneous movement of groundwater along 'streams" and conduits.

In the inland zone, emphasis was placed on the Munro Springs playa model, the Munro Springs perched pan model, the Munro Springs peat mound model, the locally developed Salt Creek peat mounds, and the perched pan inland from Bidyadanga. The results showed the importance of upwelling of groundwater to maintain the peat-floored springs, the differences between fluvially recharged pans, groundwater window wetlands, and spring fed wetlands, and also show, again, the heterogeneous movement of groundwater along 'streams" and conduits. The result here have major implications for any proposed groundwater abstraction in that it cannot be assumed that the wetland hydrology is removed from subsurface hydrology. The further implications are that, without careful study, abstraction of groundwater in the region may alter the dynamics of the hydrology that maintains the wetlands, and runs the risk of perturbating wetlands that are of International to National significance and Aboriginal Heritage significance.

While one of the objectives of the study was identification of water-dependent vegetation that may be affected by water table drawdown, detection of phreatophyte phototones by aerial photography or remote sensing remained elusive. Identification of wetland conditions, through vegetation, i.e., the phototone of vegetation in wetland situations (paperbarks swamps, dragon tree swamps, mangrove swamps, and eucalypt-lined water courses, as well as meadow, rush, or sedge vegetated wetlands), was relatively simple. However, such patterns indicating wetland conditions clearly occur within areas of lowlands such as drainage lines, basin lowlands, and low plains, i.e., areas known to be wetlands. In theory, it should be possible to extrapolate some species of these wetland vegetation associations into areas of non-wetland conditions, if these selected species of vegetation were to be groundwater dependent. The identification of phreatophytes outside of wetlands, i.e., vegetation growing on the pindan plain, or in lower areas of the pindan plain, but dependent on groundwater by tapping into the water table with their roots, was problematic, and not readily discerned by aerial photographs or remote sensing.

Evaluation of wetlands in the region required an understanding of their natural history values (through field data inventory and monitoring), an understanding of its context in a regional setting, and an understanding of the range of wetland functions. One of the problems with a full evaluation of all wetlands in the Study Area was that the region contains a large number of wetlands, many of which are inaccessible. Therefore, a preliminary analysis on the current available knowledge of wetland attributes and values was undertaken, using fieldwork results from selected sites as a basis.

The following criteria were used in evaluation: representativeness of a consanguineous suite, scarcity of wetland type, habitat diversity, geomorphic/ landscape values and geoheritage, faunal values, linkage of systems, condition of wetland. Three types of assessments were carried out on wetlands in this study: that of the Australian Heritage Commission, that used in Water Resources Council (1988) & Semeniuk (1985), and that of Hill *et al* (1996) and expanded by C A Semeniuk (1998). The procedures resulted in identifying wetlands of *outstanding significance* (with values of Statewide, National or even International significance). Wetlands of outstanding environmental significance generally satisfied more than one criterion.

Wetlands assessed as significant from a scientific, ecologic, and geoheritage perspective in this study are:

Cape Bossut embayment Munro Springs Wetland System Eighty Mile Beach Wetland System (including Anna Plains wetlands, and coastal wetlands of the Mandora Coastal wetland suite) Injudinah Swamp and associated wetlands along regional seepage lines La Grange Bay Mandora Wetland System (= Salt Creek playa chain) Munro Spring wetland system Roebuck Bay Wetland System Roebuck Plains Wetland System The Salt Creek System.

The significance of the wetlands from the aspects of Aboriginal Culture was outside the scope of this study and dealt with by Yu (1999).

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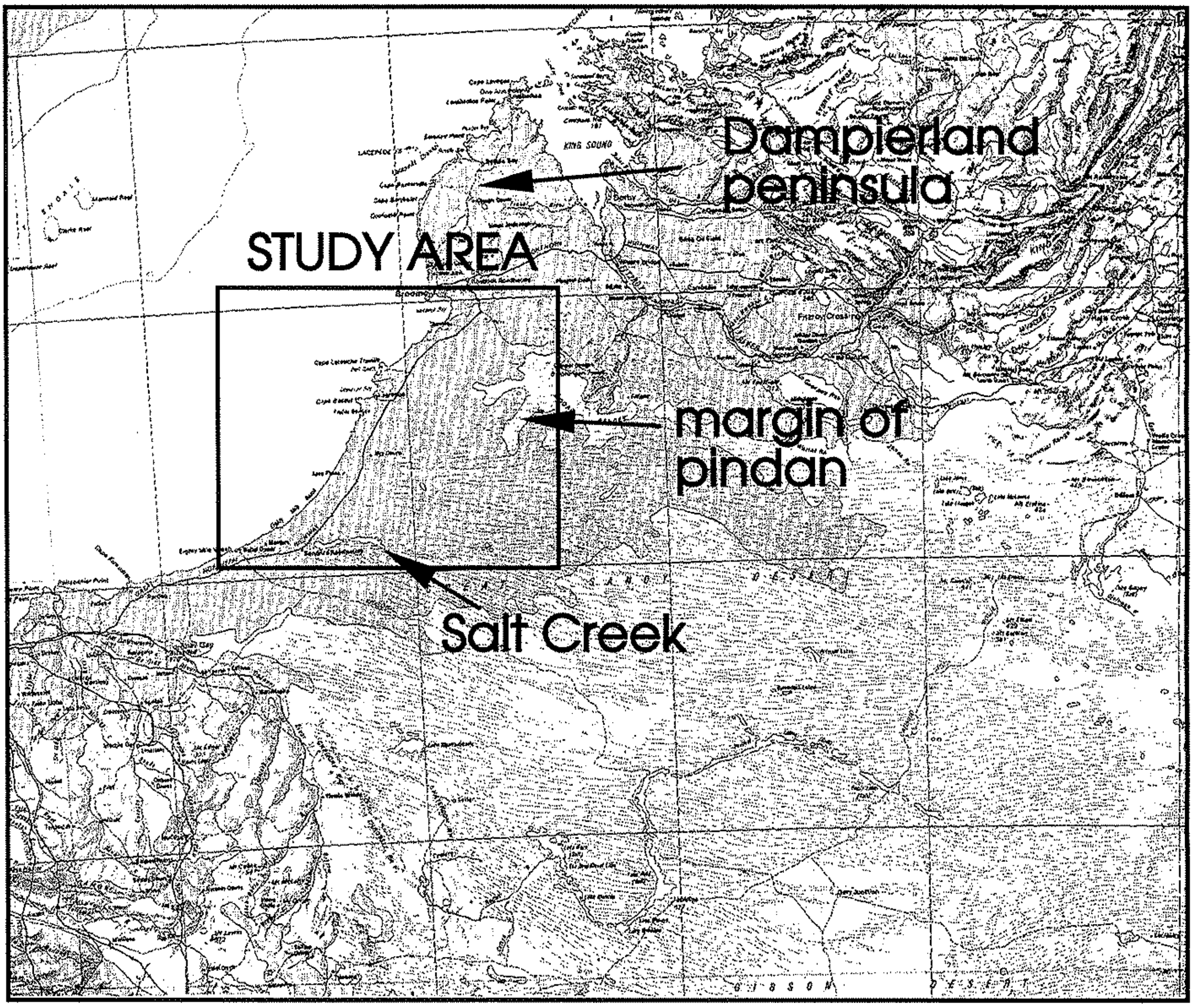


FIGURE 1: THE GREAT SANDY DESERT, AND LOCATION OF THE STUDY AREA, DEFINED BY SALT CREEK TO THE SOUTH, MARGIN OF THE PINDAN TO THE EAST, AND DAMPIERLAND TO THE NORTH

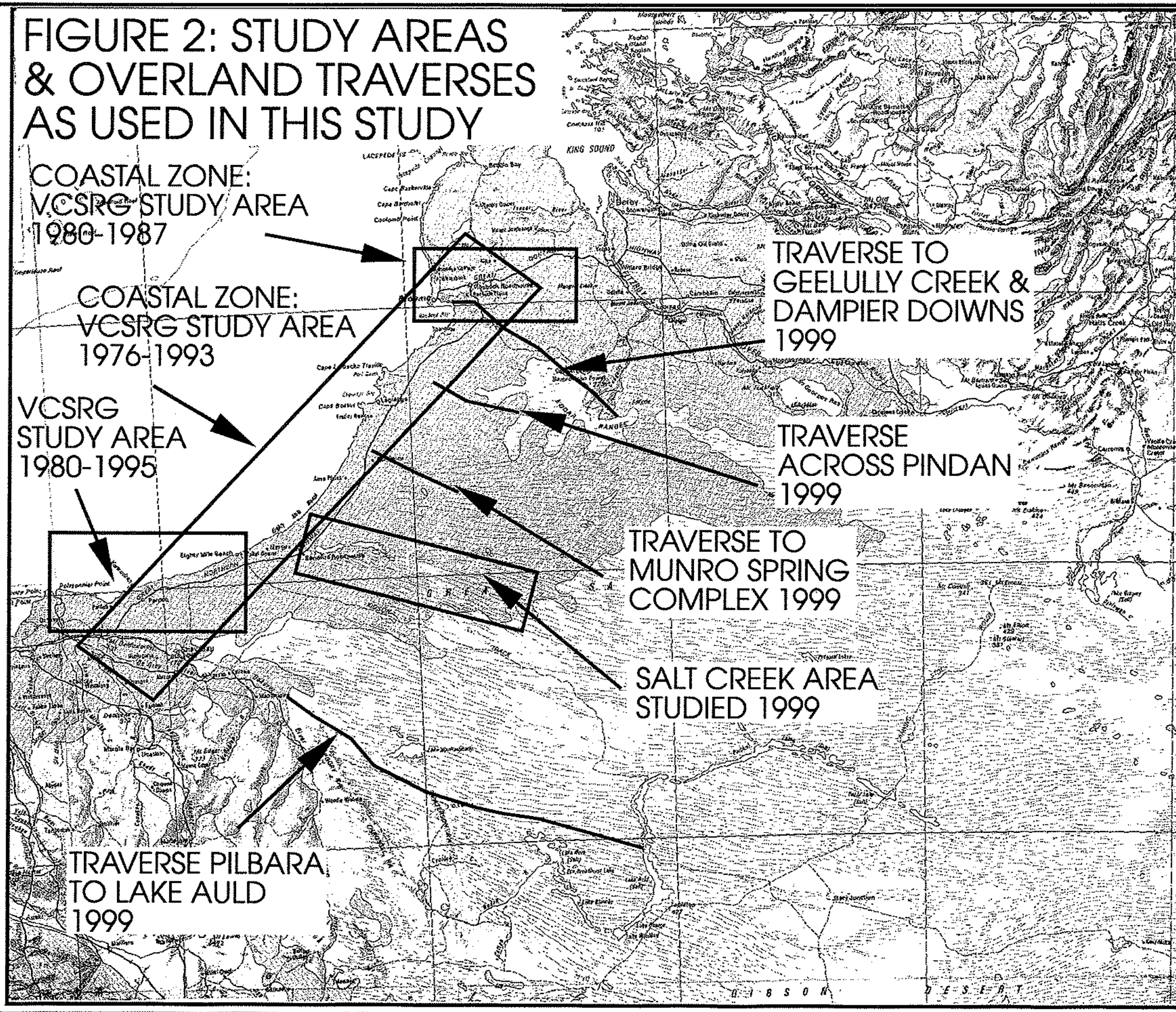


FIGURE 2: STUDY AREAS
& OVERLAND TRAVERSES
AS USED IN THIS STUDY
COASTAL ZONE:
VCSRG STUDY AREA
1980-1987
COASTAL ZONE:
VCSRG STUDY AREA
1976-1993
VCSRG
STUDY AREA
1980-1995
TRAVERSE TO
GEELULLY CREEK &
DAMPIER DOIWNS
1999
TRAVERSE
ACROSS PINDAN
1999
TRAVERSE TO
MUNRO SPRING
COMPLEX 1999
SALT CREEK AREA
STUDIED 1999
TRAVERSE PILBARA
TO LAKE AULD
1999
KING SOUND

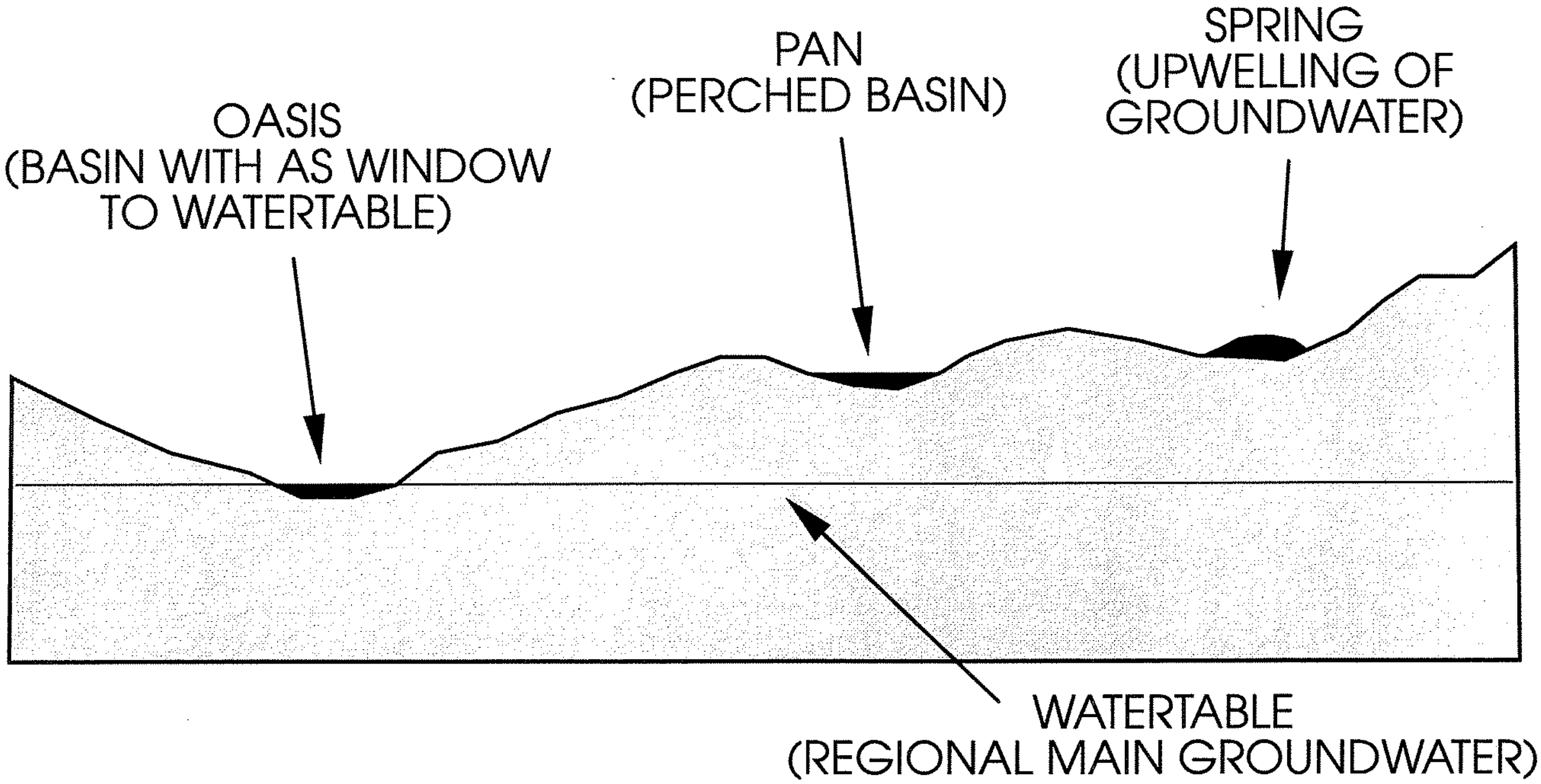


FIGURE 3: THE LANDSCAPE AND HYDROLOGICAL SETTING TO THE THREE TYPES OF BASIN WETLANDS IN THE STUDY AREA

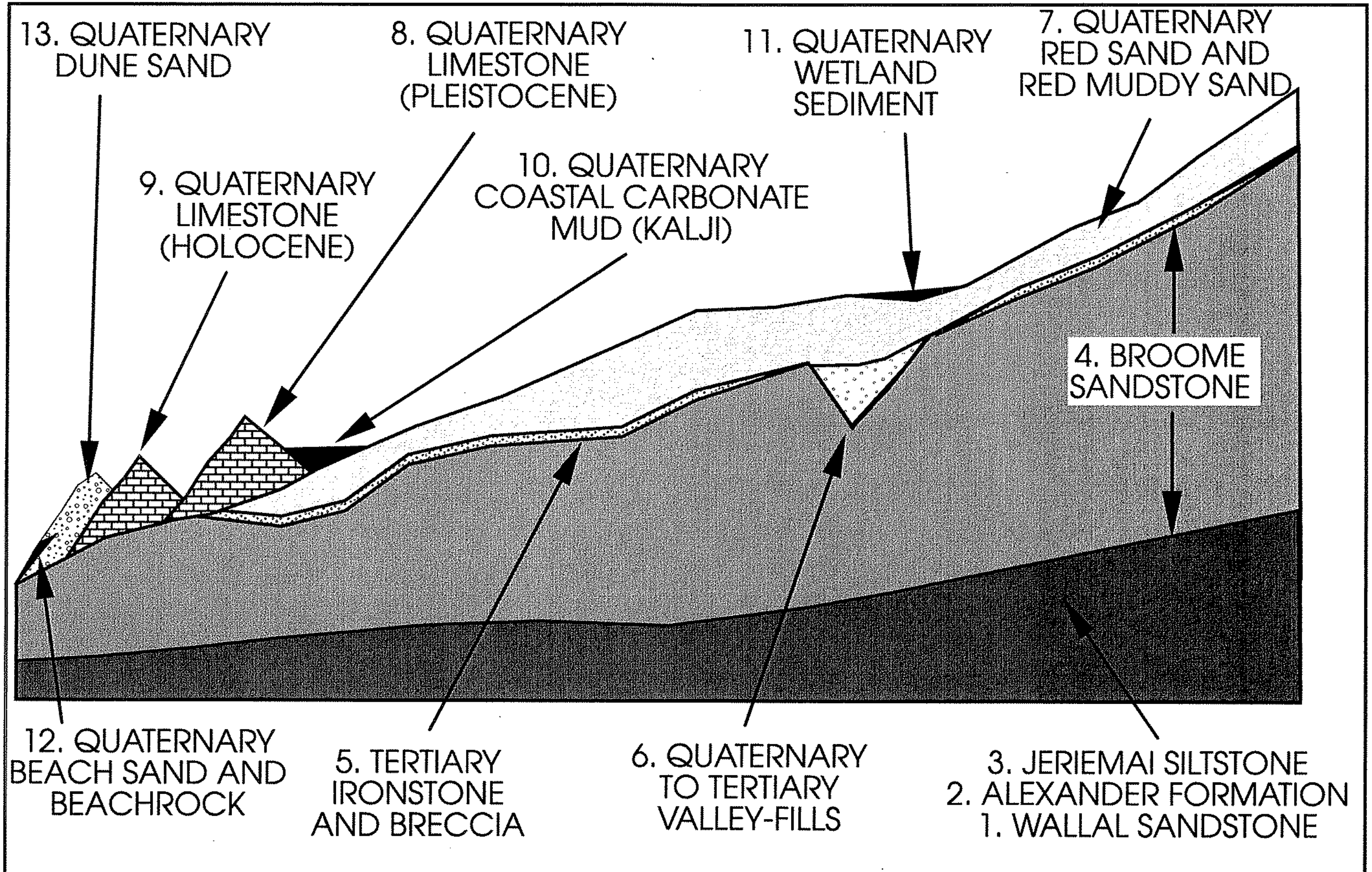
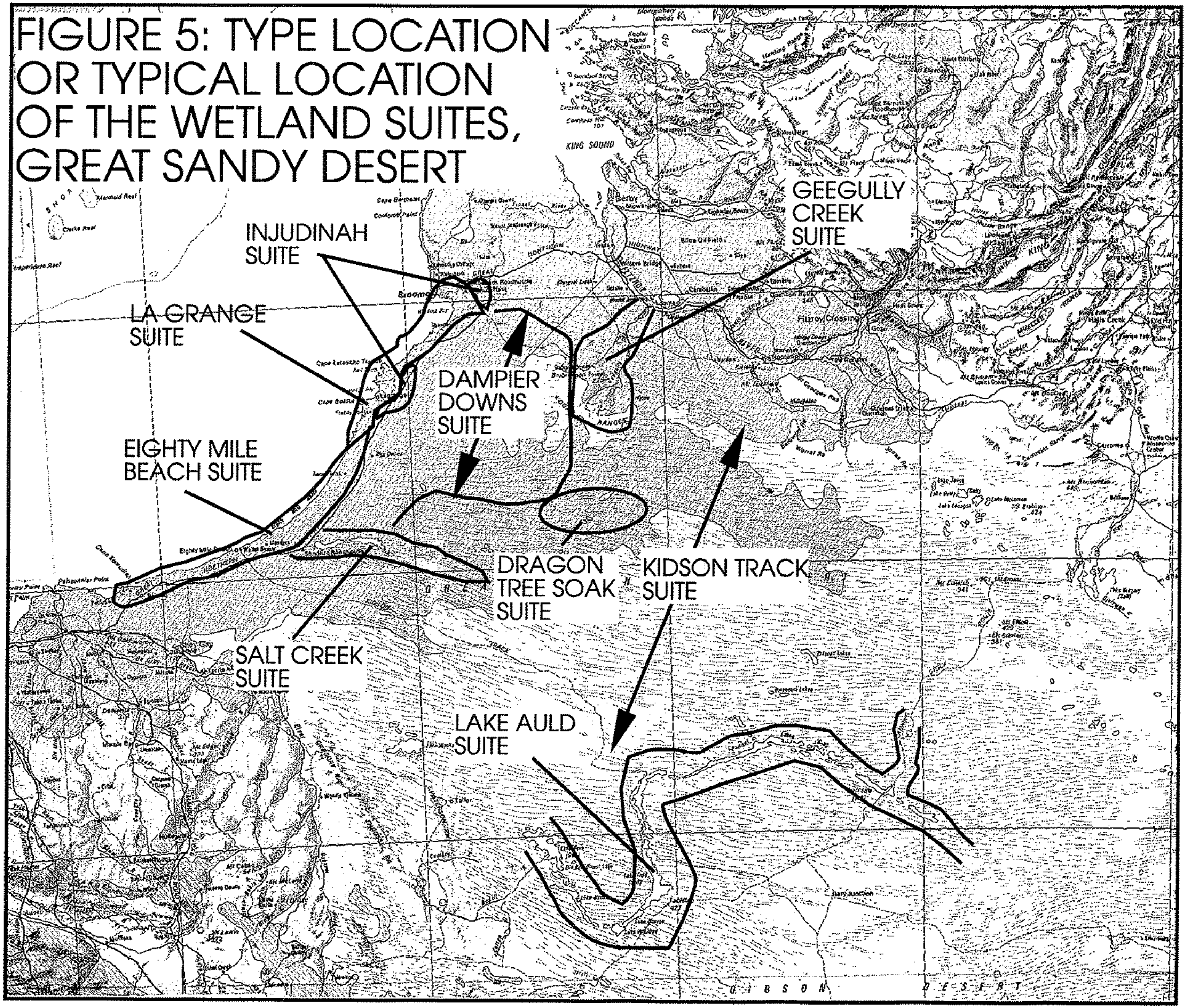


FIGURE 4: STRATIGRAPHIC FRAMEWORK OF THE STUDY AREA

FIGURE 5: TYPE LOCATION OR TYPICAL LOCATION OF THE WETLAND SUITES, GREAT SANDY DESERT



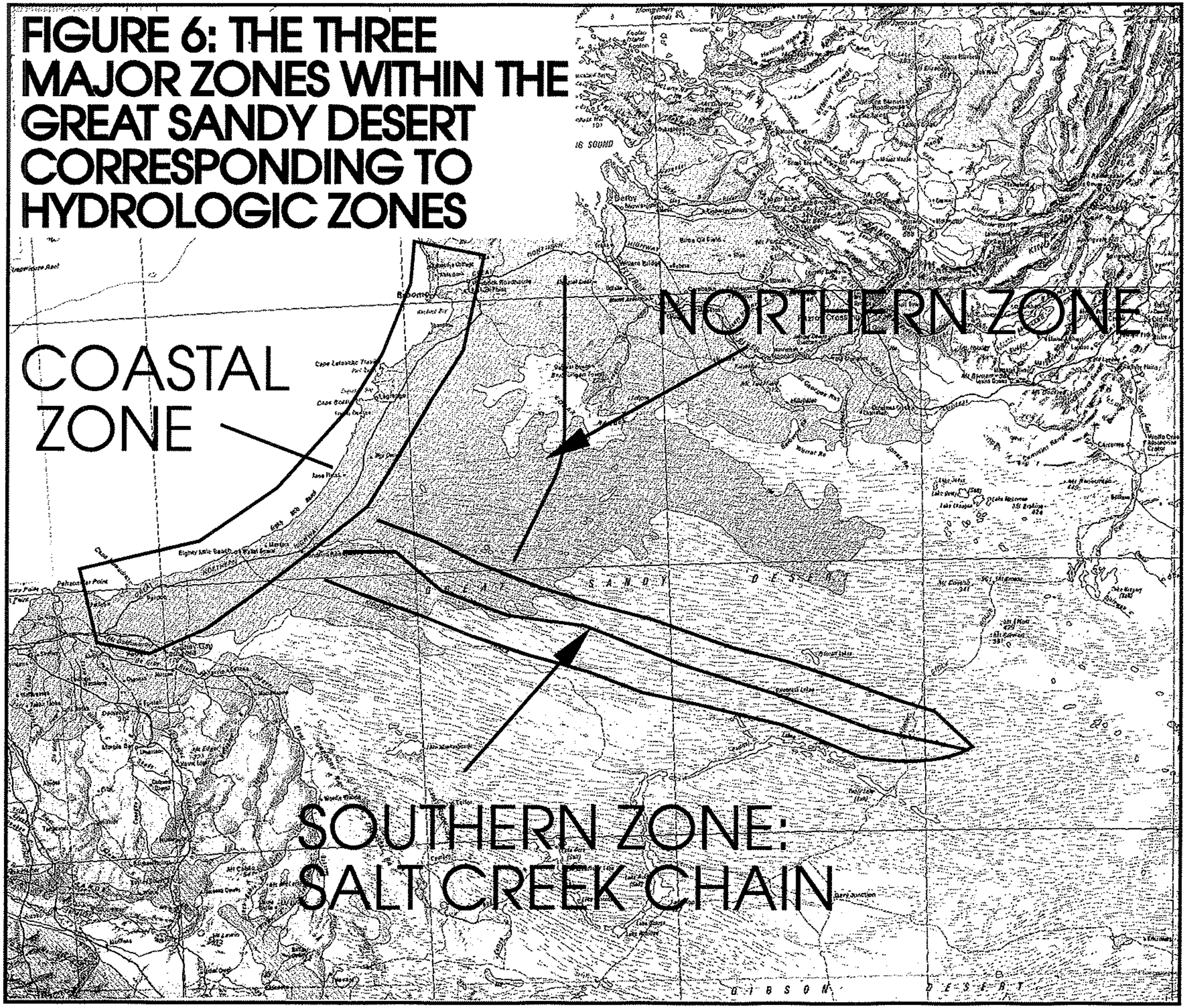


FIGURE 6: THE THREE MAJOR ZONES WITHIN THE GREAT SANDY DESERT CORRESPONDING TO HYDROLOGIC ZONES

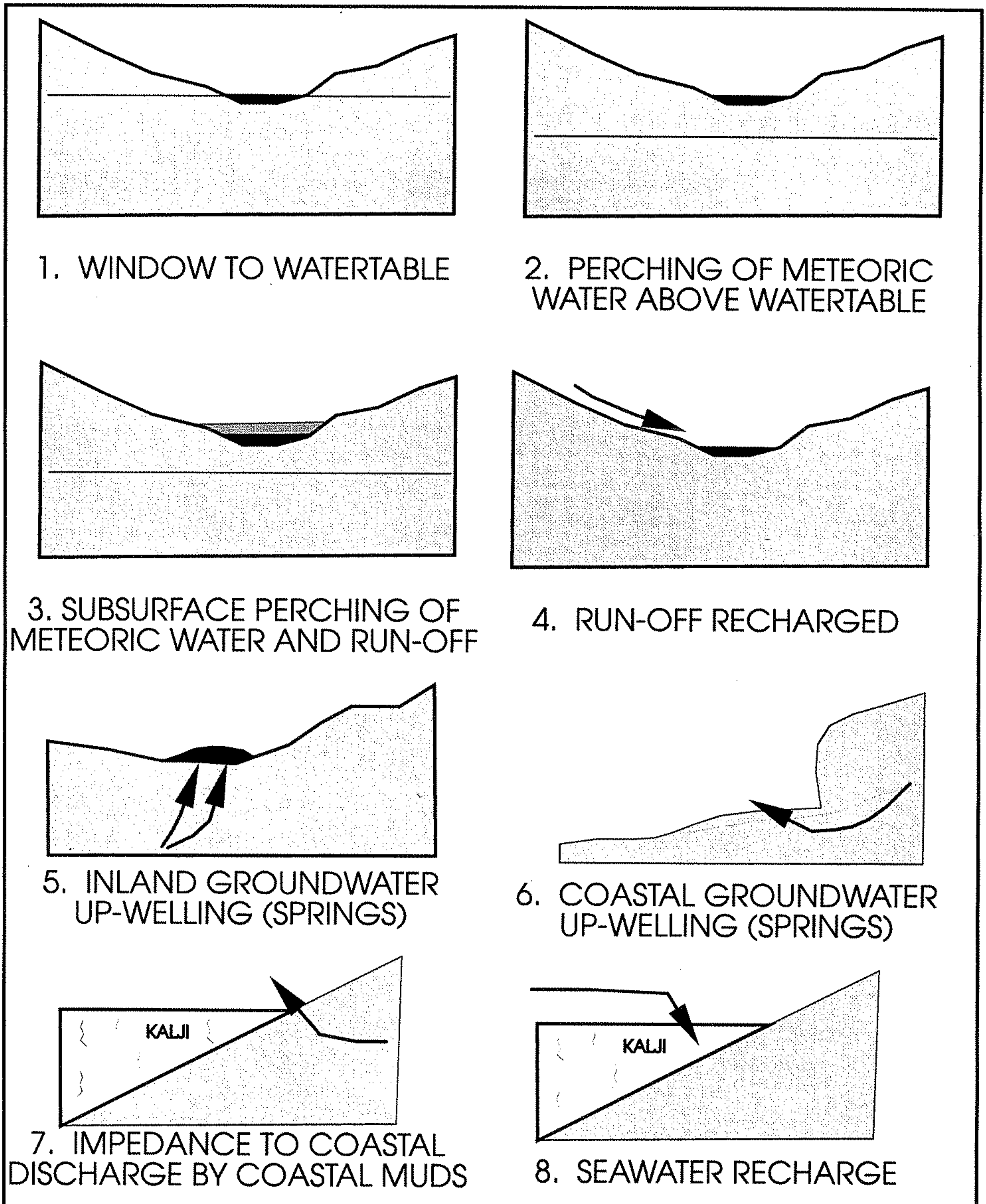


FIGURE 7: MAIN HYDROLOGICAL MECHANISMS MAINTAINING WETLANDS IN THE NORTH-WESTERN GREAT SANDY DESERT

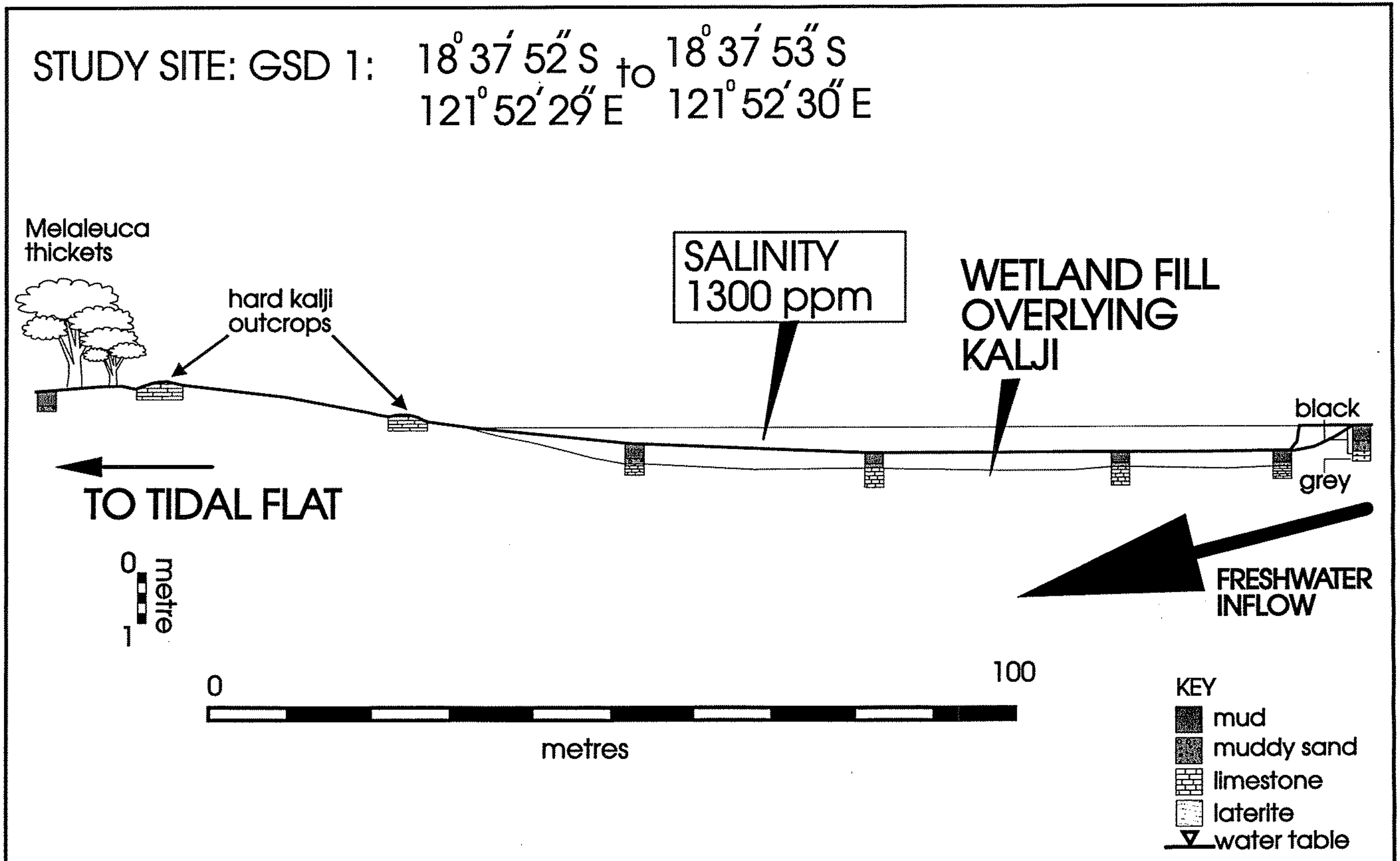


FIGURE 8: STUDY SITE GSD 1: COASTAL ZONE OF HIGH FRESHWATER DISCHARGE IMPEDED BY A WEDGE OF KALJI

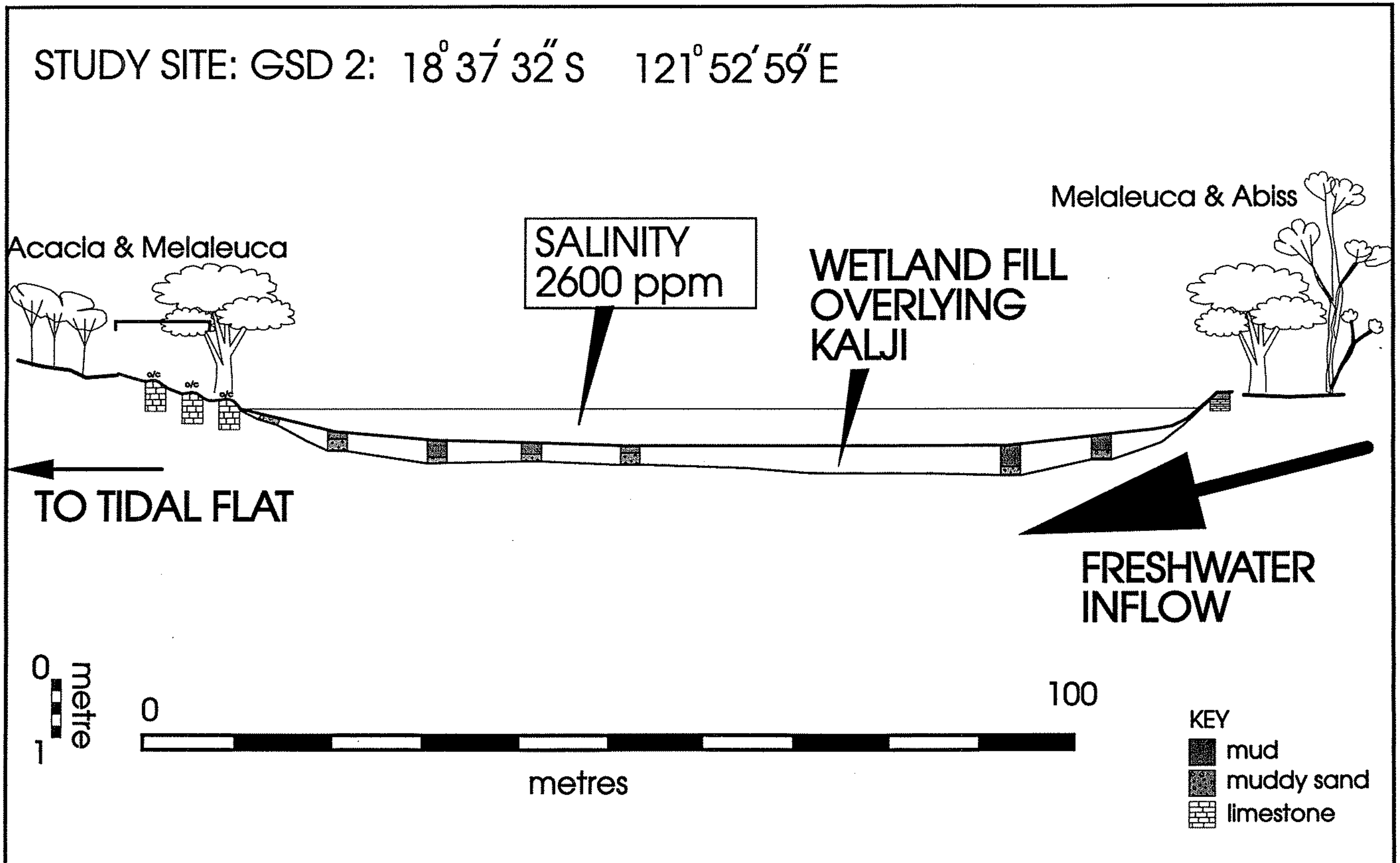


FIGURE 9: STUDY SITE GSD 2: COASTAL ZONE OF HIGH FRESHWATER DISCHARGE IMPEDED BY A WEDGE OF KALJI

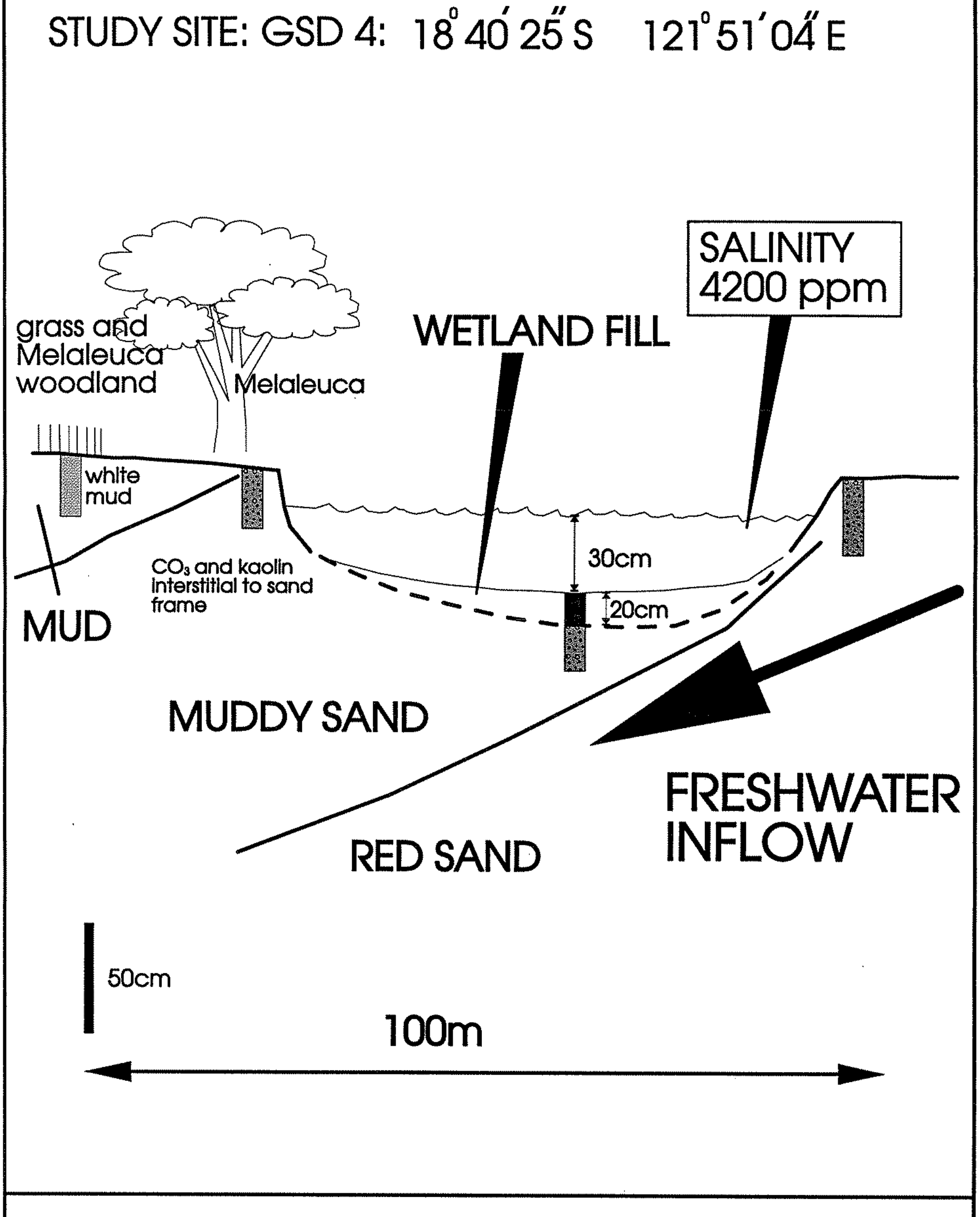


FIGURE 10: STUDY SITE GSD 4: COASTAL ZONE OF LOW FRESHWATER DISCHARGE IMPEDED BY A WEDGE OF KALJI

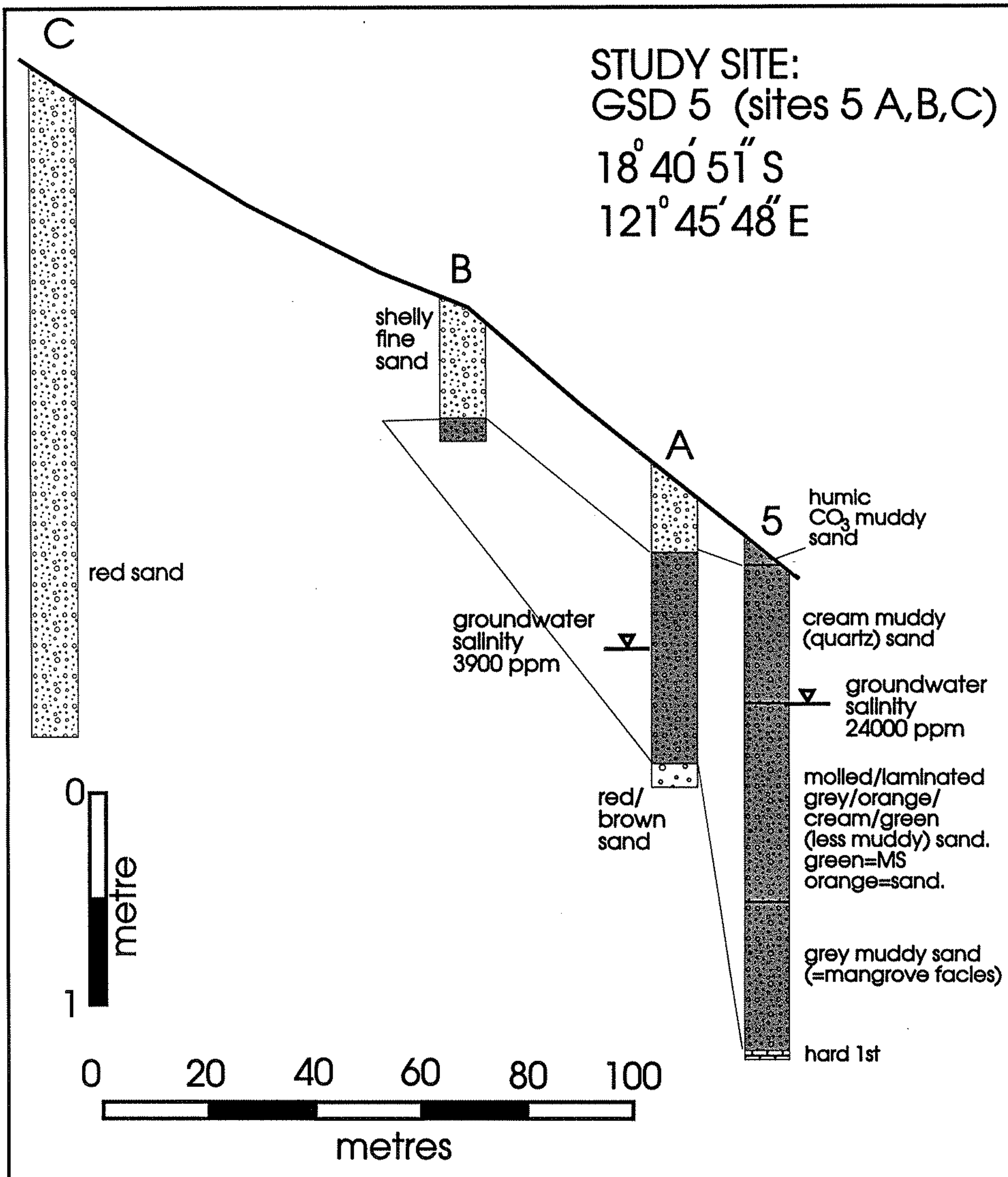


FIGURE 11: STUDY SITE GSD 5: LOW GRADIENT DISCHARGE OF FRESHWATER FROM DUNES TO TIDAL FLAT

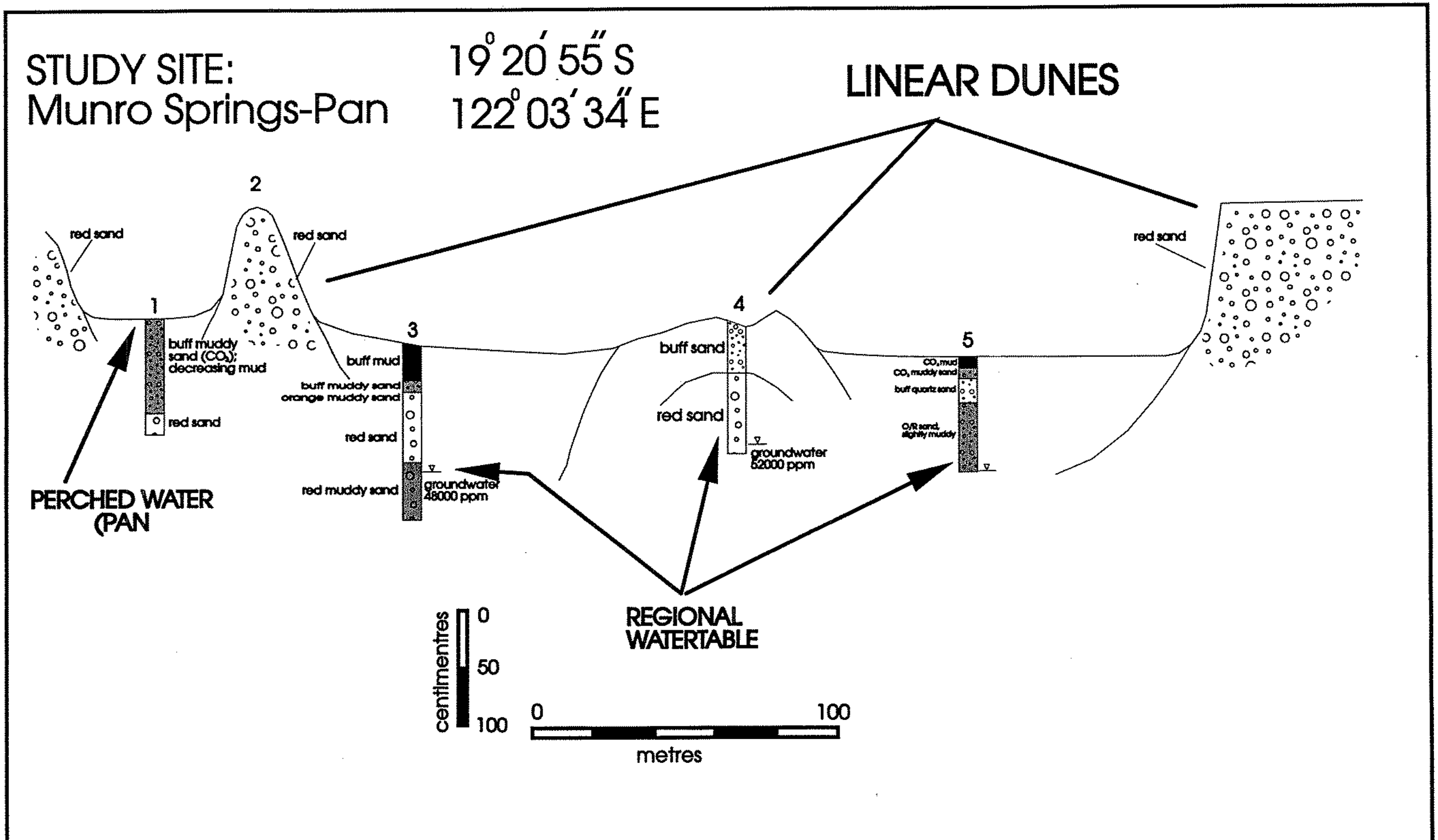


FIGURE 12: STUDY SITE MS-PAN: PLAYAS ALONG VALLEY TRACT, AND PANS ASSOCIATED WITH OVERFLOW RUN-OFF

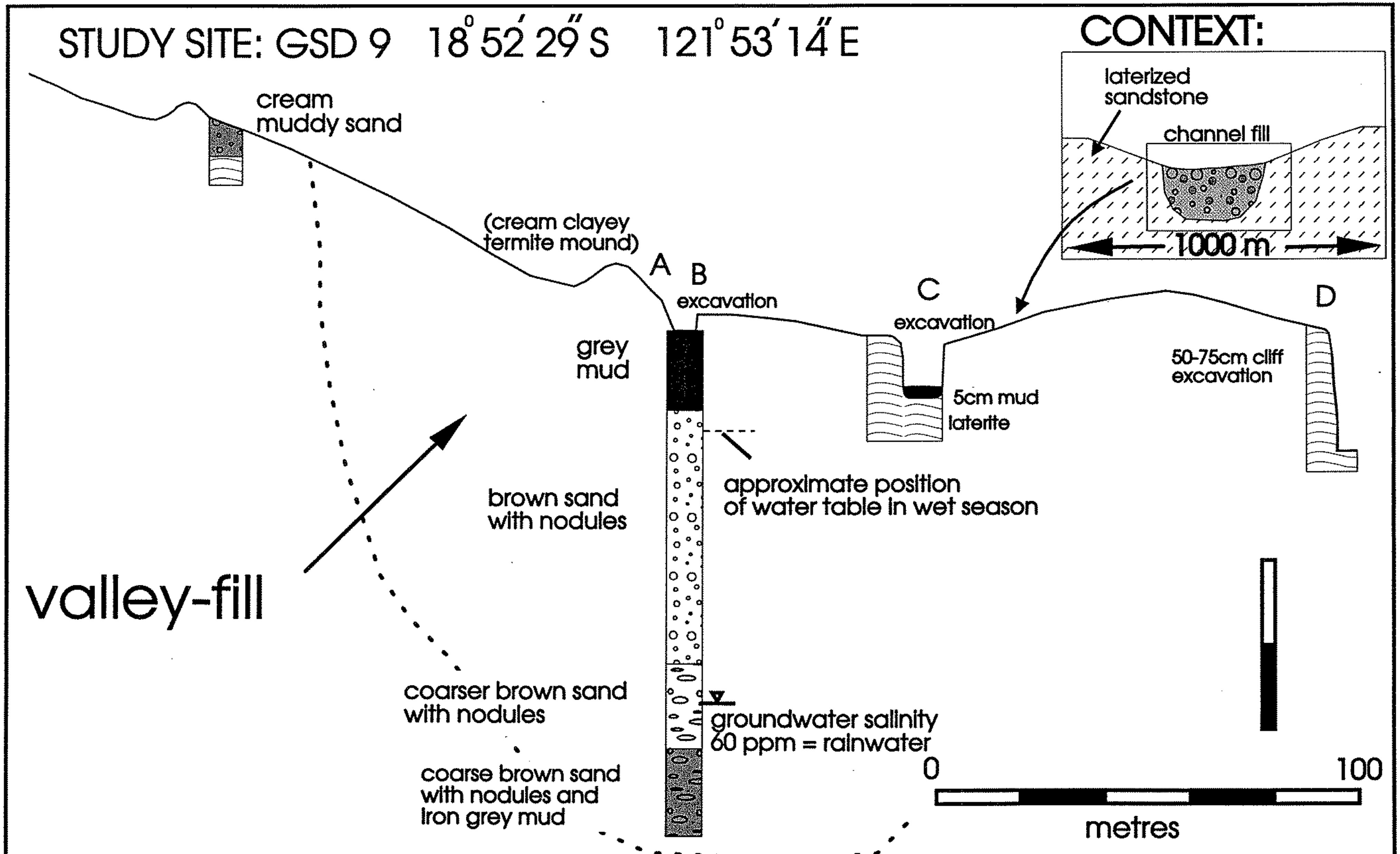


FIGURE 13: STUDY SITE GSD9: VALLEY CUT INTO BROOME SANDSTONE, FILLED WITH ALLUVIUM

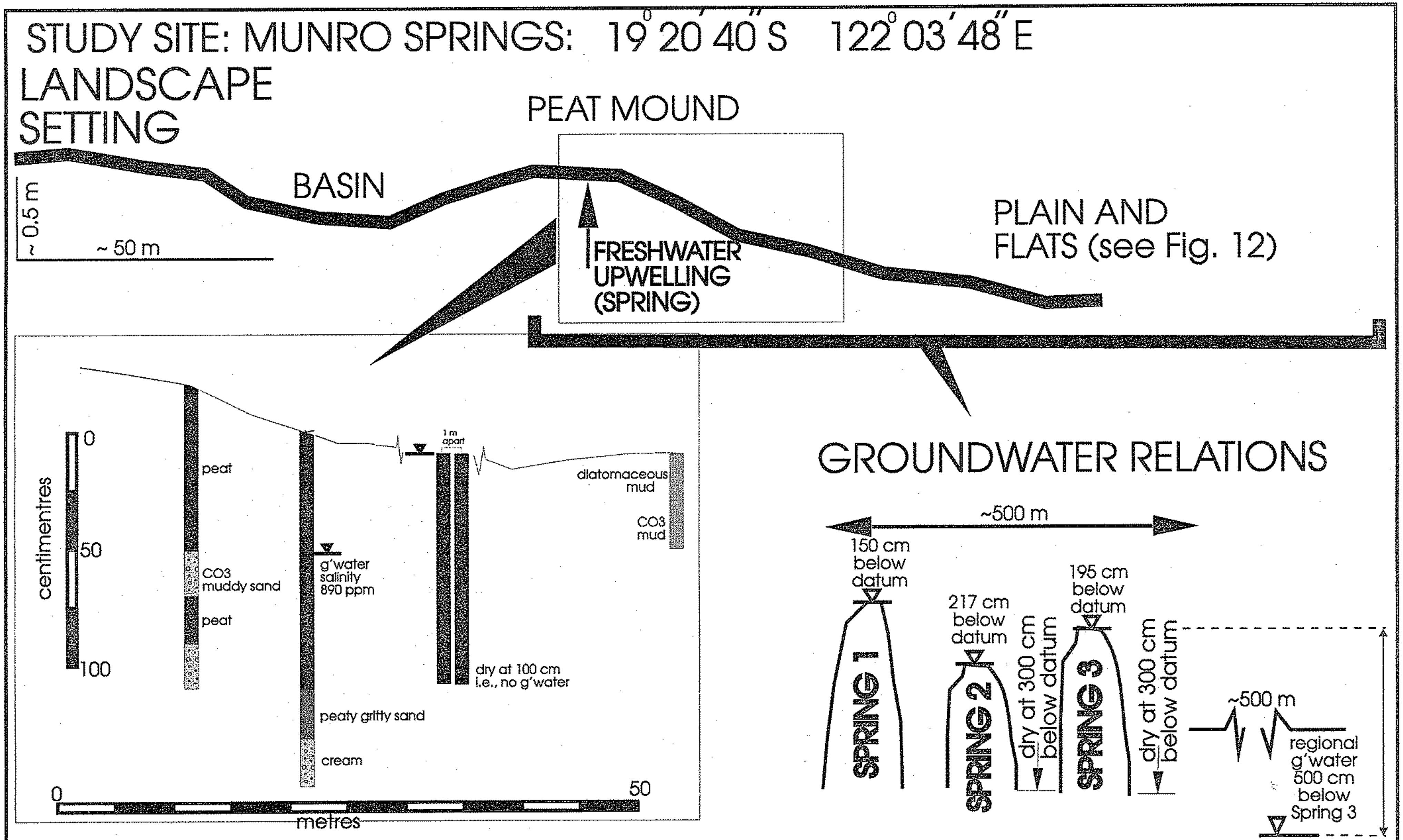


FIGURE 14: STUDY SITE MUNRO SPRINGS: INLAND SPRING WITH DEVELOPMENT OF PEAT MOUND WITHIN BASIN OF MUD UNDER CONDITIONS OF SUBSTANTIAL FRESHWATER DISCHARGE

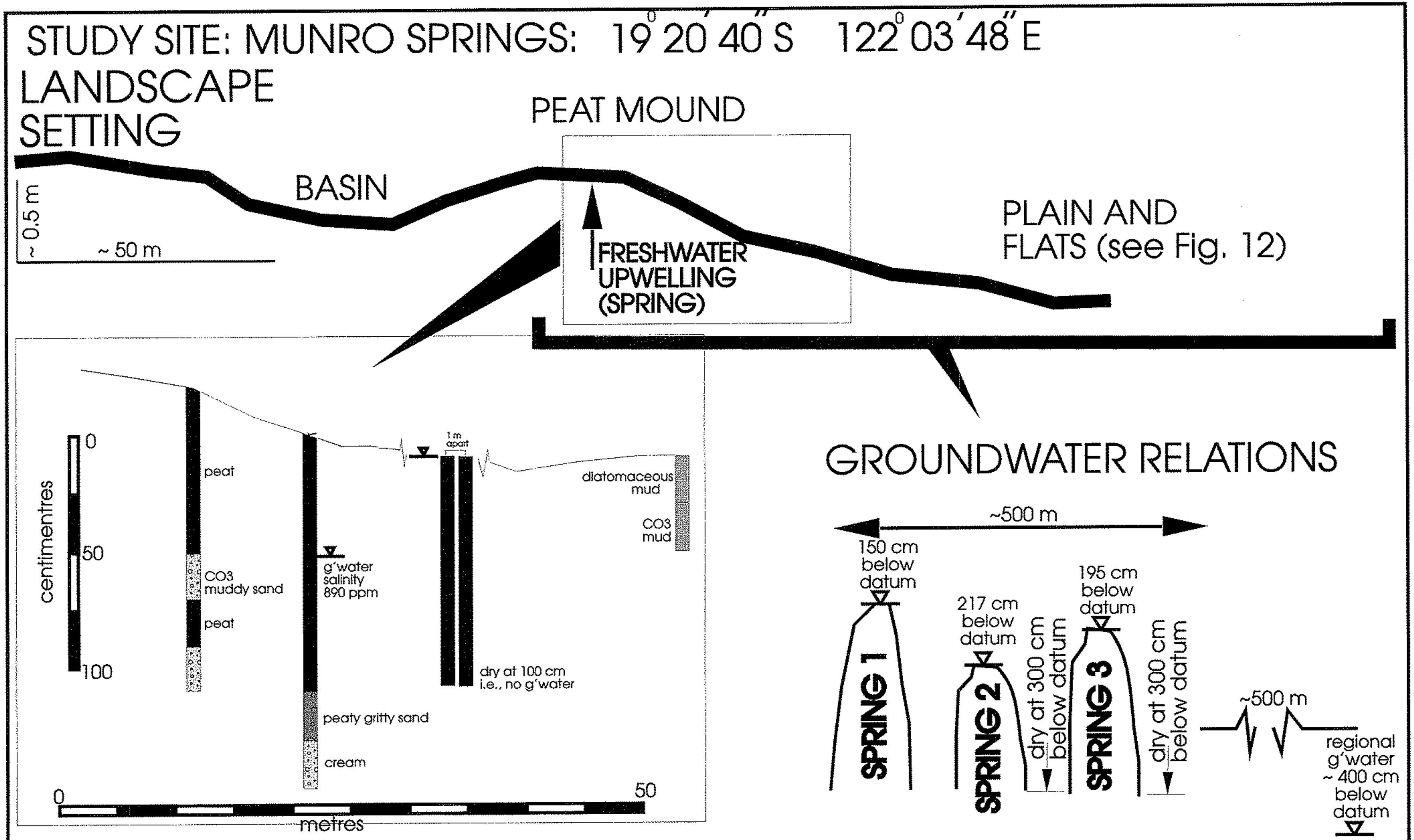


FIGURE 14: STUDY SITE MUNRO SPRINGS: INLAND SPRING WITH DEVELOPMENT OF PEAT MOUND WITHIN BASIN OF MUD UNDER CONDITIONS OF SUBSTANTIAL FRESHWATER DISCHARGE

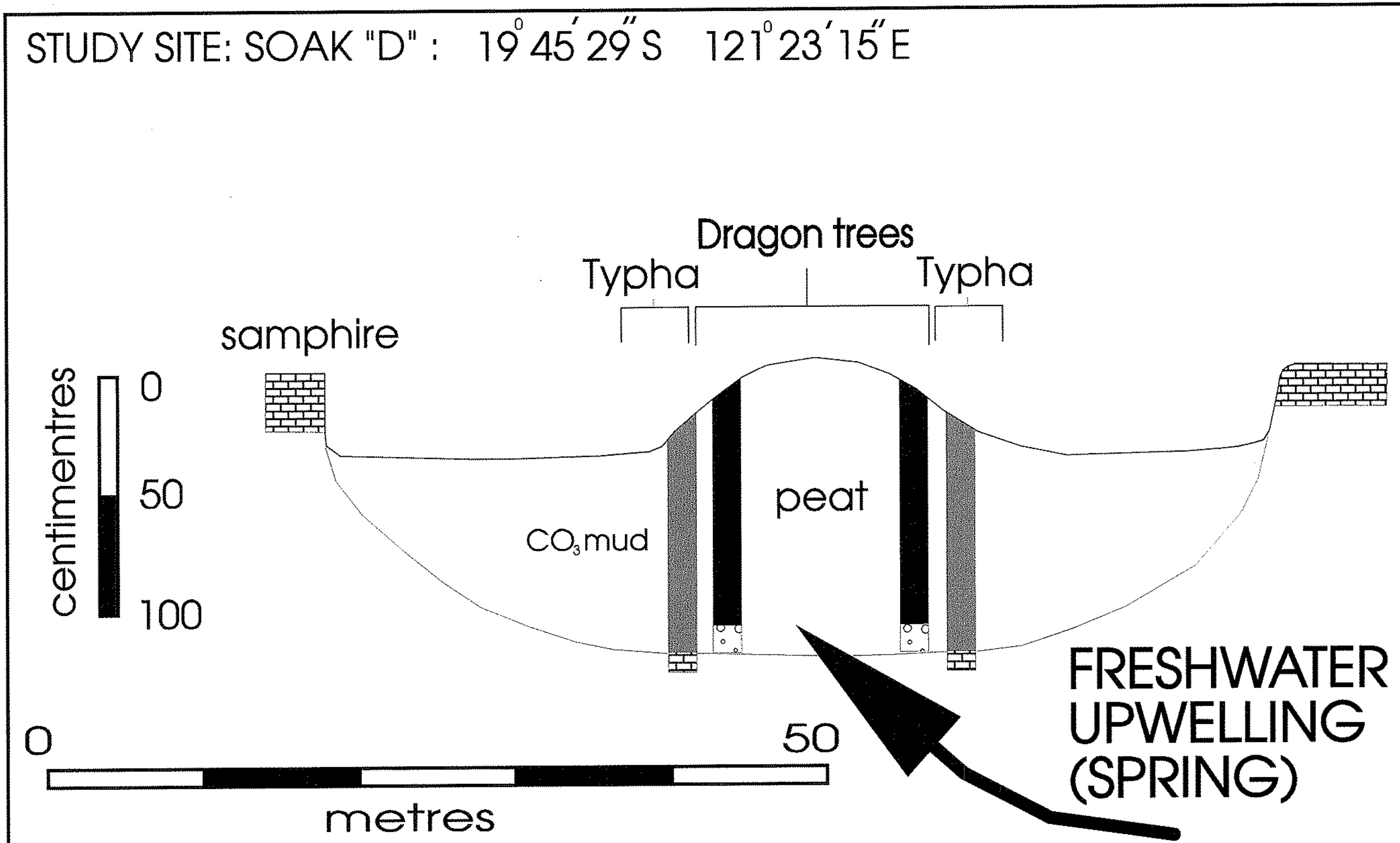


FIGURE 15: STUDY SITE SOAK -"D" : INLAND SPRING WITH DEVELOPMENT OF PEAT MOUND WITHIN BASIN OF MUD

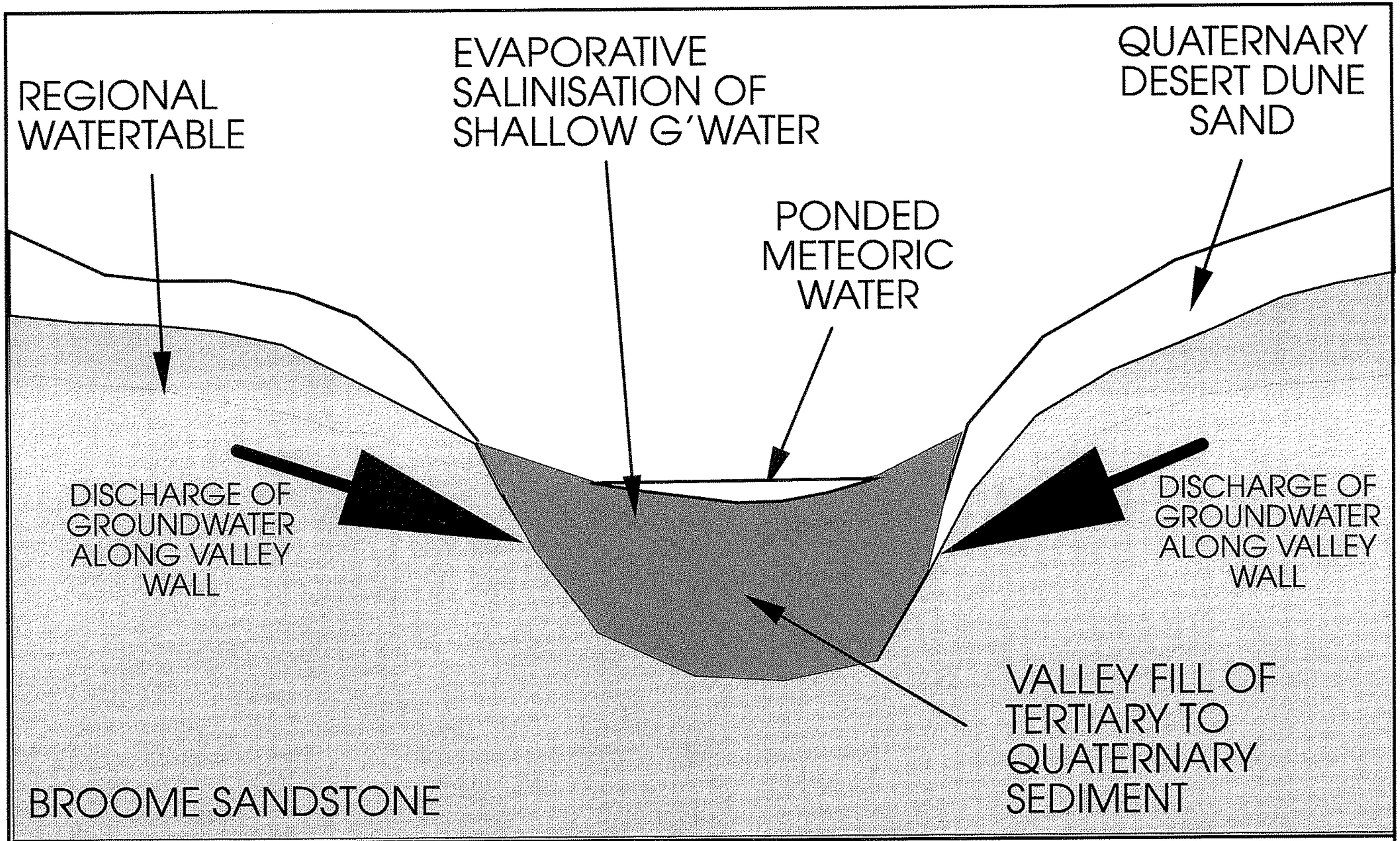


FIGURE 16: VARIOUS HYDROLOGIC SITUATIONS ALONG THE SALT CREEK VALLEY TRACT

FIGURE 17: WETLANDS OF SIGNIFICANCE IN THE STUDY AREA OF THE NORTHWESTERN GREAT SANDY DESERT