

4. LANDFORMS AND SOILS

4.1 ASSESSMENT CRITERIA

4.1.1 EPA Objective

The EPA management objectives for landforms and soils are:

- *To maintain the integrity, ecological functions and environmental values of soil and landform.*
- *To ensure that rehabilitation achieves an acceptable standard compatible with the intended land use and consistent with appropriate criteria.*

The EPA management objective for geoheritage is:

- *To ensure that the geoheritage values of the biophysical environment are not adversely affected.*

4.1.2 EPA Position statements and guidance

Guidance No. 6 (2006b)

Guidance Statement No. 6 *Rehabilitation of Terrestrial Ecosystems* discusses the return of biodiversity in rehabilitated areas and promotes the use of completion criteria and definitions for the rehabilitation of natural ecosystems that, amongst other things, acknowledges the consequences of permanent changes to landforms and soils. The Guidance follows that full restoration of plant communities is not typically possible due to these permanent changes however, the aims of rehabilitation are still to ensure the long term stability of landforms and soils and to repair to the best extent possible the capacity of the ecosystem to provide habitats for biota and services to people.

Guidance No. 10 (2006c)

Guidance Statement No. 10 *Level Of Assessment For Proposals Affecting Natural Areas Within The System 6 Region And Swan Coastal Plain Portion Of The System 1 Region* touches on the relationship between regional vegetation patterns and the underlying factors of landform, soils and climate. It also contains criteria for assessing the conservation significance of natural areas, including consideration of geological and geomorphological aspects.

Guidance No. 19 (2008b)

Guidance Statement No. 19 *Environmental Offsets* discusses the role of conservation offsets in mitigating residual impacts of certain proposals, as a tool for achieving a net environmental benefit. One of the principal criteria of the Guidance is that offsets are 'like for like' and that this includes landform and soil type attributes.

Guidance No. 33 (2008b)

Guidance Statement No. 33 *Environmental Guidance for Planning and Development* provides information and advice to assist in land use planning and development processes to protect, conserve

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and enhance the environment. In regards to landscapes and landforms, the Guidance Statement lists the following environmental values that might be considered during these processes:

- ecological values (landscapes reflect environmental health and represent ecological systems)
- geological and geomorphological values
- aesthetic values
- recreation opportunities
- economic and tourism opportunities
- social opportunities
- sense of place and spiritual experience
- heritage values
- opportunity for informal and formal study of natural and human modified environments
- opportunity to gain scientific knowledge and understanding of natural processes, including evolutionary processes.

The Guidance Statement further lists areas that the EPA considers to have landscapes and landforms of high conservation significance:

- the public conservation reserve system: national parks, conservation parks, nature reserves, regional parks, marine parks, marine nature reserves and marine management areas, and land acquired and managed for such purpose pending formal reservation
- areas recommended for protection in the Conservation Through Reserves Committee's Systems 'Red Book' reports except where superseded by later conservation recommendations endorsed by government
- regionally significant natural areas in Perth's Bush Forever, and in Regional Open Space Reserves in the Greater Bunbury Region Scheme and the Peel Region Scheme
- areas recommended by the DEC, and endorsed by government, for inclusion in the conservation estate
- natural areas on formally recognised national, international and regional heritage lists, for example, World Heritage property, Register of the National Estate, Biosphere reserves under the UNESCO Man and Biosphere program, Ramsar wetlands and Directory of Important Wetlands in Australia
- Conservation category wetlands and their buffers
- 'wild rivers', as identified by the Australian Heritage Council and the Department of Environment and Conservation, and their buffers
- natural areas of significant scientific, heritage or other interest as identified in any other scientific study or recommended by any formally recognised process or authority, subject to acceptance by the EPA.

The EPA expects that adequate areas representing the natural landscapes, landforms and geomorphological processes within each region of the state will be protected. The best examples of each type are likely to be of high conservation significance and require a high level of protection.

The conservation significance of the Proposal area, assessed against the above criteria (and others), is described in Section 8.

Guidance No. 51 (2004d)

Guidance Statement No. 51 *Terrestrial Flora and Vegetation Surveys for Environmental Impact Assessment in Western Australia* describes the expected standards and protocols for terrestrial flora and vegetation surveys. The Guidance suggests that the range of landforms correlates to the complexity of vegetation and diversity of habitats.

4.1.3 Other relevant legislation, policies or management objectives

Soil and Land Conservation Act 1945

The *Soil and Land Conservation Act 1945* (SLC Act) and the corresponding regulations manage, amongst other things, changes to drainage (including removal of vegetation) that results in erosion of landforms and soils.

Proposed Framework for Managing Acid Sulfate Soils (DoE 2003b)

The Proposed Framework document lays out the overarching strategy for managing acid sulfate soils in W.A. and includes the development of responsibilities, guidelines, maps and assessment criteria. These guidelines and criteria are applied in this assessment.

Draft Soil and Water Conservation Guidelines (DEC 2008a)

The DEC guidelines applies to the operation of disturbance activities in State Forest and describes the practices to promote the conservation of soil and water values. It provides guidance on maintaining the soil structure and processes.

4.1.4 Environmental Scoping Document

The Environmental Scoping Document (ESD, Strategen 2007a), provided a preliminary review of the landform and soils of the Proposal area and the surrounding regions and indicated that the following information would be included in the ERMP, relating to this factor:

- to identify landform functions by overlaying soil mapping units with topographic sequences
- to further examine the relationship between vegetation distribution and landform characteristics such as: elevation, drainage, slope, exposure, soils, subsoils, soil profiles, rock layers, soil moisture patterns and root-water relationships
- to conduct a more detailed assessment of potential acid sulfate soils and, if shown to be necessary by the assessment, prepare an acid sulfate soil management plan
- to map the distribution and characteristics of the dominant soil profiles and topsoil types
- to include soil management as part of a review of the rehabilitation successes and failures of the proponent.

The ESD also included the following in relation to rehabilitation of the abiotic landscape:

- to prepare a thorough prescription for managing soil materials as part of the rehabilitation plan, to maximise recovery and utilisation of rehabilitation resources and to restore hospitable and appropriate soil profiles
- that the prescription would include such measures as topsoil mapping; the demarcation of special management areas (e.g. translocation, dieback, etc) and the deep ripping of each major horizon to address compaction.

4.1.5 Definitions and concepts

Geodiversity

The natural range (diversity) of geological (bedrock), geomorphological (landform) and soil features, assemblages, systems and processes. Geodiversity includes evidence for the history of the earth (evidence of past life, ecosystems and environments) and a range of processes (biological, hydrological and atmospheric) currently acting on rocks, landforms and soils (RFASC 1998).

Geoheritage

The EPA definition of geoheritage is: ‘those features of special scientific or educational value which form the essential basis of geological education, research and reference – or those considered by the geological community to be worthy of protection or preservation’ (EPA 2008a).

Landform

A landform is equivalent to a geomorphological unit and is defined in the landscape by its physical attributes, such as surface form and elevation. Landforms reflect geomorphological processes and may support particular ecological communities, biota and ecosystem processes.

Landform element

A landform element is broadly defined as a morphological part of a component landform. Different elements of the same landform may have differing microclimates and soils, which may affect vegetation and moisture availability. Typical landform elements include: crest, hillock, ridge, slope, flat and depression. Some landscape classification systems (e.g. ACLEP, ASRIS) use a hierarchy of spatial descriptors, in which landform elements are a sub-set of soil-landform units (e.g. of DAWA 2003).

Soil-landform unit

A soil-landform unit is based primarily on land pattern, which is a combination of landform and soil properties. Soil-landform units have been mapped for the Proposal area by the Department of Agriculture and Food (DAFWA), as part of its regional mapping studies for the south-west of Western Australia.

4.2 DESCRIPTION OF FACTOR

4.2.1 Overview of major landforms and geological features

Generally, the landforms and soils of the Whicher Scarp reflect the transitional nature of its location between the elevated Blackwood Plateau and the Swan Coastal Plain (Webb et al. 2006).

Blackwood Plateau

The Blackwood Plateau has a gently undulating surface covered by lateritic gravel and sand. It typically ranges from 80 m to 180 m above sea level and is underlain by Mesozoic sediments and Bunbury Basalt. Much of this area is poorly drained (CALM 1987). In the Proposal area, the elevated laterised ridges of the Blackwood Plateau coincide with the south-eastern margins of the Happy Valley deposits (Ridge Hill shoreline), at about 120 mAHD.

Swan Coastal Plain

Deposition of marine sediments and deposition of weathered and eroded Yilgarn Block material are the two main soil forming processes governing the distribution of soils on the Swan Coastal Plain (Bolland 1998). Coastal dune systems, formed by deposition of marine sediments, can include sea material and material of Yilgarn Block origin that is re-deposited onshore. Wind erosion of coastal dunes generally results in inland migration of the dune material. Coastal Plain soils occur between coastal dunes and inland scarps and generally consist of colluvium and alluvium from the weathering of the Yilgarn Block. There is scope for significant interaction between the two main soil forming processes, which may account for the wide range of soil-landscape units identified in the Swan Coastal Plain region.

The Proposal sits within the Geographe Bay catchment area, which contains a variety of soil-landscape units that have been formed through various processes of erosion and deposition over time (Hall et al. 2006). The coastal plains are dominated by the Abba soil-landscape unit, which is characterised by flat, poorly drained, grey deep sandy duplex soils. Bassendean, Forrestfield, and Pinjarra soil-landscape units also occur on the coastal plain adjacent to the Scarp. The Coastal Plain reaches an elevation of around 60 m above sea level at the base of the Whicher Scarp.

Whicher Scarp

The Whicher Scarp is a sickle-shaped landform unit that lies between the Blackwood Plateau and the Swan Coastal Plain and extends from Burekup, where it meets the Darling Scarp, to Dunsborough, where it meets the Leeuwin Ridge (Webb et al. 2006). The Whicher Scarp covers about 21,000 ha and rises to over 130 mAHD in places (DoW 2007b). It is incised by a series of rivers draining from the Blackwood Plateau.

Ridge Hill Shelf

The Ridge Hill Shelf is described by McArthur and Bettenay (1960) as foothills along the base of the Darling and Whicher Scarps. Baxter (1977), in a more detailed geological description, divides the Ridge Hill Shelf into two components:

- the Ridge Hill Dune System, “situated on the upper edge of the Ridge Hill Shelf, is a podsolised beach ridge and dune system incised into and overlapping the Whicher and Darling Scarps, with a base of approximately 76 mAHD”

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- the Yoganup Dune System, being “podsolised dunes and beach ridges at the foot of the Ridge Hill Shelf, lying between 25 and 50 mAHD”.

The Happy Valley deposits are part of the Ridge Hill Dune System, with a basement at approximately 80 mAHD.

4.2.2 Regional soil-landscape systems

The regional dataset for soil-landscape mapping relevant to the Proposal area is *Soil-Landscape Zones of the South West of Western Australia* (DAFWA-006), which is administered by the Department of Agriculture and Food (DAFWA). The 1:100 000 scale soil-landscape mapping is a combination of soil types and landscape components. However, because of diversity of certain landscapes, the map units at this scale still may not capture all of the landscape components.

Within the DAFWA system, a hierarchy of mapping units has been developed for soils, allowing information to be presented at different scales. The mapping hierarchy has six levels: Region, Province, Zone, System, Subsystem and Phase. For the first three levels, the Proposal area sits within the Donnybrook Sunkland Zone of the Swan Province, which is a component of the Western Region. The identifiers of the remaining map levels are provided in Table 4-1. The Subsystems and Phases are mapped in Figure 4-1.

Table 4-1 Soil-Landscape mapping units relevant to the Proposal (DAWA 2003)

Landform-soil System	Landform and Geology	Typical Soils	Subsystems and phases relevant to Proposal
Whicher Scarp System (214Ws)	Low scarp slopes and terrace. Laterite, colluvium and alluvium over sedimentary rocks	Duplex sandy gravels and yellow deep sands and sandy earths, loamy gravels, wet and semi-wet soils	WC2 Whicher Subsystem, gentle slopes phase
			WCv Whicher Subsystem, valleys phase
Forrestfield System (213Fo)	Undulating foot slopes of the Darling and Whicher Scarps. Colluvium over granitic and sedimentary rocks	Duplex sandy gravels, pale deep sands and grey deep sandy duplexes	CSs Phase (Low relief, rapidly drained, deep bleached grey sands and occasionally deep yellow brown sands)
Goodwood Valleys System (214Gv)	Major valleys. Weathered mantle and colluvium over sedimentary rocks	Duplex sandy gravels and deep sands	RO3 Rosa Subsystem low slopes phase
Blackwood Plateau System (214Bp)	Lateritic plateau with broad swampy depressions. Deeply weathered mantle over sedimentary rocks	Duplex sandy gravels, and deep sands	KI Kingia Subsystem

Kingia Subsystem

The Kingia (KI) Subsystem is a widespread component of the Blackwood Plateau System and described as broad lateritic crests with gravels, often forming drainage divides. Soils are typically duplex sandy gravels (Worsley and Worsley-1 Soil Series), shallow gravels and deep sands (Lennard and Lennard 1 Soil Series).

Rosa Subsystem

The Rosa (RO) Subsystem is a component of the Goodwood Valleys System, mapped by Tille (1996) as valleys formed by the dissection of the Blackwood Plateau by rivers and streams. The Rosa

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Subsystem consists of valley side slopes and may contain loamy gravels (yellow-brown) of the Cundinup Soil Series. The Lennard, Lennard-1 and Wahkinup Soil Series are also common within the Rosa Subsystem.

There are three phases of the Rosa Subsystem, with the Proposal affecting the Low Slopes (RO3) phase, described as “Low valley slopes (gradients 5-20%), duplex sandy gravels with some loamy gravels and yellow sands”.

Whicher Scarp Subsystem

The Whicher Scarp Subsystem (Ws) covers an area of 20 709 ha (Keighery et al. 2008) and comprises two subsystems:

- the Whicher (WC) Subsystem, 20 – 60 m above the Swan Coastal Plain, consisting of two phases (Slopes and Valleys, delineated on gradient) with mainly sandy gravels or some deep sands (WC2), and typically a shallow, seasonally active creek bed cuts the valley floor (WCv)
- the Yelverton (YL) Subsystem, 10 – 40 m above the Swan Coastal Plain, consisting of ten phases, with a range of soils including duplex sandy gravels (10%), yellow deep sands, loams and laterites (ironstone).

The Yelverton Subsystem extends from the Capel River south, so is not located within the area of the Proposal. North of the Capel River, the lower slopes and foothills of the Whicher Scarp are mapped as part of the Forrestfield System.

4.2.3 Regional geoh heritage values

The “Whicher Range Area” is in the Register of the National Estate¹⁰ (Place ID 9400), but is not included on the Commonwealth Heritage List, National Heritage List or World Heritage List for natural values. The Statement of Significance (from its 1978 listing) reads: “New and rare species of plants (e.g. *Eucalyptus haematoxylon* and *Grevillea* species) endemic plant species also present (such as *Grevillea* and *Banksia* species) digenetic species of scientific importance. Conservation through Reserves Committee Reserve recommended 1.3.” The Australian Heritage Commission advises that it is in the process of revising official statements for places listed prior to 1991, and the statement has not yet been revised by the Commission.

A more recent entry on the Register specifically for the formally proposed 6240 ha Whicher Range Nature Reserve (see Section 8), which is on the Register as an ‘Indicative Place¹¹’, contains more detail on the significant values of the area (Place ID 18355). The nominator’s Statement of Significance reads as follows:

“Whicher Management Priority Area (flora, fauna and landscape) is an area of immense importance to our understanding ecological and evolutionary aspects of Australia's natural history. It houses a diverse range of vegetation types, complementary to the varied landforms and soil

¹⁰ <http://www.environment.gov.au/heritage/index.html>

¹¹ Defined as: ‘data provided to or obtained by the Heritage Division has been entered into the database. However, a formal nomination has not been made and the Council has not received the data for assessment. The data in the place does not necessarily represent the views of the Council or the Minister.’

types. Many of the vegetation type comprise a rich diversity of species, some of which are rare, endemic and/or part of relic populations well out of their natural range. The area has been used for scientific study of speciation of one species *Dampiera linearis*. Given the structural and functional diversity of the ecosystems and given their pristine condition there is great potential for further scientific investigation in this reserve. Although not thoroughly investigated, the diversity of fauna commensurate with the vegetation diversity has been noted. Whicher Management Priority Area is situated in a vast and scenic landscape relatively unaffected by European occupation, it therefore embodies many wilderness qualities now quite uncommon in the south-west forest region of Western Australia (WA).” (http://www.environment.gov.au/cgi-bin/ahdb/search.pl?mode=place_detail;place_id=18355, 31 March 2009).

4.2.4 Studies by the Proponent

Assessment overview

Intensive on-ground surveys and the application of geological data from mineral exploration programs have been used to generate local-scale¹² maps of key landform elements, different soil profiles and topsoil distribution, for the purposes of:

- defining habitats/boundaries to assist in the classification and mapping of vegetation communities
- mine and rehabilitation planning
- identifying areas with hydrological function.

While these maps go to some extent towards identifying various abiotic habitats across the Happy Valley tenements, there are limited assessment tools at this scale. Most assessments require additional aspects, such as flora and fauna, to assign conservation significance to each mapping unit. Those assessment tools that might apply to local landform and soil maps include:

- identifying geological features that have or support important or unique ecological functions or environmental values (EPA 2004f)
- geo-heritage - significant landforms and landscape components
- the use of geo-diversity values as surrogates for biodiversity values (DEC 2007a).

Refinement of regional mapping by ESM (1999)

In 1998 and 1999, Environmental Survey and Management Pty Ltd (ESM) was commissioned to study and describe the landforms and soil profiles of the Proposal area at a scale of 1:25,000, based itself on the 1:100,000 soil mapping prepared by Tille (1996, in ESM 1998). Soil samples to a depth of 2 m were collected from each of the units and the results related to the regional data set.

The distribution of the landform-soil systems at a scale of 1:25,000 for the Proposal area is shown in Figure 4-2. For the Proposal area, the map shows a catenary sequence of upland Kingia soils through gentle mid-slope Whicher Valley or Rosa Subsystems down to the low foothills of the Cartis land unit of Churchwood and McArthur (1980).

¹² approx 1:10,000, as opposed to 1:100,000 of the soil landform maps of DAFWA

The map generated by ESM differs substantially from the DAFWA dataset and this is both a result of the different interpretation of soil and landscape characteristics by the different authors as well as the normal limitations of applying relatively large scale (i.e. 1:100,000) maps to local features.

Essentially, ESM found two local features (or 'phases') in the Proposal area that are not visible in the regional dataset¹³:

1. The presence of occasional, localised shallow sheets of grey-brown sand overlying broad laterite horizons within the Kingia Subsystem, sometimes containing seasonal perched water (concave landform with impeded drainage) with vegetation markedly different to that of the surroundings.
2. The highest ridges of the Whicher Subsystem that extend out onto the Whicher Scarp are very similar to the geology and vegetation of the slightly higher ridges and crests of the Kingia subsystem, although the two are typically discontinuous.

ESM also generated generalised soil profiles for each of the landscape-soil units and this work was used for the more intensive soil mapping and profile investigations undertaken by the Proponent in 2007/08 (see below).

Local mapping of soils and geology

A number of additional studies have been undertaken, consistent with commitments given in the Environmental Scoping Document, to better characterise the soil and land units within the mining tenements and impact areas and thus improve the reliability of vegetation mapping and rehabilitation planning.

Geological model

The Happy Valley deposits have been extensively drilled and logged by Bemax on a (typically) 50 m by 25 m grid, down to the top of the underlying geological (i.e. Leederville) formation. Soil samples were taken over every 1 m interval and lithology recorded and clay, oversize and heavy mineral content assayed. This information was incorporated into geological modelling software (Gemcom © Surpac ®) and cross-sections of the deposit's geology produced. These cross-sections were used to install groundwater monitoring wells, place costeans and assist in mapping and presenting the boundaries of vegetation communities and rehabilitation management areas. The entire geological database was provided to Parsons Brinkerhoff (PB) for use in its assessments of the hydrogeology and acid sulfate soils (described later).

The relevant observations from the geological model include:

1. The base of the Ridge Hill dune system (i.e. top of the Leederville Formation) is at approximately 85 mAHD for both of the Happy Valley deposits.
2. The Happy Valley South orebody consists of an upper strand of aeolian origin, located above a laterite/gravel unit and a clay unit, and several lower strands located beneath these units. The extent of the upper strand is larger than the lower strands, i.e. the pit boundary includes areas where mining may only be to 3 or 4 metres, corresponding to the upper surface of the laterite/gravel unit.
3. The landform of the Happy Valley North orebody appears more eroded.

¹³ This is to be expected in large scale, regional maps (e.g. see Schoknecht et al. 2004).

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4. The lower strands are covered by clay and gravels that have washed down from the plateau.

Distribution of topsoil types

In 2007, an exercise to document and map the dominant soil types (topsoil and subsoil) of the vegetated areas of the mining tenements was undertaken. The program consisted of collecting samples on a grid pattern of 125 m for areas of native vegetation within the proposed disturbance footprint and 250 m for areas of native vegetation outside of the disturbance area. The dominant soil types are shown in Figure 4-3 and are described as follows.

Table 4-2 Dominant soil types of project area

Key soil type and dominance	Description
Shallow Brown and/or Grey Sandy Gravels over Laterite on upper slopes (46% of sites)	Depending on the site, the upper profile of this soil type varies considerably in relation to the amount of sand and gravel present; however, most sites possess an impenetrable layer of laterite within the first 0.5 m of the surface. This soil type is broadly distributed within the mid-upper slopes of the project area and outcrops on the surface as the parent rock type.
Deep Grey Sands on lower slopes (29% of sites)	This soil type is broadly distributed within the project area. Apart from a darker organic layer near the surface part of the profile, this soil is predominately even textured and coloured fine grained sand within one metre of the surface that occurs predominantly on the lower slopes and flatter areas.
Deep Orange and Yellow Sands on mid-upper slopes, Happy Valley South (20% of sites)	The deep orange sands are also even textured and coloured fine grained sand, however, the colour of the sand varies across the site from pale yellow to dark orange/brown. It occasionally contains some loam at depth but is often tightly packed and dry.
Shallow grey sands over laterite on upper flats (3% of sites)	These sites represented localised features. Typically, the upper sand horizon was less than 30 cm and evidence of impeded drainage (damp/saturated sands) were observed at some sites. Not associated with drainage lines.

Depth to laterite

The depth below the surface of the (uppermost) lateritic layer within the mining tenements was surveyed using two methods:

1. Examination of the geological records from the exploration program, for the in and near-pit areas.
2. Records from the 2007 soil survey (where laterite is less than 1 m below the surface).

Visual observations of lateritic outcropping were also recorded. The results are shown in Figure 4-4 and support the findings of ESM (1999) that the highest ridges of the Whicher Valleys phase share similarities with the crests of the Kingia phase, although the laterite in the former is considerably less consolidated, containing more friable gravel. An area of deep sands, where the laterite layer was located more than 5 m from the surface, was identified on the Happy Valley South deposit (see below).

The shallow laterite layer was found to be present across most of the proposed pit area. Its role in vegetation distribution and the potential impact of removing the laterite in terms of rehabilitation is discussed in Section 5 of this ERMP.

Costeans

Two test pits were excavated at Happy Valley North in 2003, to a maximum depth of 8 m, specifically examining soil strata, root distribution and groundwater in-flows (Cable Sands 2003). Soil samples

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were collected for assay and hydrologic characterisation. In addition, the project aimed to correlate results from the drill-hole data set obtained during exploration of the deposits with key geological features in the upper profile.

Following on from the above 2003 study, Bemax excavated a series of 5 test pits down to the laterite layer in 2008. Soil samples were collected and root distribution and soil depths recorded. One of the test pits (No. 4) was located within the deep sands on Happy Valley South, where the depth to laterite was confirmed as being 5 m below the surface. Another test pit was located adjacent to a streamline on Loc 4965 (pit No. 2) and others on the boundaries between different vegetation types. None of the test pits encountered standing water or excessive soil moisture (excavation occurred in June) and all pits encountered massive laterite at 2 to 5 m below ground surface. The information from the test pits has been incorporated into the Integrated Mining and Rehabilitation Plan.

Overview of key landform elements

The results of local surveys confirm the transitional (i.e. erosional and depositional) nature of the landscape of the Proposal area, and that these characteristics change over very small areas. Generally, the landscape consists of a number of typically localised elements that are readily identifiable, within a mosaic that reflects the transition between upland lateritic crests and the foothills of the lower slopes. The role of the drainage lines in transporting fluvial materials is also dominant.

The aerial extent of the key surface features is shown in Figure 4-5 and related to geological cross sections shown in Figure 4-8 and Figure 4-9.

Upland laterite ridges and crests

The dominant landform feature of the upslope areas (elevations higher than ~110 mAHD) to the east of the deposits is defined by the surface expression of the laterite sheets and gravels of the Blackwood Plateau system/Kingia sub-system. Underlying the laterite and gravels are well-structured clayey sands and mottled sandy clays, with plant roots recorded to 8 m (Cable Sands 2003).

Upland shallow sands over laterite

Several localised areas of shallow, highly leached grey sands over massive laterite with impeded drainage were first identified by ESM in 1999, who described them as “Kingia shallow sands over laterite (KI2)”. ESM sank a single drill hole and recorded grey sands over sandy clays over laterite at a depth of 2 m, with a saturated zone 0.8 – 2.0 m below the surface. The saturation at the drill hole site was confirmed in the 2007 studies and an third area identified in addition to those mapped by ESM (1999). Analysis of aerial photographs and other drill results from ESM (1999) indicate that the boundary of these areas is generally sharply defined.

The presence of the saturated layer 10 years after the detailed drilling of the Happy Valley deposits (50 m by 25 m grid) and again in 2007, is of interest and indicates strongly that the lateral movement of water through this landscape feature is as equally impeded as the vertical movement. The presence of clays and sandy clays for at least a metre over the laterite, as recorded by ESM (1999) further supports this premise.

Mid-slope gravel ridges

ESM (1999) discusses briefly the presence of “isolated lateritic outcropping soils within Whicher formations”, mapping the locations as Kingia sandy gravels (KI1) and not differentiating them from

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the KII areas on the upland crests, which is more typically associated with this description. A comparison of the results from drill holes in the upland Kingia landform unit and the localised units show little variation between the two. However, the 2007 study believed the profile of the outcrops to be more weathered than that of the upland crests, on the basis of the gravelly soils being generally more friable than that of the uplands.

Underlying the sandy gravel is massive brown-yellow sandy clay loam, with occasional mottles to a depth of at least 6 m, of very low permeability (as evidenced by deep sump and gravel pit on Loc 4965 (Figure 4-7)).

Yellow sandplain

Down-slope and adjacent to the shallow and surface lateritic crests, including the isolated outcroppings as described above, are located sizeable areas of yellow sands, up to 5 m deep, overlying massive laterite. Site 1 (Happy Valley North) and Site 4 (Happy Valley South) from the 2008 costeans correspond with the distribution of this landscape unit.

These sands are well oxidised, ranging in colour from pale yellow/grey to a rich orange and have a aeolian/fluvial origin, as evidenced by the homogeneity of the grain size and the inclusion of a heavy mineral component. The topsoil is typically very thin (~20 mm) and poorly structured and contained numerous roots. The topsoil at Site 4 of the 2008 study (Figure 4-3) showed exceptionally high levels of nitrogen (as NH_4 and NO_3) but low organic carbon. Levels of exchangeable iron were also high, and may be responsible for the extremely low available P. The number of roots in the deeper soil decreased rapidly for both of the costean sites, although this may be a result of the low numbers of trees and dominance of shrubs in the semi-disturbed areas chosen for the costeans.

The clay content of the yellow sand varies between 2 and 5 percent and the single grain structure and weak coherence indicates a very high hydraulic conductivity, resulting in rapid infiltration of rainfall. There were, however no indications of saturation (e.g. mottling, colour change) above the laterite. While the costeans, which were excavated in late April, showed a very dry soil profile, the September 2007 topsoil mapping study showed a very moist soil (sampled to 1 m depth).

The laterite sublayer slopes from east to west and also from north to south on both deposits, so the depth of the sand layer varies from 1 to 5 m. The 2007 study showed that many samples within this landscape feature contained varying amounts of gravel, mostly in the upper profile and seemingly independent of the overall depth to the laterite.

In comparison to the Happy Valley South sandplain soils, the Happy Valley North sandplain area contains significantly more areas of grey sands and gravels. The well-defined area of yellow sandplain at Happy Valley South (Figure 4-5) was not replicated over any appreciable area of Happy Valley North, although single sites from the 2007 study bore notable similarities.

Foothills and lower slopes

The prevalence of grey sands and gravelly sands in the upper soil profile, elevation and slope was used to define the foothills, described by ESM (1999) as “Cartis lower sandy slopes and sandplains”, although this landscape feature does not have a well-defined boundary. The loose sandy profile typically grows paler with depth. Infiltration rates (saturated hydraulic conductivity) are very high (~8 m/day (Aquaterra 2005)). It has low chemical fertility due to its sandy texture, low PRI and reactive iron. The topsoil layer can be quite well defined and thick (up to 300 mm), with abundant roots and high organic carbon. However, in open areas, the depth of topsoil was considerably thinner

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(<50 mm) and paler, indicating the topsoil is easily leached/bleached. Lateritic boulders occasionally outcrop along the lower west-facing slopes (approx 90 mAHD) and along steep valley walls.

Drainage lines

Drainage lines are not well defined in the landscape by abrupt changes in soil characteristics, or by vegetation (Bennett 2006, Keighery et al. 2008). Instead, the most common observation is a trend from brown sandy loams to grey sands, transported down-slope from (presumably) aeolian deposits and sheets on the upper slopes and crests. While a deeper, impeding laterite layer was potentially identified beneath the creeklines (costean No. 2), this same layer is quite widespread and showed no indications of prolonged saturation. Additionally, the creeklines all have a substrate of silty, gravelly sands, as opposed to massive laterite or clay.

Overview of key soil profiles

Three key soil profiles were identified in the proposed Happy Valley mining areas, which are described for the purposes of assisting rehabilitation planning (Figure 4-6).

Kingia – Loamy sands and gravel

Predominantly consists of a shallow layer of aeolian grey sands over laterite as either a consolidated layer or heavy gravel, although the laterite outcrops the surface on occasions. Underlying the laterite is a layer of yellow gravelly sandy loam blending into mottled sandy clay of varying thickness and depth.

Further down is light grey plastic clay with red mottles. No ground water was evident through this profile, i.e. it is not saturated.

Whicher Sandy Slopes - Deep sandy gravel

This profile is similar to Kingia, but has been differentiated based on depth of upper sand in the profile and vegetation cover. The upper sand of this profile is less loamy and considerably deeper in comparison to Kingia, and tends to be more yellow than grey. Soils below this stratum tend to be less clayey than Kingia and roots exist through the entire profile. It is a transitional profile, with the clays of Kingia being washed down slope (possibly to form the Rosa subsystem) and replaced with sands and gravel from upslope. This profile is considered to vary only slightly across the scarps, slopes and valleys of the Whicher subsystem.

Sandplain

As the name suggests, the Sandplain profile comprises a deep sandy profile comprising yellow sand with a low clay fraction. Depth of sand ranges up to 5-6 m before intersecting a consolidated lateritic layer which is understood to play no significant hydrological function. Understorey plant roots are concentrated in the upper 500 mm of the profile, with tree roots extending sparsely to depth.

Acid sulfate soils investigations

In 2008, Parsons Brinkerhoff (PB 2008a), was commissioned to conduct a series of investigations into the geology and hydrogeology of the Happy Valley deposits, with the objective of assessing the acid generating potential of lithologic units that would be disturbed (or dewatered) during the development of the deposits. The investigation was in response to:

- the Department of Environment (DoE) draft *Identification and Investigation of Acid Sulfate Soils* guideline (2006), that identifies mineral sands deposits and areas where iron minerals (such as laterite) and waterlogged conditions as areas with a high risk of acid sulfate soils being present and requiring investigation
- the results of a 2001 preliminary sampling program reported in the Environmental Scoping Document (Strategen 2007a), which returned a sample result of 0.039% total sulfur and was considered by the DEC to be above the action criteria for loamy sands (0.03% oxidisable sulfur).

In brief, the PB investigations ascertained that there was a low risk of acid generation associated with the lithologies of the site. Lateritic gravels were encountered during the investigation but laboratory tests indicated they were not acid forming. The groundwater table was not intersected to the depth of mining but the potential for localised, seasonal perched water tables was acknowledged. A summary of the PB investigations is provided as Appendix S1 and the report itself is available on CD-ROM.

4.3 ASSESSMENT OF POTENTIAL IMPACTS, MITIGATION AND RESIDUAL IMPACTS

4.3.1 Sources of potential impact

The Proposal includes the following activities or environmental aspects that may potentially affect the integrity, ecological functions or environmental values of soils and landforms:

- the removal of topsoil and sub-strata to the depth of mining, necessary to access the underlying ore reserves within the pits (74 ha)
- the removal of topsoil only, for those areas outside of the pits required for infrastructure, including roads (174 ha)
- the wet separation of heavy minerals from the orebody and the resultant creation of sand and clay tailings streams
- the disturbance of soil materials ascertained to have a low risk of acid generating potential
- the use of heavy machinery, which may compact soil materials
- loss of soil material or landform stability through erosion.

4.3.2 Potential impacts to regional soil-landscape systems

The proposal to mine mineral sands will require the excavation of several pits to access the underlying ore reserves, to a total of 74 ha. The pits will be backfilled with a combination of mine tailings (sand, clay and rock) followed by overburden and upper and topsoils, as per the draft Integrated Mining and Rehabilitation Plan (IMRP). While every effort will be made to recreate a soil profile under vegetated areas that effectively mimics the characteristics of the original landform, the overall structure will vary from the original, to some extent. The relative reduction in each landform-soil subsystem that will be affected by the Proposal is listed in Table 4-3, using values based on the distribution of the subsystems over the northern Whicher Scarp¹⁴ only.

¹⁴ The Environmental Scoping Document identified that the areas of the Whicher Scarp north of Sues Rd differed from the remainder of the Scarp, after Webb et al. 2006.

Table 4-3 Relative impact (extent) on the three landform-soil subsystems (from DAFWA 2006)

Landform-soil subsystem/phase	Extent on north Whicher Scarp	Extent within HV tenements	Extent within mine pits	Relative impact on north Whicher region
214GvR03	2352 ha	226 ha	9 ha	4%
214WsWC2	2940 ha	386 ha	59 ha	15%
214WsWCv	510 ha	126 ha	7 ha	6%

4.3.3 Potential impacts to significant landforms and elements

The Proposal will affect two landform elements that are regionally restricted, namely the mid-slope gravel ridges and the yellow sandplain on mid-upper slopes.

Impacts to distribution of mid-slope ridges

The Proposal will partially affect one of the four examples of this feature mapped during the studies of the mining tenements. This area, at Happy Valley South, will be disturbed by mining (i.e. mine pits). Although one of the other examples at Happy Valley North is proposed to be cleared, this is for infrastructure only and will not disturb the soil profile to any great extent. The ecological values as habitat for flora and fauna are described in Sections 5 and 6, respectively, and this landform element is not considered to be regionally or locally significant.

Impacts to distribution of yellow sandplain

The Proposal will affect significantly the major local occurrence of the yellow sandplain landform element identified at Happy Valley South. The yellow sandplain element has been identified as having particularly significant environmental values for flora and fauna, including habitat for regionally significant flora and vegetation communities. Subsequently, the Proponent has located other examples of yellow sandplain to the north and south of the Proposal area and has also committed to sacrificing the mineral component of the upper yellow sands to a depth of 0.7 m, equivalent to the rooting depth of the herb/shrub layer that contributes to the ecological importance of the unit.

4.3.4 Potential impacts to topsoils and subsoils

As described in section 2.5, the Proposal involves the sequential stripping of multiple layers of topsoils and subsoils, including overburden, in order to access the mineral sands deposits. While a detailed schedule for removing, storing and replacing these layers has been prepared as part of the Proposal, the processes involved are relatively large scale and generic. The constraints of the management approach and the potential residual impact that may result to the relevant environmental values of the landform and soils are described below.

Loss or dilution of topsoil

Topsoil will be stripped in two layers and the aim is for direct replacement of at least 40% of topsoil for the Whicher slopes community in State Forest at Happy Valley North, and 90% of topsoil for the Sandplain community in State Forest at Happy Valley South, as outlined previously in Section 2.5.4. However, some material may be required to be stockpiled depending on the progression of mining. Where this is necessary, the period of stockpiling will be minimised as far as practicable and the

stockpiles will be kept low to reduce the material drying out and becoming susceptible to wind erosion.

Spread of dieback and/or weeds

Large areas of the Proposal area are affected by weeds (due to past clearing) and/or dieback. Both of these threatening processes have the potential to spread through soil and reduce the environmental values of healthy, unaffected soils.

Removal of laterite

As a result of mining, the laterite layer that is present in the soil profile through much of the Proposal area will be removed. The laterite but primarily the clayey soils beneath it are believed to reduce downward hydrological movement, with moisture captured and building up at this point. While the underlying clay soils will be replaced as per the Integrated Mining and Rehabilitation Plan (IMRP, presented in Volume 2), the replacement of the laterite layer is considered to be too problematic, as the laterite layer currently allows root penetration into the underlying profile and there is no guarantee that a remade layer would offer such opportunity. Instead, the broken laterite material will be buried beneath the reconstructed profiles or blended with other overburden materials to create material with similar properties to the gravels which are relatively common in the area.

Following the removal of this layer and replacement with freer-draining soils; saturation is less likely to accumulate to the same extent and it is expected that the vegetation community composition might shift to more dry, sandplain species. There is also the possibility that free-draining soil might reduce the spread of dieback.

Soil profiles

For vegetated areas, excavation activities are expected to affect approximately two-thirds of the area of disturbance, meaning that the soil profile of one-third of the disturbance area will not be affected. Where the soil profile is required to be recreated, the following actions and principles will apply:

- original soil profile to be documented
- no mine tails within 4 m of the surface for areas of native vegetation; 1 m for pasture (however, the upper 1 m may contain blended clay fines to improve productivity), with no dominant/significant fines layers within the top 6 m
- an overburden plan to be developed, with some overburden potentially sourced from nearby Gwindinup South operations
- to reduce compaction, once the lower layers of the soil profile have been reinstated (prior to topsoil replacement) they shall be deep ripped.

Soil chemistry

There are no widespread acid sulphate soils or sodic soils in the Proposal area. The established procedures for removing, storing and replacing the different types and layers of soils and subsoils will minimise the potential for this aspect to inhibit rehabilitation outcomes. Additionally, the topsoil nutritional status will be monitored (see Section 5). In recognition of the minor hazard posed by the Proposal, Bemax will implement the following management measures aimed at protecting the surrounding environment:

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- establishment of creek buffers (see Section 7.4.1 for details)
- diversion of all drainage waters into the mine process water circuit, for treatment and monitoring
- monitoring of any water discharged from the site, in terms of quality and quantity, and monitoring of receiving waters.

The environmental and social values of the surrounding water resources are described in Section 7.

Soil and landform stability

The Proposal area contains some steep slopes (up to 40%) and is dissected or within proximity to a number of creeks. A 30 – 50 m buffer has been applied to all creeks, with no clearing permitted in these areas and rehabilitation of previously disturbed areas occurring progressively. A drainage plan will be prepared prior to any ground disturbance to address potential water erosion, with bunds created around the rehabilitation areas to avoid incursion of surface flows. Additionally, within the rehabilitation areas, the approach to water erosion will comprise:

- sheet flow should be limited in sandy soil areas
- in other areas the sites will be surveyed, then the surface will be ripped/furrowed cross-contour to slow the movement of water downslope.

The potential for wind erosion of the rehabilitated areas will be reduced by the location and geometry of surrounding stockpiles, with vegetation surrounding most of the sites also shielding the exposed surfaces.

4.4 LANDFORM AND SOIL MANAGEMENT MEASURES IN DETAIL

4.4.1 Integrated Mining and Rehabilitation Plan

The Proponent has prepared a draft Integrated Mining and Rehabilitation Plan (IMRP), which is consistent with Guidance Statement No. 6 (EPA 2006b) and addresses the requirement for rehabilitation definitions and completion criteria that acknowledge the permanent changes to the landform. The IMRP also includes processes for ensuring those changes are minimised.

Relevant rehabilitation definitions

The IMRP contains the following rehabilitation definitions, or objectives, that are relevant to the restoration of landforms and soils:

- to return to those areas disturbed by mining, stable and appropriate topography, hydrology, soil profiles and topsoils (i.e. abiotic factors) determined by pre-disturbance studies as being best able to satisfy the final land-use concepts and other rehabilitation objectives
- to maximise the use of rehabilitation resources available on-site.

These objectives are, at a minimum, consistent with the standard definitions of the EPA (2006b).

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Completion criteria

The IMRP also contains the following proposed completion criteria and management actions (some have been completed) that are relevant to the achievement of the above rehabilitation definitions or objectives:

- Proposal area has been mapped for dieback, and dieback management zones will have been agreed with regulatory authorities
- prior to commencement of clearing, prepare a drainage plan for implementation in the cleared area
- prior to commencement of clearing, delineate disturbance boundaries with white sighter wire
- keep open areas to a workable minimum
- segregate topsoil on basis of vegetation type and dieback status
- strip native vegetation topsoil in two layers: 0 – 50 mm and 50 – 200 mm
- strip native vegetation topsoil during dry conditions wherever practicable
- strip upper topsoil with GPS buckets and stockpiled into pre-determined locations
- stockpile native vegetation topsoil separately to farmland topsoil
- keep stockpiled native vegetation topsoil over cleared native vegetation areas to a maximum height of 1 m for upper topsoil and 2 m for lower topsoil
- reshape and rip native vegetation topsoil stockpiles to promote native species establishment where topsoil will not be direct and seasonal returned
- strip farmland topsoil to a depth of 200 mm in one layer
- keep farmland topsoil stockpiled over cleared farmland areas to a maximum height of 4 m and stabilised with annual grasses where required
- stockpile overburden as separate piles based on soil profile, soil type, and dieback status
- integrate landform design with surrounding forest landscape so as to not cause an impediment to access for longer term management by regulatory authorities
- spread topsoil over 100% of the rehabilitated mine path
- achieve direct and seasonal return of topsoil over 40% of the Whicher Slopes community in State Forest at Happy Valley North, and 90% of the Sandplain community in State Forest at Happy Valley South
- update clearing, mine schedule, and topsoil handling plans at six monthly intervals and compare with on-ground survey to ensure compliance
- replace specific overburden types at defined points within the post-mining soil profile
- re-contour surface with grader following survey (in line with pre-mining contours)
- deep rip re-contoured surface with conventional triple-tine attachment at half machine width (D9) intervals
- replace lower topsoil from vegetated areas at 200 mm depth using tractors and GPS buckets
- replace upper topsoil from vegetated areas at 50 mm depth using tractors and GPS buckets

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- no hazards resulting from mining (pollutants, debris etc.) to be present over the mining lease
- for each stage of mining, establish post soil reconstruction test pits to assess the following chemical and physical parameters to confirm they are capable of supporting the proposed revegetation cover: nutrients, pH and EC, particle size distribution (proportions of sand, silt and clay), bulk density
- no uncontrolled surface runoff or soil erosion that restricts access by four wheel drive, is unstable and degrading, and/or compromises landuse objectives
- reduce risk of dieback spread through application of dieback hygiene measures
- surfaces stable with no evidence of surface erosion that is likely to limit establishment of a native vegetation cover (post rehabilitation phase)
- reconstructed soil profile does not restrict vertical root development of tree species
- dieback survey and mapping indicates that dieback management procedures have effectively contained dieback spread (post rehabilitation phase).

The procedures that will be implemented by Bemax to ensure the implementation of the above actions and achievement of outcomes are also described in the IMRP.

4.4.2 Environmental Management and Monitoring Plan

The proposed Environmental Management and Monitoring Plan (EMMP), which is provided in Volume 2 of the ERMP, includes measures to protect the surrounding environment from emissions from the Proposal area, including soil erosion (airborne and waterborne) and water pollution, such as that that might be associated with disturbance of potential acid sulfate soils (but a low risk).

4.5 PREDICTED ENVIRONMENTAL OUTCOME

Soils and landform elements have been described and mapped to a high level of detail, with three major soil profile types being identified, corresponding to position in the landscape and depth to the lateritic layer that underlies much of the area. The level of investigation is sufficient for the purposes of predicting impacts and for the preparation of detailed management plans and that the study commitments of the ESD have been fulfilled. The results of the investigations have also been applied to the assessment of vegetation and flora in Section 5 and of fauna in Section 6. This is particularly relevant to determining the significance of the potential impacts to the mid-slope gravel ridges and the yellow sandplain landform elements.

In regards to management of potential impacts to landforms and soils, there is a high level of confidence that:

- stable landforms and soil surfaces can be achieved
- productive soil profiles that mimic the broad characteristics of the three major profiles identified in the assessment can be recreated, including their key ecological functions
- the rehabilitation potential of the topsoil resource can be maximised, with a focus on the priority yellow sandplain and Whicher sandy mid-slopes habitats
- the effects of potential acid sulfate soils will be insignificant and easily detected and managed.

Best Practice management measures will be applied to controlling the spread of dieback disease through the movement of soils, including segregation of materials and complete hygiene control for vehicles and other equipment used in the mining process.

4.5.1 Potential residual impacts

The following residual effects on environmental values may occur as a result of the Proposal:

- for pit areas that will experience extensive disturbance to the soil profile (74 ha), there may be:
 - a reduction in landform heterogeneity
 - a shift towards freer-draining (sandplain) habitat
- for all areas under native vegetation that will be disturbed (155 ha), there may be:
 - a moderately increased risk of dieback being spread to currently uninfested areas
 - the potential for decreased landform productivity, until soil processes become re-established.

The significance of these residual impacts and proposed offsets are discussed in Section 11 of the ERMP.

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Table 4-4 EIA Summary table - Landforms and Soil

Management Objective	Potential Impact	Proposed Management
To maintain the integrity, ecological functions and environmental values of soil and landform	Reduce or alter the environmental values of the Proposal footprint by altering topsoil and/or soil compaction.	Topsoil will be removed in two layers prior to commencement of significant earthworks and stockpiled on basis of land use, vegetation cover and dieback status. Topsoil layers will be removed and replaced using best practice equipment. Minimum performance targets direct and seasonal return of topsoil have been proposed: 40% for Whicher soils, 90% for yellow sandplain soils. Subsoils will be ripped prior to replacement of topsoils, to address compaction issues – this will be confirmed by monitoring.
	Reduce or alter the ecological functions and environmental values of the pit areas by altering soil profile.	Rehabilitation of the top 6 m of the soil profile will be conducted in accordance with agreed prescriptions for each of the four key profiles.
	Reduce soil or landform integrity as a result of erosion.	Soil erosion will be managed by ensuring site works are properly drained and that rehabilitation incorporates natural drainage lines and is promptly stabilised and/or revegetated.
	Reduce environmental values of soil as a result of disturbing acid sulphate material (low risk).	Risk has been assessed as low, however, a monitoring program has been prepared as part of the Water Resources Management Plan.
To ensure that rehabilitation achieves an acceptable standard compatible with the intended land use and consistent with appropriate criteria	Generic/common potential impacts, as described in EPA Guidance Statement No. 6.	An Integrated Mining and Rehabilitation Plan has been prepared in draft form and will be finalised at the conclusion of the EIA process. The Plan has been reviewed and is considered to be consistent with the EPA Guidance Statement No 6 on Rehabilitation.
To ensure that the geoheritage values of the biophysical environment are not adversely affected	Reduce the diversity of landform elements across the Proposal footprint by poor rehabilitation of soils and landforms.	Key soil profiles of the landforms that will be mined have been developed based on field work and these will be rehabilitated to agreed prescriptions and in agreed areas, best matching pre-mining conditions.