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Bayonet Head Outline Development Plan – Southern Area
Hydrogeology and Hydrology

Report for Coffey Environments, Albany Office.

August 2008

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Report No. Crisalis JI08_V2

Executive summary

The Environmental Protection Authority (EPA) instructions for preparation of the Public Environmental Review for Lot 1000, Lower King Road (Bayonet Head Development) requested that the hydrology of the site be described and possible impacts of residential development addressed due to the concern that any alteration to the existing hydrological regime at the site may have the potential to significantly impact wetlands and also areas of dryland vegetation, within and adjacent to Lot 1000. The hydrological connectivity between the wetlands of the area was previously unknown and without that information, potential impacts could not be determined. In addition, an understanding of the hydrology of the area is required to determine any potential impacts to groundwater systems and surface water sources (for example Yakamia Creek and Oyster Harbour).

Coffey Environments are involved in the evaluation of environmental impacts of the Bayonet Head development in Albany. As part of this work, they require specialist assessment of the hydrology and hydrogeology of the development and adjacent areas, to assist in defining environmental impacts on groundwater and on paluslope wetlands within the development area. The specialist review of hydrogeology and hydrology of the area was carried out by Crisalis International Pty Ltd with assistance from Coffey Environments in May-August 2008.

The paluslope wetlands at the proposed Bayonet Head development are associated with higher ground above and west of Oyster Harbour. Here, soils of fine sand A horizons, often with laterite gravel, overly clay B Horizons. These soils are apparently underlain by weathered Pallinup Siltstones.

A hydrogeological investigation was carried out at the site, specifically to determine:

- Water table contours (piezometric surface) within the shallow sand aquifer on the flanks of the plateau area;
- Possible hydrogeological linkages between paluslope wetlands and linkages between paluslope wetlands and surface drainages / creek lines;
- Responses of groundwater levels to rainfall events;
- The nature and depth of any impervious layers within the soil profiles and possible perching of groundwater within shallow soils;
- To analyse all data and determine a conceptual model which can be used to assess potential impacts of land development for housing on the site, and to determine possible land management practices which minimise impacts and protect vulnerable paluslope wetland areas.

A network of 20 monitoring bores (50mm diameter piezometer tubes) were emplaced at the site in May 2008 for monitoring of groundwater levels over time at the site (Figure 1).

The groundwater level data from the site indicates two distinct aquifer systems. The first is associated with shallow perched groundwater on clay soils on the plateau, associated with wetlands 31/40 and D, where groundwater is mostly within 1-2m of the surface above elevations of 40m AHD from May to early August 2008. The second deeper system has an inferred elevation of ~30m AHD beneath the plateau, decaying to elevations of around 20m AHD to the northeast around wetland 41, to the southwest around wetland 29 and either side of the catchment divide. There is a more subdued gradient to the east towards wetlands 8/15. Groundwater levels at the site broadly follow surface topography.

The vegetation associated with the paluslope wetlands 31/40 and D on the plateau on the upper reaches of the catchment undoubtedly derive water from localised perched shallow aquifers, with water seemingly being present over summer periods in these areas in sands above a relatively thick (1-1.5m) layer of clay. It seems likely these might be recharged periodically by summer rainfall, although there is insufficient data to confirm this. Natural recharge from rainfall falling on the inferred areas of perched water rapidly recharges the perched groundwater zones above what appears to be thicker clay soils than elsewhere on the plateau. Although there is undoubted slow leakage through the clays to the deep groundwater system and lateral drainage down hydraulic gradient, it seems likely that there is sufficient water retained within the perched zones or within the thicker clay soils to maintain the paluslope wetland vegetation over summer periods. The urban development here would be unlikely to impact recharge rates, if developments were kept outside a relatively small buffer zone (e.g. 30-50m) from the wetland areas.

The wetlands on the slopes around the plateau (29, 41, 8/57) are mostly associated with the deep groundwater table, where this comes closer to the surface at break-in-slope areas within the shallow valleys, or to poorly developed perched water tables as at wetland 8/57. The relatively low hydraulic conductivity of the soils allows maintenance of high hydraulic gradients. Clearly, there is an overall rise in the deep water table over time from winter recharge and a rapid response of the deep groundwater table to rainfall events at wetland 29 and slow decay of the peaks between rainfall events. It is considered likely that rapid groundwater recharge through unsaturated soils within the area is caused by infiltration through preferred pathways such as root channels.

Any changes in recharge to the deeper groundwater system potentially could impact wetlands 29, 41 and 8/57. This could occur by raising groundwater levels over the area if recharge increases as a result of increased surface drainage onto soils from roof areas and roadways/paths, reduced losses by evaporation and reduced transpiration if vegetation is removed from the developed areas.

Alternatively, if stormwater is exported off-site, recharge rates would decrease substantially and groundwater levels in the deep aquifer system would fall, potentially impacting vegetation associated with the wetlands and base flow to creeks such as Yakamia Creek to the south. Clearly, the latter impacts are to be avoided if possible, and attempts should be made to try and maintain groundwater levels and recharge rates at approximately current levels for maintenance of the wetland vegetation and the hydrologic environment generally.

Increased infiltration and recharge in summer as a result of development would be unlikely to be problematic, as groundwater level declines (which typically occur in summer) would be reduced. The main problem would be in winter, through significant increases in recharge. This would clearly need to be managed.

It is understood that houses in the development are likely to have rainwater tanks for collection of roof water. Thus at least a proportion of influent rainfall would be removed from the system. Rain falling on impervious surfaces (roads, paths) would presumably be collected in storm drains and infiltrated as discussed above, adding to recharge through permeable soils (gardens, public open space). The latter would still be higher than under natural conditions (e.g. if these areas were mainly grassed or vegetated with shallow-rooted plants), although planting of some of these areas with deep-rooted native vegetation would bring recharge closer to natural conditions. It also is likely that increases in recharge could be minimised by localised infiltration of stormwater over the area, rather than centralised infiltration (e.g. through a small number of larger compensation basins), to maximise transpiration.

It is recommended that a buffer zone of 30-50m around wetland 29 to the south would allow direct protection of the paluslope vegetation. It is unclear whether a buffer zone around wetlands 8/57 would be appropriate, given that this area already has urban development and roadway on it. Wetland 41 to the north of the development area is relatively small and similarly may not warrant a buffer zone.

The deep groundwater table did not intercept the surface at any point within the site over the monitoring period, although it is possible that this occurs offsite and down-gradient within the valleys, forming spring-lines which would provide base flow for small creeks, such as Yakamia Creek to the south of Bayonet Head. It is likely any groundwater discharge is some considerable distance from the site boundaries, and the development at Bayonet Head would provide only a part of base flow to this and other creeks, proportional to the development drainage area.

The shallow and deep groundwater systems at Bayonet Head are distinct from groundwater system on low lying land between the site and Oyster Harbour. Given the separation of these groundwater systems it is concluded that any changes in recharge to the Bayonet head site due to development would have negligible influence on groundwater system on the dune sands, or on the hydrology of Oyster Harbour.

It is recommended that monitoring of groundwater over time is carried out at the site to determine possible impacts of the development on groundwater levels and on paluslope wetland vegetation, particularly at those wetlands on the slopes such as wetland 29. Monitoring of water levels can be used for public awareness and community involvement in maintaining the wetlands, if for example bores are fitted with floating, graduated poles, which indicate to everyone the level of groundwater. These have been used successfully in Wheatbelt towns suffering from dryland salinity and rising groundwater levels.

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Figure 4b. Comparison of variation with time in groundwater levels in bore MBA (wetland 29) with Albany daily rainfall (from the Bureau of Meteorology) 4 July to 3 August 2008.

Figure 5. Conceptual model of deep groundwater flows (blue arrows) around wetland areas (shown in green) at the Bayonet Head site.

1. Background

The proposed development of Lot 1000 Lower King Road is currently the subject of formal assessment (Public Environment Review) by the Environmental Protection Authority under Sections 38(1) of the *Environmental Protection Act 1986*. In addition, Pt Lot 1 Yatana Dr and Lot 476 Sibbald Road is subject to assessment (Environmental Review) under Section 48A of the *Environmental Protection Act 1986*. The location of these areas is shown in Figure 1.

The Environmental Protection Authority (EPA) instructions for preparation of the Public Environmental Review for Lot 1000, Lower King Road requested that the hydrology of the site be described and possible impacts of residential development addressed. In development of the subsequent scoping document, the EPA requested the following:

'Any alteration to the existing hydrological regime has the potential to significantly impact wetlands and also areas of dryland vegetation, within and adjacent to Lot 1000. The hydrological connectivity between the wetlands of the area is unknown and without that information, potential impacts cannot be determined. In addition, an understanding of the hydrology of the area is required to determine any potential impacts to groundwater systems and surface water sources (for example Yakamia Creek and Oyster Harbour). Accordingly, the hydrological study should comprise a <u>comprehensive hydrological investigation (i.e. groundwater and surface water characteristics, including water source, flows and direction); and hydrological regimes (including timing, frequency, duration, extent, depth and variation)</u>

The EPA Service Unit has also foreshadowed that the area subject to the Environmental Review (Pt Lot 1 Yatana Dr and Lot 476 Sibbald Rd, Bayonet Head) will also need to present similar site specific hydrological information. To provide a complete overall picture this investigation has been designed to investigate the hydrogeology and hydrology of Lots 1000 & 1001 Lower King Road, Part Lot 1 Yatana Dr and Lot 476 Sibbald Road, Bayonet Head. Wetlands on the site have been mapped (Coffey Environments, 2008) and numbered consistent with Department of Water (2007). The wetlands are shown in Figure 1.

The objectives of the study are to:

- Describe the hydrology of the area in terms of groundwater and surface water characteristics, including water source, flows and direction.
- Describe hydrological regimes including timing, frequency, duration, extent, depth and variation.
- Determine whether the wetlands within and adjacent to Lot 1000 are groundwater dependent or perched.
- Determine whether the wetlands are reliant on rainfall and/or surface water flows.

- Predict likely alteration to the existing hydrological regime as a result of development and the subsequent potential impacts on wetland and dryland vegetation.
- Determine the hydrological connectivity between the wetlands of the area, if any and predict potential impacts of development.
- Determine if there are likely to be impacts to groundwater systems and surface water sources (for example, Yakamia Creek and Oyster Harbour) as a result of the proposed development.
- Collect pre-development baseline data for groundwater levels.

Coffey Environments are involved in the evaluation of environmental impacts of the Bayonet Head development in Albany. As part of this work, they require specialist assessment of the hydrology and hydrogeology of the development and adjacent areas, to assist in defining environmental impacts on groundwater and on paluslope wetlands within the development area.

Crisalis International Pty Ltd was requested by Coffey Environments to review available information relating to the site and adjacent areas, advise on a program of investigative drilling and monitoring to provide appropriate information relating to hydrology of the wetland areas and any connections with shallow groundwater, to allow a proper evaluation of impacts of development of the site specifically on wetlands and groundwater. Coffey Environments carried out drilling in May 2008, and the following report details results and analysis of monitoring data collected subsequently from the bores from 28 May to 4 July 2008, along with information on soils, geology and hydrogeology of the site.

2. Geological Setting

Moncrieff (1992) describes the general regional geology of the region around Albany, with Proterozoic basement rocks of the Stirling Range Association consisting of gneiss, granite and meta-sediments, overlain in places by Eocene Plantagenet Group sediments which generally consist of impervious siltstones (Pallinup Formation) overlying more permeable sandstones of the Werrillup Formation. The Plantagenet Group, Pallinup Formation are overlain by a relatively thin veneer of sand and laterite.

Laterite and associated sand are identified in the area of the Bayonet Head development. These soils were identified by Churchward et al (1988) as sands and laterite on elongate crests underlain by Pallinup Siltstones which are deeply weathered, forming a lateritic duricrust. The soils are described as yellow duplex profiles dominant with light grey-brown to light brown-grey fine sand A horizons, often with much laterite gravel and boulders. They also report a yellow-brown mottled clay B Horizon below. Investigation pits excavated through the thin soils around the wetland in the southwest of the development (Table 1) identified some “coffee rock” (considered to be laterite) forming an impervious layer upslope of the wetland paluslope, and an impervious “sandy clay” beneath more permeable sands, which is broadly consistent with the likely lithology beneath the sandy soils and above the Pallinup Formation siltstones.

Moncrieff (1992) similarly reports that the sand/laterite regionally "forms discontinuous capping of older rocks". The laterite is generally overlain by sand and ranges from massive cemented laterite to loose pisolites less than 3m thick.

It is concluded that the paluslope wetlands at Bayonet Head development are associated with the thin sands and laterite along the crest and higher ground above and west of Oyster Harbour. Two wetlands (31/40 and D) sit astride a topographic plateau and hydrogeologic catchment divide running east-west across the development area. The other wetlands mostly occur on the flanks of the plateau, generally associated with break-in-slope, e.g. wetland 41 in a valley to the northeast of wetlands 31/40 and northwest of wetland D, wetlands 8/57 to the east of wetland D and wetland 29 to the southwest of wetlands 31/40 in Figure 1.

3. General Hydrogeology

There is no information on regional groundwater beneath the Bayonet Head site, although bores identified on low lying land to the south of the development are possibly associated with a regional groundwater table in dune sands. The shallow groundwater levels in these bores at elevations just above sea level indicate that groundwater associated with the Bayonet Head paluslope wetlands has little direct connection with groundwater on the lower lying ground around Oyster Harbour, i.e. the shallow groundwater system beneath the development site is a separate and distinct hydrogeological system, localised to the higher ground, possibly occasionally feeding surface creeks on the flanks of the crests.

The thin sands and laterite were not considered to be prospective for groundwater supplies by Moncrieff (1992) because of their thin and discontinuous nature. However, shallow perched water tables were identified as occurring within the sands on higher ground in the landscape above the regional water table.

4. Investigation

Investigation of shallow soils around the southwest wetland (Wetland 29) using shallow pits to depths of up to 3.7m by Coffey Geotechnics (2005) provides useful information on shallow soil lithology and piezometric surface (3-dimensional water table elevation) within the sands beneath and around the paluslope wetland 29.

In Table 1, lithological logs indicate that the sand aquifer is present across the entire area, with occasional laterite at lower depths (recorded as coffee rock). Groundwater was intercepted within mid-parts of all three sections at shallow depths, generally associated with a shallowing of topographic slope (referred to as break-in-slope) where groundwater recharge would be expected to be increased compared with steeper slopes and consequently groundwater levels would be somewhat closer to the surface. The paluslope wetland 29 is located in a shallow valley, with groundwater shows being found in pits at the lower end of the break-in-slope.

Following this initial soils study, a hydrogeological investigation was carried out at the site, specifically to determine:

- Water table contours (piezometric surface) within the shallow sand aquifer on the flanks of the plateau area;
- Possible hydrogeological linkages between paluslope wetlands and linkages between paluslope wetlands and surface drainages / creek lines;
- Responses of groundwater levels to rainfall events;
- The nature and depth of any impervious layers within the soil profiles and possible perching of groundwater within shallow soils;
- Determine a conceptual model which can be used to assess potential impacts of land development for housing on the site, and to determine possible land management practices which minimise impacts and protect vulnerable paluslope wetland areas.

A network of 20 monitoring bores (50mm diameter piezometer tubes) were emplaced at the site in May 2008 for monitoring of groundwater levels over time (Figure1, Table 2). These include:

- Four sets of two nested bores within each paluslope wetlands 31/40, 41, D, and 8/57, and one deeper bore in wetland 29 for monitoring water level changes beneath the wetlands. Bore screens were set approximately 2-3m below surface in shallow bores for identifying and monitoring "perched" groundwater close to the surface above any clay or low permeability horizon. Deeper bores (including the one bore at wetland 29) were drilled to identify and monitor any deeper groundwater;
- Eleven additional 50mm bores were emplaced mostly outside of the paluslope wetlands with screens set at 2-3m bgl or as appropriate to below groundwater level outside of the identified paluslope wetland areas, for assessment of the extent of any perched groundwater around the wetlands;
- Two of the above deeper bores at paluslope wetlands 29 and D were fitted with automatic water level recorders and loggers for assessment of response of groundwater levels to rainfall events (i.e. to determine how rapidly infiltration of water takes place);
- "Slug" tests were carried out on bores at wetlands 29 and D to assess hydraulic conductivities of soils in the area, using the water level probes and loggers to determine groundwater level recoveries over time after introducing a "slug" of water to raise water levels in each bore. Slug test data analysis was carried out using Hvorslev method (Freeze and Cherry, 1979).

Groundwater levels were measured manually using a water level dipper (electric contact gauge) monthly where groundwater was found to be present, and all bores were surveyed in to top-of-casing to allow determination of water table contours across the site. Bore details (AHD datum levels for top-of-casing, depth drilled, screen lengths etc) are given in Table 2. Recorded water level changes between 28 May and 3 August for all bores are given in Tables 3 a-d. The latter period of monitoring, essentially from early to late winter, was considered adequate to provide necessary data for development of a conceptual hydrogeological model for the site, and to provide baseline data on development of perched groundwater associated or otherwise with wetlands at the site.

5. Results

5.1 Groundwater level monitoring

Groundwater was identified in shallow bores in wetlands 31/40 and D on the plateau, but not in the deeper bores at these locations. The shallow groundwater in these wetlands was interpreted as perched groundwater within 1-2m of the surface, ponded on a thick (2-3m) clay layer. Deeper bores into sands at both locations were both dry throughout the monitoring period, confirming the perched nature of the shallow groundwater at these locations.

Shallow bore P5 outside the wetland areas but close to the plateau was dry during the monitoring period. This bore P5 showed only a thin layer of clay (~0.25m thick). These results suggest an association between perched groundwater and greater thickness of clay and wetlands on the plateau area. Other bores which were within or close to the wetlands showed water levels in May and June (P10), from June to August (P6), and July and August (P3, P9). Bore P6 outside of the main wetland areas were dry in May but contained groundwater from June to August, whilst shallow bore P4 in a similar position was dry throughout the monitoring period.

Two bores drilled at wetlands on the flanks of the plateau (41 and 8/57) show a different situation, with shallow bores drilled to a clay layer being dry, but deeper bores showing groundwater levels at depths of ~5-7m bgl (Tables 3a-d). Groundwater in the deeper bores was interpreted as being associated with a deeper water table beneath a clay layer higher in the soil profile, and significant depth to groundwater. Groundwater levels at wetland 29 in the southwest of the area are also at low elevation, and are similarly interpreted as being consistent with levels in the deep groundwater system beneath the site. However, these levels are ~1-2m below surface at this location, as observed in the earlier trenching investigation by Coffey Geotechnics (2005).

Reduced groundwater levels (to m AHD) for all bores have been mapped and contoured to show the distribution of groundwater levels across the site, and the association of this with wetland areas. This is shown in Figure 2 for data in July 2008, when most bores contained groundwater.

Similarly, vertical section A-A' across the topographic and hydrogeological catchment divide along the length of the plateau (bores P9, MBB, 5, MBD, 3 and MBE) have been plotted in Figure 3a, showing topographic height, lithological summary (sand/clay etc), groundwater depth in July 2008, position of a clay layer recorded in bore logs associated with a shallow perched water table beneath wetlands 31/40 and D, and bottom of hole. Dry bores at this time are also recorded [as (d)]. Vertical section A-B from wetland B (bore P9, MBB) northeast to wetland C (bore MBC and bore P4) along a likely groundwater flow direction are shown in Figure 3b.

The groundwater level contours for July 2008 show a consistent pattern which broadly mimics the surface topography at the site, with quite strong groundwater gradients on the flanks of the plateau, particularly in the northern part of the site. Contours have been inferred from topography where no bores existed to complete the overall pattern (dashed lines). Very shallow groundwater gradients are observed in the two wetlands on the plateau (31/40 and D), with water table heights generally above 40m AHD. These contrast with much stronger gradients on the flanks of the plateau. The distribution of groundwater levels above 40m AHD have been taken as indicative of the distribution of the perched groundwater table, shown as green line shading in Figure 3a. These areas broadly coincide with the identified extent of the wetlands 31/40 and D.

The vertical sections in Figure 3a and 3b provide more detailed summaries of the hydrogeology of the site. The section along the catchment divide (Figure 3a) clearly identifies the zones of perched groundwater at shallow depths overlying clay soils which appear to be thicker beneath wetlands 31/40, D and 8/57. The areas of perched groundwater do not show a saucer-shaped accumulation above the clay, but appear to have a gradient which matches surface topography where the clay layer is apparently thicker. The vertical scale of Figures 3a and 3b are greatly exaggerated compared with the horizontal scale, so the configuration of perched water table is also highly exaggerated in this direction. However, as can be seen from the topographic gradients in these areas, there is very little slope to the perched water table, and thus these largely reflect areas where water has accumulated on top of zones where the clay layer is somewhat thicker than in areas outside of wetlands 31/40 and D, e.g. at bore P5.

As indicated above, unsaturated sandy soils underlie both perched zones (dry deep bores at MBB and MBD). Extension of the perched zones are identified between wetlands 31/40 and D (at bore 5) only in August, and between wetlands D and E (bore P3) in July and August, with these developing above an identified thin clay layer. This indicates that at least along the catchment divide (running along the plateau) there are two distinct areas of perched groundwater associated with the wetlands 31/40 and D (Figure 3a) which exist even at the start of winter in late May, with wider development of perched areas as winter progresses.

Groundwater at wetlands 8/57 is present at significant lower elevations of around 29.5m AHD. The preferred explanation for this, as indicated above, is that this represents a deeper groundwater table at elevation around 30m AHD (i.e. at approximately the same elevation across the catchment divide). This has been indicated on Figure 3a as a dashed (inferred) line. Unsaturated sands exist between this water table and the perched groundwater. It is clear that water from the perched zone would leak slowly through the clay to some extent, recharging the deeper groundwater in underlying sands. It has not been possible to determine the depth of this regional water table from the network of deeper bores.

The vertical section along the flow line in Figure 3b again shows the perched groundwater zone associated with wetlands 31/40 extending to the edge of the plateau but apparently no further. The groundwater level elevation at wetland 41 (bores MBC [shallow and deep]) is much lower than at other wetlands in the vicinity, and an inferred deeper water table is shown here extending from an elevation of around 30m beneath wetlands 31/40 to 21.8 beneath wetland 41. The water table contours suggest a strong hydraulic gradient here of around 0.1, typical of soils of lower permeability.

Groundwater levels around wetland 29 in the southwest of the site are again much lower than those in the north, with deeper groundwater levels around 20m AHD, and groundwater flowing to the southwest within a topographic valley. Bore logs at this location (MBA, P11 and P12) indicate mainly sand with minor sandy clay. Hydraulic gradients generally are lower, around 0.03.

Water level variability over time (every 2 hours from 28 February 2008 until early June and then every 10 minutes until early July) has been measured in bore MBA using an Odyssey water level recorder and data logger. Similar data was obtained from wetland D between 4 July and 3 August. The results of this are shown in Figures 4a and 4b along with daily recorded rainfall for Albany over these periods from the Bureau of Meteorology.

In Figure 4a (bore MBA), there is considerable variability over time in groundwater levels (deep groundwater table), with rapid rises in level associated with peak periods of rain. The rapid rises of groundwater levels in response to rain indicate rapid infiltration through the soils, presumably through preferred pathways such as root channels. The hydrograph peaks decay more slowly over time between rainfall events, although there is an overall rise in groundwater levels over time between 28 May and 4 July. The decay in groundwater levels between rainfall events indicates the effects of subsurface down-gradient drainage of groundwater beneath the topographic valley (i.e. subsurface drainage), and possibly the effects of vegetation water use. There is thus a clear impact of rapid recharge by rainfall of the deep aquifer and a more subdued and gradual drainage of water from the soil beneath the wetlands.

Variation in groundwater level over time beneath wetland D (bore MBD) shows a similar relationship to peak rainfall events (Figure 4b). Again there is a small decay in groundwater level between peak rainfall events, perhaps somewhat muted compared with that in Figure 4a.

The results of the slug tests to determine hydraulic conductivity of soils at wetlands 29 and D are shown in Attachment 2, using Hvorslev analysis of test results. The latter determinations are consistent at both sites, being ~0.18m/d and 0.2m/d, similar to that for fine sands.

Monitoring of groundwater level responses to rainfall events indicates rapid recharge of groundwater, whilst lateral movement of deeper groundwater from the plateau towards the wetland areas would be slow. This can be estimated using Darcy's law, using the estimated hydraulic conductivities and hydraulic gradients, and assuming a typical porosity for aquifer sands of 0.3. Darcy's Law can be used to determine groundwater velocity, from

Average groundwater velocity (v in m/y) = $365 \; (K \; i \; / \; \Theta)$ ……….(Equation 1)

Where K is the hydraulic conductivity (0.2 m/d)
i is the hydraulic gradient (varying from 0.03 to 0.1)
and Θ is the porosity (0.3)

The average lateral groundwater velocity thus varies from ~7m/y (southwest area) to ~25m/y (northeast as in section A-B, Figure 3b), which are relatively low.

5.2 Conceptual model of groundwater flow

The above assessment thus provides a reasonably consistent conceptual model of the hydrogeology at the Bayonet Head site. The data indicate two distinct aquifer systems. The first is associated with shallow perched groundwater on clay soils on the plateau, associated with wetlands 31/40 and D, where groundwater is mostly within 1-2m of the surface above elevations of 40m AHD from May to early August 2008. The second deeper system has an inferred elevation of ~30m AHD beneath the plateau, decaying to elevations of around 20m AHD to the northeast around wetland 41 and to the southwest around wetland 29 either side of the catchment divide. There is a more subdued gradient to the east towards wetlands 8/15 as in Figure 3a.

The perched groundwater must infiltrate through the lower permeability clays on which groundwater is perched, recharging the deeper groundwater system beneath the wetlands. It seems likely that all the wetlands are recharged quite rapidly by rainfall events, despite measured low saturated hydraulic conductivities of soils associated with the wetlands. This rapid response is often observed where soils have secondary permeability due to preferred pathways for water infiltration. These are possibly associated with root channels or other conduits, noted in similar areas around Albany (McGrath, 2007).

The vegetation associated with the paluslope wetlands 31/40 and D on the plateau on the upper reaches of the catchment undoubtedly derive water from the perched shallow aquifer, with water seemingly being present in these areas in sands above a relatively thick (1-1.5m) layer of clay over summer periods. It seems likely these might be recharged periodically by summer rainfall, although there is insufficient data to confirm this.

The wetlands which are mainly in valleys on the flanks of the plateau to the northeast, east and southwest do not seem to be associated with perched groundwater, except for wetland 8/57 which showed a perched water table only in August 2008 (Tables 3a-d). Instead these are associated with break-in-slope areas within the shallow valleys, where groundwater recharge would be higher. Two of these areas also seem to be associated with significant thicknesses of clay higher in the profile at wetlands 41 and 8/57 (the latter presumably being the strata where perched groundwater developed), but not at wetland 29 where groundwater is much closer to the surface. It is possible that deeper groundwater at the former locations supports the paluslope vegetation, although this might be related more to the presence of water storage in the clay strata, or to poorly developed perched water tables as in wetland 8/57 late in the winter period. The groundwater close to the surface at wetland 29 in the southwest clearly would support vegetation here, as the soils do not have a well developed clay horizon.

These wetlands on the flanks of the plateau are fed by lateral groundwater flow which itself is likely recharged by rainfall infiltrating through soils on the plateau and from leakage through the perched zones. The relatively low hydraulic conductivity of the soils allows maintenance of high hydraulic gradients. Clearly, there is an overall rise in the deep water table over time from winter recharge and a rapid response of the deep groundwater table to rainfall events at wetland 29 (early hydrograph peaks) and slow decay of the peaks between rainfall events (Figure 4).

Groundwater flow lines for the deep aquifer system are shown in Figure 5, based on actual and inferred groundwater contours for the deep system. These show the wetlands 31/40 and D on the plateau which are maintained by the shallow, localised perched aquifers. The deeper groundwater system exists beneath these, and must be recharged by these to some extent, although direct recharge would also take place from areas outside these wetlands. Deep groundwater flows are dominated by the catchment divide running along the plateau, which separates broad north-easterly flows from those broadly to the southwest. Deep groundwater flow lines converge towards three main areas – to the southwest (wetland 29), from the western edge of the plateau towards the northeast as in section A-B (Figure 3b) and from the eastern edge of the plateau to the east and northeast as in the eastern part of section A-A' (Figure 3a). All these areas are in shallow valleys extending from the plateau, which form the main drainage areas for groundwater at the site. The paluslope wetlands have developed at breaks-in-slope within these valleys.

The deep groundwater table did not intercept the ground surface at any point within the site over the monitoring period, although it is possible that this occurs offsite and down-gradient within the valleys, forming springlines which would provide baseflow for small creeks, such as Yakamia Creek to the south of Bayonet head. It is likely any groundwater discharge is some considerable distance from the site boundaries, and the development at Bayonet Head would provide only a part of baseflow to this and other creeks, proportional to the development drainage area.

The shallow and deep groundwater systems at Bayonet head are distinct from groundwater system on low lying land between the site and Oyster Harbour, although it is possible that regional groundwater from the site does recharge groundwater on the sand plain. Given the rates of flow, and likely high rates of recharge to the shallow dune sands, it is concluded that any changes in recharge to the Bayonet head site due to development would have negligible influence on groundwater system on the dune sands, or on the hydrology of Oyster Harbour.

6. Possible Impacts of Development on the Wetlands and Vegetation.

Possible impacts on wetlands associated with perched groundwater on the plateau (31/40 and D) and those associated with the deep groundwater system (29, 41 and 8/57) are considered separately, as these present quite different systems at the Bayonet Head site.

6.1 Wetlands 31/40 and D associated with perched groundwater at higher elevations.

These wetlands, where groundwater is within 1-2m of the surface are located close to the catchment divide on the plateau, and thus recharge to these is unlikely to be impacted by urban developments at the site. Natural recharge, for example from rainfall falling on the inferred areas of perched water in Figure 2, would recharge the perched groundwater zones above what appears to be thicker clay soils than elsewhere on the plateau. Although there is undoubted leakage through the clays to the deep groundwater system, and lateral drainage down hydraulic gradient (section A-B in Figure 3b), it seems likely that there is sufficient water retained within the perched zones or within the thicker clay soils to maintain the paluslope wetland vegetation. The urban development here would be unlikely to impact recharge rates, if developments were kept outside a relatively small buffer zone (e.g. 30-50m) from the wetland areas.

6.2 Paluslope wetlands 29, 41 and 8/57 within shallow valleys on the flanks of the plateau

These wetlands are mostly associated with the deep groundwater table, where this comes closer to the surface at break-in-slope areas within the shallow valleys and where groundwater recharge would tend to be higher than on the steeper slopes. Any changes in recharge to the deeper groundwater system potentially could impact these wetlands.

This could occur by raising groundwater levels over the area if recharge increases as a result of increased surface drainage onto soils from roof areas and roadways/paths, reduced losses by evaporation and reduced transpiration if vegetation is removed from the developed areas.

Alternatively, if stormwater is exported off-site, recharge rates would decrease substantially and groundwater levels in the deep aquifer system would fall, potentially impacting vegetation associated with the wetlands and base flow to creeks such as Yakamia Creek to the South. A buffer zone of 30-50m around wetland 29 to the south would allow direct protection of the paluslope vegetation. It is unclear whether a buffer zone around wetlands 8/57 would be appropriate, given that this area already has urban development and roadway on it. Wetland 41 to the north of the development area is relatively small and similarly may not warrant a buffer zone.

Clearly, adverse impacts of changes in the hydrogeological regime around the wetlands are to be avoided if possible, and attempts should be made to try and maintain groundwater levels and recharge rates at approximately current levels for maintenance of the wetland vegetation and the hydrologic environment generally, although it is not possible to determine what this is with any precision.

Increased infiltration and recharge in summer, as a result of development, would be unlikely to be problematic, as groundwater level declines, which typically occur in summer would be reduced. The main problem would be in winter, through significant increases in recharge. This would clearly need to be managed.

It is understood that houses on the development are likely to have rainwater tanks for collection of roof water. Thus at least a proportion of influent rainfall would be removed from the system. Rain falling on impervious surfaces (roads, paths) would presumably be collected in storm drains and infiltrated as discussed above, adding to recharge through permeable soils (gardens, public open space). The latter would still be higher than under natural conditions (e.g. if these areas were mainly grassed or vegetated with shallow-rooted plants), although planting of some of these areas with deep-rooted native vegetation would bring recharge closer to natural conditions. It is also likely that increases in recharge could be minimised by localised infiltration of stormwater over the area, rather than centralised infiltration (i.e. a small number of larger compensation basins), to spread infiltration over a larger area.

The average groundwater velocities determined above (~7-25m/y) indicate a slow movement off-site, despite rapid rates of vertical infiltration through unsaturated soils from the surface. This would potentially allow significant opportunity for transpiration if open areas could be vegetated with natural deep rooted (phreatophytic) vegetation which are able to transpire water from below the water table.

The above provides a qualitative assessment of how increased recharge might be managed, although it is recommended that groundwater levels are monitored regularly within the wetland areas to determine whether increased recharge is taking place. Some assessment would need to be done to determine appropriate levels for maintenance of vegetation in these areas. Certainly the 1-2m depth below surface as in the plateau wetlands would seem to be a useful target in these areas and at wetland 29 in the southwest. As indicated above, groundwater levels at wetlands 41 and 8/57 are significantly deeper, and the presence of a thick clay layer at these locations may be more important for maintaining vegetation in these areas. Monitoring of shallow bores as well as deeper bores at these locations would be recommended as increased recharge could develop perched water tables above the clays.

Monitoring of water levels can be used for public awareness and community involvement in maintaining the wetlands, if for example bores are fitted with floating, graduated poles, which indicate to everyone the level of groundwater. These have been used successfully in Wheatbelt towns suffering from dryland salinity and rising groundwater levels.

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7. References

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Table 1 (below). Selected information from logs of investigation pits, southwest wetland, for each section (information provided by Coffey Geotechnics, 2005).

TP No	GW depth below surface	Groundwater Level mAHD	Ground Level mAHD	Soil Type	Depth of pit in m AHD	Test Pit depth	
Transect A- north to south							
TP 89			33.5	silty sand over coffee rock	30.2	3.3	soil moist
TP100			31.5	silty sand	27.8	3.7	soil moist
TP106			27	silty sand	24	3	soil moist
TP125	2	23.75	25.75	silty sand	23.25	2.5	soil moist
TP131	2.5	19.5	22	peaty silty sand over silty sand	19.3	2.7	ponding of surface water/soil moist
TP163			22	silty sand	19	3	soil moist
TP159			21.5	silty sand	18.4	3.1	soil moist
Transect B- west to east							
TP128			27	silty sand	24	3	soil moist
TP129			25.5	silty sand	22.5	3	soil moist
TP130	2.3	21.2	23.5	silty sand	20.9	2.6	soil moist over groundwater
TP131	2.5	19.5	22	peaty silty sand over silty sand	19.3	2.7	ponding of surface water/soil moist over groundwater
TP132	2	20.5	22.5	silty sand	19.9	2.6	soil moist over groundwater
TP133			25	silty sand over coffee rock	22.3	2.7	soil moist

Transect C-west to east							
TP127			28	silty sand	25.3	2.7	soil moist
TP126	2.1	23.15	25.25	silty sand	22.75	2.5	soil moist over groundwater
TP125	2	23.75	25.75	silty sand	23.25	2.5	soil moist over groundwater
TP124			25.5	silty sand	22.6	2.9	soil moist
TP123			27	silty sand	23.8	3.2	soil moist
TP122			28.5	silty sand over coffee rock	25.2	3.3	
Transect D-west to east							
TP103			29	silty sand	25.3	3.7	soil moist
TP104			28	silty sand	24.8	3.2	soil very moist
TP105			27.5	silty sand	24.6	2.9	soil moist
TP106			27	silty sand	24	3	soil moist
TP107			27	silty sand	24.5	2.5	soil moist
TP108			29	silty sand over clayey sand	26	3	soil moist

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Transect E- north to south					0		
TP88			34	silty sand becoming darker and wetter at depth	30.4	3.6	soil moist to wet
TP101			31	silty sand over coffee rock	28	3	Soil moist
TP105			27.5	silty sand	24.6	2.9	soil moist
TP126	2.1	23.15	25.25	silty sand	22.75	2.5	soil moist over groundwater
TP130	2.3	21.2	23.5	silty sand	20.9	2.6	soil moist over groundwater
TP164	2.5	21	23.5	silty sand	20.5	3	soil moist over groundwater
TP160			22	silty sand	18.8	3.2	soil moist
Transect F- north to south					0		
TP90			34.5	silty sand over coffee rock	31.4	3.1	soil moist
TP99			30.75	silty sand	27.25	3.5	soil moist
TP107			27	silty sand	24.5	2.5	soil moist
TP124			25.5	silty sand	22.6	2.9	soil moist
TP132	2	20.5	22.5	silty sand	19.9	2.6	soil moist over groundwater
TP147	2.1	18.65	20.75	uncemented coffee rock	18.15	2.6	soil moist over groundwater
TP158	1.5	18	19.5	silty sand over uncemented coffee rock	16.9	2.6	soil moist over groundwater

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Pt ID	Datum top of casing	Datum ground level	Base of bore
	m. AHD		
MB-A	22.030	21.520	16.810
MB-B(deep)	41.559	41.079	31.069
MB-B(shallow)	41.594	41.079	39.604
MB-C(deep)	28.616	28.021	21.136
MB-C(shallow)	28.457		25.712
MB-D(deep)	43.420	42.992	33.420
MB-D(shallow)	43.416		40.916
MB-E(deep)	35.240	34.671	28.743
MB-E(shallow)	35.100		32.615
P1	25.614	25.191	23.139
P3	42.796	42.346	40.306
P4	22.208	21.726	19.721
P5	41.118	40.531	36.118
P6	36.807	36.215	33.817
P7		36.108	0.000
P8	44.306	43.76	41.811
P9	47.281	46.743	43.281
P10	44.086	43.537	40.586
P11	24.568	24.037	19.068
P12	18.494	18.307	15.819

Table 2. Details of 50mm bores emplaced at Bayonet Head, May 2008.

Pt ID	SWL	SWL	pH	Temp	Comments
	m.bgl	**m. AHD**		**Degrees C.**	
MB-A	1.657	18.467	5.140	18.600	dark brown silty
MB-B(deep)			-	-	dry
MB-B(shallow)	1.550	41.154	6.000	20.550	tannin stained
MB-C(deep)	6.825	27.961	5.450	19.100	dark brown silty
MB-C(shallow)			-	-	dry
MB-D(deep)			-	-	dry
MB-D(shallow)	2.180	43.096	5.040	19.800	light brown silty
MB-E(deep)	5.730	34.473	5.320	19.600	light brown silty
MB-E(shallow)			-	-	dry
P1			-	-	dry
P3			-	-	dry
P4			-	-	dry
P5			-	-	dry
P6		33.817	-	-	dry
P7		0.000	-	-	missing
P8			-	-	dry
P9			-	-	dry
P10	3.050	43.636	5.420	21.500	brown tannin stain
P11	4.490	23.558	5.080	19.500	dark brown silty
P12	2.054	17.873	5.180	18.000	dark brown silty

Table 3a. Water level, pH and temperature monitoring of groundwater for 1 May 2008, Bayonet Head site, Albany. SWL = standing water level in bore; m.bgl = metres below ground level; m. AHD is metres above Australian Height Datum.

Pt ID	SWL m bgl	SWL mAHD	pH	Temp Degrees C	Comments
MB-A	1.473	18.283	5.25	17.3	very silty, brown, continous flow
MB-B(deep)	-		-	-	dry
MB-B(shallow)	1.076	40.680	5.09	17.7	very silty, brown, very slow recharge > 30minutes
MB-C(deep)	6.586	27.722	5.19	17.5	very silty, brown, slow recharge
MB-C(shallow)	-		-	-	dry
MB-D(deep)	-		-	-	dry
MB-D(shallow)	1.411	42.327	5.21	17.8	very silty, brown, slow recharge
MB-E(deep)	5.486	34.229	5.39	19.0	very silty, brown, slow recharge
MB-E(shallow)	-		-	-	dry
P1	-		-	-	dry
P3	-		-	-	dry
P4	-		-	-	dry
P5	-		-	-	dry
P6	2.456	36.273	6.33	18.5	clear
P7		0.000			Bore destroyed
P8	-		-	-	dry
P9	-		-	-	dry
P10	2.944	43.530	5.14	18.5	
P11	4.420	23.488	5.29	17.1	
P12	2.005	17.824	5.33	17.2	

Table 3b. Water level, pH and temperature monitoring of groundwater for 3 June 2008, Bayonet Head site Albany.

Pt ID	SWL	SWL	pH	Temp.	Comments
	m.bgl	m. AHD		Degrees C	
MB-A	1.040	20.990	4.46	15.2	
MB-B(deep)	-		-	-	dry
MB-B(shallow)	0.812	40.782	4.27	15.5	
MB-C(deep)	6.873	21.743	5.50	17.2	
MB-C(shallow)	-		-	-	dry
MB-D(deep)	-		-	-	dry
MB-D(shallow)	1.080	42.336	3.45	15.2	
MB-E(deep)	5.210	30.030	5.91	16.8	
MB-E(shallow)	-		-	-	dry
P1	-		-	-	dry
P3	1.083	41.713	4.49	15.9	
P4	-		-	-	dry
P5	-		-	-	dry
P6	1.551	35.256	4.96	17.3	
P7		0.000			bore destroyed
P8	1.471	42.835	5.76	15.9	
P9	3.549	43.732	5.60	16.3	
P10	2.608	41.478	4.25	17.0	
P11	4.181	20.387	4.81	17.3	
P12	1.778	16.716	4.37	16.8	

Table 3c. Water level, pH and temperature monitoring of groundwater for 3 July 2008, Bayonet Head site, Albany.

Pt ID	SWL	SWL	pH	Temp.	Comments
	m.bgl	m. AHD		Degrees C	
MB-A	0.669	21.361	4.73	13.6	
MB-B(deep)	-				dry
MB-B(shallow)	0.551	41.043	3.97	13.6	
MB-C(deep)	6.764	21.852	5.19	17.0	light tannin stain but clear
MB-C(shallow)	-				dry
MB-D(deep)	-				dry
MB-D(shallow)	0.536	42.880	5.68	13.4	
MB-E(deep)	5.266	29.974	4.74	16.0	light tannin stain but clear
MB-E(shallow)	1.024	34.076	6.64	13.1	tannin stain but clear
P1	2.460	23.154			too shallow to sample
P3					bore destroyed
P4	-				dry
P5	-				dry
P6	1.281	35.526	4.58	15.0	
P7					bore destroyed
P8	1.155	43.151	5.53	13.6	
P9	3.034	44.247	4.96	15.0	tannin stain but clear
P10	2.184	41.902	3.89	15.5	
P11	3.792	20.776	4.77	14.9	tannin stain but clear
P12	1.417	17.077	4.73	13.8	

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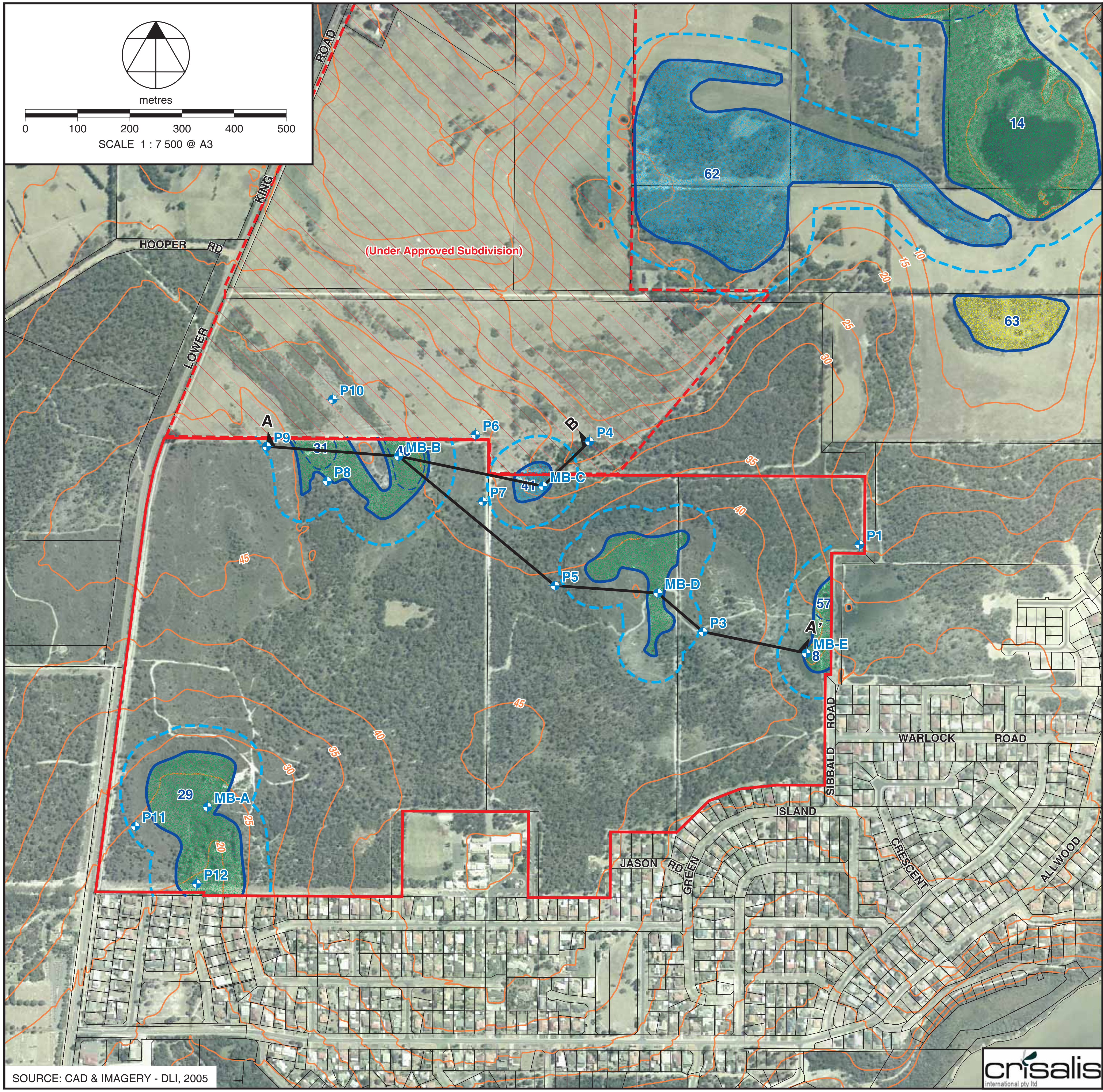
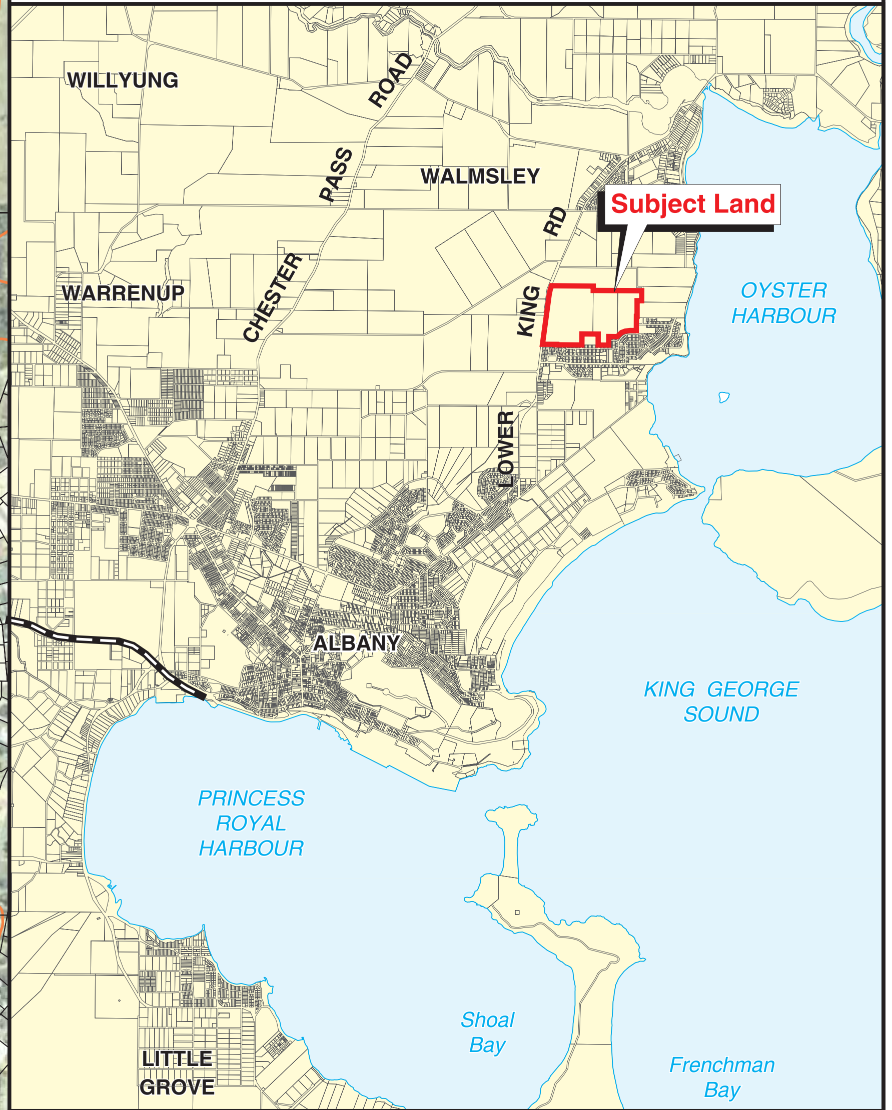


LEGEND

- Study Area Boundary
- Cadastral Boundary
- Wetland Boundary
- 50m Buffer from Wetland Boundary
- 40 Department of Water Wetland Mapping (DoW, 2007)
- Topographic Contour
- Monitoring Bore Location

WETLAND EVALUATION CATEGORIES

- Conservation
- Resource Enhancement
- Multiple Use



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BAYONET HEAD OUTLINE DEVELOPMENT PLAN
SOUTHERN AREA - HYDROLOGY & HYDROGEOLOGY

MONITORING BORES AND CROSS SECTIONS A-A' AND B-B'

FIGURE 1

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metres

0 100 200 300 400 500

SCALE 1 : 7 500 @ A3

LEGEND

- Study Area Boundary
- Cadastral Boundary
- Topographic Contour
- Monitoring Bore Location
- 21.73 Groundwater Level (m AHD)
- Groundwater Level Contour - Verified (m AHD)
- Groundwater Level Contour - Inferred (m AHD)
- Perched Groundwater

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BAYONET HEAD OUTLINE DEVELOPMENT PLAN

SOUTHERN AREA - HYDROLOGY & HYDROGEOLOGY

GROUNDWATER LEVEL CONTOURS

FIGURE 2

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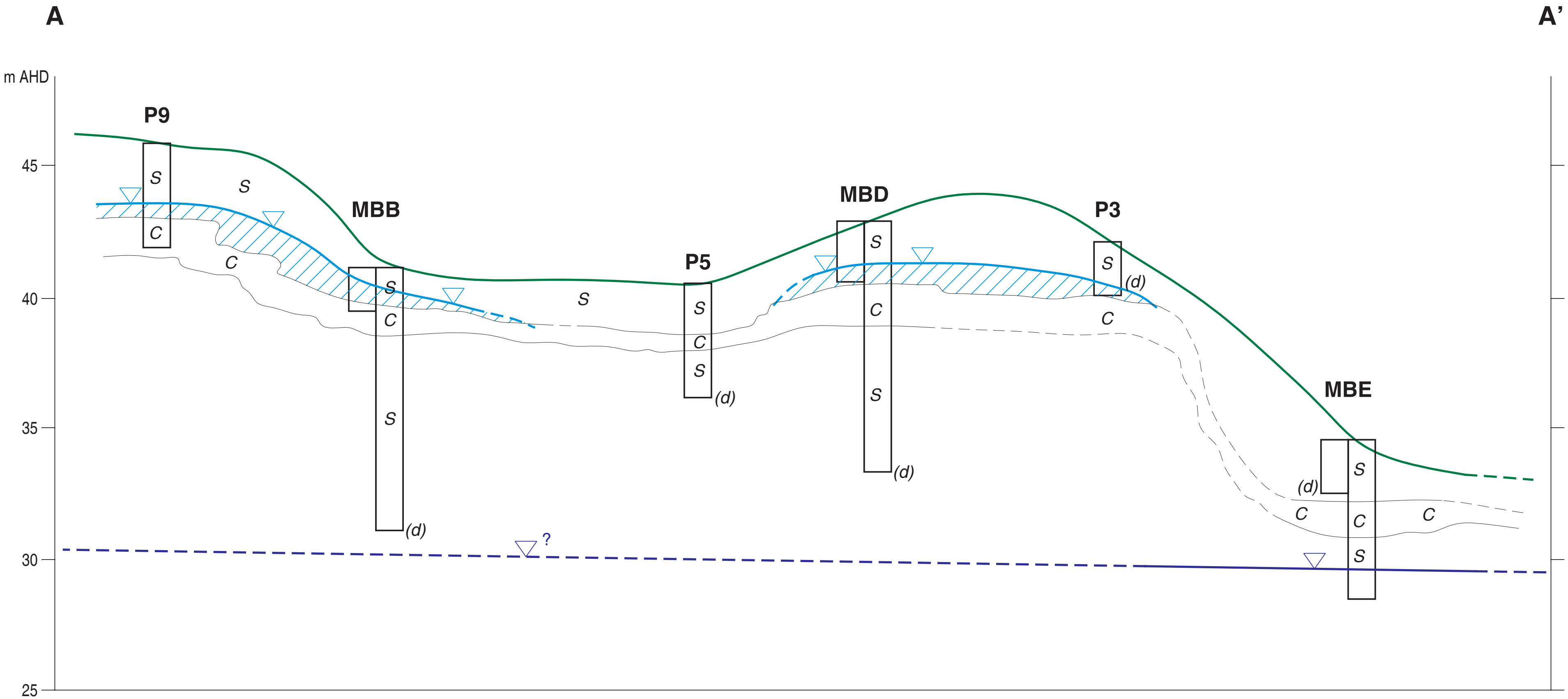
BAYONET HEAD OUTLINE DEVELOPMENT PLAN
SOUTHERN AREA - HYDROLOGY & HYDROGEOLOGY
VERTICAL SECTION A - A'

FIGURE 3a



LEGEND

- Inferred Zone of Perched Groundwater
- Perched Groundwater SWL (July 2008)
- Inferred/Actual Deep Groundwater SWL

S	Sand
C	Clay
(d)	Bore Dry

SOURCE: Crisalis, 2008.

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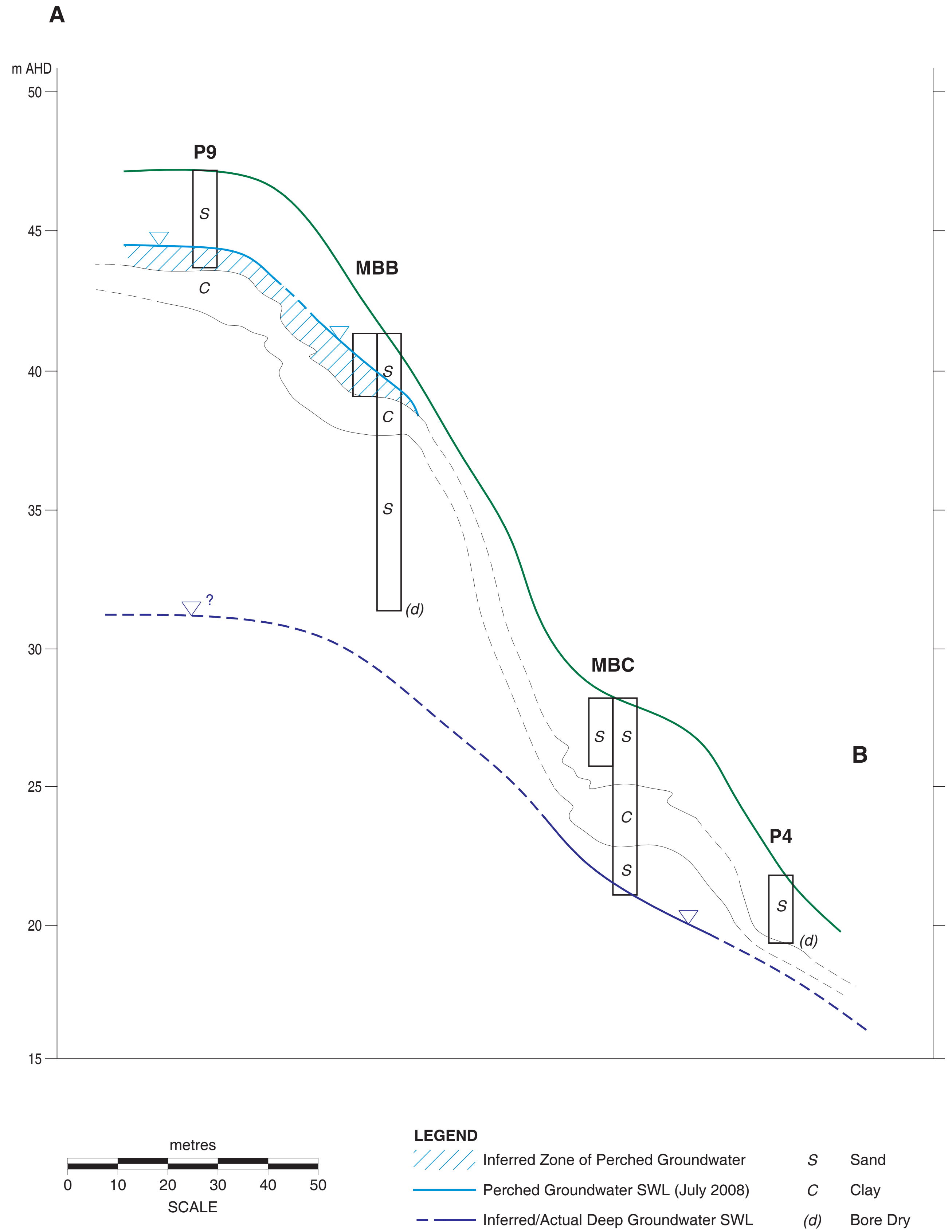

SOURCE: Crisalis, 2008.

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BAYONET HEAD OUTLINE DEVELOPMENT PLAN
SOUTHERN AREA - HYDROLOGY & HYDROGEOLOGY

VERTICAL SECTION A - B

FIGURE 3b

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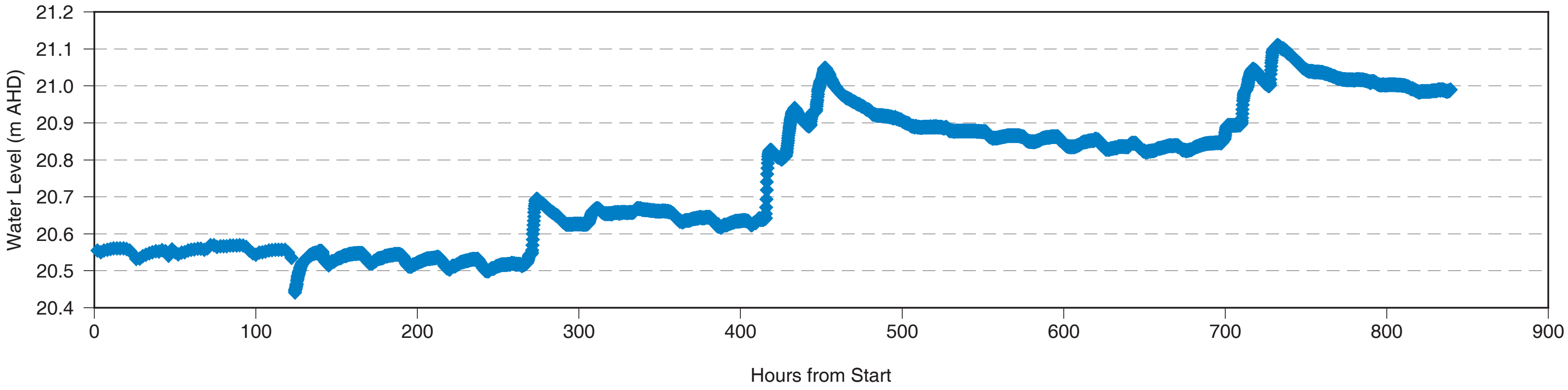
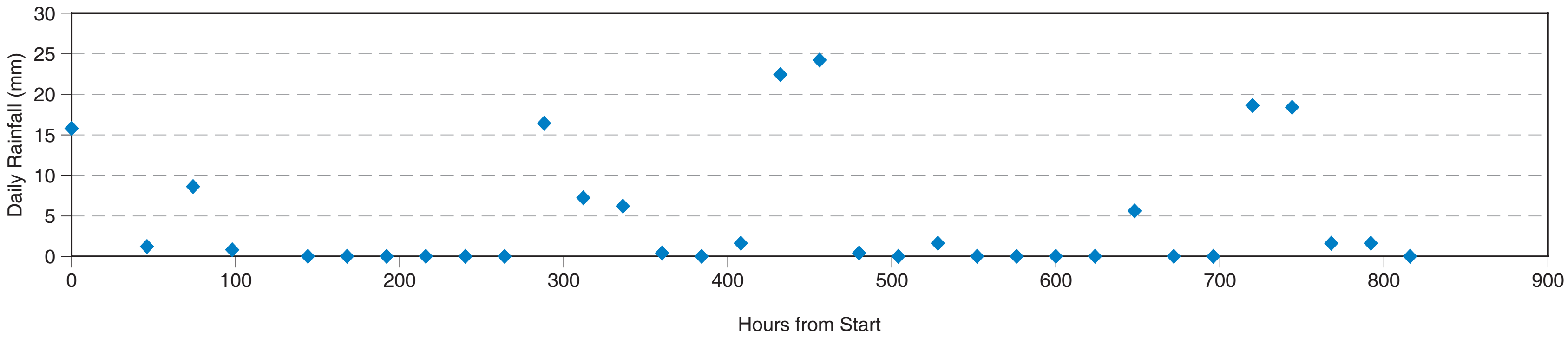
SW WETLAND (BORE MBA)



ALBANY RAINFALL



SOURCE: Crisalis, 2008.

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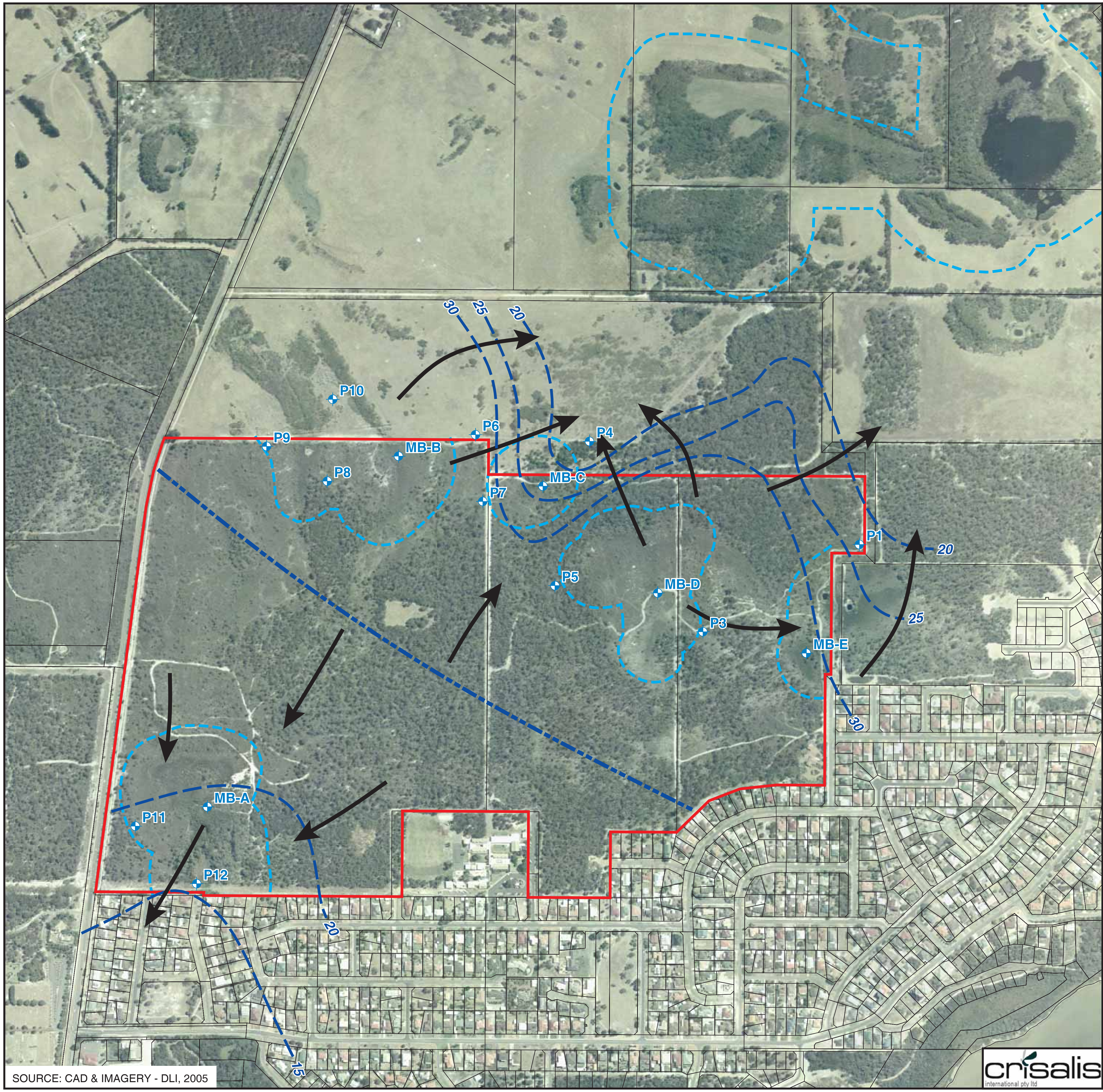
BAYONET HEAD OUTLINE DEVELOPMENT PLAN
SOUTHERN AREA - HYDROLOGY & HYDROGEOLOGY
COMPARISON GROUNDWATER LEVEL & RAINFALL
FIGURE 4



metres

0 100 200 300 400 500

SCALE 1 : 7 500 @ A3

LEGEND

- Study Area Boundary
- Cadastral Boundary
- Topographic Contour
- 50m Buffer from Wetland Boundary
- Monitoring Bore Location
- Groundwater Level Contour (m AHD)
- Catchment Divide Along Plateau
- Groundwater Flow Direction

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BAYONET HEAD OUTLINE DEVELOPMENT PLAN
SOUTHERN AREA - HYDROLOGY & HYDROGEOLOGY

CONCEPTUAL MODEL
DEEP GROUNDWATER FLOW

FIGURE 5

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