The Geology of the Shrub Swamps within Angus Place/Springvale Collieries

Preliminary Report

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TABLE OF CONTENTS

LIST OF FIGURES

1. Introduction

The current report discusses the influence of the upper geological strata in the Angus Place/Springvale lease areas on the occurrence of the Newnes Plateau Shrub Swamps (NPSS).

The Newnes State Forest comprises the majority of the study area and the Angus Place/Springvale leases contain two NSW State listed Endangered Ecological Communities (EECs), namely the Newnes Plateau Shrub Swamps (NPSS) and the Newnes Plateau Rush Sedge Snow Gum Hollow Wooded Heath Grassy Woodland (NPRSSG). The Newnes Plateau Hanging Swamps (NPHS) are also present in the study area and, together with the former communities, form part of the Federally listed Temperate Highland Peat Swamp on Sandstone (THPSS). The present study focuses on the Newnes Plateau Shrub Swamps (NPSS) in the study area.

2. Regional Geology

Angus Place and Springvale Collieries are located near the outermost portion of the Western Coalfield, being situated on the central western margin of the Sydney Basin. Strata of Permian and Triassic age overlie folded Silurian and Devonian rocks which sit on a Palaeozoic basement. Quaternary alluvium is present in river valleys.

During the Permian, two major periods of peat deposition occurred across the Sydney Basin, the second phase resulting in the formation of the Illawarra Coal Measures in the study area, of which the Lithgow Coal Formation is mined at Angus Place/Springvale. As the Sydney Basin thins towards its western margin, both the Illawarra Coal Measures and the overlying Triassic Group are attenuated in thickness when compared to lateral equivalents in the Southern Coalfield.

The Western Coalfield contains minimal structural disturbance, with a regional dip in the Lithgow area of less than one degree with a dip direction of approximately 65 degrees. Monoclinal structures trend roughly north-south in the Western Coalfield accompanied by associated sub-parallel faulting. Basaltic flows and igneous intrusions occur in the general region but are absent from the study area.

3. Local Geology

The Angus Place/Springvale lease areas, located on the extreme western margin of the Sydney Basin, display a diminution of the full Permo-Triassic sequence present in other areas of the basin. Consequently, the Illawarra Coal Measures are comparatively thin in the study area and the overlying Triassic strata incorporate only the Narrabeen Group, with the Hawkesbury Sandstone and Wianamatta Group absent. Figure 1 shows the stratigraphic sequence present in the study area.

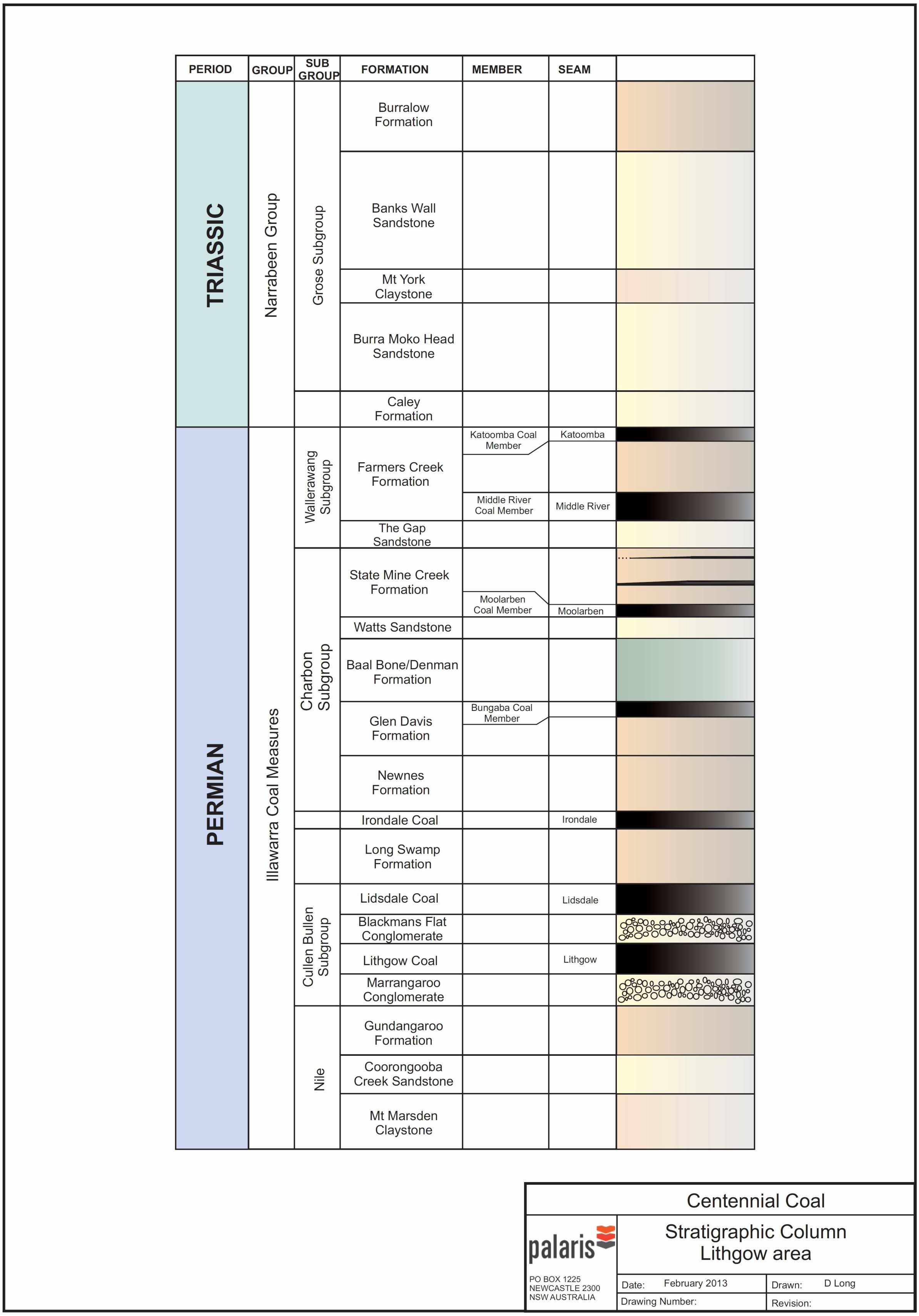

Figure 1 Stratigraphic Column for Angus Place/Springvale

The Permian strata in the Angus Place Place/Springvale area include several coal-bearing units interspersed with sandstones, shales and minor tuffaceous claystones.

The Triassic sequence consists predominately of fine-to-coarse-grained sandstones, shales, siltstones and claystones of the Narrabeen Group. This fluvial sequence is punctuated by the Mt York Claystone Formation, a persistent and characteristic non-tuffaceous claystone unit described below.

4. Structure and Topographic Expression

The topography of the study area (Figure 2) is characterized by significant NNW- and NNE- trending lineaments in association with minor east-west features. It has been noted by previous workers, for example, SRK (2012), that surface lineaments, such as ridges, rivers and creeks, reflect underlying geological structures.

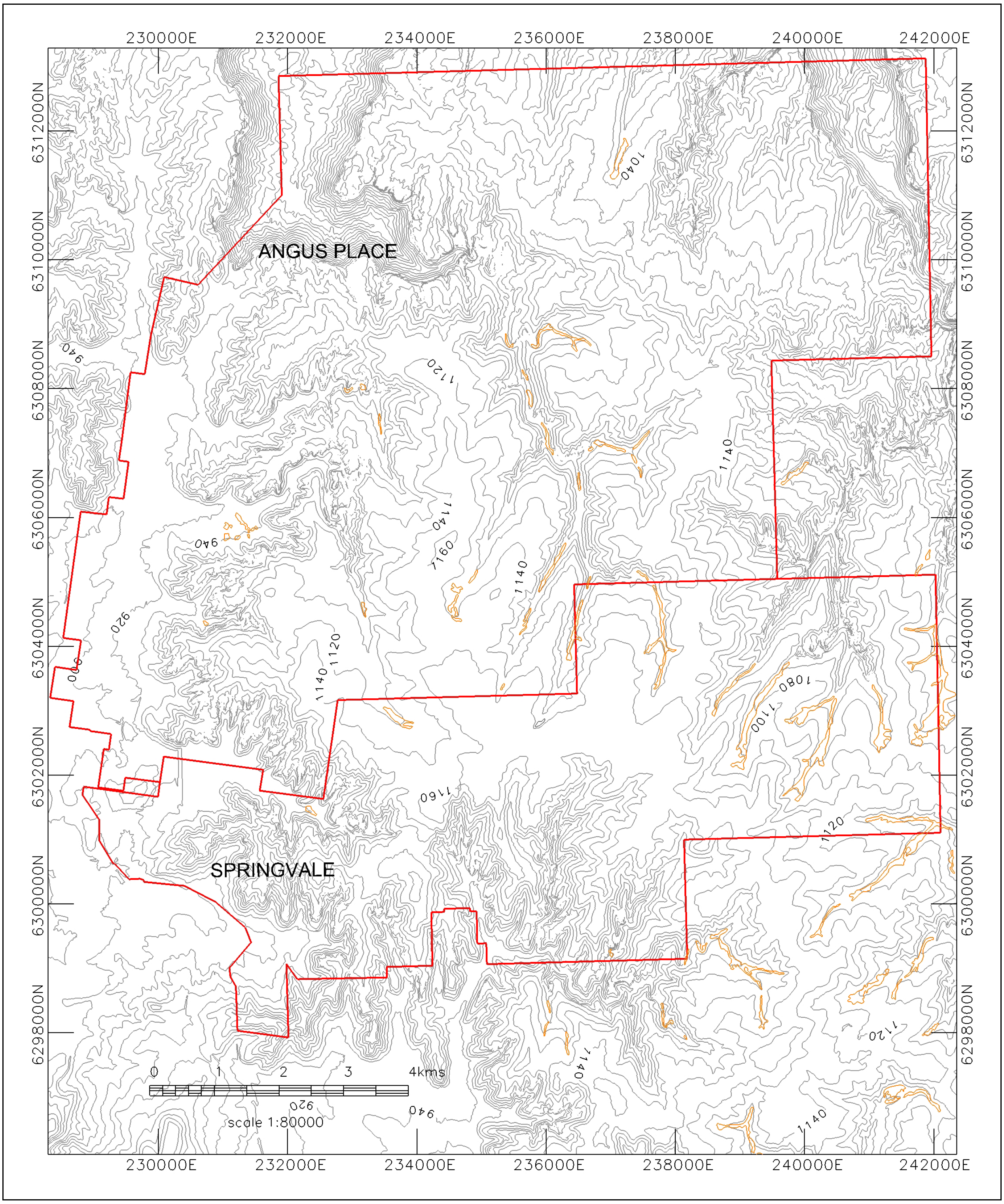

Figure 2 Topography of Angus Place/Springvale
(Shrub swamps shown in orange)

In the Angus Place/Springvale area, basement geological structures are believed to impact strongly on the overlying Permo-Triassic sequence, particularly as the latter is comparatively thinner than in the southern and eastern regions of the Sydney Basin, where the stratigraphic sequence is more extensively developed.

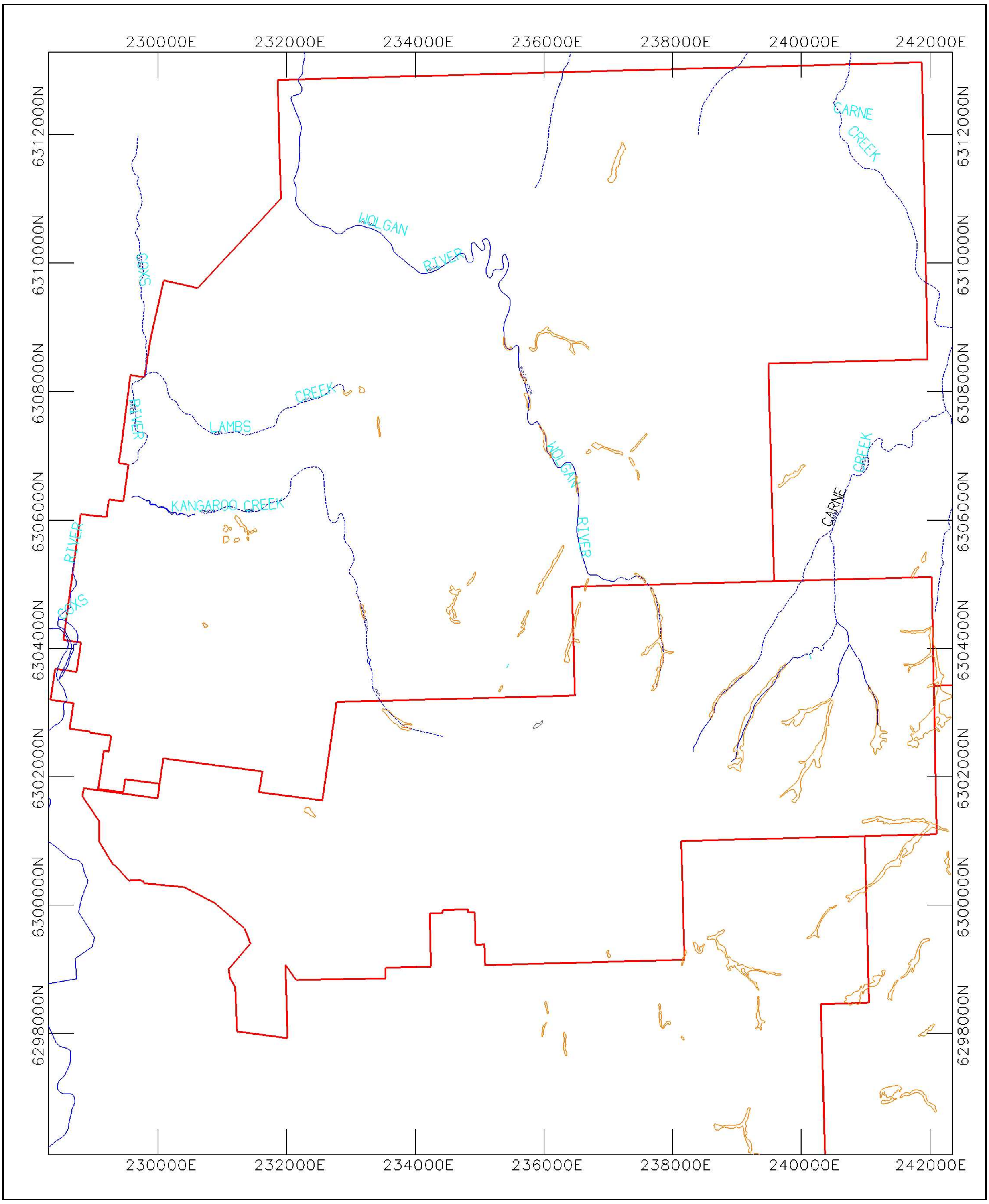

Figure 3 Angus Place / Springvale Major Rivers and Creeks

Cox's Creek to the immediate west of the study area reflects the predominantly north-south trending pattern of lineation that characterizes the study area (Figure 3). Within the Angus Place/Springvale lease areas, the Wolgan River assumes a NNW direction as it flows from its headwaters at the base of the elongated ridge system in Springvale (Figure 2) and continues downstream in the same northwesterly direction to the northern extent of the study area. The east-west topographic feature present in the area is denoted along the length of the Wolgan River by numerous short-term swings in this river from the east to the west. These diversions increase in size and frequency as the Wolgan travels north-west from its headwaters.

Similar occurrences are noted in Kangaroo Creek where the upper reaches reflect the NNW flow direction of the Wolgan River. Again, the east-west topographic feature is apparent in several minor swings from east to west before this creek assumes a final westerly swing before joining the north-south oriented Cox's River. Lamb's Creek, immediately north of Kangaroo Creek is influenced solely by this east-west topographic feature.

Carne Creek displays a NNW orientation in its lower reaches to the north-east of the study area, but adopts a NNE lineation in its upper reaches, such that the Sunnyside East, Carne West and Gang Gang tributaries also follow the same NNE trend. West Wolgan, East Wolgan, Narrow Swamp and West Wolgan watercourses to the west also adopt the NNE trend.

Rattlesnake Creek, a lower tributary of Carne Creek, displays a marked east-west lineation, similar to that of Lamb's Creek, while Snake Swamp and Tri-Star Swamp also favour the east-west lineation present. The latter host watercourse is influenced by the NNE and NNW lineations, where the upper reaches follow both regional preferences.

Perhaps the best illustration of the interaction of the NNW-NNE and east-west structural/topographic systems occurs near the confluence of the upper tributaries of the Wolgan River, where the NNW trending Sunnyside Swamp host creek makes an abrupt westerly change in direction and then is met by the NNW-trending East Wolgan Creek. All structural elements are present at this site, before the Wolgan River then continues along its predominant NNW-trending direction.

SRK (2012) noted three structural trends in the Angus Place/Springvale area. These included a north-south trend, (including NNE and NNW), a marked NW trend and a less dominant NE trend. These lineaments are considered to represent surface expressions of basement trends. Hence the east-west trending features which are present in the study area are likely to be less persistent, shallow level features, possibly en-echelon features linking the dominant NNE-NNW structural zones which occur throughout the study area and beyond.

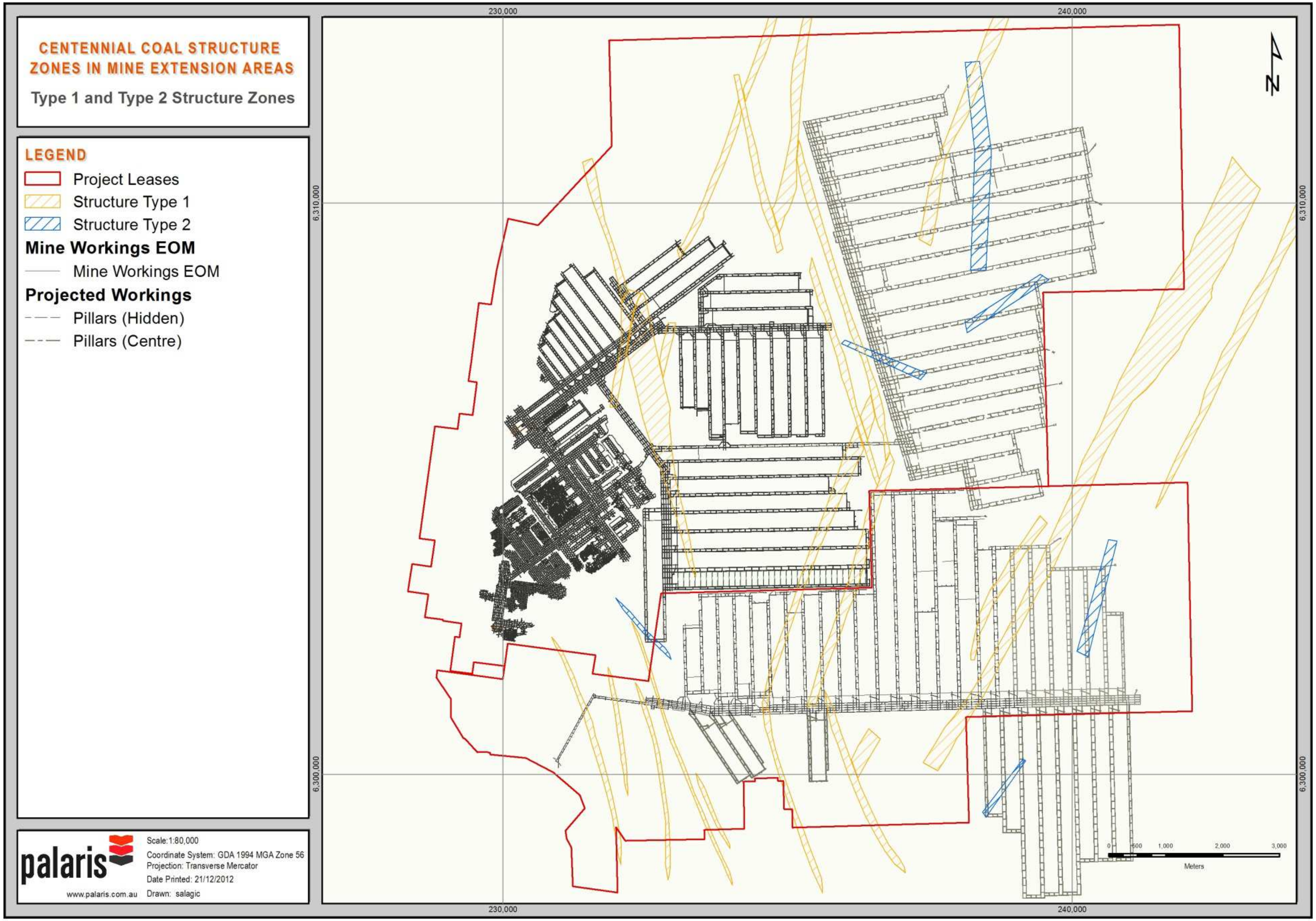

Figure 4 Angus Place / Springvale – Structure Zones (Palaris 2012)

The Type 1 features shown on Figure 4 are NNW- and NNE-trending basement-to-surface structural zones throughout the Angus Place and Springvale leases. Wolgan River and Carne Creek and their respective tributaries represent surface expressions of the two Type 1 lineament directions.

Hence there exists a dominant north-south structural trend across the study area, with a persistent but less significant east-west trend also present. The “Springvale Ridge” system (Figure 2), which will be discussed in subsequent sections, displays a predominant east-west orientation, continuing into Clarence Colliery to the east of the study area. However, this ridge system, at its southern extension, adopts a north-south lineation. In addition, the elevated ridge system which extends from Angus Place to Springvale via Sunnyside ridge trends in a NNE direction. The area south of the “Springvale Ridge” system displays more dominant north-south lineaments as reflected both in Figures 2 and 4, with minor east-west topographic expressions, such as the Marrangaroo Creek and Farmers Creek watercourses, together with the creek to the south west of the Springvale lease which incorporates the shrub swamp near the downcast shaft.

It would appear that the geological structures in the basement rocks which form part of the Lachlan Fold Belt are reflected, at least in part, in the surface topography of the Triassic sequence above.

5. Stratigraphy

In the present report, only the Triassic strata of the Banks Wall Sandstone and the overlying Burralow Formation will be discussed in detail, since it is only within these two units in which the Newnes Plateau Shrub Swamps (NPSS) are situated. However, the Mt York Claystone Formation is also included due to the important role it plays in the hydrology of both the shrub and hanging swamp systems of the Newnes Plateau.

I. Burralow Formation

This formation consists of medium- to coarse-grained sandstones interbedded with frequent sequences of fine-grained, clay-rich sandstones, siltstones, shales and claystones. These latter fine-grained units can be several metres in thickness and their presence differentiates the Burralow Formation from the underlying Banks Wall Sandstone. The base of the Burralow Formation is defined in this study as the base of the lowermost significant fine-grained, clay-rich unit above the more sandstone-rich lithology of the Banks Wall Sandstone.

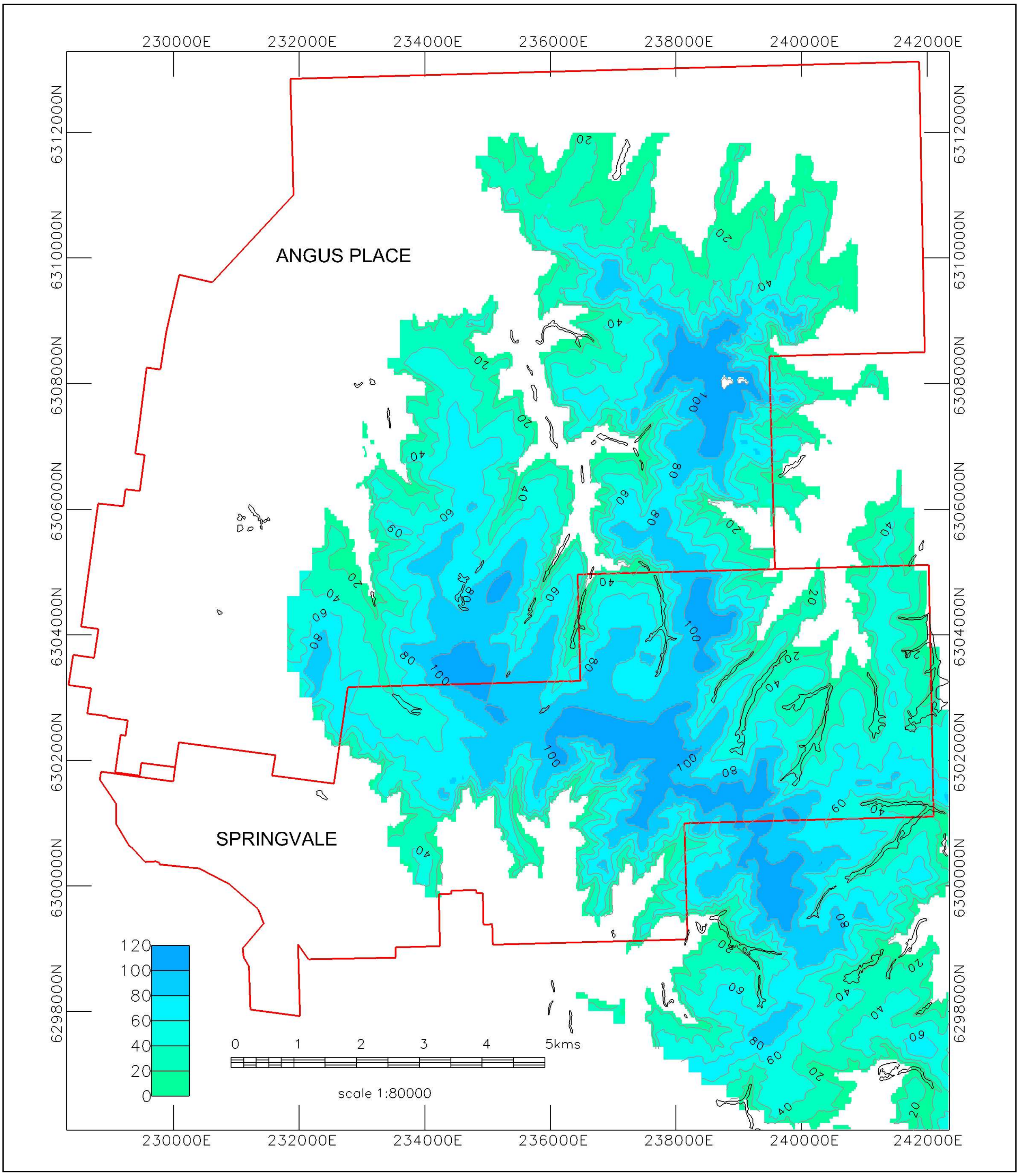

Figure 5 Burralow Formation Isopach
(Note: shrub swamps shown with black outline)

Figure 5, an isopach of the Burralow Formation, shows maximum thicknesses of approximately 110 metres, principally in the north-east of Angus Place East and the south-eastern extent of Springvale Colliery at the headwaters of East Wolgan, Sunnyside, Sunnyside East, Carne West, and Gang Gang Shrub Swamps. Hence the Burralow Formation, as defined in the study area, is thicker than previously proposed in the general Lithgow region in earlier works, for example, Goldbery (1972) and Herbert and Helby (1980).

McHugh (2011) studied the upper stratigraphy of the Angus Place/Springvale leases, in particular the Burralow Formation, and identified both a lithological and topographic link between the presence of the Burralow Formation and the occurrence of the Newnes Plateau Hanging Swamps (NPHS). Several of the claystone horizons, together with clay-rich, fine-to-medium grained sandstones and shales were found to be acting as aquitards, or semi-permeable layers. These aquitards decrease the hydraulic gradient of rainwater and groundwater movement percolating through the weathered and semi-weathered strata of the Burralow Formation and form a permanent water source for the formation and maintenance of the hanging swamps. In total, McHugh identified seven units, designated YS1 to YS6 (including the areally-limited YS5a), which were capable of sustaining the hanging swamps in the area, provided the topographic conditions were amenable to the formation of a hanging swamp.

Further, the presence of these aquitards in the Burralow sequence also performs a vital function in the presence and persistence of the Newnes Plateau Shrub Swamps. The importance of the hydrological implications of these aquitards in the study area will be discussed in subsequent sections.

II. Banks Wall Sandstone

The dominant lithology of the Banks Wall Sandstone is medium- to coarse-grained sandstone, with the formation having an average thickness of just under 100 metres. The steep-sided cliff faces comprising the banks of the Wolgan River and Carne Creek consist of the massive sandstones of the Banks Wall Sandstone.

A significant characteristic of this unit is its deep weathering pattern, with zones of iron-stained sandstone alternating with zones of relatively unweathered sandstone. This trend continues throughout the formation and also extends into the sandstone layers of the Mt York Claystone, the Burra-Moko Sandstone and the Caley Formation. Core photographs from Angus Place and Clarence Colliery to the south-west of the study area indicate that the depth of weathering extends to approximately 210 metres.

The minimal gamma response of the Banks Wall Formation, as shown in downhole geophysical logs, reflects the overall low clay content and relative absence of fine-grained units. This has resulted in the informal term “muted zone” used to describe this unit in terms of its geophysical response. The significance of this term will be discussed in subsequent sections.

The Banks Wall Sandstone is underlain by the first significant claystone band of the Mt York Claystone.

III. Mt York Claystone

The top of the Mt York Claystone is partly gradational with the overlying Banks Wall Sandstone and is defined for the purposes of the present study as the uppermost fine-grained horizon that is thicker than 2 metres. Stratigraphically, it is situated approximately 100-110 metres above the Katoomba Seam. Typically the unit comprises up to three discrete claystone bands up to 4 metres thick, the principal horizon displaying the characteristic red-brown colour of the unit. These two- to three claystone horizons are interbedded with sandstone/siltstone bands up to 8 metres in thickness. The average thickness of the correlated Mt York Claystone in the study area is 22 metres and the unit has a gradational lower boundary with the Burra-Moko Sandstone below. That is, thick claystone bands also occur within the underlying formation and it is sometimes debatable where the boundary should be defined.

6. Newnes Plateau Shrub Swamp Morphology

Previous studies of the Angus Place/Springvale area do not typically include the presence of the Burralow Formation, and instead refer to the Banks Wall Sandstone as the uppermost outcropping unit. The Burralow Formation is crucial in the development and maintenance of both the Newnes Plateau Shrub Swamps (NPSS) and, in particular, the Newnes Plateau Hanging Swamps (NPHS). However, the present study focuses predominantly on the Newnes Plateau Shrub Swamps.

Figure 6 shows the distribution of Newnes Plateau Shrub Swamps throughout the study area in relation to Burralow Formation outcrop. The Junction Swamp (JC), which is a hanging swamp (NPHS), is also included for the purposes of this study.

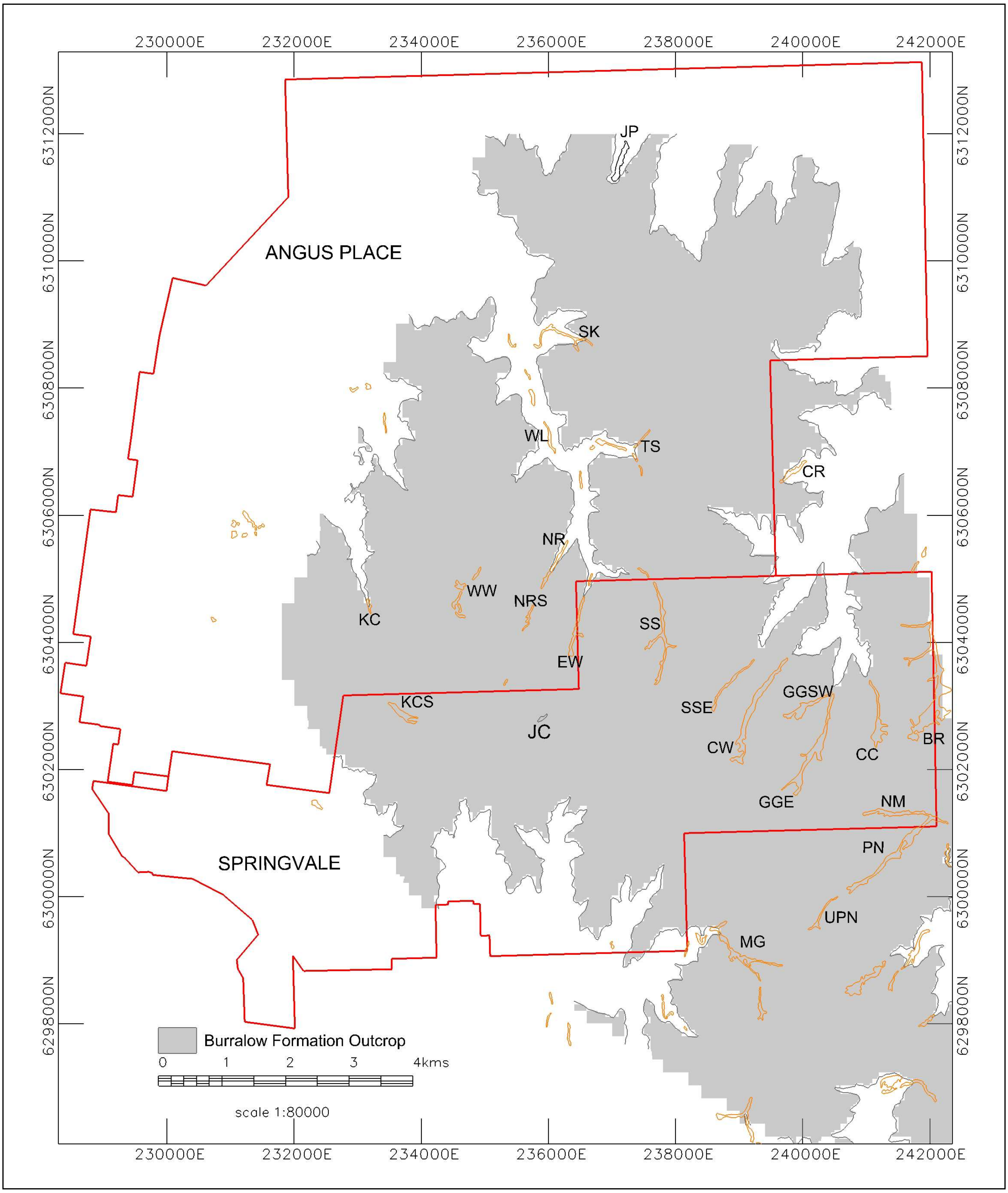

Figure 6 Shrub Swamp Locations and Burralow Fm Outcrop

Key to swamp abbreviations:
JP: Japan, SK: Snake, WL: Wolgan, TS: Tristar, CR: Crocodile, NR: Narrow, NRS: Narrow South, WW: West Wolgan, EW: East Wolgan, KC: Kangaroo Creek, KCS: Kangaroo Creek South, JC: Junction, SS: Sunnyside, SSE: Sunnyside East, CW: Carne West, GGSW: Gang Gang Southwest, GGE: Gang Gang East, CC: Carne Central, BR: Barrier, NM: Nine Mile, PN: Pine, UPN: Pine Upper, MG: Marrangaroo Creek

The majority of the shrub swamps are located within the confines of the Burralow Formation, particularly in the Springvale lease. However, some shrub swamps are situated wholly within the Banks Wall Sandstone in the Angus Place lease, while a smaller population comprises “mixed-type” swamps. These latter shrub swamps are located such that their upper reaches are located within the Burralow Formation but terminate in the Banks Wall Formation, as the host creek erodes down into the country rock distally from the watershed areas where these shrub swamps are predominantly located.

The underlying lithology of each shrub swamp controls its morphology and often, areal extent. Topography also plays a role in shrub swamp morphology, however the presence or absence of a Burralow Formation substrate largely dictates the shape and extent of a particular shrub swamp. Hence Banks Wall-type and “mixed-type” shrub swamps are generally smaller in area and occur in relatively steep-sided gullies.

In comparison, the Burralow-type shrub swamps characteristically occur in much broader and gently sloping depressions (Figure 6) and are commonly longer and permanently waterlogged in their lower reaches.

7. Burralow Formation Aquitards (YS6 to YS1)

As previously indicated, the aquitard units of the Burralow Formation play a critical role in the formation of the Newnes Plateau Hanging Swamps, and a similarly important role in the presence and maintenance of the Newnes Plateau Shrub Swamps.

Aquitards are semi-permeable units which permit only relatively small amounts of water to percolate through them into the underlying strata. Aquitards retard water flow underground; that is, they act as a partial barrier to downward groundwater movement. Aquitards separate aquifers and partially disconnect the flow of water underground, directing water downdip to discharge points in nearby gullies.

Due to the number of suitably thick aquitards in the Burralow Formation, there is a significant decrease in the flow of water vertically through the strata due to gravity in this upper unit. This effectively retains increased volumes of water within the formation; water that would otherwise flow down-gradient through to underlying formations.

While the dominant lithology of the Banks Wall Formation consists of medium- to coarse grained sandstones with only minor finer grained units, the Burralow Formation is relatively rich in interbedded fine-grained, clay-rich sandstones, shales, siltstones and claystones. Although the Burralow Formation consists of abundant fine-grained semi-permeable units, it was determined that only units of approximately two metres or above in thickness would be capable of acting as an aquitard that would alter the hydraulic gradient for a hanging swamp to form. The development of the latter feature would also depend on topographic constraints.

With seven such identified aquitards in total (YS6, YS5, YS5a, YS4, YS3, YS2 and YS1), there is a significant retardation of water percolation through the Burralow Formation from surface to base to permit the formation not only of the Newnes

Plateau Hanging Swamps, but to significantly contribute moisture at outcrop points in gullies containing the Newnes Plateau Shrub Swamps. Groundwater sourced from the presence of aquitards thus supplements input from precipitation, which assists in maintaining the floristic community of the resultant shrub swamp.

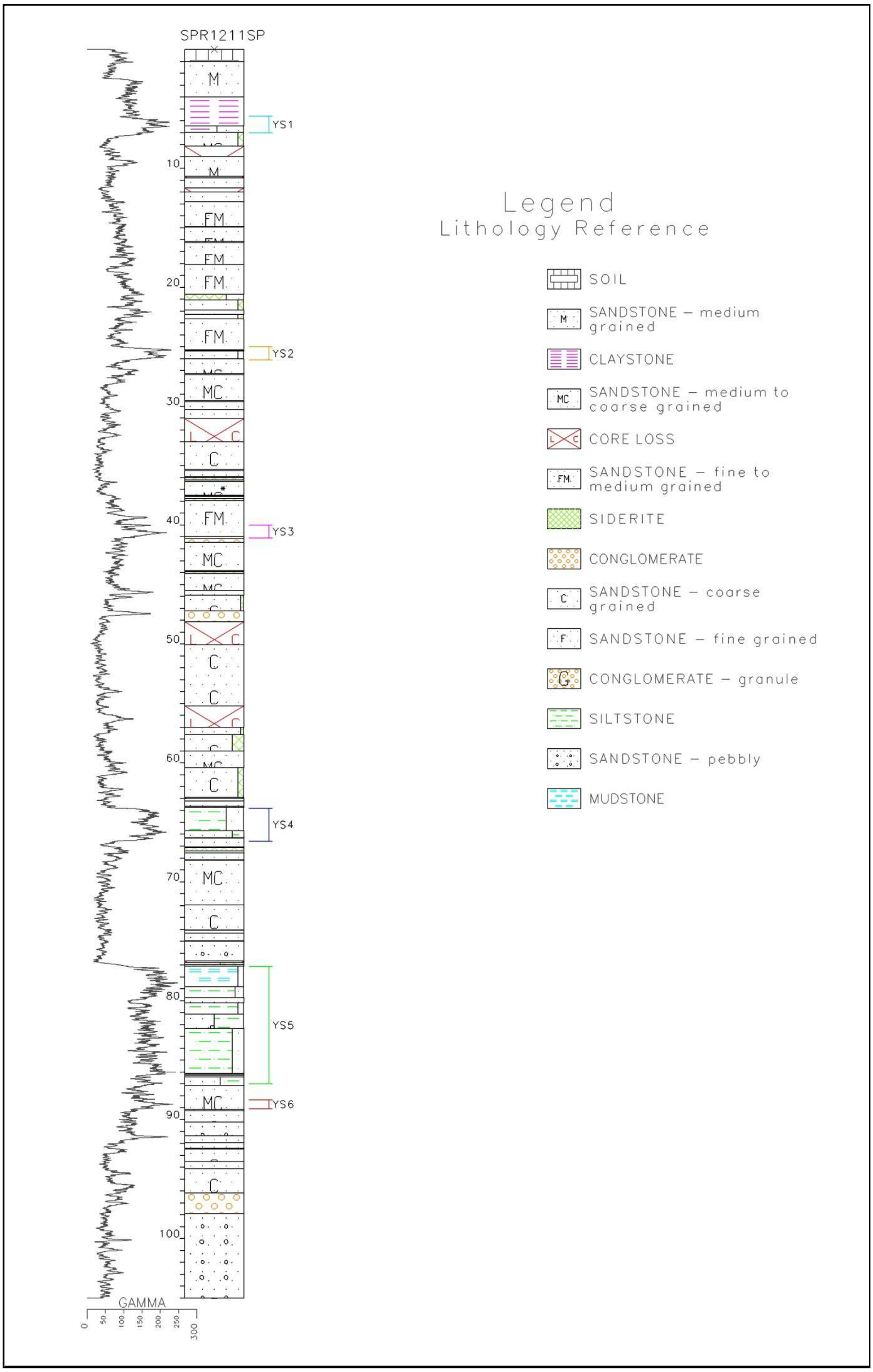

Figure 7 SPR1211SP Graphic Lithological Log

Figure 7 displays an example of the full suite of functioning aquitards from YS1 to YS6 (note YS5a is absent from this borehole). Appendix A shows core photographs covering the interval shown in Figure 7.

SPR1211SP is a fully-cored hole in the Angus Place/Springvale area and the resultant gamma response highlights the clay-rich shales, fine sandstones and claystones that serve to act as a sequence of progressive semi-impermeable horizons within the Burralow Formation. These horizons essentially maintain the hydraulic head higher than would be expected and thus provide a permanent water source for both the associated hanging swamps and the shrub swamps that are located adjacent to down-dip discharge points.

The sole unconfined aquifer in the study area lies above the YS1, the remainder of the strata between aquitards in the Burralow Formation act as individual "aquifers" at surface points where the coarser sandstone units of the formation crop out on gully sides. The high degree of weathering of many of the sandstone units also assists in this process, and is also indicative of the degree of water movement through these units.

By contrast the Banks Wall Sandstone gamma response is considerably muted compared to that of the Burralow, containing relatively few semi-permeable units and hence is easily differentiated in downhole logging from the overlying Burralow Formation. In hydrogeological terms, the Banks Wall Sandstone is referred to as the "muted zone" for the purposes of this report, that is, it is not a source of groundwater originating from the presence of aquitard horizons.

8. Hydrogeological Influence of the Mt York Claystone

The Mt York Claystone acts as a major hydrological confining unit and, as noted by McHugh (2011), effectively forms a more efficient hydrological barrier than the thinner aquitards of the upper sequences. This is due to its lithological composition, its greater thickness, which averages over 20 metres in the study area, and its lateral continuity.

The Mt York Claystone lies between the upper Narrabeen Group (Burralow Formation and Banks Wall Sandstone) and the underlying Burra-Moko Head Sandstone and Caley Formation as shown in Figure 8 below.

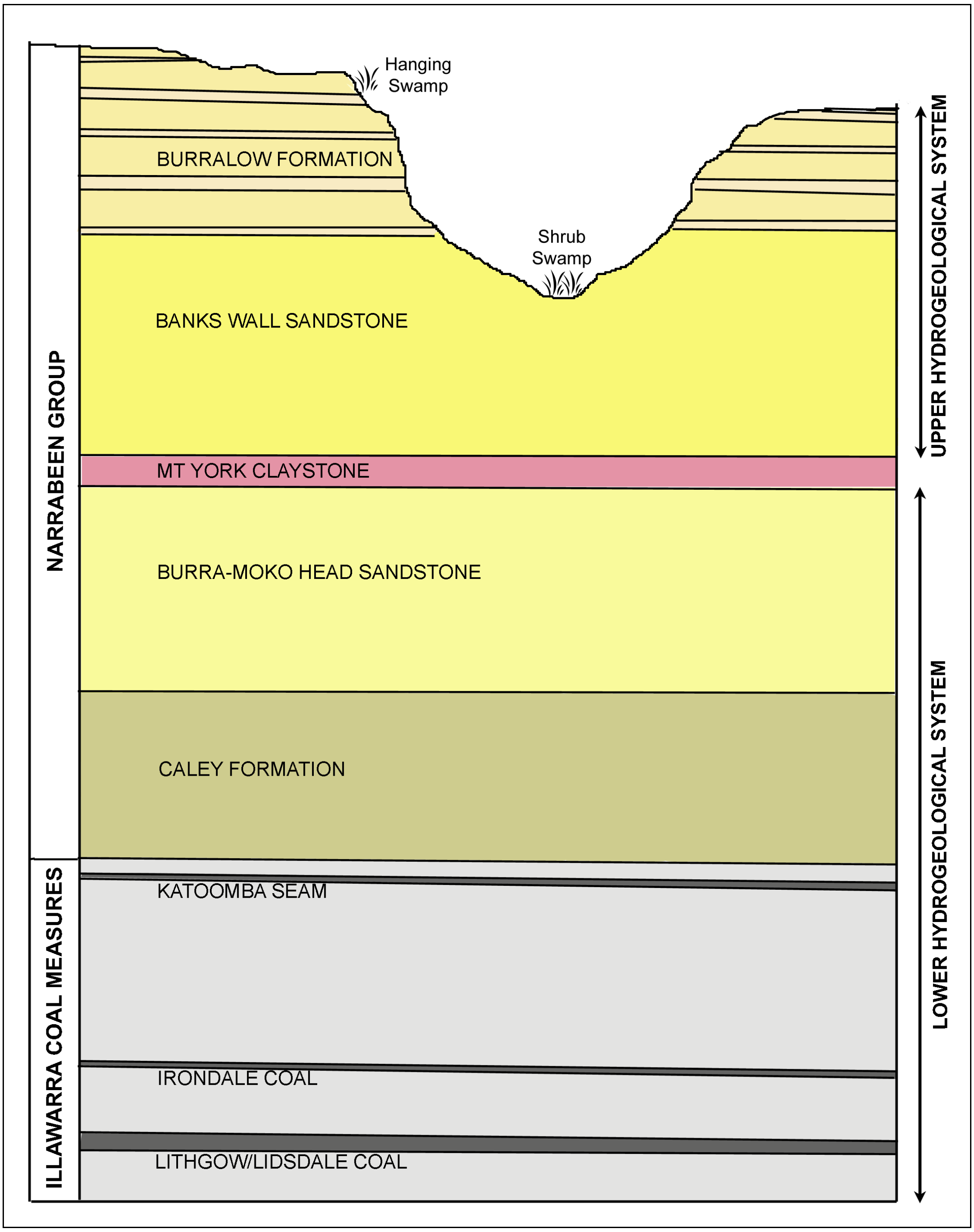

Figure 8 Schematic Hydrogeolocial Section

Figure 8 shows the presence of a dual hydrological system operating in the study area, with the upper hydrological system located above the Mt York Claystone and the lower hydrological system below the base of the Mt York Claystone. This diagram also illustrates schematically the manner in which Newnes Plateau Hanging Swamps are associated with outcropping aquitards of the Burralow Formation and the Newnes Plateau Shrub Swamps benefit from the presence of these aquitards by redirecting groundwater laterally to gully discharge points. This diagram shows a Banks Wall-type shrub swamp which is discussed below.

9. Burralow-type Shrub Swamps versus Banks Wall-type Shrub Swamps

The presence of the Burralow Formation is essential to the formation of both the Newnes Plateau Shrub Swamps (NPSS) and the Newnes Plateau Hanging Swamps (NPHS). The series of aquitards present in the Burralow Formation are intimately linked, together with topographic factors, with the formation of the hanging swamps, which occur at outcrop points of suitable aquitards.

Similarly, the Newnes Plateau Shrub Swamps would not exist without the presence of the Burralow Formation and its characteristic groundwater-retaining properties, since the aquitards provide an important supplementary and permanent supply of water to the shrub swamps located within the Burralow Formation

Shrub swamps located within the Banks Wall Sandstone also attain substantial seepage from the Burralow Formation (see Japan Shrub Swamp below) but do not in general benefit from the degree of groundwater seepage that shrub swamps in the Burralow Formation experience. Hence, the morphology of the Banks Wall-type shrub swamps differs significantly from that of the Burralow-type.

Figure 9 below shows a longitudinal section down the centre-line of Carne West Shrub Swamp which is a Burralow-type Shrub Swamp. This swamp has a fall of approximately 55 metres and, as shown, the gully floor passes stratigraphically from above the YS3 through to the YS5 at the lower extremity of the swamp. Hence groundwater can be sourced from strata above YS2 and YS3 from the upper reaches to the endpoint of the swamp, from above YS4 midway along the swamp course to its endpoint and from aboveYS5 near the lower reaches.

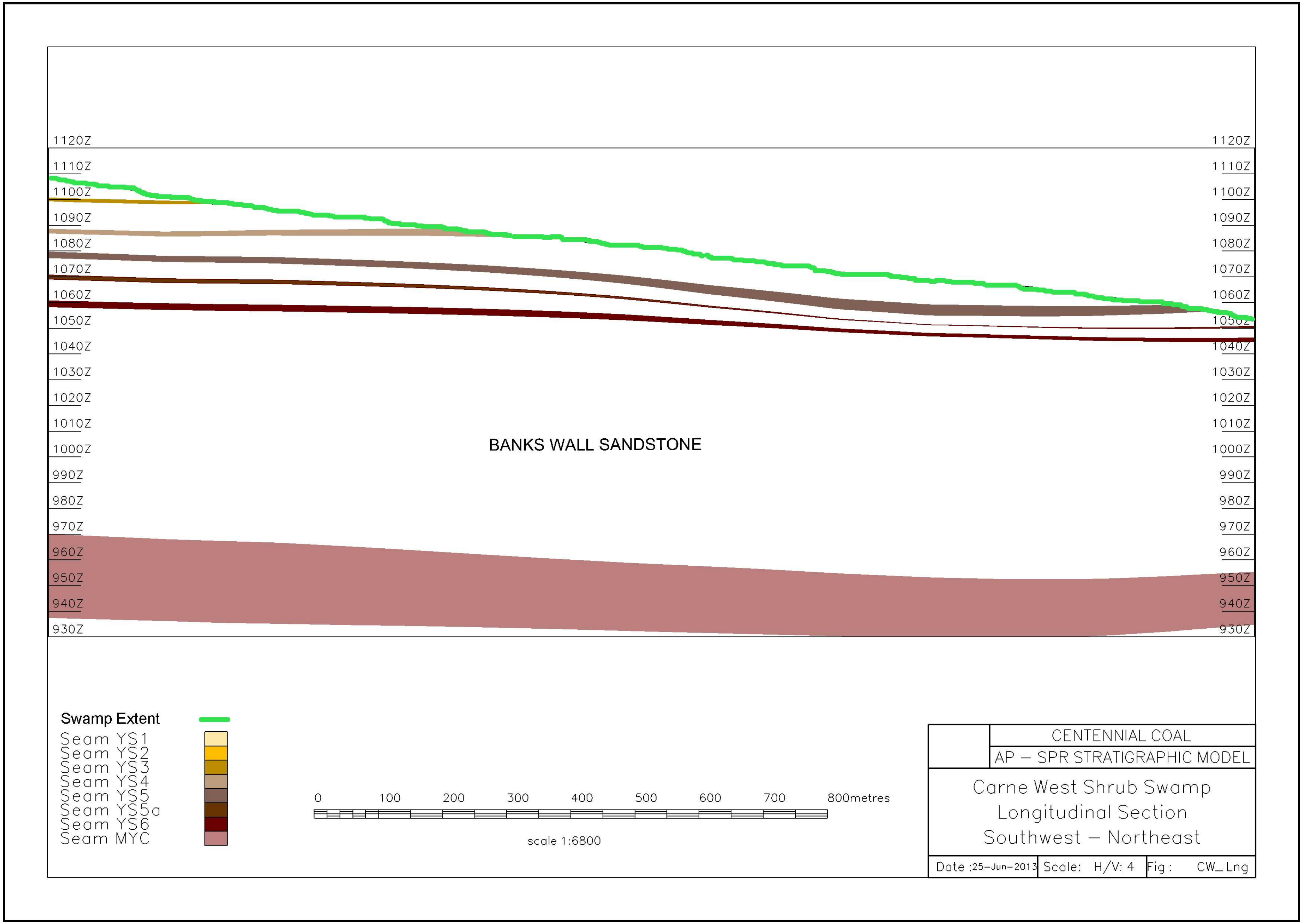

Figure 9 Longitudinal Section of Carne West Shrub Swamp

Figure 10 shows the Carne West Shrub Swamp (including Carne West Hanging Swamp) and the outcrop of the YS plies in plan form. The YS2 can be clearly seen to be a source of groundwater seepage in the far upper reaches of the swamp, augmented in the upper reaches by the YS3 and in the middle reaches by the YS4. Note that YS1 supports the Carne West Hanging Swamp and would also retain groundwater in the upper sequences of the gully sides which would slowly percolate down to the gully floor. Hence, in conjunction with annual precipitation, the YS aquitards assist in providing supplementary groundwater to shrub swamps which are contained within the Burralow Formation. In addition, Carne West Shrub Swamp has a relatively large recharge area as will be discussed in further detail in subsequent sections.

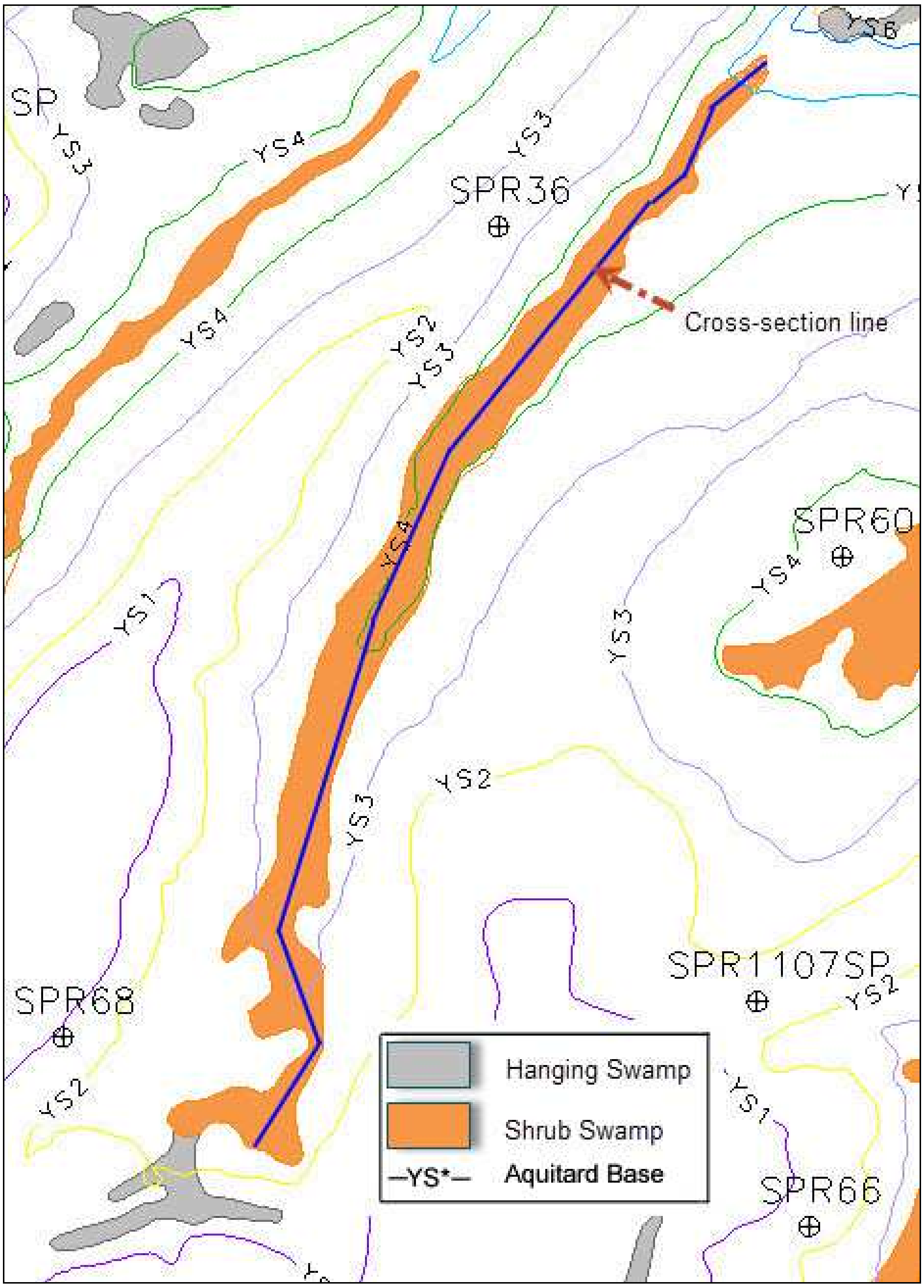

Figure 10 Plan of Carne West Shrub Swamp

By contrast, Japan Shrub Swamp is situated wholly within the Banks Wall Formation. Figure 11 is a longitudinal section of the swamp. Occurring stratigraphically below the Burralow Formation, no aquitards are present to prevent unimpeded groundwater percolation or to direct groundwater laterally to discharge points along the length of the swamp.

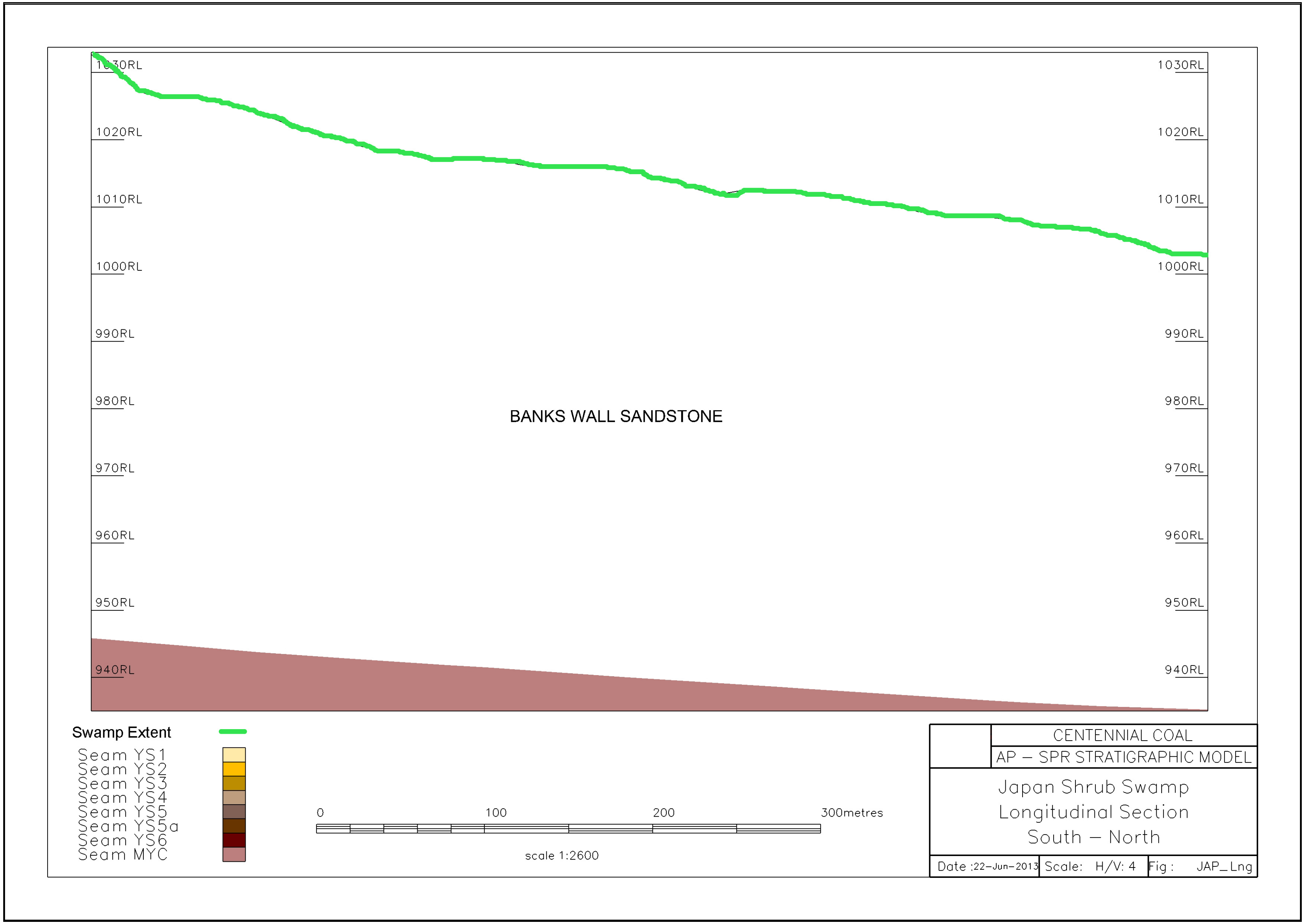

Figure 11 Longitudinal Section of Japan Shrub Swamp

Figure 12 shows a plan of the Japan Shrub Swamp and associated Japan Hanging Swamps. The latter are supported by groundwater seepage from above plies YS6 and YS5a, predominantly around the headwaters of the swamp.

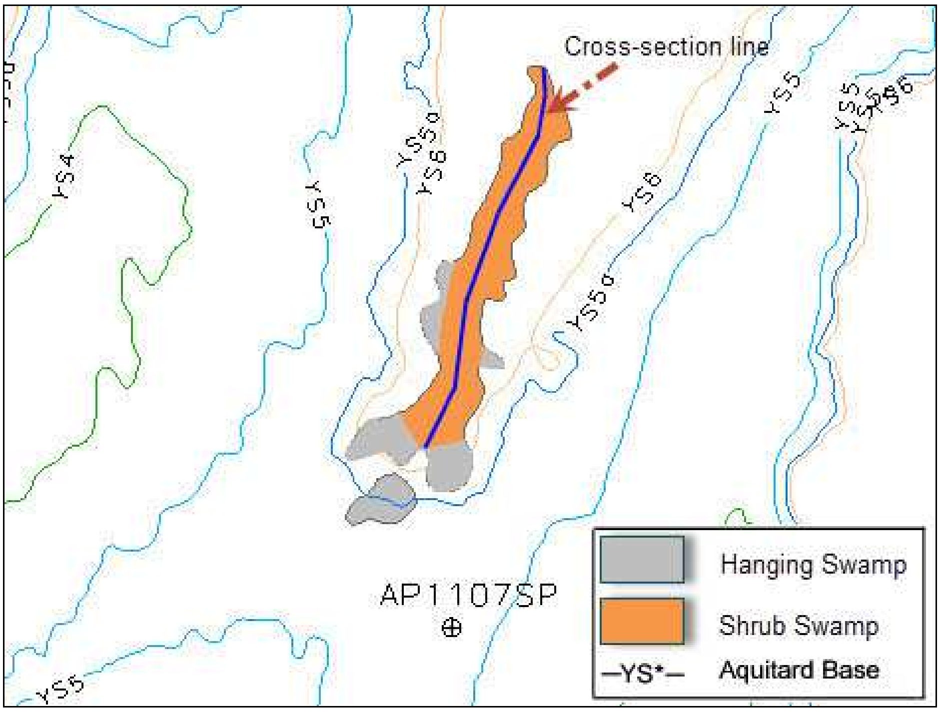

Figure 12 Plan of Japan Shrub Swamp

The Japan Shrub Swamp itself is located in a steep-sided gully, is 0.75km in length with a fall of 32 metres. Japan is the largest shrub swamp in the study area and differs noticeably in morphology from those swamps which are located within the Burralow Formation. Unlike Carne West Shrub Swamp discussed above, there are no aquitards outcropping along the length of the drainage line to assist with direct groundwater input. However, plies YS6, YS5a and to a lesser extent, YS5, would retain groundwater in the upper steep sides of this gully, which would eventually percolate down into the gully floor, thus providing a ready source of moisture in addition to precipitation. Ply YS4 to the west of the swamp is too distal to be a source of groundwater seepage.

Hence the Banks Wall Sandstone with its predominantly sandstone sequences results in areally smaller swamps. In addition, the lithological floor of the gullies of this swamp type allow for less erosion thus forming steep-sided gullies compared to the generally broader and longer Burralow-type shrub swamps. In comparison with swamps such as Carne West above, the recharge area is also smaller.

Figure 13 shows a cross section spanning Sunnyside Shrub Swamp, Sunnyside Ridge, Sunnyside East and Carne West Shrub Swamps. All three swamps are located wholly within the Burralow Formation.

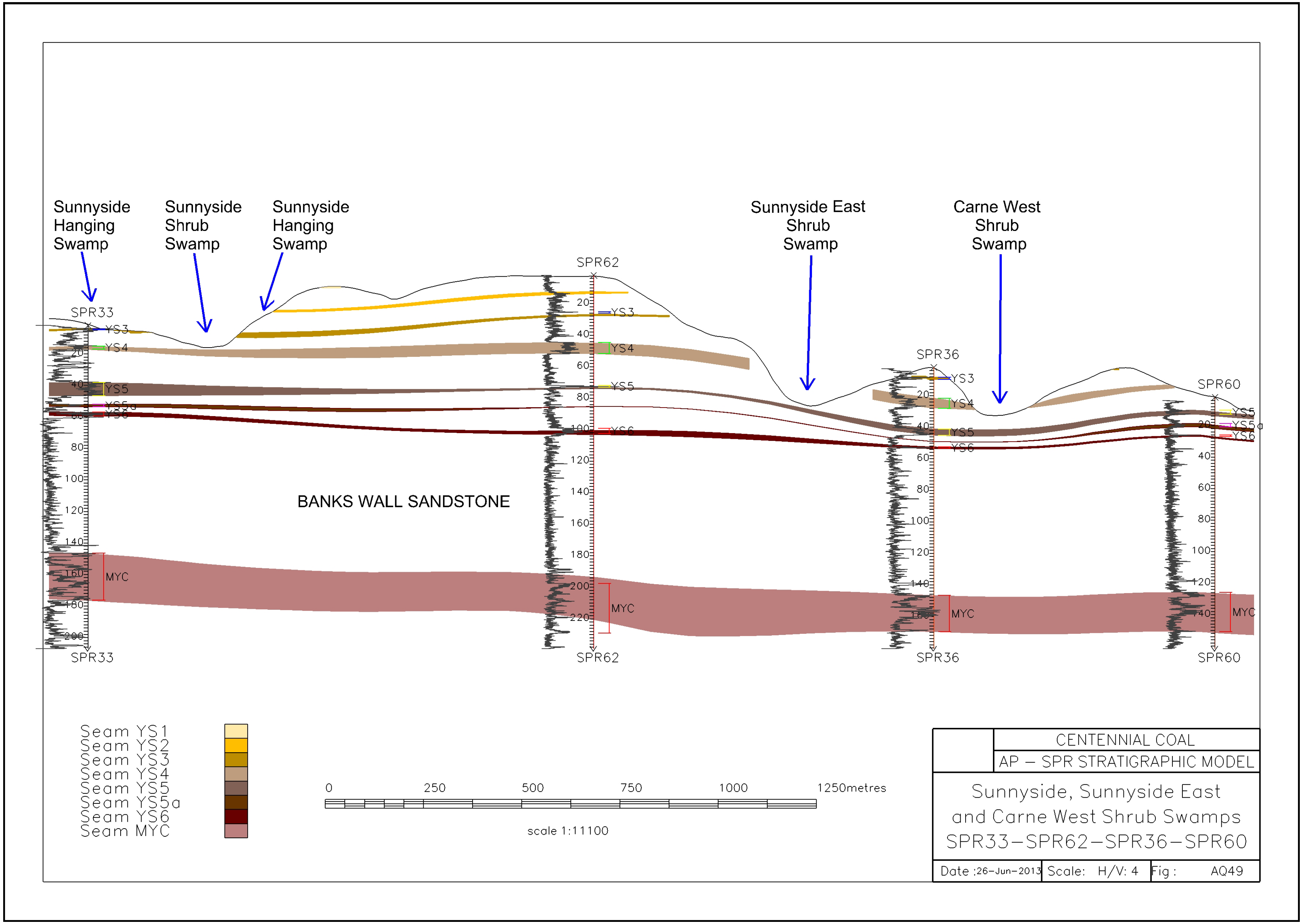

Figure 13 Sunnyside - Sunnyside East - Carne West Shrub Swamps Cross Section

Swamp profiles in the eastern Burralow-type shrub swamps are generally asymmetrically concave with the lowest depression to the west of centre, often adjacent to the steeper side of the pertinent gully. This asymmetric profile can be seen in Figure 13 in the case of Sunnyside East and Carne West Shrub Swamps. This swamp morphology contrasts with that of the Banks Wall-type shrub swamps of which Japan Shrub Swamp (Figure 14 below) is a typical example. Banks Wall-type shrub swamps in general have much steeper-sided valley walls and a narrower width as compared to Burralow-type swamps.

Figure 13 also illustrates the difference in geophysical response between the Banks Wall Sandstone and the overlying Burralow Formation. This west-east cross section, encompassing boreholes SPR 33, SPR 62, SPR 36 and SPR60, clearly shows the generally muted response of the Banks Wall Sandstone compared to the Burralow Formation. The latter displays increased gamma response associated with clay-rich aquitard horizons. The gamma response of the Mt York Claystone stratigraphically below the Banks Wall Sandstone also reflects the high clay content of this formation. Hence, in geophysical terms, the Banks Wall Sandstone is referred to in this study as the “muted zone”, as noted in Section 5.2 above.

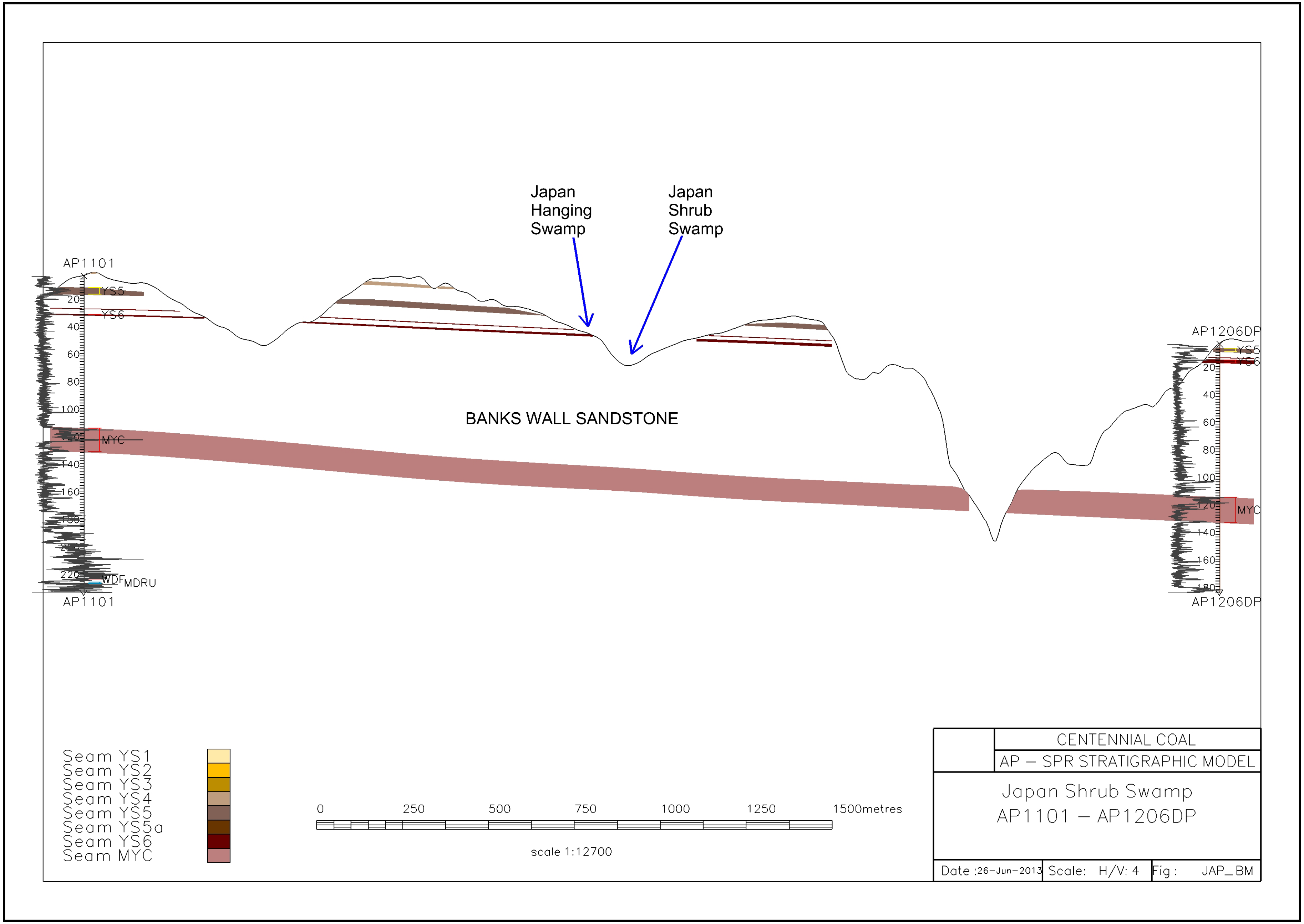

Figure 14 Japan Shrub Swamp Cross Section

Further to the concept of Burralow versus Banks Wall-type shrub swamps, Aurecon (2009) noted that the northern section of East Wolgan Shrub Swamp (see Figure 33, Section 12) was narrow and poorly developed with rock bars exposed in the creek bed, as compared to the more southerly section of the swamp where no rock is exposed, and the swamp is better developed and much wider. This observation is illustrated in Figure 34, which demonstrates that East Wolgan is a "mixed-type" swamp with the northern, lower reaches underlain by the Banks Wall Sandstone and the upper reaches by the Burralow Formation. East Wolgan Shrub Swamp is discussed in detail in subsequent sections.

Benson and Baird (2012) stated that monitoring of swamps in the western part of the Newnes Plateau revealed that these swamps are drier than those in the east. Further, the eastern swamps were all associated with *Epodisma minus, Grevillea acanthifolia,* and *Epacris paludosa* which were virtually absent from the western swamps. This again reflects the influence of Burralow Formation thickness on both swamp morphology and swamp vegetation, due to its ability to retain water due to the presence of numerous semi-permeable layers.

10. Topography, Burralow Formation and Shrub Swamp Morphology

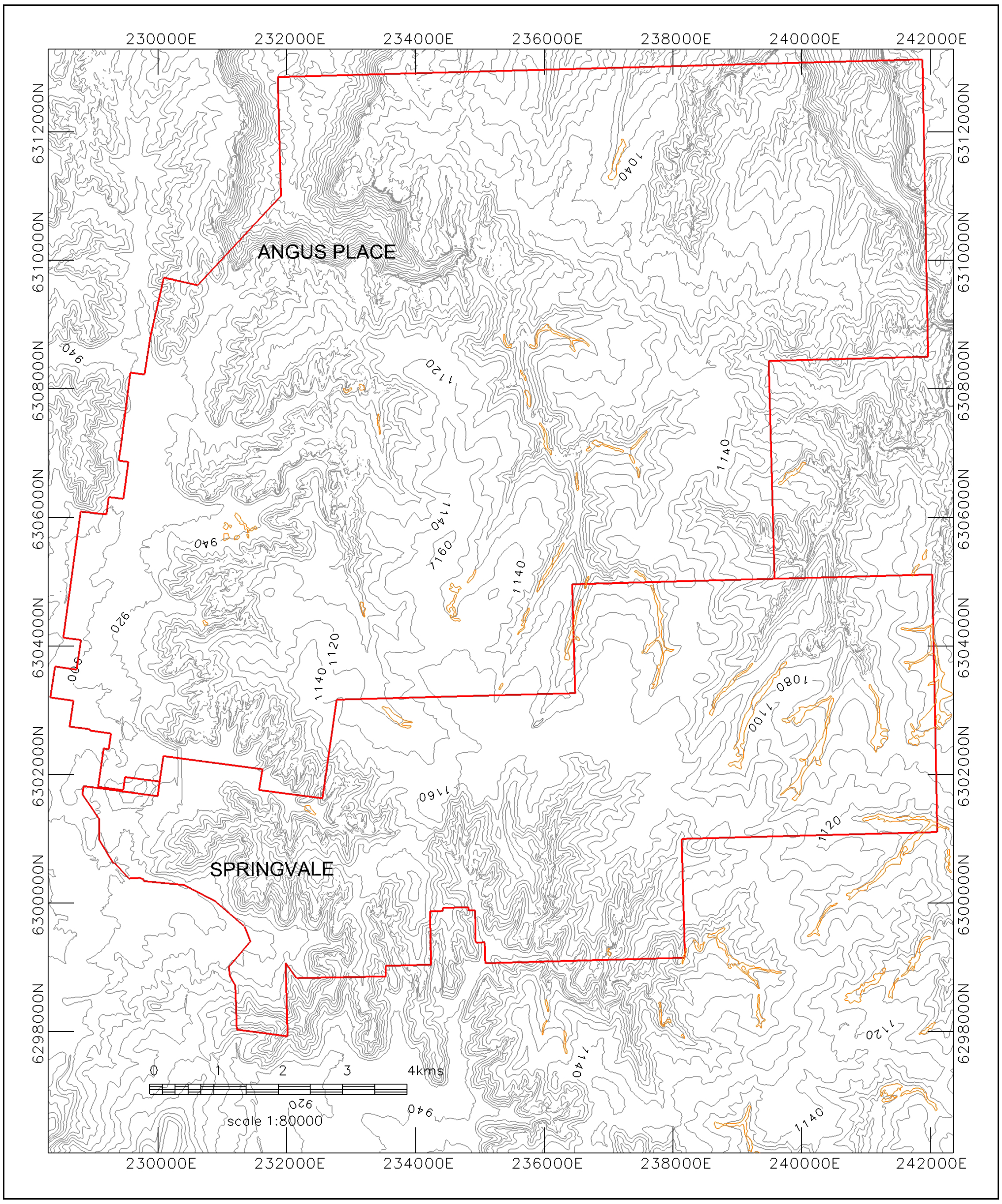

Figure 15 Topography and Shrub Swamp Locations in Angus Place/Springvale

Figure 15 shows topography and shrub swamp locations for the Angus Place/ Springvale leases. As shown, the length, breadth and frequency of shrub swamps in the study area generally increase to the south-east, principally in the Springvale Colliery lease. This is due in part to the topography present but is also dependent upon the thickness of the Burralow Formation across the study area.

As more clearly shown in Figure 6 in Section 5, there is a persistent pattern of increasing shrub width and length towards the south and east of the study area.

The highest point on the Newnes Plateau in the study area is 1180 metres but an arbitrary topographic height of 1150 metres has been selected to illustrate the dominant ridge systems in the area (Figure 16).

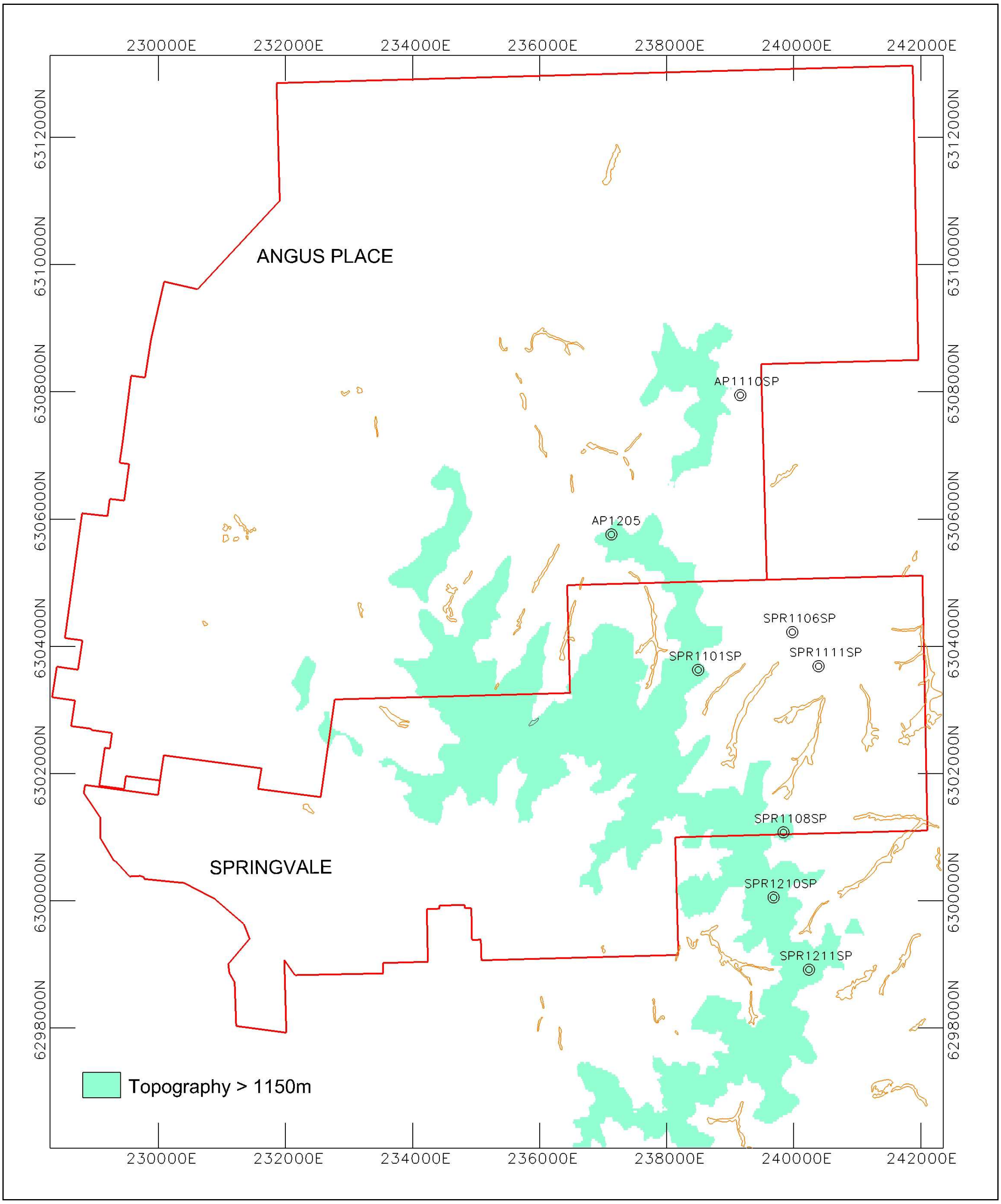

Figure 16 Topography in Study Area above 1150 metres

As illustrated above, in Angus Place the highest elevation is 1150 to 1160 metres and is located west of AP1110SP. This short piezometer hole is located topographically lower than the arbitrary 1150 metre cut off, but still contains the full YS6 to YS1 sequence. Geophysically logged holes in the most elevated area of Angus Place also indicate that the full aquitard sequence from YS6 to YS1 is present..

The maximum thickness of the Burralow Formation in Angus Place is 100 – 110 metres and coincides with the highest catchment area as described above. Hence, there is a positive correlation between Burralow Formation thickness and topographic elevation.

A second, more extensive ridge system (> 1150m -1180m) is present in the Springvale area (Figure 16) and represents the most elevated region of the study area. This ridge system extends from south of the West Wolgan Shrub Swamp to south of the Narrow, East Wolgan, Sunnyside, Sunnyside East, Carne West, Gang Gang, Pine and Marrangaroo Creek Shrub Swamps, thus creating an extensive watershed for the formation of the creeks which support the above watercourses. Further, this topographic feature, like the elevated plateau in Angus Place described above, is underlain by the maximum thickness of the Burralow Formation and contains the full sequence of YS aquitards. Again there exists a positive correlation between topography and Burralow Formation thickness at this location.

An outlier of elevated topography occurs to the north-west of West Wolgan Shrub Swamp which serves to supplement groundwater seepage to this swamp complex via the series of aquitards present in the Burralow Formation at this location.

These elevated ridges, particularly the elongated twelve kilometre system in the Springvale area, are important recharge areas for both the hanging and shrub swamps. In Angus Place, the 1150+ metre zone is more areally restricted and few major waterways are associated with this feature. The nearest shrub swamps are Tri-Star and Snake Shrub Swamps to the west at a distance of between one to two kilometres, and Crocodile Shrub Swamp, which lies stratigraphically in the Banks Wall Sandstone, over one kilometre to the east (Figure 6).

The Springvale ridge system provides not only an extensive recharge area for the associated creeks and shrub swamps, but the maximum thickness of the Burralow Formation is an important component in the hydrological cycle that drives the formation of both shrub and hanging swamps in the region.

The full YS aquitard sequence (YS6 to YS1) is present in all cored holes within the designated 1150+ metre shaded area, that is, AP1110SP, AP1205, SPR1108SP, SPR1210SP and SPR1211SP. Borehole SPR1101SP, located between Sunnyside and Sunnyside East Shrub Swamps, does not contain the YS6 ply as the borehole was terminated above this horizon.

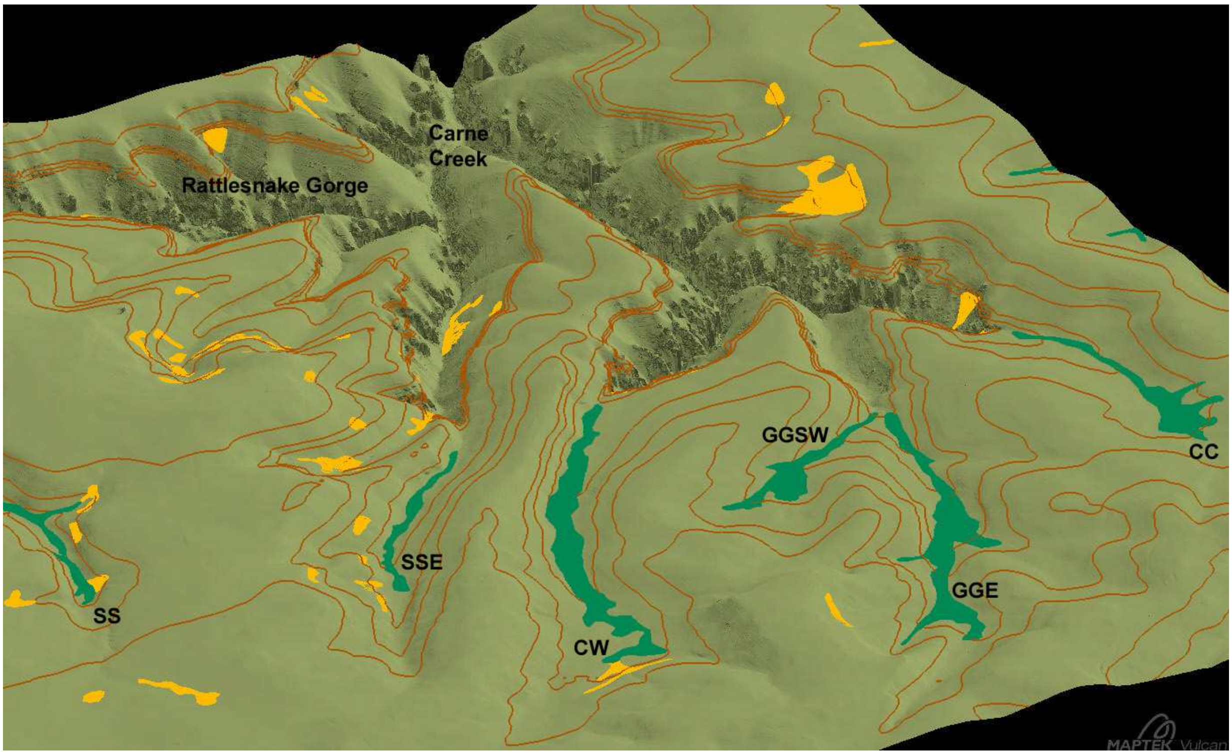

Figure 17 Schematic View of Carne Creek Shrub Swamp Systems

Figure 17 shows a view looking north-west from the direction of the Springvale ridge system. Aquitard horizons which support the shrub and hanging swamps are shown in brown. Shrub swamps are marked in green and hanging swamps in yellow.

Carne West Shrub Swamp (CW) with its associated Newnes Plateau Hanging Swamp can be seen in the middle foreground. To the east is Gang Gang Shrub Swamp (GGSW and GGE), while Carne Central Shrub Swamp (CC) is to the extreme right of the figure.

To the west of Carne West swamp lies Sunnyside East Shrub Swamp (SSE) together with an array of hanging swamps associated with several aquitards cropping out west of this swamp. The lower tip of Sunnyside Shrub Swamp (SS) can be observed in the left foreground on the opposing side of Sunnyside Ridge which forms part of the extensive recharge areas discussed above.

This figure illustrates the extensive subcrops of aquitards present in this area of the Angus Place/ Springvale lease. As the regional dip is less than one degree, the aquitard horizons generally follow topography. Hence there is a relative lack of aquitard outcrops in the flatter, elevated ridge areas, whereas the gully sides form frequent outcrop points. As was noted in Section 9, aquitard horizons crop out along the sides of valley walls, as well as within gully floors, thus supplying a constant source of groundwater moisture for both the shrub swamps in the gullies and the hanging swamps that occur along cliffs and the steeper upper sections of valley sides.

The presence of hanging swamps throughout the lease area is an important indictor of the amount of groundwater contained within the aquitard/aquifer system operating throughout the vertical extent of the Burralow Formation. As noted above and shown in Figure 17, there exists an extensive suite of hanging swamps to the immediate west of Sunnyside East Shrub Swamp. Sunnyside Shrub Swamp also has associated hanging swamps, the southern examples of which can be seen in the above figure. Other hanging swamps are present in Figure 17, including those in Rattlesnake Gorge, the western tributary of Carne Creek in the upper left of this figure. The latter demonstrate the typical outcrop pattern for hanging swamps.

Hanging swamps occur in both high and low relief areas, while shrub swamps are restricted to areas of low relief. The formation of a hanging swamp is dependent on the presence of a suitably thick aquitard (generally > 2 metres) and the appropriate topography. The hanging swamps of the Newnes Plateau are discussed in a separate report, however their presence and morphology are indicative of considerable reserves of water held within aquifer units of the Burralow Formation, which is also of crucial importance to the development of shrub swamps.

As can be observed in Figure 17, by virtue of the regional dip, the aquitard horizons are often present along the sides of ridges and thus follow the gully sides of the host creek below. The presence of aquitards at these locations leads to the occurrence of valley wall seepage which is an important source of moisture for the shrub swamps in the upper reaches of both Carne Creek and the Wolgan River.

Apart from the seven major aquitards discussed earlier (that is, YS6, YS5a, YS5, YS4, YS3, YS2 and YS1), thinner aquitard unit also are present within the Burralow Formation which, while they may not be capable of forming a hanging swamp, nevertheless supply a constant source of seepage at outcrop localities.

The presence of swamps in catchment headwaters cannot be fully explained by rainfall alone and require an additional continuous source of hydration though periods of restricted rainfall. As noted in Section 9, the presence of the Burralow Formation is essential to the formation of both hanging and shrub swamps. Goldney et al (2010) stated “normal flood hydrographs generated from rainfall are expected to rise and fall reasonably rapidly in response to rainfall events, and thereafter, to feed low baseline flows maintained by a combination of valley-side and in-stream seepage”. Piezometer readings, both in-stream and on ridge locations, record only part of the full hydrological picture for any given swamp system. Valley wall seepage, which occurs however minutely at some locations along aquitards outcrops, still permits continuity of hydration during periods of drought.

Figure 17 illustrates the relative abundance of aquitards in the Burralow Formation providing continual groundwater supplies to both shrub and hanging swamps along valley sides. Aquitards also crop out within the host gully of a shrub swamp, for example, in Carne West and Gang Gang Shrub Swamps, and hence provide additional input of groundwater to the valley wall seepage. The latter phenomenon accounts for the relatively extensive morphologies of these two shrub swamps. This concept will be further discussed in a later report.

11. Major recharge areas within the Angus Place/Springvale Leases

The “Springvale Ridge” system as noted above provides a major recharge zone for the shrub swamps to the north and south of this feature. The western half of the ridge system contains numerous boreholes which were geophysically logged (eg. SPR24, SPR 31, SPR 25R, SPR 44, SPR52, SPR35 and SPR 51) in which the full YS1 to YS6 sequence is present. Several short piezometer holes were also cored in the eastern extent of this elevated zone, with results as follows:

- In AP1110SP, the closest cored borehole to the Angus Place 1150+ m zone, the strata from approximately 6m to 36m consists largely of slightly weathered to unweathered fine- to medium-grained sandstone interspersed with thin zones of more highly weathered material. It is this resistant sandstone cap which likely forms the Angus Place elevated zone to the immediate west.

- AP1205 is similar to AP1110SP, with the resistant/competent sandstone extending to approximately 30m.

- SPR1108SP consists of slightly weathered fine-to-medium sandstone from 6m to 13m. From 13m to 42m, the strata consists of slightly weathered to unweathered fine- to medium-grained sandstone interspersed with zones of more highly weathered material. Figure 18 shows core photographs from 6 to 13.5 metres within this hole and illustrates the competent nature of this near-surface material.

- SPR1210SP contains a slightly weathered sandstone/siltstone cap from 6 to 8 metres, but this is underlain by more highly weathered material than shown in the previously discussed boreholes.

- SPR1211SP contains slightly weathered fine siltstone from 6 to 8 metres, but below this depth, there is a higher proportion of moderately to highly weathered material than slightly weathered, competent material.

The common feature from each of these bores is the presence of relatively unweathered, competent strata at very shallow depth.

By comparison, boreholes SPR1106SP and SPR1111SP which are located near the confluence of the Sunnyside East, Carne West and Gang Gang Creeks show quite different lithological patterns. Although both located in the Burralow Formation, these bores contain non-competent, heavily weathered and iron-stained material near the surface and hence, at this RL, no ridge system exists. Figure 19 shows the material present in the upper 12.3 metres of SPR1111SP which clearly demonstrates the extreme weathering at this site.

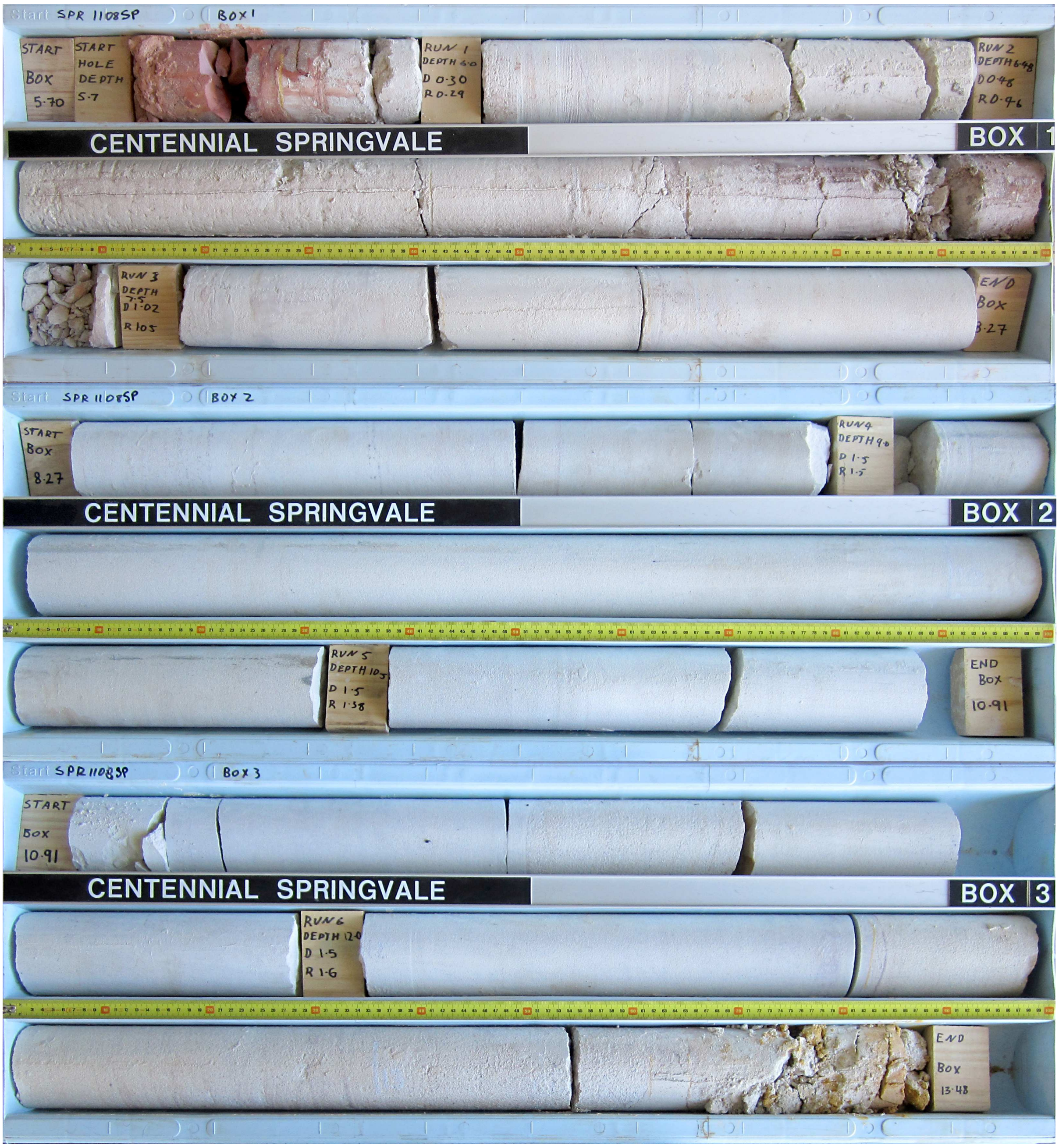

Figure 18 Core Photos of SPR 1108SP (6-13.5 m)

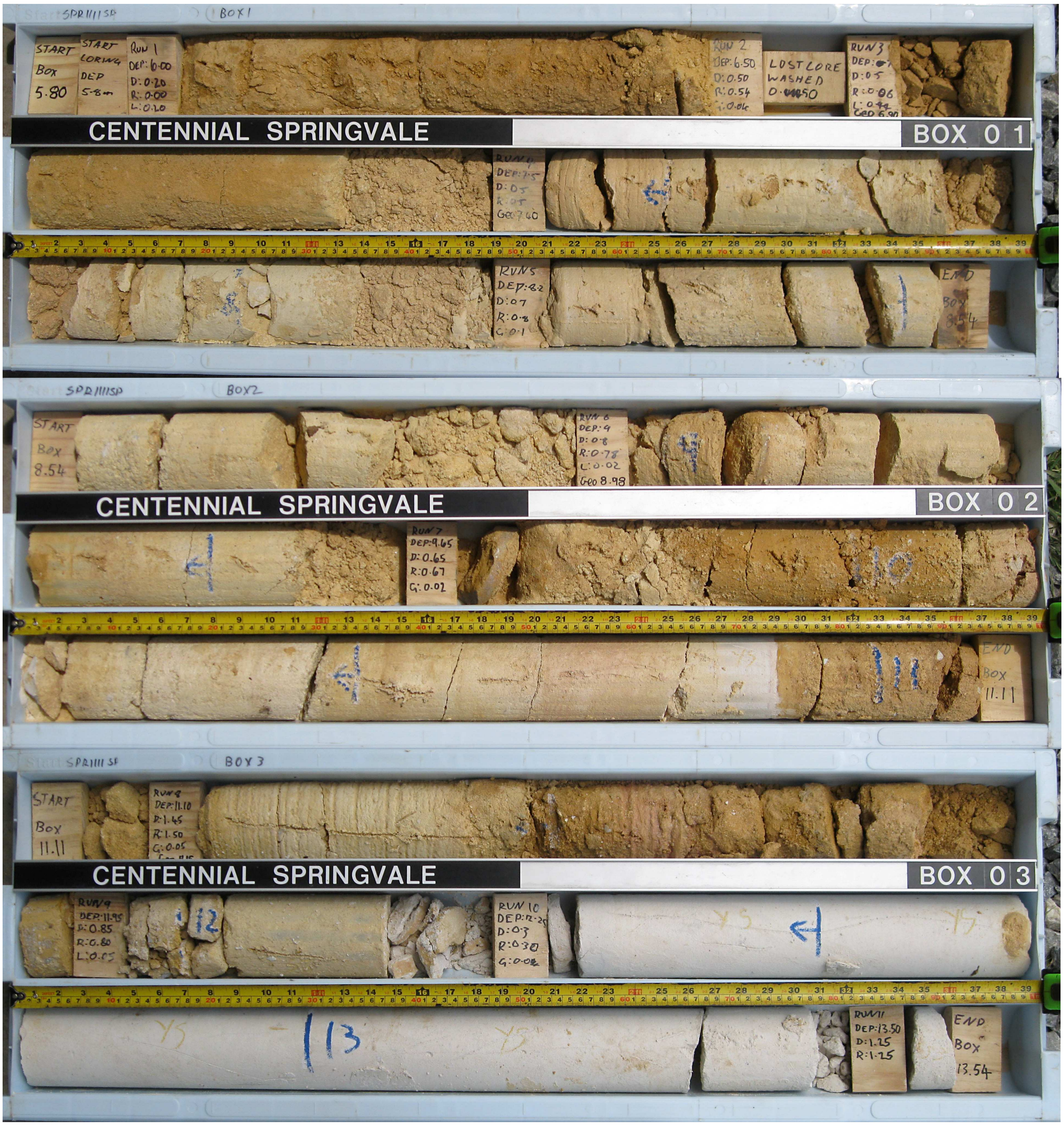

Figure 19 Core Photos of SPR1111SP (6-12.3m)

12. Selected Newnes Plateau Shrub Swamp Descriptions

A selection of shrub swamps in the Angus Place/Springvale area are described below in order to present an overall understanding of the varying morphologies between differing lithologically-controlled shrub swamp types. As described in Section 8, the underlying lithology plays an important part in the morphology of the resultant shrub swamp.

I. Japan Shrub Swamp

This swamp was discussed in detail in Section 8 and comprises a Banks Wall-type shrub swamp.

II. Kangaroo Creek Shrub Swamp

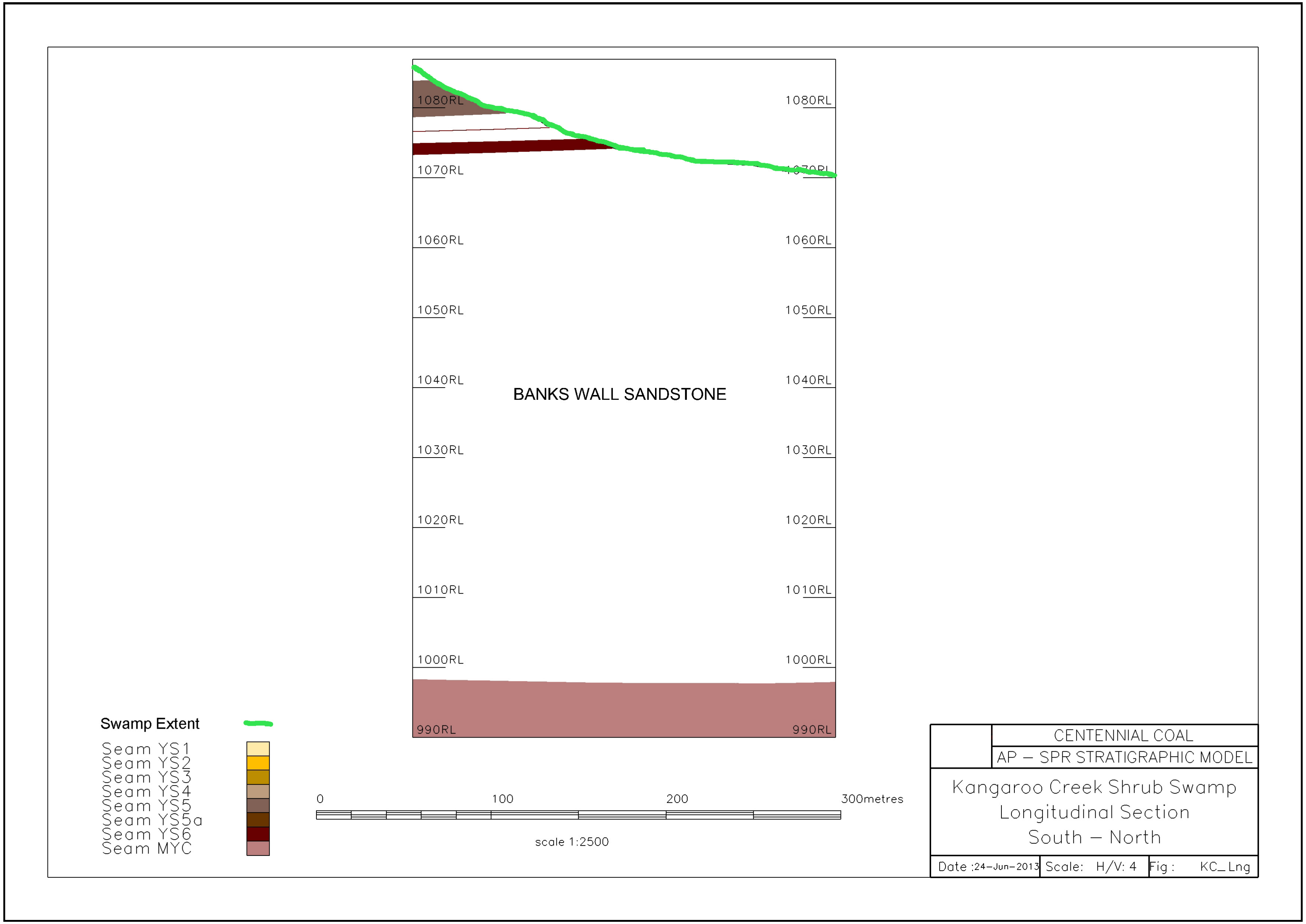

Figure 20 Longitudinal Section of Kangaroo Creek Shrub Swamp

Figure 20 is a longitudinal section of Kangaroo Creek Shrub Swamp which trends approximately north-south, with a small easterly incursion into a tributary of Kangaroo Creek. It has a fall of approximately 15 metres.

This 250m-long swamp is situated in a narrow gully between the YS4 and the YS6 horizons in its upper reaches before the host creek erodes downwards into the Banks Wall Sandstone for the remainder of its length. Hence this swamp is a “mixed-type” swamp. However, it is supported hydrologically by the relatively thick YS5 aquitard which, owing to the narrowness of the creek due to its Banks Wall Sandstone substrate, permits the YS5/YS5a/YS6 suite of aquitards to supply groundwater seepage via the resultant “aquifers” for the full length of the swamp. This is shown more clearly in Figure 21, a plan of Kangaroo Creek Shrub Swamp.

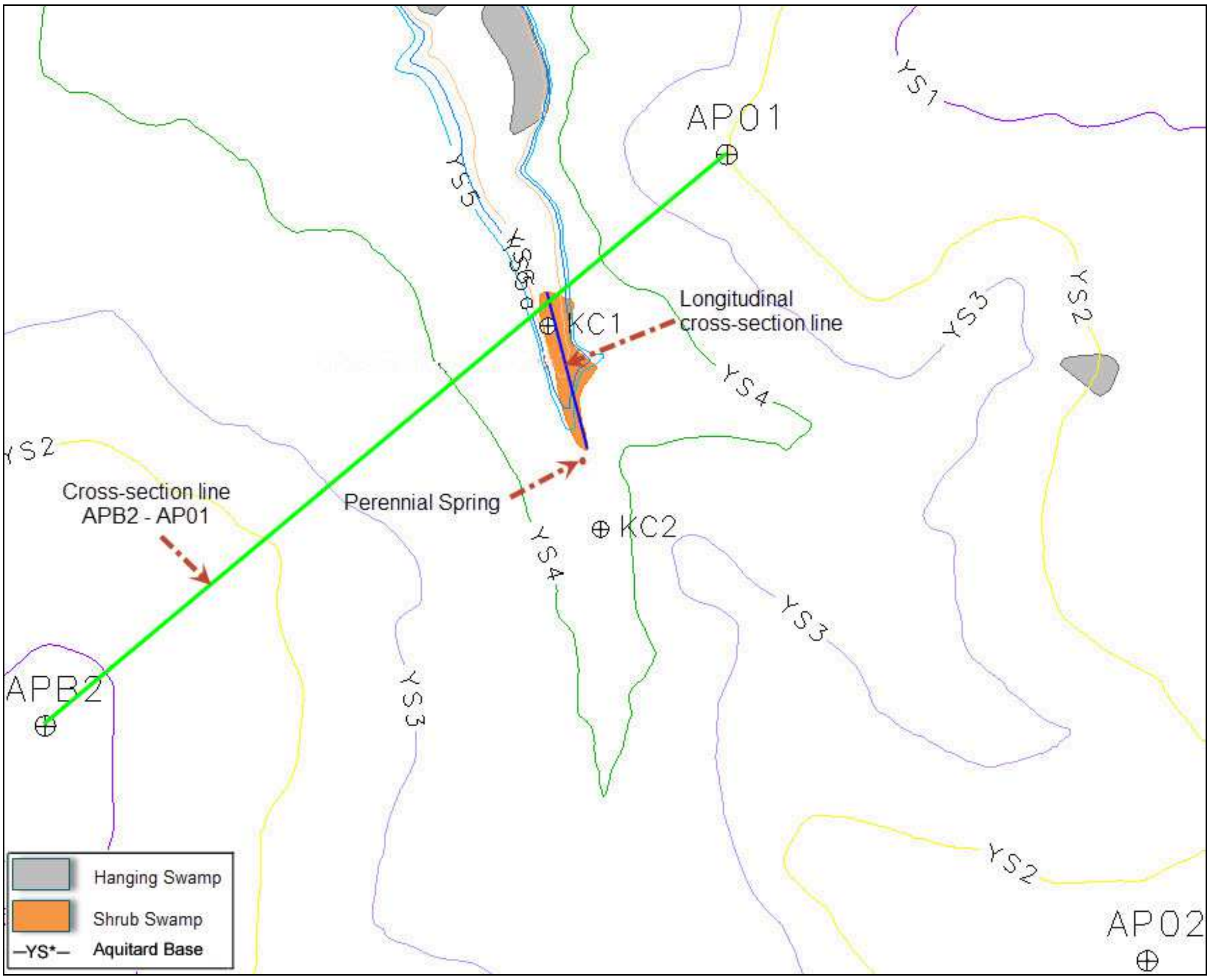

Figure 21 Plan of Kangaroo Creek Shrub Swamp

In this diagram, the narrowness of the swamp is readily apparent as well as the proximity of the YS5 and YS6 aquitards to the swamp, together with the outcropping of the Banks Wall Sandstone beneath the YS6 aquitard, approximately midway down the length of the swamp. Figure 25 provides a more detailed plan of this swamp and its associated aquitards.

Figure 22 shows a south-west to north-east cross-section from APB2 to AP01 which transects Kangaroo Creek Shrub Swamp and also piezometer KC1. At the point of transection of KC1, the shrub swamp is situated within the Banks Wall Sandstone, but lies approximately four metres below the YS6 and YS5 plies, which form the upper reaches of this swamp, as shown in Figure 20. Figure 22 also illustrates the substantial thicknesses in this area of the YS3, YS4 and YS5 aquitards, which all assist in retaining available groundwater in these upper sequences to support this swamp, despite its largely Banks Wall substrate. This diagram also illustrates the increased gamma responses within these boreholes in both the Burralow Formation and the Mt York Claystone due to higher occurrences of clay-rich, fine-grained lithologies in these units as compared to the relatively “muted zone” of the Banks Wall Sandstone, as discussed previously.

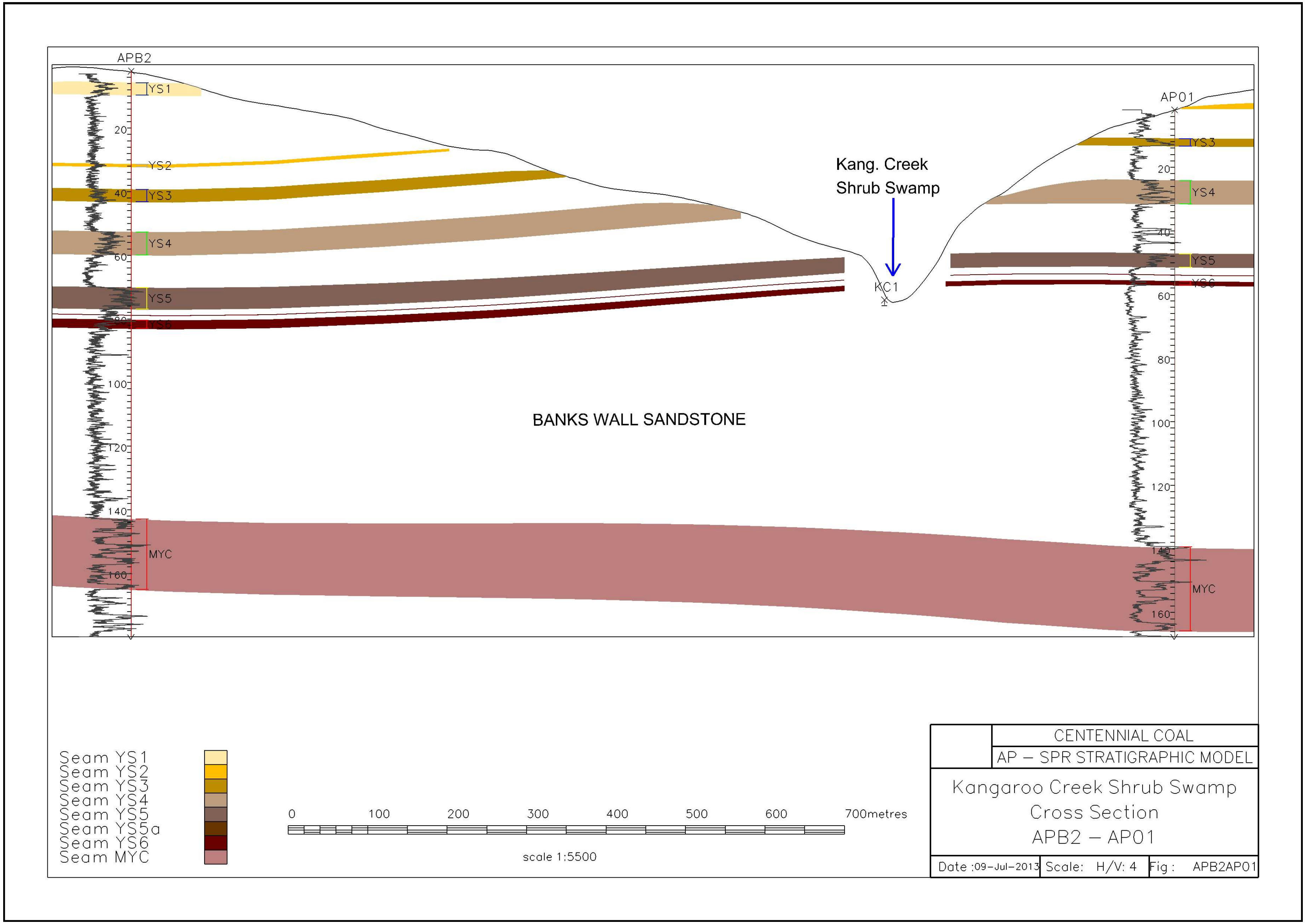

Figure 22 Cross Section through Kangaroo Creek Shrub Swamp

A permanent spring is located approximately 20 metres to the south of the upper reaches of Kangaroo Creek Shrub Swamp. Spring co-ordinates are 233202E 6304430 (GDA).

Figure 23 Spring in Upper Reaches of Kangaroo Creek

Figure 23 shows the spring at the upper reaches of Kangaroo Creek in addition to the mudstone unit with groundwater flow from the top of unit (beneath feet of observer). This unit is the top of the YS5 aquitard and water is emanating from the "aquifer" that is confined by YS4 and YS5, both relatively thick mudstone/claystone units.

Figure 24 Pond Below Spring in Kangaroo Creek

Figure 24 taken slightly downstream shows both the top of the YS5 aquitard in the background and the pond which forms at the upstream extent of the shrub swamp. The YS6 aquitard is approximately six metres below the base of the YS5 ply and may possibly be acting to maintain this degree of pooling at this location.

Figure 25 shows the areal extents of this shrub swamp, together with the projected outcrops of the aquitard horizons YS4, YS5, and YS6.

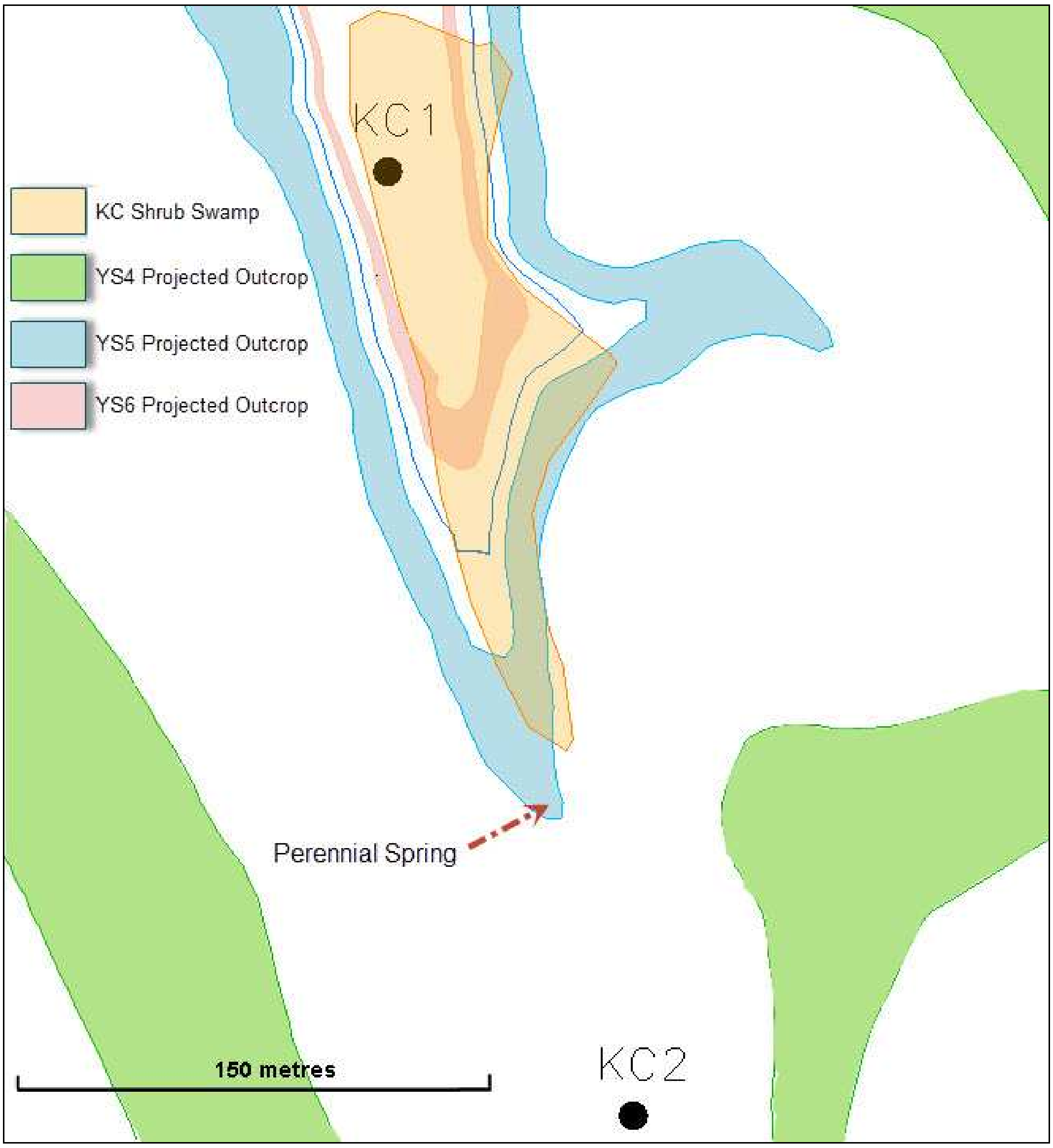

Figure 25 Detailed Plan of Kangaroo Creek Shrub Swamp and Modelled Geology

The location of the spring in the above diagram is immediately adjacent to the projected roof of the YS5 ply, an approximately 5.5 metres thick mudstone horizon that is shown in Figure 22. The modelled geology at this location is essentially based on three boreholes, AP01, AP02 and APB2 (see Figure 20), which are approximately 1 kilometre apart. AP01 is the nearest of the bores to the spring, at a distance of 500m, while AP02 and APB2 are both approximately one kilometre from the spring.

It is suggested that the spring should theoretically discharge water from the top of the YS5 ply (that is, the base of the “aquifer” between YS4 and YS5). The fact that the spring is located less than 20m from the projected outcrop of the YS5 roof, indicates that geological modelling of the major units within the Burralow Formation at this location is relatively accurate.

Kangaroo Creek Shrub Swamp spans longwalls 940 and 950, which were completed in May 2008 and January 2010 respectively. Two open hole piezometers, KC1 and

KC2 (Figure 25) were installed to measure groundwater levels in the Kangaroo Creek drainage line. The former is located in the lower reaches of Kangaroo Creek Shrub Swamp while the latter is sited approximately 110 metres upstream from the shrub swamp. Recent groundwater monitoring results by Aurecon (2013) confirmed the spring was flowing at the time of monitoring.

Groundwater levels at KC1 appear to have been affected by the longwalling of LW940 which was below the lower reaches of the swamp, as there was a sudden reduction in groundwater levels in June 2008, unrelated to rainfall. As shown in Figure 26, measured groundwater levels respond to rainfall events, and standing water levels reach pre-mining levels after significant rainfall events. However, for KC1 measured groundwater levels have yet to completely return to pre-mining levels.

Longwall 950 undermined KC2 in January 2010. LW960, 150 metres to the south of this monitoring site was concluded in May 2010. As Figure 26 shows, no impact from longwalling was noted in the groundwater monitoring record from the KC2 site (Aurecon, 2013).

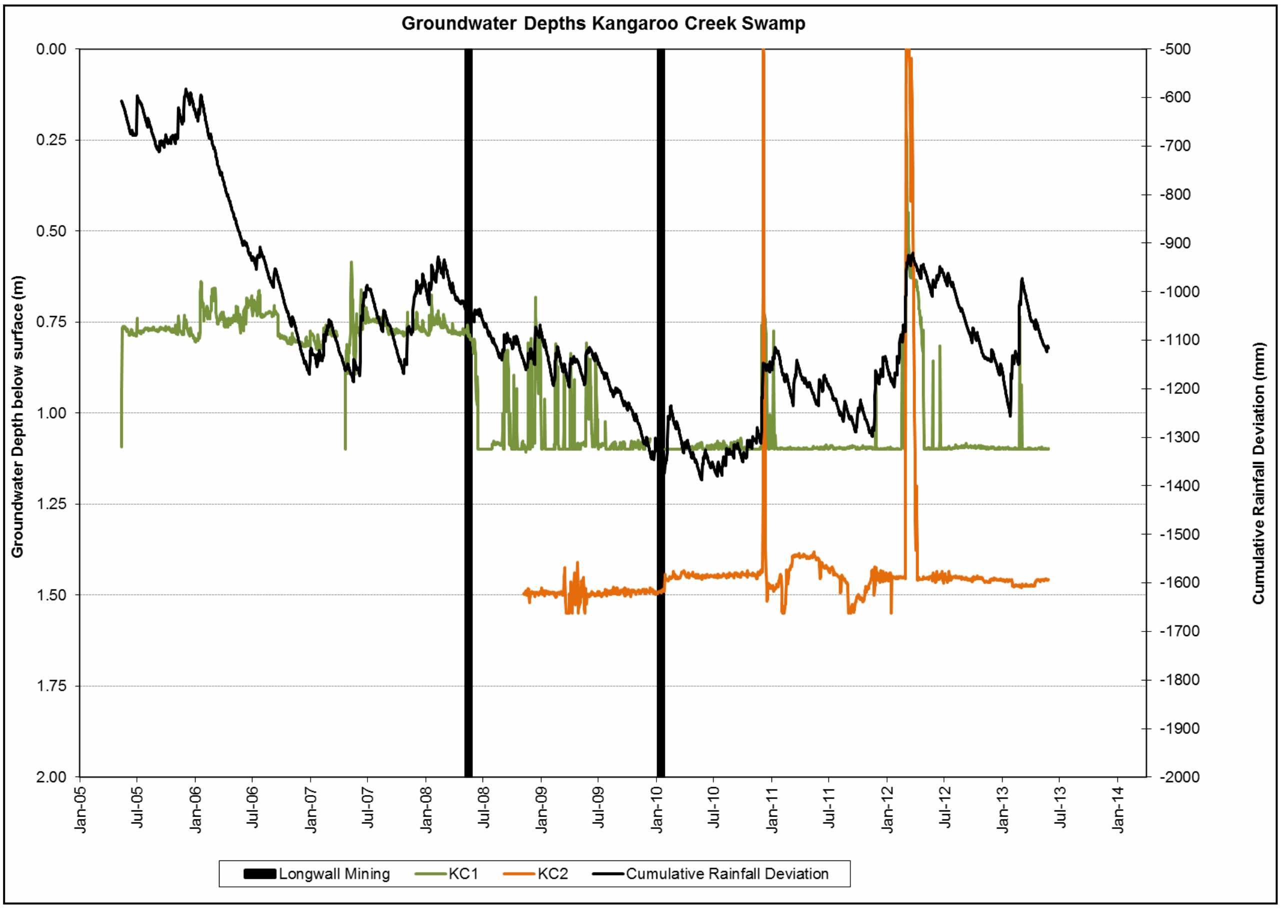

Figure 26 Hydrograph for Kangaroo Creek Shrub Swamp

Figure 27 shows the western valley wall adjacent to Kangaroo Creek Shrub Swamp. Taken in July 2013, the photo outlines the presence of healthy swamp vegetation in the valley walls surrounding the swamp, thus further demonstrating that the groundwater supply from the spring and valley wall seepage has not been interrupted by longwall mining and that groundwater inputs to the swamp hydrological system remain intact.

Figure 27 Western Valley Flank of Kangaroo Creek Shrub Swamp

Figure 28 has been photographed from the pond immediately below the permanent spring at Kangaroo Creek swamp and is oriented upwards towards the western flank of the swamp, as per the previous photo. The large eucalypt shown in Figure 27, to the right of centre, growing above the aquitard horizon, can also be seen in Figure 28, towards the upper right corner of the photograph.

The photographs shown in Figures 23, 24, 27, 28 and 29 (below) provide a visual representation of the geology, hydrological regime and vegetation at this site from the spring location at the southern extension of this swamp to the lower reaches of Kangaroo Creek.

Figure 28 Western Valley Flank from Pond Perspective

Most significantly, neither longwall event appears to have impacted on the vegetation in the swamp to any significant degree (Aurecon, 2013). Figure 29 shows a view of Kangaroo Creek looking south, as per the former photos, taken in July 2013. The spring as shown in previous photos is obscured by the swamp vegetation in the foreground.

Figure 29 Kangaroo Creek Shrub Swamp

It is concluded that the upstream reaches of Kangaroo Creek at KC2 were unaffected by mining, while the lower reaches of Kangaroo Creek at KC1 were temporarily affected by mining induced cracking. It is expected that over time any cracks present will infill with sediment and that mining-induced effects will be temporary. Most significantly, the perennial spring fed by the aquifer between the YS4 and YS5 aquitards was unaffected and hence the main creek body has remained permanently wet below the spring and the pond (Aurecon, 2013), indicating that underground mining has not resulted in any long-term negative effects on this shrub swamp.

III. West Wolgan Shrub Swamp

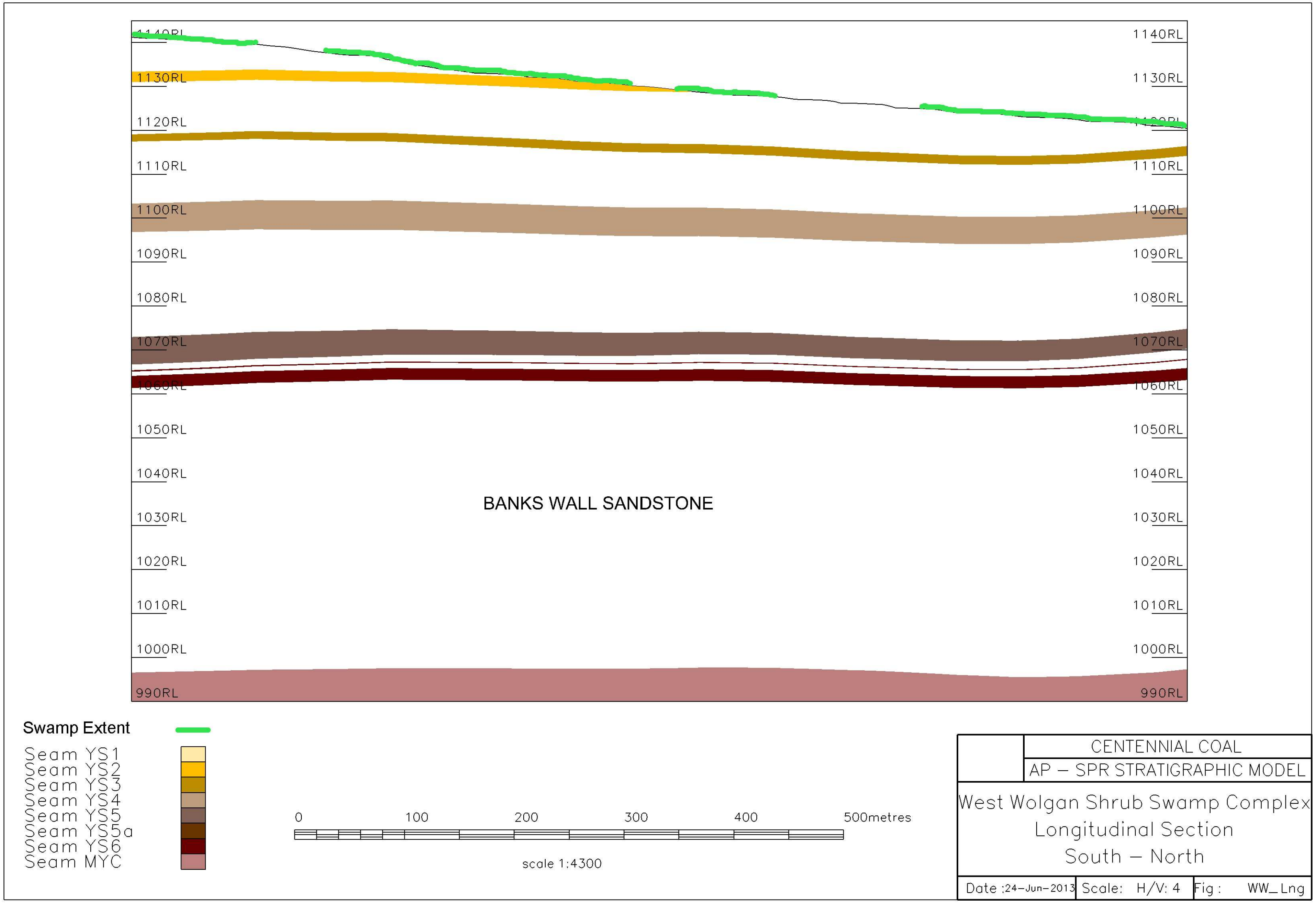

Figure 30 Longitudinal Section of West Wolgan Shrub Swamp Complex

Figure 30 is a longitudinal section of the West Wolgan Shrub Swamp Complex. This feature consists of a string of disconnected shrub swamps with a fall along the host creek of approximately 21 metres. The southern reaches of the complex lie stratigraphically between the YS1 and YS2 aquitards while the northern half of the complex is situated between the YS2 and YS3 horizons. Thus, this swamp is wholly contained within the Burralow Formation.

Figure 31 is a plan of the West Wolgan Complex and illustrates the relationship between the presence of the aquitards and shrub swamp formation. As shown, the YS1 ply is also associated with the hanging swamps at this location.

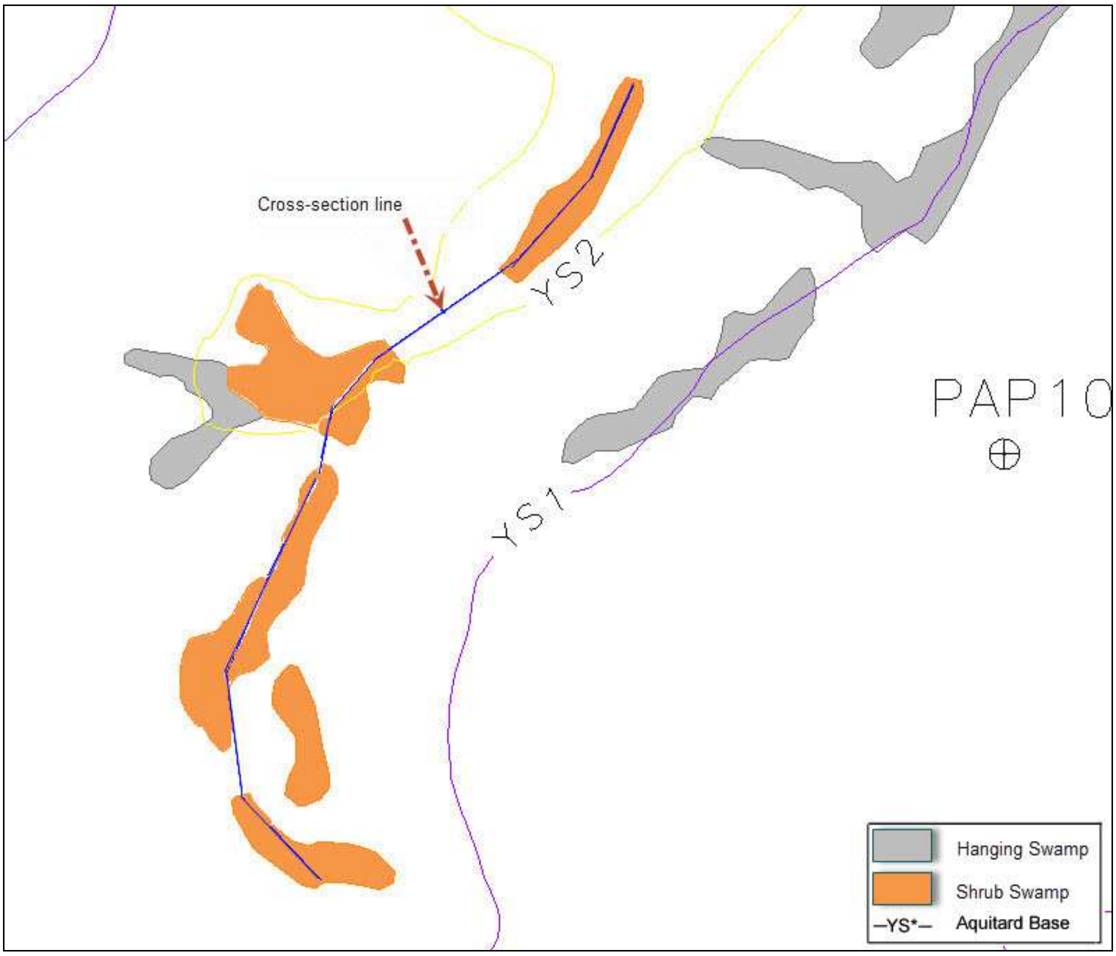

Figure 31 Plan of West Wolgan Shrub Swamp Complex

IV. Junction Hanging Swamp

The Junction Hanging Swamp is approximately 200m in length and is situated stratigraphically within the Burralow Formation. In Figure 32 below, a cross-section has been created between two piezometer holes, JCT2 and JCT 3, which are immediately south of the hanging swamp.

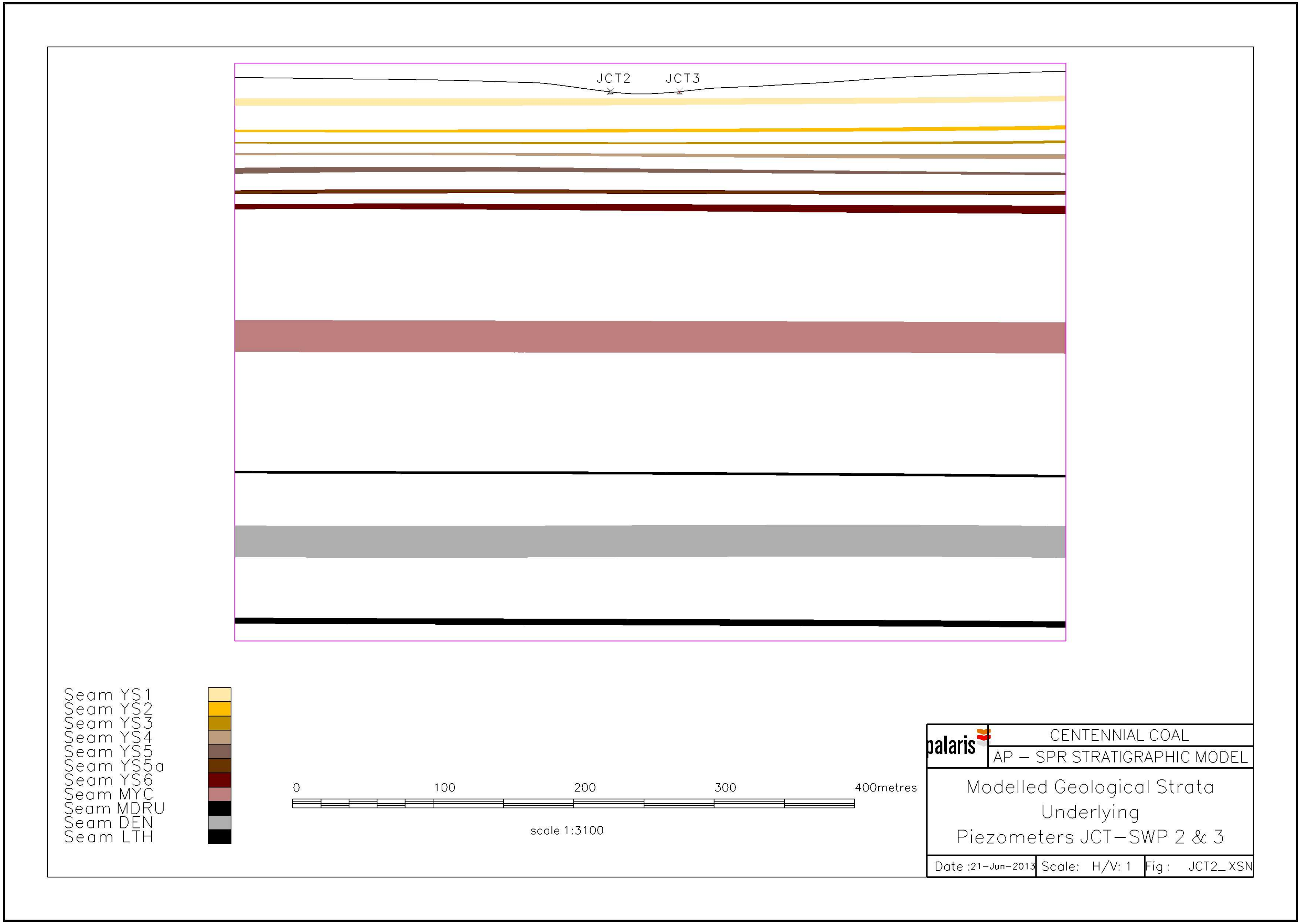

Figure 32 Cross Section South of Junction Hanging Swamp

Figure 33 shows a plan of the main Junction Hanging Swamp and its two southern outliers, together with the section line location. The YS1 aquitard controls water movement at this location hence this hanging swamp is reliant on both rainwater and groundwater seepage. However, this hanging swamp complex is immediately adjacent to a large recharge area to the west, south and south-east which would assist in supplying both direct precipitation as well as groundwater percolation into the unconfined aquifer above YS1.

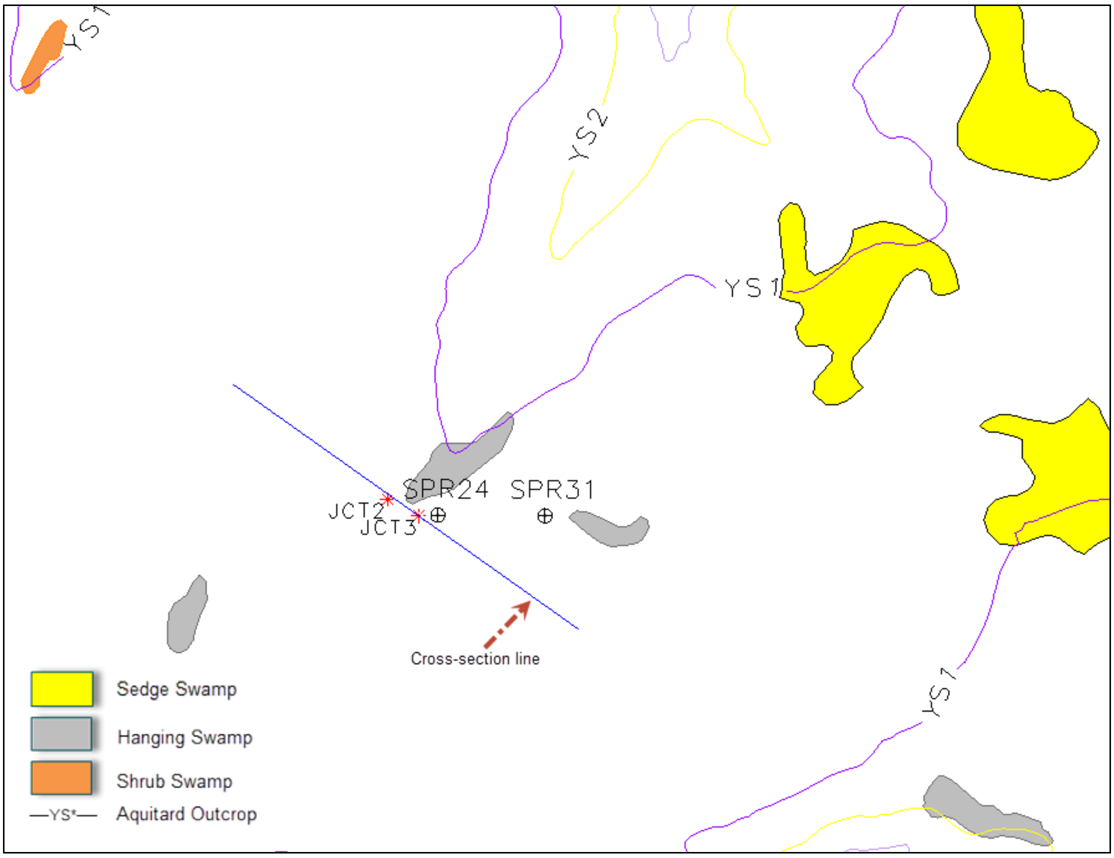

Figure 33 Plan of Junction Hanging Swamp

V. Narrow Shrub Swamp and Narrow South Shrub Swamp

Narrow Shrub Swamp

This shrub swamp consists of a 900 metre northern (lower) section (Narrow Shrub Swamp) and a 500m southern section (Narrow South Shrub Swamp) which both lie in a western tributary of the Wolgan River. Narrow Swamp has a fall of 35 metres, and is shown in longitudinal section below.

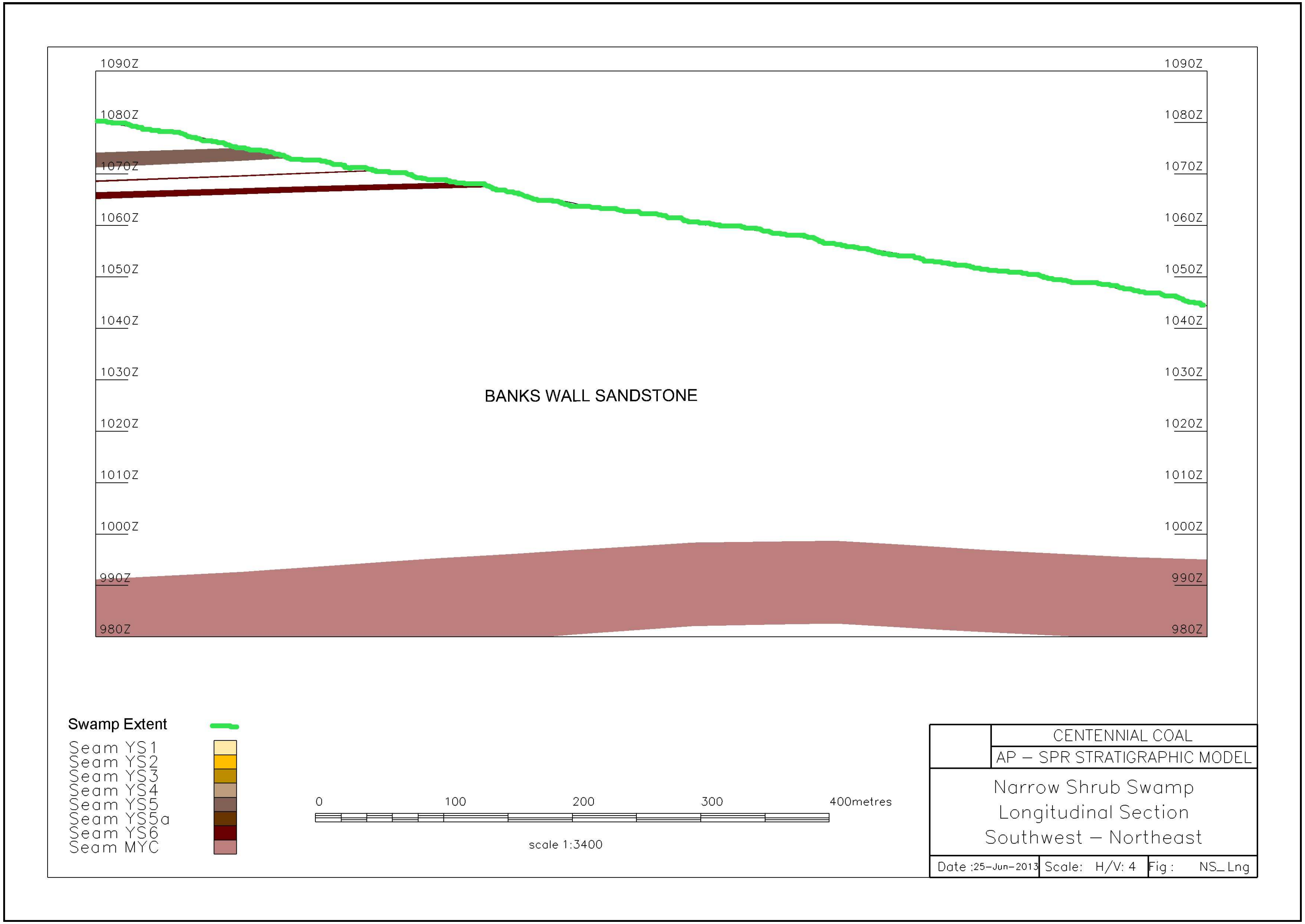

Figure 34 Longitudinal Section of Narrow Shrub Swamp

The lower (northern) reaches of this section of the swamp are stratigraphically located in the Banks Wall Formation as shown in Figure 34. Also, as shown, the southern section of Narrow Swamp lies stratigraphically between the YS4 and the YS6 horizons. Hence the Narrow Swamp Shrub Swamp is a "mixed-type" swamp.

Narrow Shrub Swamp terminates at 235887E 6304847 (GDA), before reappearing 0.25km to the south in the upper reaches of this tributary.

Figure 35 is a plan of Narrow Shrub Swamp and reflects the narrowness of the swamp due to the extensive presence of a Banks Wall substrate. However, because of the morphology of the swamp, the close proximity of the YS2, YS3, YS4 YS5 YS5a and YS6 aquitards create a hydrological environment conducive to maintaining adequate groundwater levels to sustain the presence and morphology of this swamp.

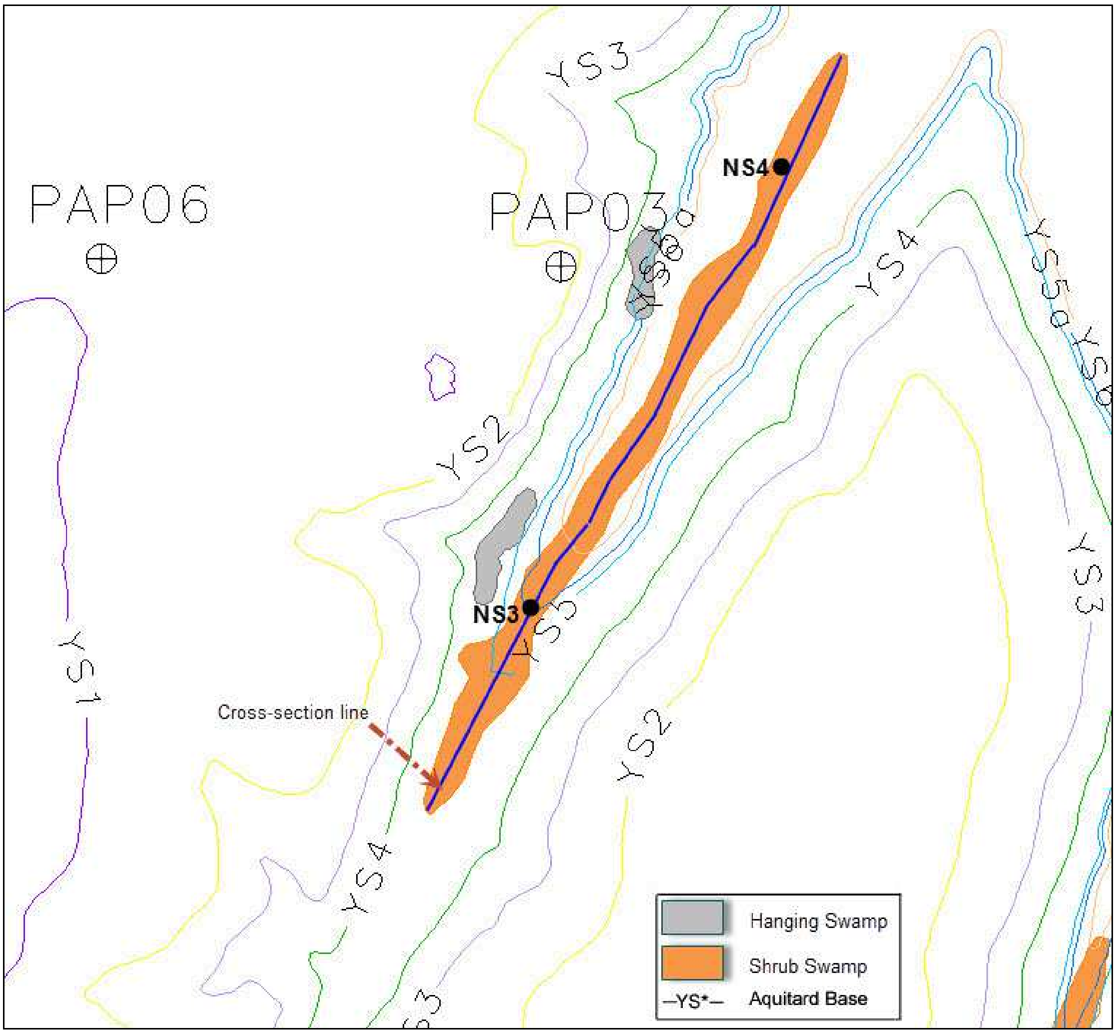

Figure 35 Plan of Narrow Shrub Swamp

Narrow South Shrub Swamp

The Narrow South Shrub Swamp resumes in the upper reaches of this tributary at 235758E 6304847 (GDA). Figure 34 shows a longitudinal section of this swamp, which is wholly contained within the Burralow Formation and has a fall of 20 metres. This section of Narrow South Swamp lies stratigraphically between the YS3 and the YS4 plies.

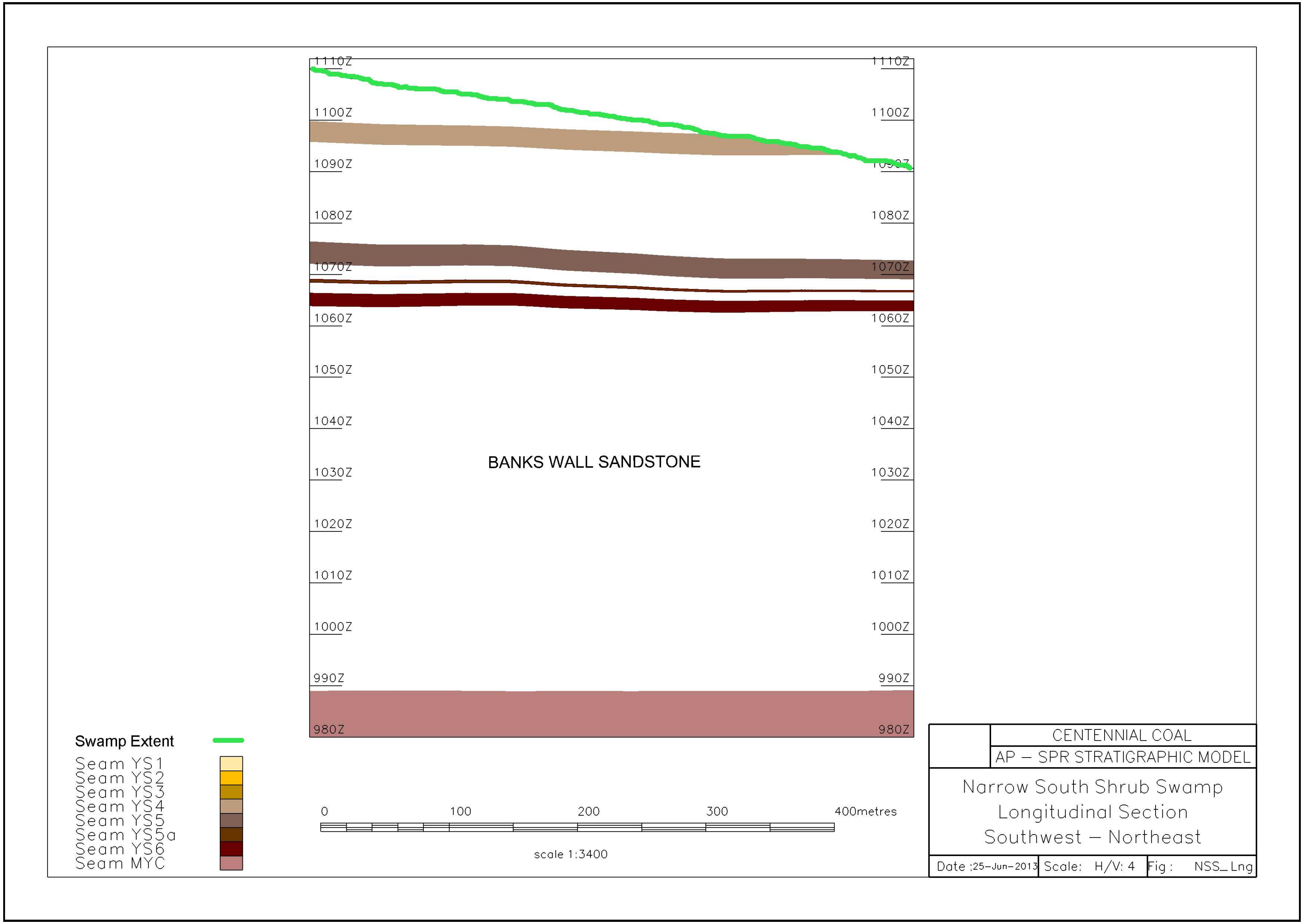

Figure 36 Longitudinal Section of Narrow South Shrub Swamp

Figure 37 is a plan of Narrow South Swamp. Stratigraphically the swamp lies between aquitard horizons YS3 and YS4, with YS1 and YS2 being groundwater retarding horizons which would support the development of the hanging swamp to the west of this swamp.

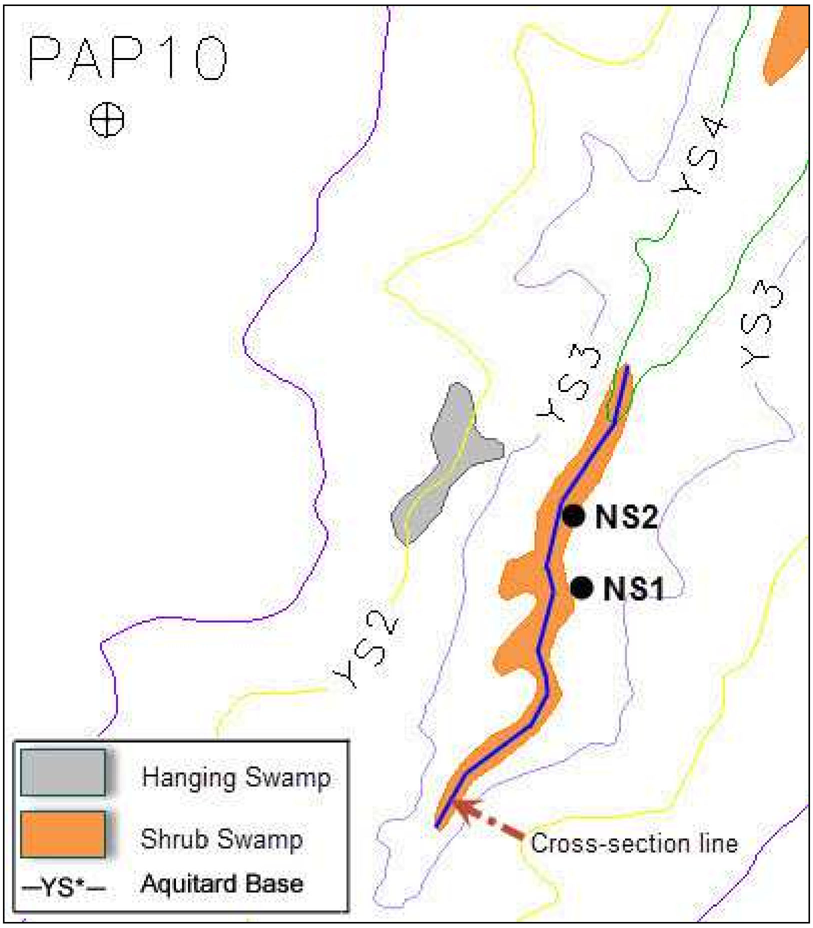

Figure 37 Plan of Narrow South Shrub Swamp

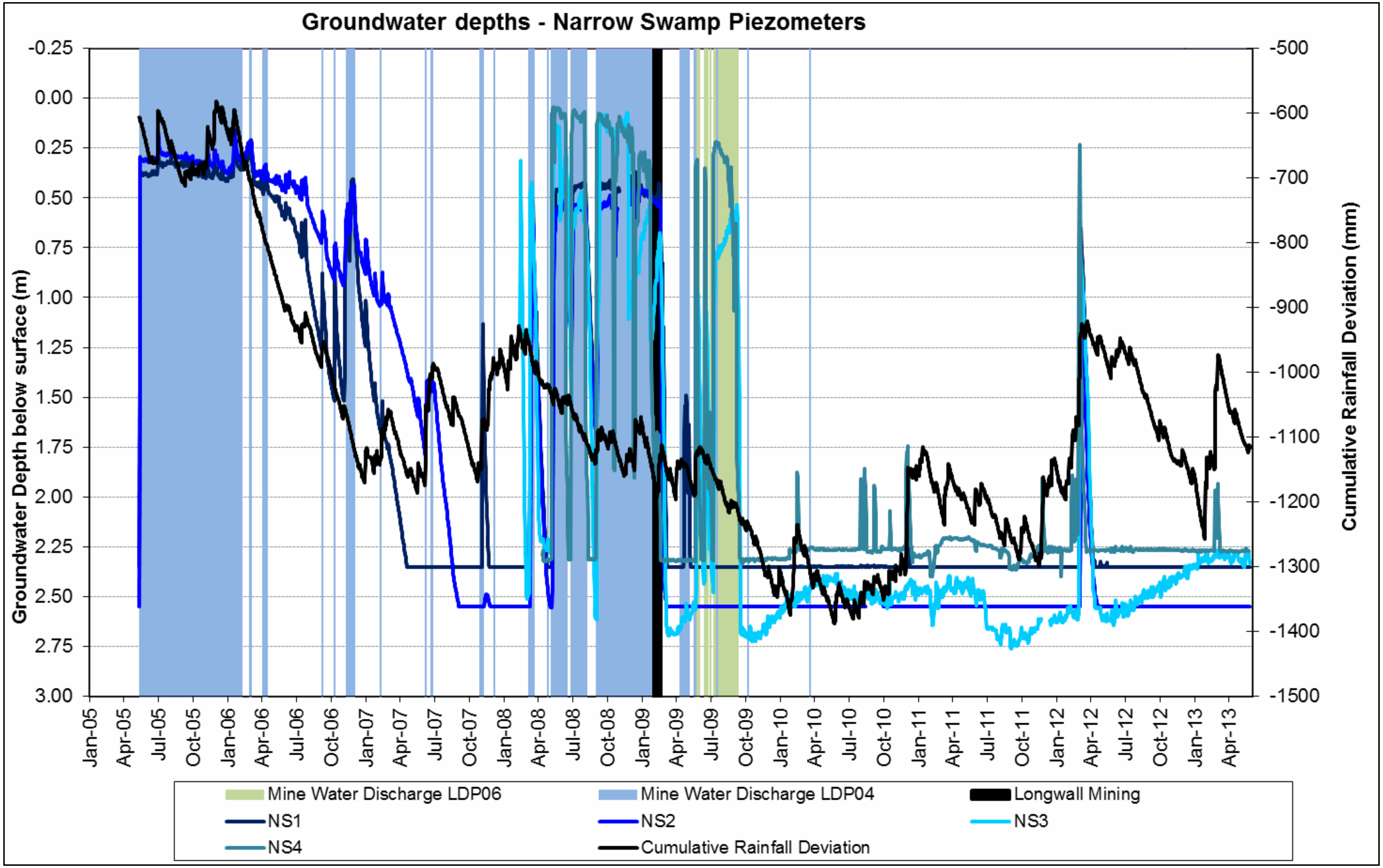

Figure 38 Hydrograph of Narrow Shrub Swamp

Figure 38 illustrates groundwater levels for both Narrow and Narrow South shrub swamps for the period January 2005 to April 2013. During this time span, two major discharge events from LPD04 occurred from June 2005 to March 2006, and from May 2008 to February 2009, as shown in blue in the above figure. A third discharge from LDP06 in mid 2009 is shown in green above. Piezometers NS1 and NS2 are located in Narrow Swamp while, piezometers NS3 and NS4 are situated in Narrow South Swamp (Figures 35 and 37). Since emergency discharges have ceased, the groundwater pattern of both swamps, which comprise the Narrow Swamp complex, have reverted to their natural pattern of displaying rainfall-dependent profiles. Hence piezometers NS1, NS2, NS3 and NS4 all register rainwater-dependent profiles, particularly in response to significant precipitation in April 2012.

Taken as a whole, both Narrow Shrub Swamp and Narrow South Shrub Swamp lie between the YS3 ply and the Banks Wall Sandstone and is considered a “mixed-type” swamp. Hence from the upper reaches to where this tributary joins the Wolgan River, this shrub swamp gradually changes position in the stratigraphic sequence from the “aquifer” between the YS3 and the YS4 horizons down to the Banks Wall Formation in its lower reaches.

VI. East Wolgan Shrub Swamp

The East Wolgan Shrub Swamp consists of a relatively small shrub swamp (150 metres in length) immediately south of the location at which two major tributaries join to form the Wolgan River. The East Wolgan Swamp in its entirety trends roughly north-south. This small northern extension of the swamp is situated wholly within the Banks Wall Sandstone and is located in the plan diagram below at the flexure point just north of where YS6 crops out.

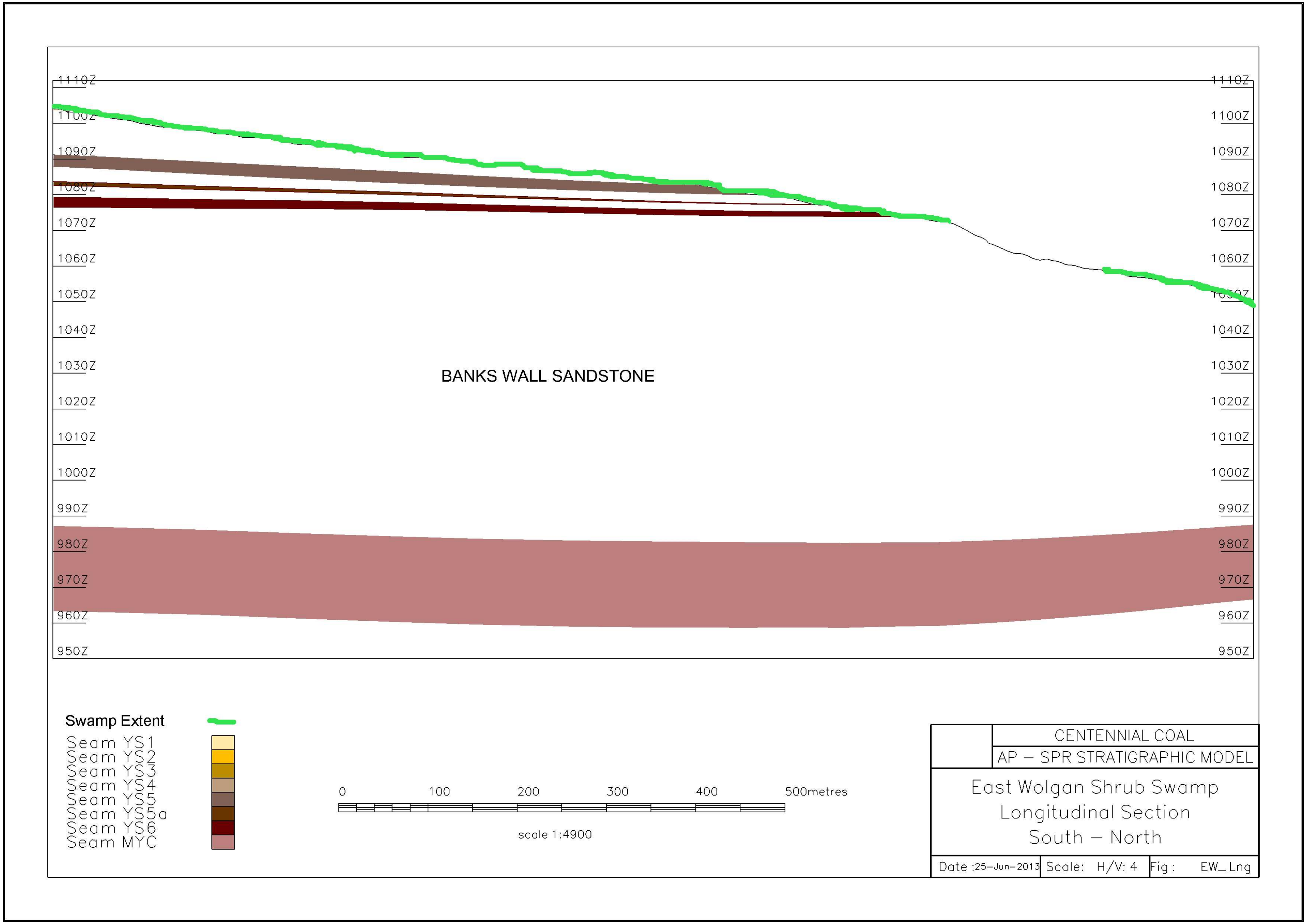

Figure 39 Longitudinal Section of East Wolgan Shrub Swamp

The main section of the East Wolgan Shrub Swamp is approximately 1km in length and trends roughly north-south (Figure 39). The extreme lower reaches of the main swamp, as with the northernmost extension discussed above, are stratigraphically located within the Banks Wall Formation, while the majority of the swamp is located in the Burralow Formation between the YS4 and the YS6 aquitards. To the east of this shrub swamp, as shown in Figure 40, there is a small hanging swamp which is associated with the YS1 and YS2 horizons.

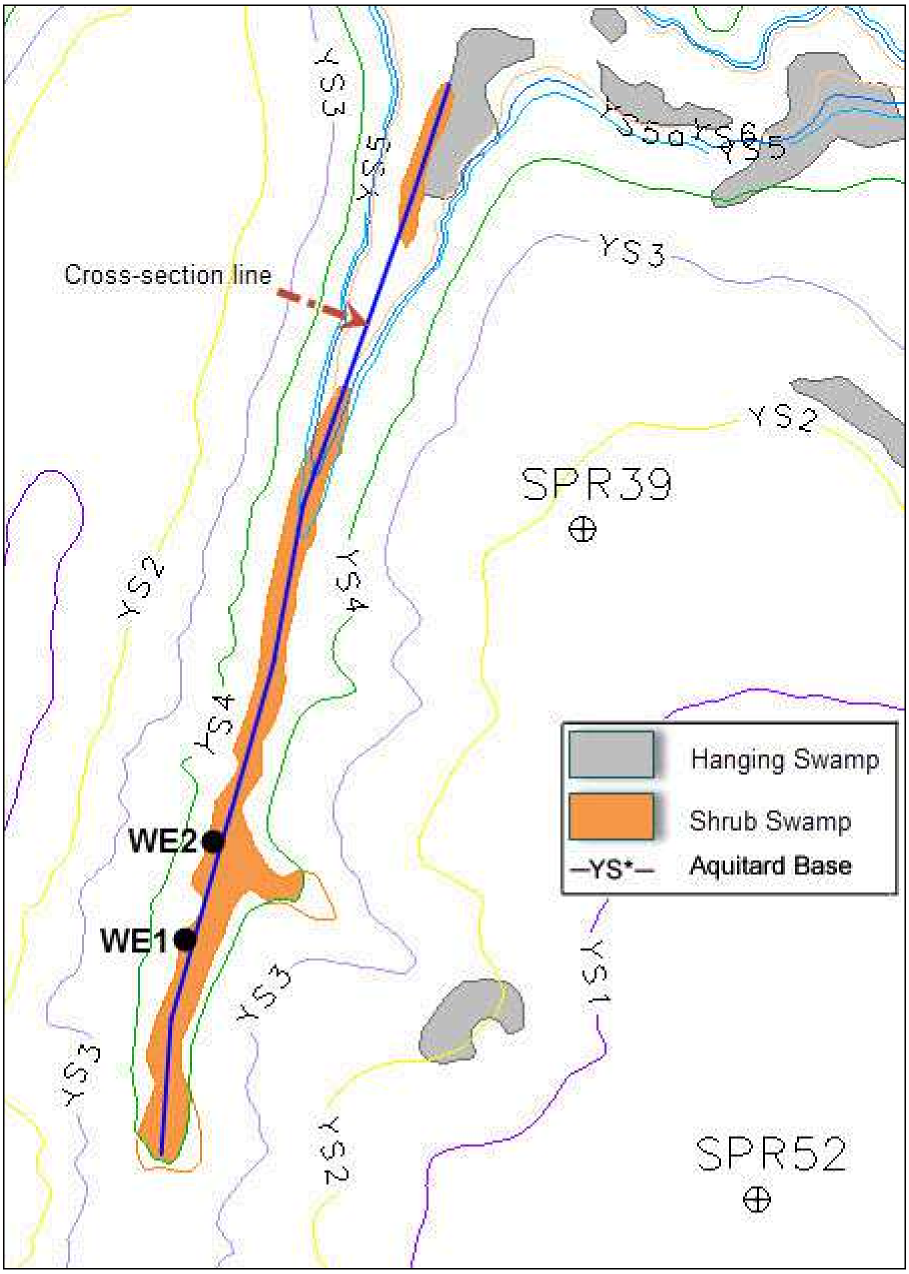

Figure 40 Plan of East Wolgan Shrub Swamp

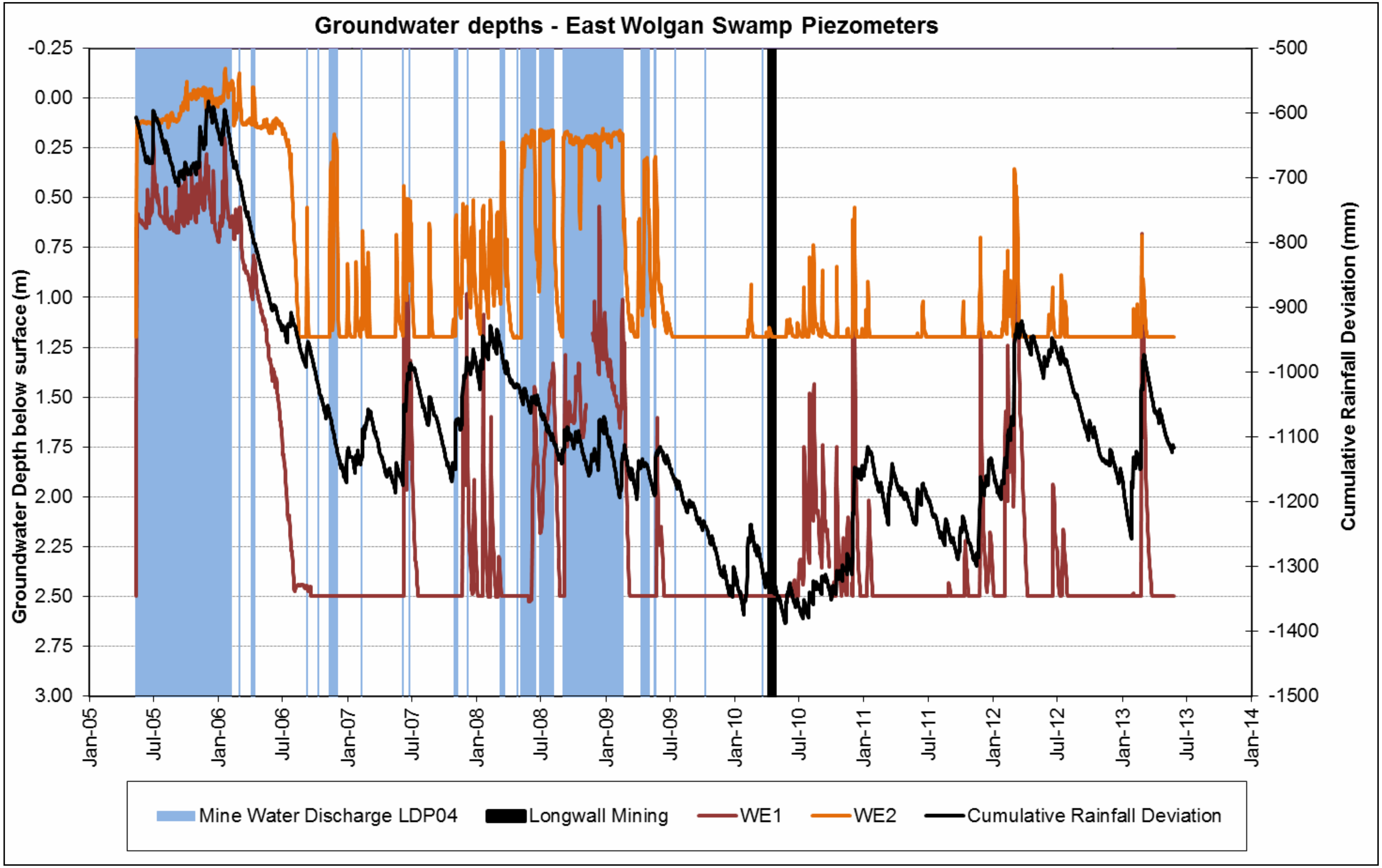

Figure 41 Hydrograph of East Wolgan Shrub Swamp

Like Narrow Swamp, East Wolgan Swamp has also been subjected to prolonged mine water discharge from July 2005 to mid-2006, and again in June 2008 to March 2009. Longwalling occurred during May 2010 (Figure 41). As with Narrow Swamp, the post-discharge groundwater levels have reverted to their natural pattern of displaying a rainfall-dependent profile in response to significant rainfall events. Post-discharge and post longwalling groundwater monitoring by piezometers WE1 and WE2 (Figure 40) display typical profiles for rainwater-dependent shrub swamps.

VII. Sunnyside West

Figure 42 is a cross-section through Sunnyside West Swamp which transects piezometer site SSW1. At this location, the piezometer hole is located above the full suite of the YS1 to YS6 aquitards in the Burralow Formation. Sunnyside West is a Newnes Plateau Rush Sedge Snow Gum Hollow Wooded Heath Grassy Woodland (NPRSSG).

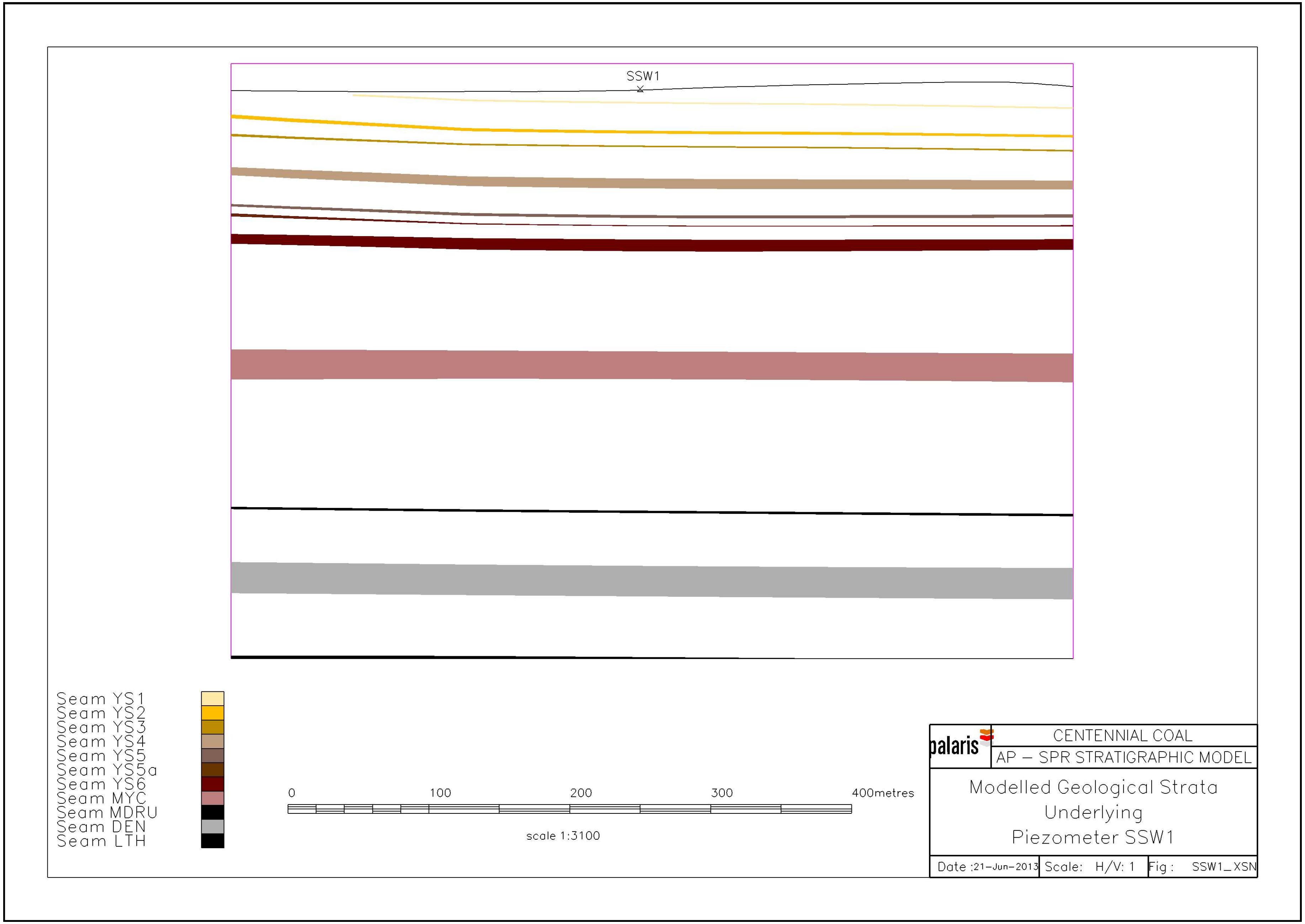

Figure 42 Cross Section through Sunnyside West Shrub Swamp

This is also illustrated in Figure 43, where the piezometer location is topographically higher than the uppermost aquitard in the area.

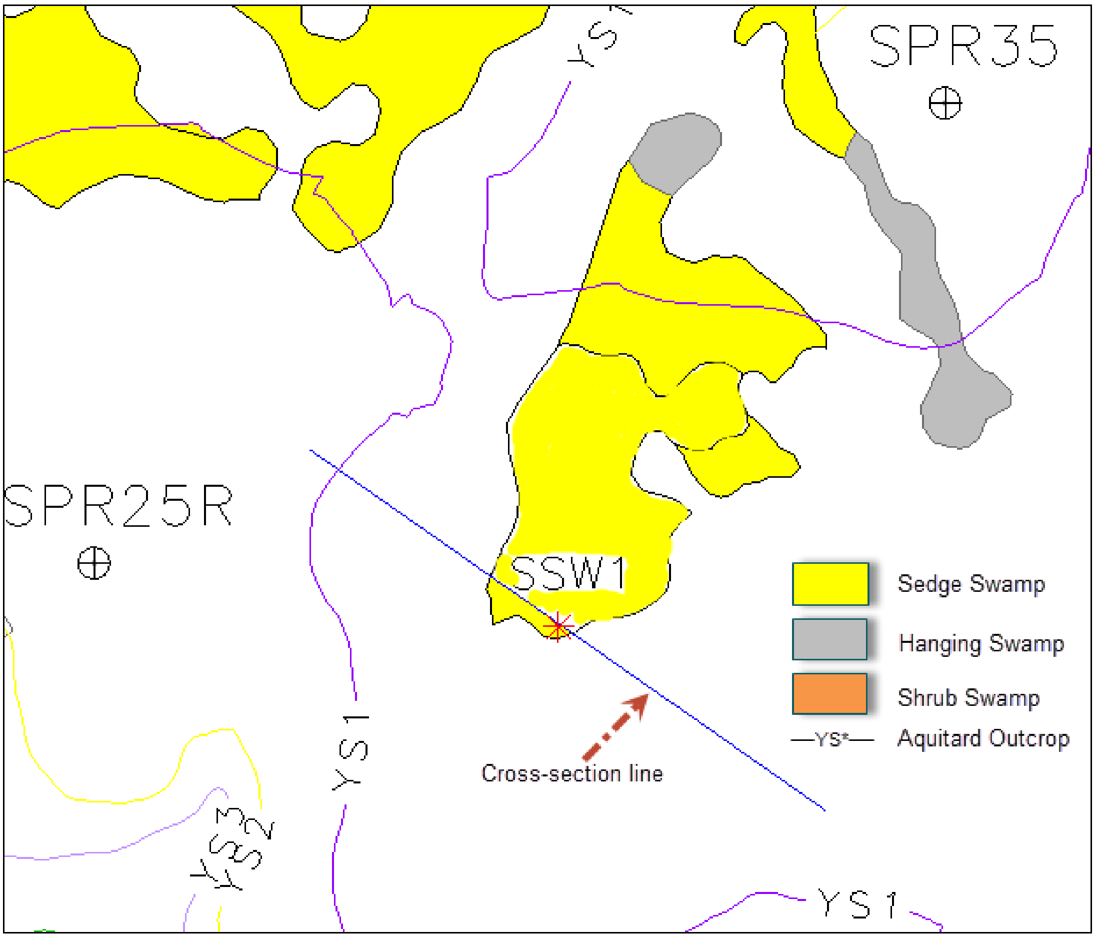

Figure 43 Plan of Sunnyside West Shrub Swamp

VIII. Sunnyside Shrub Swamp

The Sunnyside Shrub Swamp lies in the eastern tributary of the Wolgan River and consists of a principal swamp, approximately 1.5km in length, and a small (200m) shrub swamp at its northern extension. The principal swamp trends north-south with a fall of 38 metres.

At its northernmost extent, near the V-Notch Weir, the principal swamp is located between the YS4 and YS5 horizons, while its upper reaches are situated stratigraphically between the YS2 and the YS4 horizons. The small northern extension coincides with the outcrop of the YS5 unit. Sunnyside Shrub Swamp is the first such swamp to be situated within a tributary of either the Wolgan River or Carne Creek, the major waterways in the study area, to be contained completely within the Burralow Formation.

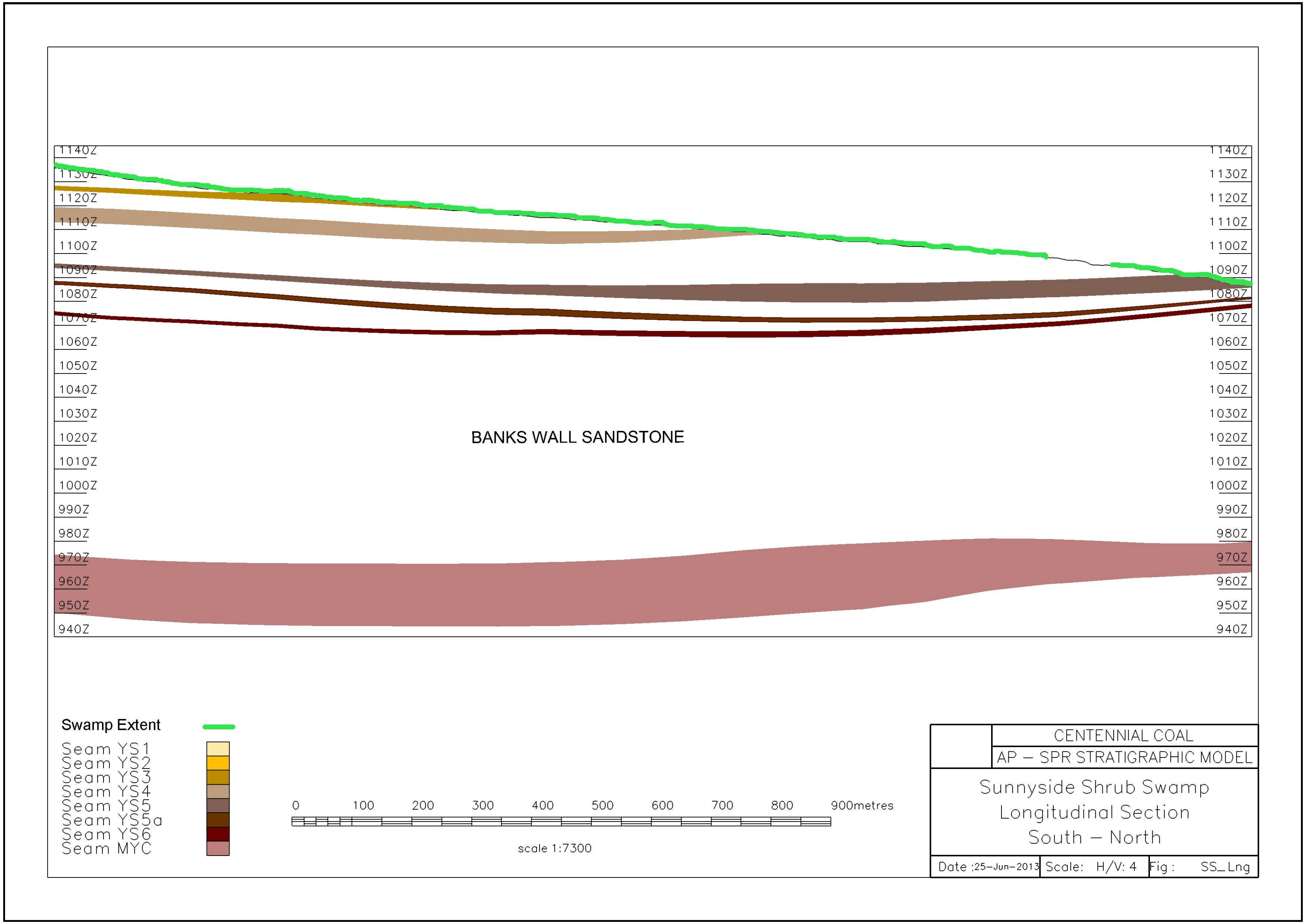

Figure 44 Longitudinal Section of Sunnyside Shrub Swamp

Figure 45 is a plan of Sunnyside Shrub Swamp and shows the association of the YS2 in the upper reaches of the swamp together with the YS3 and YS4 aquitards as potential seepage points for supplementary groundwater to enter the drainage line of the swamp as the gully cuts downwards through the stratigraphic sequence.

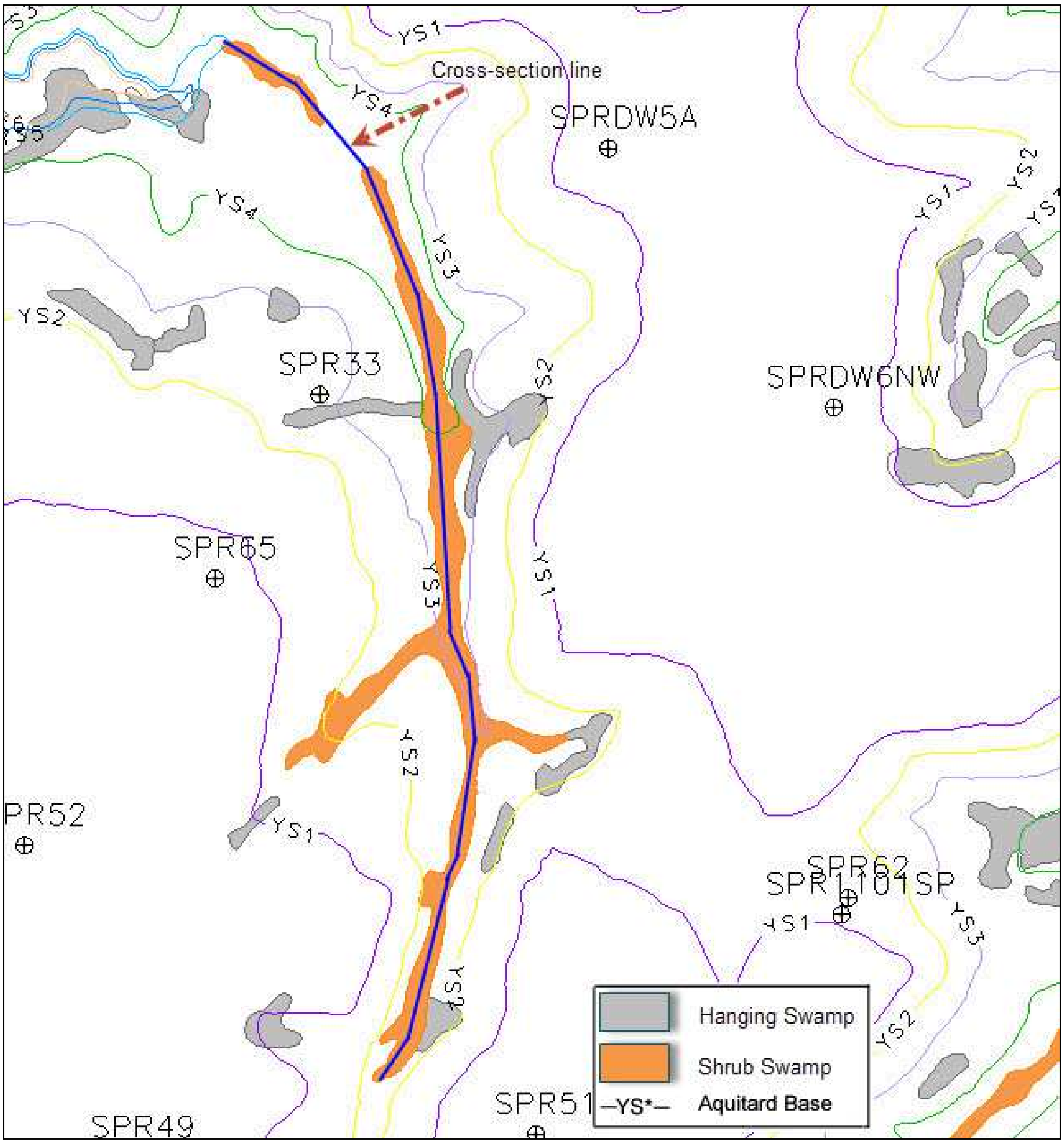

Figure 45 Plan of Sunnyside Shrub Swamp

Hanging swamps to the east and west of the shrub swamp are associated with YS1 and YS2 aquitards. The largest hanging swamp to the west grades downhill from a hanging swamp into a shrub swamp and a second, smaller hanging swamp in a small eastern tributary also grades into a shrub swamp, as shown above. This area needs to be ground-truthed to accurately delineate the relationship between the hanging and shrub swamps.

IX. Sunnyside East Shrub Swamp

Figure 46 is a longitudinal section of the Sunnyside East Shrub Swamp. It has a length of just over one kilometre and a fall of 50 metres. It is located wholly within the Burralow Formation.

This swamp lies stratigraphically between the YS4 and YS5 horizons as shown below.

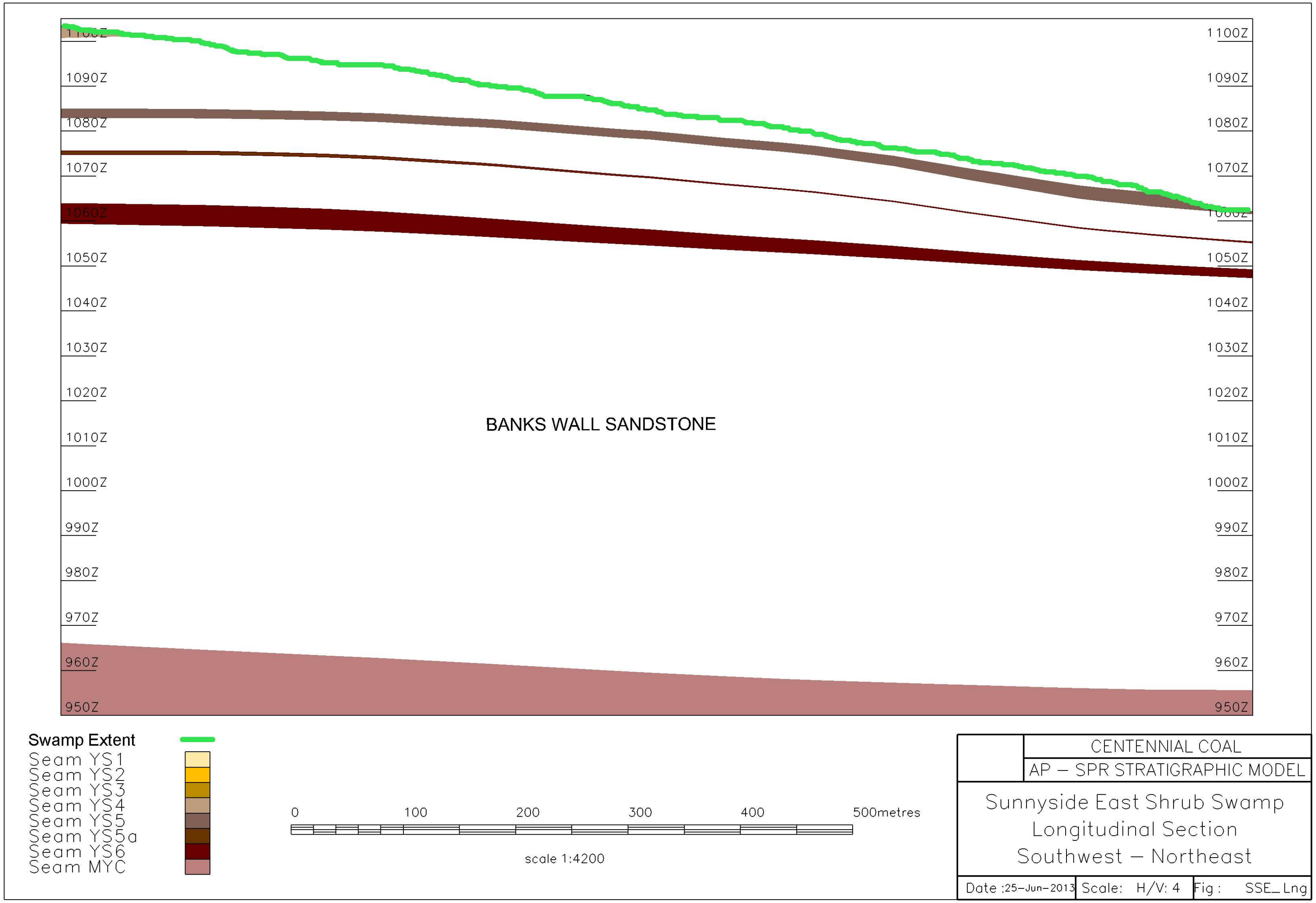

Figure 46 Longitudinal Section of Sunnyside East Shrub Swamp

In plan (Figure 47), the Sunnyside East Shrub Swamp is located between the Sunnyside Swamp to the west and the Carne West Swamp to the east. This swamp lies between the YS4 and YS5 aquitards and the host gully is a tributary of Carne Creek. The resistant cap of Sunnyside Ridge separates this swamp from Sunnyside Shrub Swamp to the west.

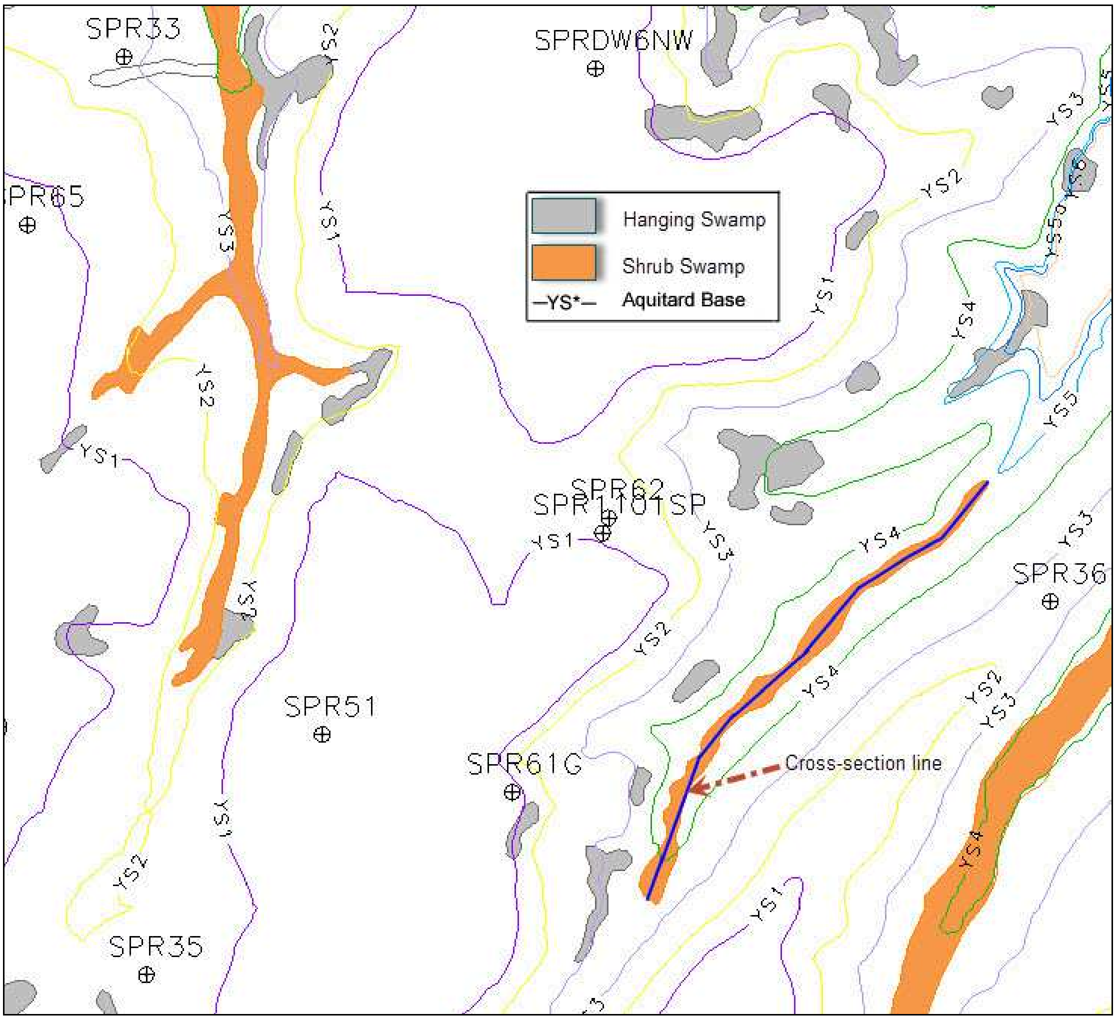

Figure 47 Plan of Sunnyside East Shrub Swamp

X. Carne West Shrub Swamp

This swamp was described in detail in Section 8.

13. Conclusions

Newnes Plateau Shrub Swamps (NPSS), Newnes Plateau Hanging Swamps (NPHS), and Newnes Plateau Rush Sedge Snow Gum Hollow Wooded Heath Grassy Woodlands (NPRSSG) are present within the Angus Place/Springvale lease areas. The present study focuses primarily on the Newnes Plateau Shrub Swamps. Not all shrub swamps in the Angus Place/Springvale lease have been included in the current study.

The occurrence and sustainability of the Newnes Plateau Shrub Swamps are multifactorial, involving a complex interplay between topography, hydrological regimes and geology.

The formation and persistence of the Newnes Plateau Shrub Swamps and the Newnes Plateau Hanging Swamps are intrinsically associated with the Burralow Formation, that is, without the presence of the latter, the presence of both swamp types would not occur in the study area.

The Burralow Formation with its suite of aquitards decreases the hydraulic gradient and thus reduces the degree of percolation of groundwater through the varying lithologies of this formation to the units below. Instead, much of the groundwater present within the Burralow Formation is redirected laterally down-dip to discharge points in nearby gullies. Precipitation is thus supplemented by moisture from groundwater sources to form several discharge horizons along the course of the host creek in which a shrub swamp is located.

In the Burralow Formation, where aquitard units are relatively plentiful, the opportunity for groundwater supplementation via valley wall seepage is common. Groundwater supplementation also occurs when aquitards outcrop within the floor of creeks, thus providing a direct means of groundwater input into the host creek. Valley wall seepage together with direct in-gully input of groundwater via aquitards permits continuity of hydration during periods of drought.

The presence of numerous hanging swamps throughout the study area is also an important indicator of the amount of water contained within the aquifer/aquitard systems within the Burralow Formation.

The Newnes Plateau Shrub Swamps are reliant on the Burralow Formation for their presence and development, although the study area does contain shrub swamps which are stratigraphically located solely within the Banks Wall Sandstone. This latter shrub swamp subtype displays an areally restricted morphology and occurs primarily in steep-sided, narrow gullies due to the underlying Banks Wall Sandstone substrate, which is less easily eroded than the lithologies which comprise the overlying Burralow Formation.

In general, shrub swamps occurring wholly within the Banks Wall Sandstone have less access to seepage at discharge points along creek beds due to the absence of aquitard horizons. Consequently this restricts the size and breadth of this shrub swamp type. Significantly, however, with the exception of shrub swamps in the

Wolgan River, the Banks Wall-type shrub swamps are invariably adjacent to subcrops of the lower Burralow Formation aquitard sequence and therefore receive substantial groundwater seepage from these horizons.

Burralow-type shrub swamps are typically more areally extensive than the Banks Wall equivalents, with generally longer and broader morphologies. This is due not only to the presence of the Burralow aquitards, but the lithological differences between the Burralow Formation and the Banks Walls Sandstone. The former promotes more areally extensive swamps while the latter, with its sandstone-based lithology, encourages steeper and deeper gullies due to its relative resistance to erosion.

In Banks Wall and "mixed-type" swamps, the lack, or partial lack, of aquifers respectively, inhibits the potential groundwater input and results in smaller, drier and narrower swamps. However, it is important to note that Banks Wall-type shrub swamps, and the "mixed-type" swamps which occur at subcrop boundaries between the Burralow Formation and the Banks Wall Sandstone, still receive seepage from the aquitard/"aquifer" sequences located stratigraphically above them.

Even in shrub swamps located solely within the Burralow Formation, the thickness of the latter can influence the extent of the size of the resultant shrub swamp. High elevation Burralow-type shrub swamps, that is, those in the upper reaches of a particular swamp, may gain groundwater solely from an unconfined aquifer and may be generally smaller in size, unless they are located adjacent to a large recharge area.

Hence, the extensive 1150+ metre ridge system in the Springvale lease, where the Burralow Formation is at its thickest, provides both a substantial precipitation recharge zone plus an array of aquitards to promote groundwater retention in the streams which flow from this watershed area, both to the north and south of the ridge line. It is for this reason that shrub swamps in the south-east of the Springvale lease are, in general, wetter and broader than those in the remainder of both leases.

Floristic differences are also apparent between the upper reaches of Burralow-type shrub swamps, where there is less opportunity for sequential aquifers to supply seepage as the gully moves lithologically downwards, as compared to the lower reaches of these swamps which are typically permanently waterlogged. Similarly, vegetation species differ between Burralow-type and Banks Wall-type shrub swamps due to varying availabilities of groundwater. This, along with hydrological inputs into the shrub swamps and hanging swamps will be discussed in a subsequent report.

Longwalling has resulted in groundwater level changes in the lower reaches of Kangaroo Creek due to mining-induced cracking. It is expected that over time any cracks present will gradually infill with sediment and that these effects will be temporary. However, the perennial spring which is fed by the aquifer-aquitard systems within the Burralow Formation was unaffected by mining and the creek remained permanently wet below the spring. This, together with the presence of healthy hanging swamps along the valley walls surrounding Kangaroo Creek shrub swamp, indicates that the water supply from the spring and valley wall seepage has not been interrupted by longwall mining and that groundwater inputs to the swamp hydrological system remain intact.

The available evidence indicates that underground mining has not resulted in any long-term negative effects on Kangaroo Creek Shrub Swamp. It is obvious from the hydrographs presented for Narrow and East Wolgan Swamps that mine water discharge had major impacts on the hydrology of these swamps over an extended period. It is also clear that mine water discharge caused impacts to Narrow and East Wolgan Swamp vegetation and that the combination of mine water discharge and mine subsidence caused localised swamp peat slumping events and cavity formation in East Wolgan Swamp in an area where a combination of contributing factors were present (including mine water discharge, topography, structural geology and mine design).

In the locations where the piezometers are installed, the baseline swamp hydrology at East Wolgan and Narrow Swamps has been established as periodically waterlogged, when the influence of mine water discharge is removed. Based on the hydrographs, the post-mining/ post-mine water discharge swamp hydrology appears to be consistent with the periodically waterlogged baseline hydrology.

By contrast, West Wolgan, Junction, Sunnyside West and Sunnyside swamps, all subjected to longwalling, display no indications of mining-induced effects to the groundwater system on which these swamps are reliant.

Finally, the presence of the Newnes Plateau Shrub Swamps are dependent on topographic, lithological and hydrological factors, which are subsequently reflected in the morphology, floristics and hydrology of the resultant shrub swamp. The manifestation of these complex interacting factors is most readily observable in the change in swamp appearance and swamp vegetation from the northern extension of the Angus Place lease through to the south and east of the Springvale Colliery lease.

14. References

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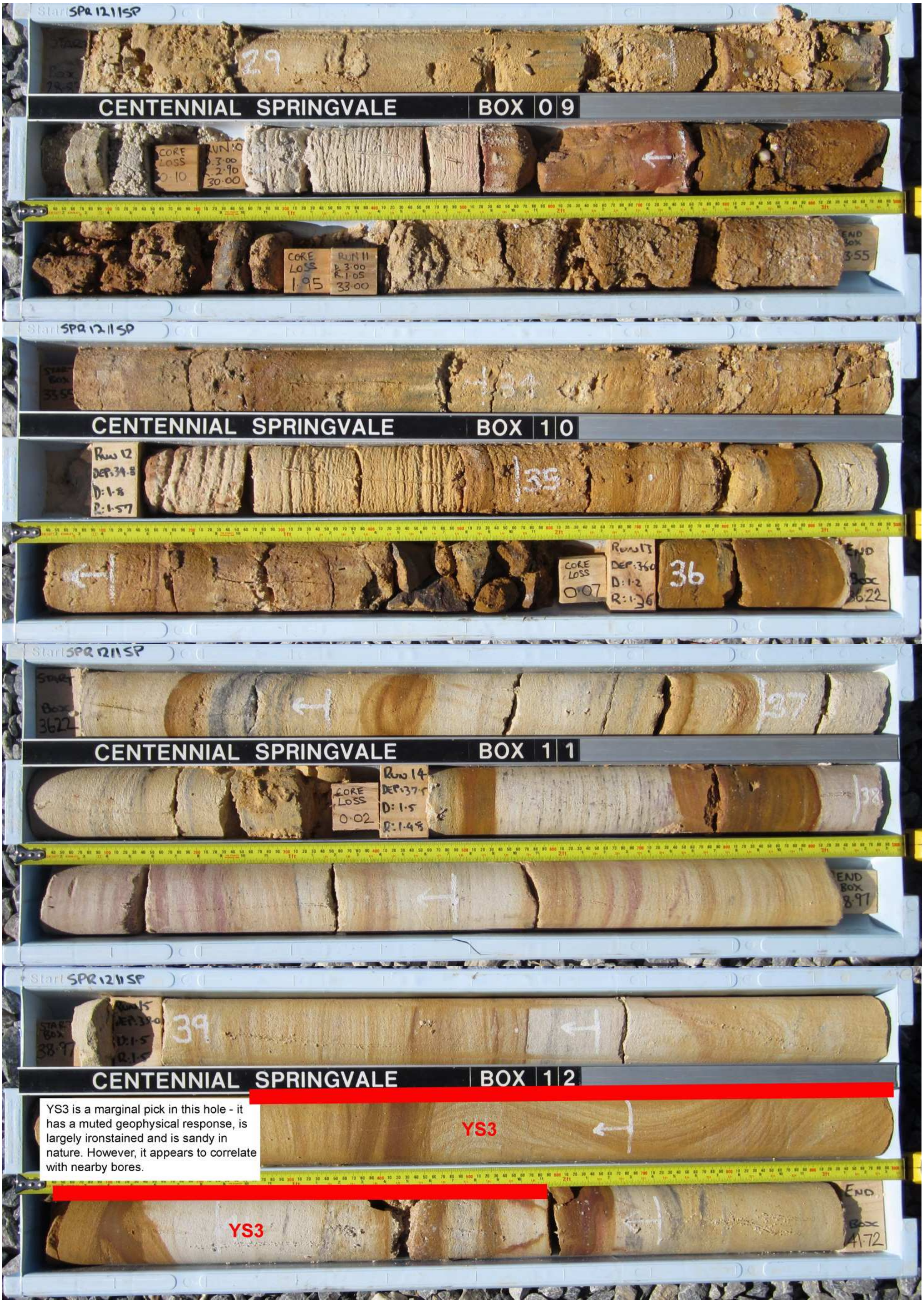
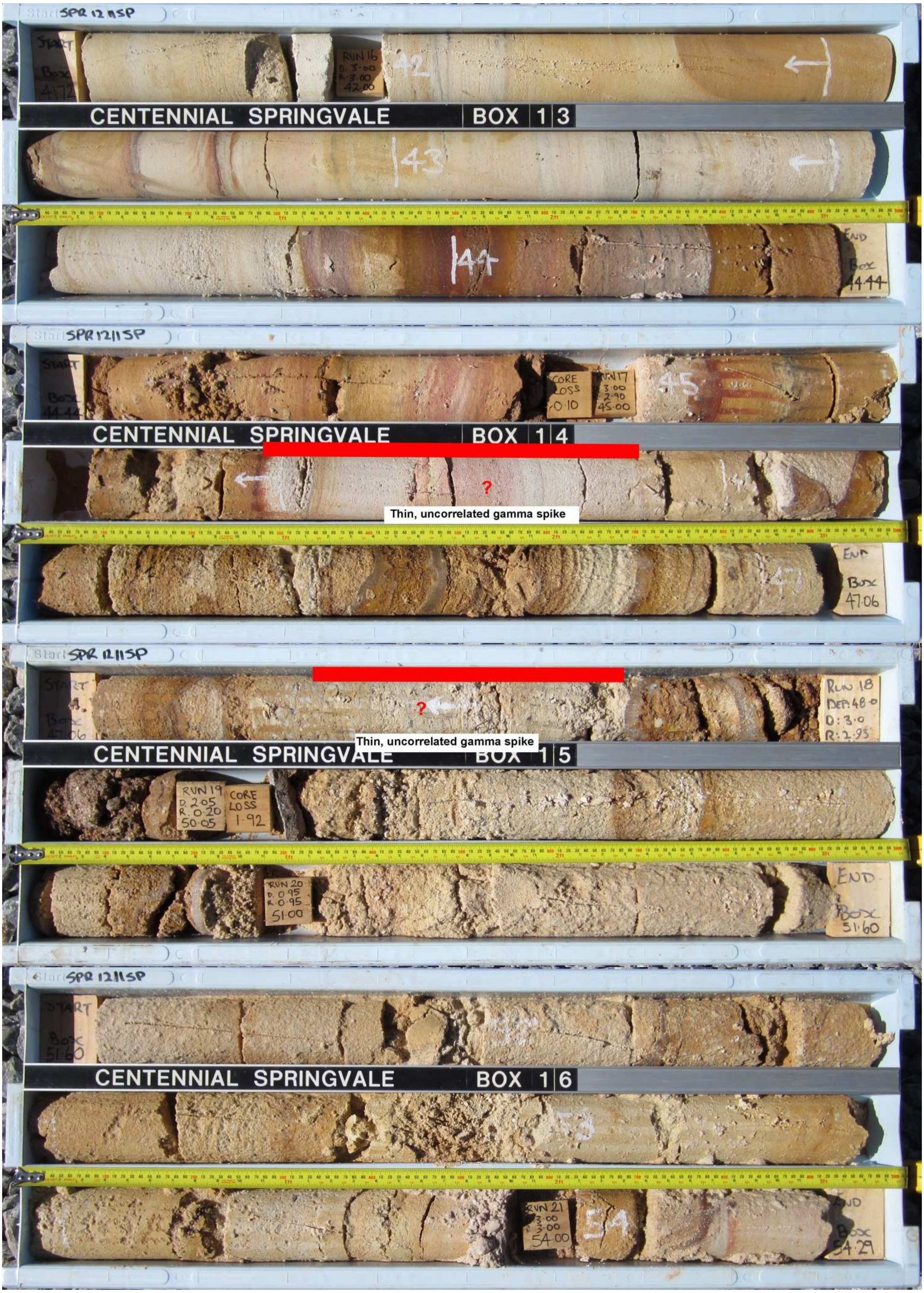
Appendix A

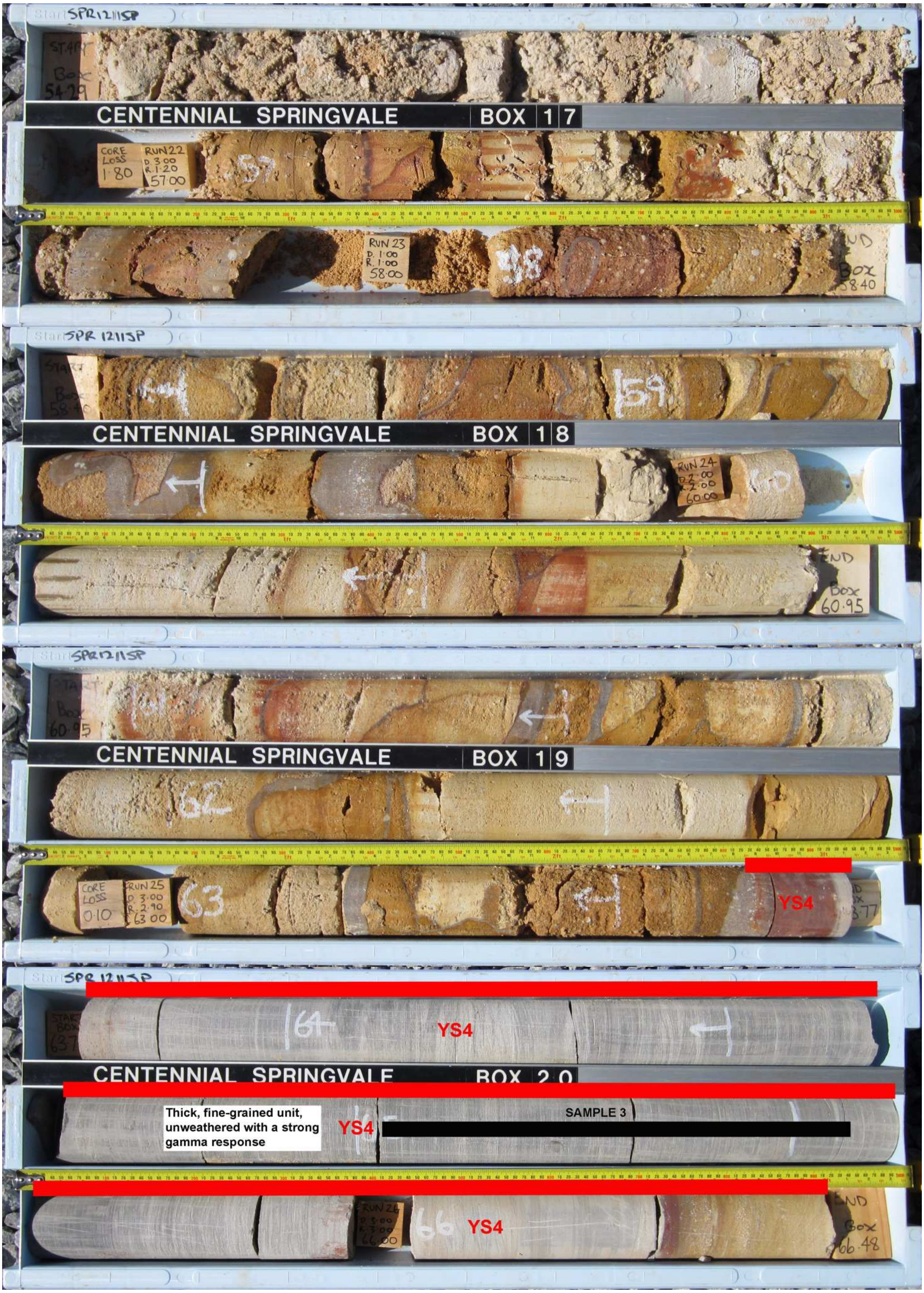
Core Photographs of SPR1211SP

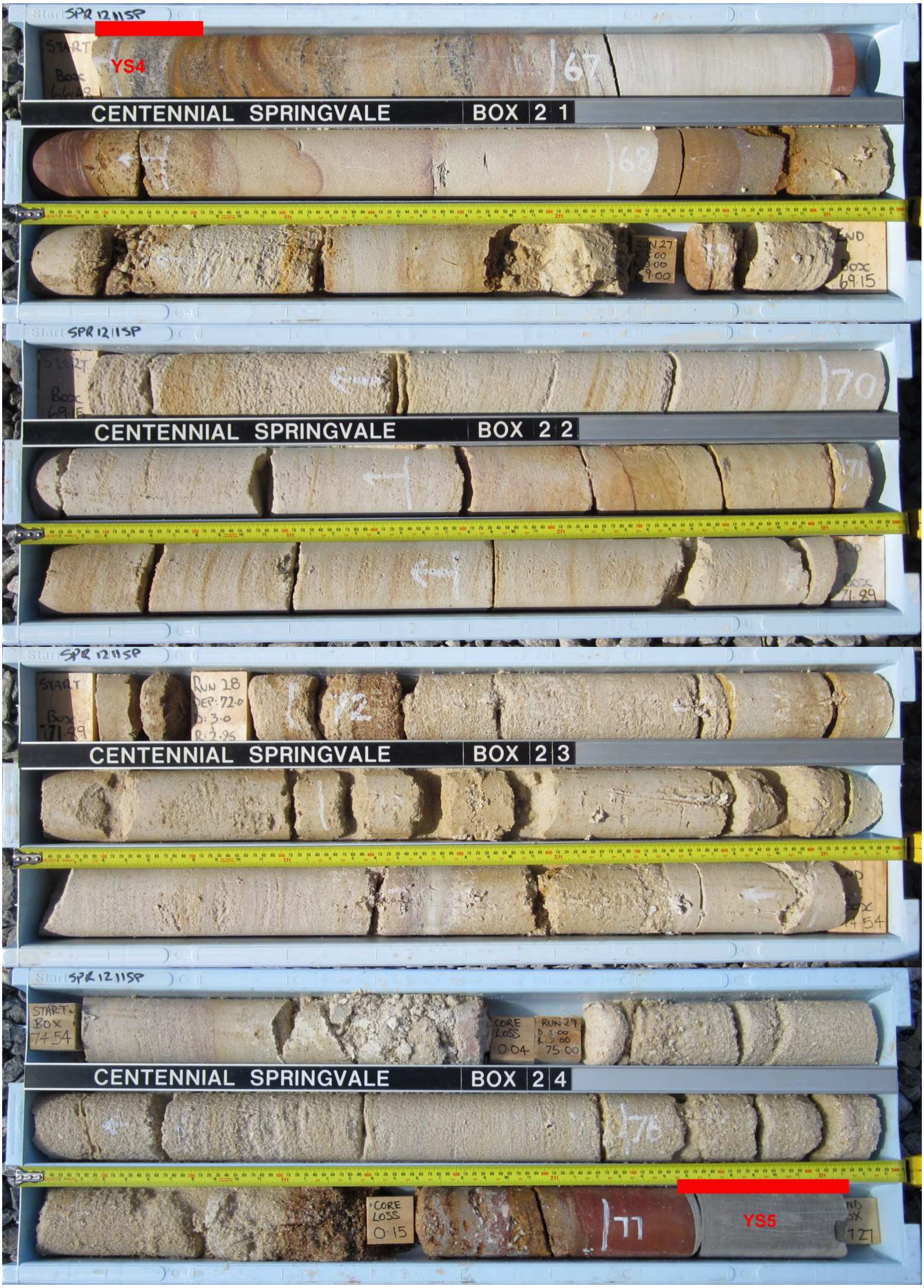
Note: Red bar indicates region of relatively high gamma response in downhole geophysics – see above graphic log.


CENTENNIAL SPRINGVALE BOX 05
CENTENNIAL SPRINGVALE BOX 06
CENTENNIAL SPRINGVALE BOX 07
YS2 has a 'muted' geophysical response, probably because it is laminated sandstone/siltstone. However, it is relatively unweathered.
YS2
YS2
SAMPLE 2
CENTENNIAL SPRINGVALE BOX 08


CENTENNIAL SPRINGVALE BOX 09
CENTENNIAL SPRINGVALE BOX 10
CENTENNIAL SPRINGVALE BOX 11
CENTENNIAL SPRINGVALE BOX 12
YS3 is a marginal pick in this hole - it has a muted geophysical response, is largely ironstained and is sandy in nature. However, it appears to correlate with nearby bores.
YS3
YS3


CENTENNIAL SPRINGVALE BOX 13
CENTENNIAL SPRINGVALE BOX 14
Thin, uncorrelated gamma spike
?
Thin, uncorrelated gamma spike
?
CENTENNIAL SPRINGVALE BOX 15
CENTENNIAL SPRINGVALE BOX 16


CENTENNIAL SPRINGVALE BOX 17
CENTENNIAL SPRINGVALE BOX 18
CENTENNIAL SPRINGVALE BOX 19
YS4
CENTENNIAL SPRINGVALE BOX 20
YS4
Thick, fine-grained unit, unweathered with a strong gamma response
YS4
SAMPLE 3
YS4


YS4
CENTENNIAL SPRINGVALE BOX 21
CENTENNIAL SPRINGVALE BOX 22
CENTENNIAL SPRINGVALE BOX 23
CENTENNIAL SPRINGVALE BOX 24
YS5


SAMPLE 4
YS5
CENTENNIAL SPRINGVALE BOX 25
YS5
YS5
YS5
CENTENNIAL SPRINGVALE BOX 26
Very thick, fine-grained unit, unweathered with a strong gamma response. Unusually thick ply, which may be due to convergence of YS5, 5a and possibly 6
YS5
YS5
YS5
CENTENNIAL SPRINGVALE BOX 27
YS5
YS5
YS5
SAMPLE 5
CENTENNIAL SPRINGVALE BOX 28
YS5
YS5
?
This sandstone unit has a similar gamma response to the fine-grained material above. It is also unweathered.

YS6
YS6
YS6 nominally picked at the base of the extended high-gamma interval; basal 0.15m is finer grained. It also marks the end of the non-weathered interval.
Top of Banks Wall Sandstone - weathered to a considerable depth, and lacking in gamma spikes.
CENTENNIAL SPRINGVALE BOX 29
CENTENNIAL SPRINGVALE BOX 30
CENTENNIAL SPRINGVALE BOX 31
CENTENNIAL SPRINGVALE BOX 32