A FLORA AND VEGETATION SURVEY OF NORTH KIMBERLEY MOUND SPRINGS, MT ELIZABETH STATION

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SUMMARY

Flora and vegetation surveys were conducted on four occurrences of a Mound Spring threatened ecological community on Mount Elizabeth Station in the Kimberley Region of Western Australia in June 2016.

Six permanent quadrats were established to describe the flora and vegetation in detail and enable replicate monitoring of long-term condition changes.

The TEC occurrences are centred on sedgelands and grasslands almost completely devoid of trees and shrubs due to a waterlogged seepage zone. At the margins are associated woodlands, affected by the hydrology of each mound spring especially immediately upslope and or downslope of the spring, and the TEC boundaries encompass this complex of communities. In particular, a boggy fernland between the spring and adjacent river is a unique fire protected area with unusual plant assemblages and likely unusual fungal diversity.

The general condition of the mound springs was excellent. Some minor cattle damage was noted where cattle had encroached into fenced areas. A total of nine plant weed species, all in low numbers, were recorded within the TEC boundaries.

A total of 122 plant species were found across the mound springs and their associated complexes.

Seven plant species are considered useful indicators of mound springs, since their occurrence is almost entirely restricted to mound springs in Western Australia. Eight plant species are considered to have Priority Conservation status in WA.

The key threats identified for the mound spring TEC are: grazing, hydrological changes (e.g. groundwater extraction), feral animals, weed invasion, altered fire regimes, and potential tourism development.

Management recommendations

- Maintain, and repair existing fences where required at all four mounds springs.
- Seek to fence additional areas of the mound spring complex at **Waterfall Yard Spring**.
- Seek to fence eroded drainage channels on the south east side near the river, and the north eastern edge of the core seepage zone at **Middle Spring**, that are not currently encompassed by fencing. Seek to fill erosion channels with rock.
- Map significant weed/s and control/eradicate them.
- Design and implement a project to determine the hydrological drivers of the mound spring ecosystems.
- Design and implement a monitoring program that utilises quadrats established during the current survey. This will probably require establishment of a more comprehensive network of quadrats, and should be designed to provide information about the success of land management in the sensitive environment of the mound spring ecosystem.

BACKGROUND

The 'Organic mound spring sedgeland community of the north Kimberley Bioregion' (north Kimberley mound springs) was endorsed as a vulnerable threatened ecological community (TEC) by the WA Minister for the Environment on 8 May 2002. The community is distinguished in particular by the invertebrate biota that inhabit them, and also the sedgelands/grasslands that typify the core seepage zones of the springs. Most other types of mound springs in the Kimberley Region are vegetated with forest or woodland.

There are nine listed occurrences of the north Kimberley mound springs: four on Mt Elizabeth Station, four on Drysdale River Station, and one on Gibb River Station. The total area of the nine occurrences is less than 100 ha, and all occur on pastoral lands. Several likely additional occurrences are known but have not been surveyed or included on the corporate TEC database.

Mt Elizabeth Station is located approximately 300km west of Kununurra, about 10km north of the Gibb River Rd. In 1999, the aquatic invertebrate fauna was sampled at Waterfall Yard spring on Mt Elizabeth Station. Halse (2001) described this wetland as worthy of conservation based on the importance of the particular invertebrate taxa present.

All known occurrences of this community are subject to the impacts of cattle. Three of the eight occurrences were partially fenced to exclude cattle when initially surveyed in 1999. However, maintenance of the fences was at that time found to be inconsistent and on one of the occurrences the fence was completely ineffective for three consecutive years between 1999 and 2001. During this time a severe erosion gully had developed at the point of outflow and had spread several meters into the mound spring landform. Another unfenced occurrence that was heavily impacted by cattle was also considered to be at serious risk from a large active erosion gully. This erosion increased in severity between inspections in 2001 and 2002.

An inspection of all the east Kimberley mound springs, excluding Black Spring, was conducted in 2009. Management agreements between the landholders and Parks and Wildlife were signed in 2011 and following this most of the mound springs were fenced during 2012–2013.

OBJECTIVES

A survey of various aspects of the biota of the north Kimberley mound springs on Mt Elizabeth Station was completed in June 2016 by Parks and Wildlife staff, a consultant botanist and Wilinggin traditional owners. This work was part of a broader biodiversity survey program on and off the conservation estate, funded under the Kimberley Science Conservation Strategy. Surveys included vertebrate and invertebrate fauna, flora and vegetation, and wetlands. This report covers the surveys of the flora and vegetation of the four occurrences of the north Kimberley mound springs TEC completed by Matthew Barrett and Valerie English between 14-20 June 2016.

The survey was completed to gather information as a basis for a more detailed description of the floristics and vegetation of the TEC. The information gathered was also used to provide recommendations about urgent management actions, will provide a basis for future monitoring, and

will assist development of a recovery plan to guide future management in the longer term. The recovery plan will include descriptions of the substrate, floristics, vegetation structure, condition, threats, and recommendations for management.

Other work that has significant linkages to this survey of the springs is the invertebrate surveys (conducted at five organic North Kimberley mound springs and at Black Spring in 2016) and vertebrate survey of one spring in 2016 (with detailed survey of the Gibb River and Drysdale River mound springs proposed for 2017-18). The results of these studies will have a significant influence on the content of the recovery plan for the North Kimberley mound springs.

METHODS

The following four mound springs were surveyed as follows:

- Waterfall Yard Spring
    - 3 quadrats established:
        - 50x50m - core seepage zone
        - 50x50m - woodland (dampland) adjacent to seepage zone
        - 40x60m – fernland downslope of core seepage zone
    - general vegetation descriptions across mound spring complex
    - flora list for vegetation of the mound spring complex.
- Middle Spring
    - 1 quadrat established (50x50m) in core seepage zone
    - flora list for vegetation of the mound spring complex.
- Gap Spring
    - 1 quadrat established (50x50m) in core seepage zone
    - flora list for vegetation of the mound spring complex.
- Mud Spring (sometimes also called Kangaroo Spring)
    - 1 quadrat established (50x50m) in core seepage zone
    - flora list for vegetation of the mound spring complex.

Quadrats were permanently marked with 1.6m star pickets with yellow caps in each corner. The north east corner pegs were marked with white stripes denoting the quadrat number (eg 2 stripes = Q2). As the quadrats are permanently marked, they are suitable for future scoring and analysis of change, for monitoring purposes.

Flora specimens were collected from the central core mound spring seepage areas, and the damplands that surround the springs. Appendix 1 provides flora lists for the mound spring complexes. The flora specimens will be provided to the WA Herbarium for lodging where suitable (collection numbers M.D. Barrett & V. English MDB 5274-5405, only a subset submitted). Following identification, the data will be added to the corporate TEC/PEC database. Samples were also taken from flora collections for DNA analysis. Incidental collections of fungi were also made, although a detailed survey was not possible with the available resources.

The quadrat information for each site include:

- GPS location

- soil and landform
- comprehensive flora list
- vegetation structure
- vegetation condition
- threatening processes
- management recommendations

These data will be added to the corporate TEC/PEC database.

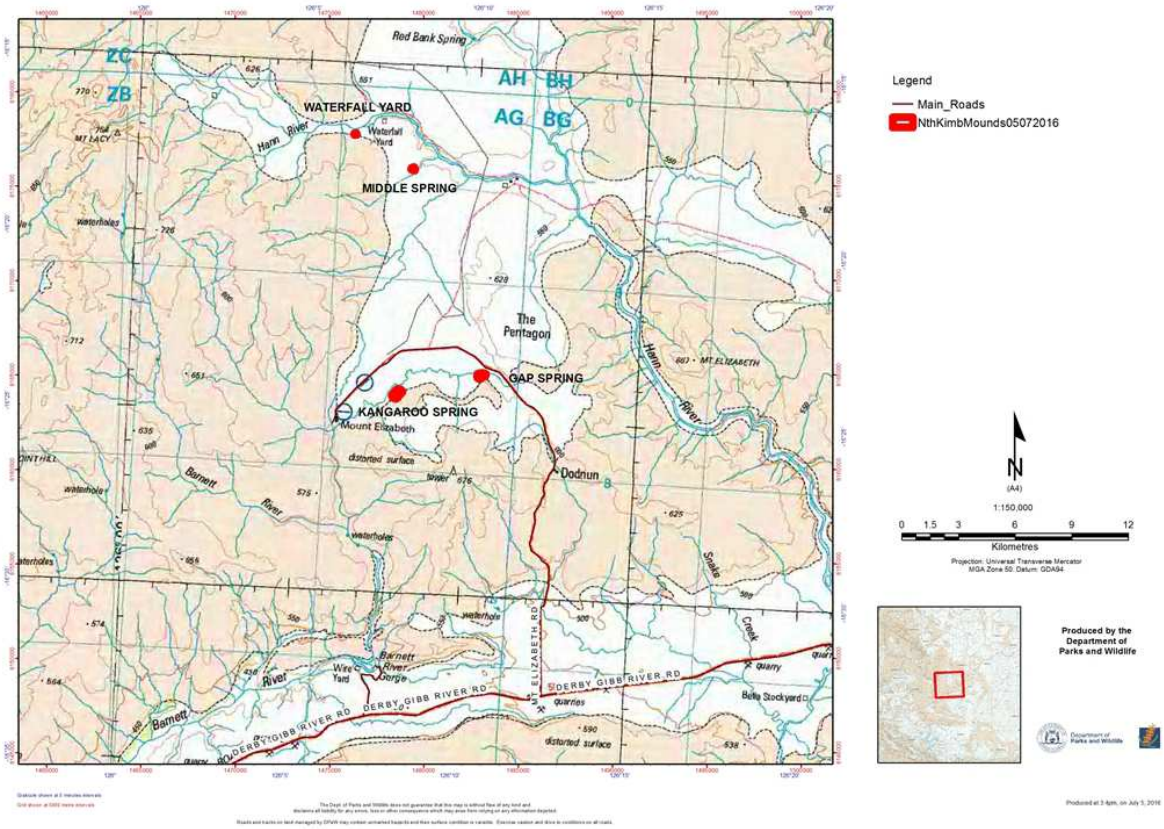
Results of wetland, vertebrate and invertebrate fauna studies have not been included herein as they will be detailed in other reports.

LIMITATIONS

The flora and vegetation of the Waterfall Yard springs were investigated in greatest detail over a total of four days, with three quadrats established in different vegetation units across the extent of the mound spring complex. One quadrat was established in the core seepage zone of the spring complex at each of the other three occurrences. Half-day surveys, only, were completed at each of these three sites.

RESULTS

Figure 1: Locations of North Kimberley Mound Springs, Mt Elizabeth Station



<u>Waterfall Yard Spring</u>

This site contains the most complex vegetation of the four springs surveyed as it contains a suite of assemblages. The sedgeland in the core seepage zone, lacking shrubs and trees, dominates the spring, surrounded by a dampland-woodland zone of relatively dense, small *Melaleuca viridiflora* trees, in places including other woodland species such as *Grevillea pteridifolia* and *Eucalyptus houseana*. Immediately south of the sedgeland is a slight rise about 20 m x 40 m containing dense woodland of *Corymbia ptyochocarpa* and other trees. The remainder of the area between the sedgeland and the Hann River (to the south and west of the core sedgeland) is a dampland dominated by *Banksia dentata* over grasses, sedges and ferns. Open *Eucalyptus* savannah woodland surrounds the spring to the north, and the transition to savannah marks the border of the TEC to the north and east, and the Hann River in the south and west.

Waterfall Yard spring sedgeland contains a diffuse discharge area (core seepage zone) about 200m in diameter (Quadrat 2) with strong microrelief across the whole surface. This zone was very wet at the time of survey, with surface water to a depth of 20cm, and about 1% cover of open water. Surface flows were noted in some areas. The core seepage zone comprised black peaty loam with dense sedges and grasses to 1.4m high, covered in vines (total ~98% vegetation cover). The core seepage zone of the swamp (represented by quadrat 2) is a sedgeland lacking shrubs or trees, dominated by *Fimbristylis tetragona*, *Fuirena umbellata*, *Germainia truncatiglume*, *Capillipedium parviflorum*, *Eragrostis potamophila*, *Eriachne sulcata*, *Eleocharis ochrostachys*, *Fimbristylis cephalophora*,

Gonocarpus chinensis, and *Eriocaulon inapertum*. The dodder *Cassytha capillaris* twines over all species, and many other sedges and herbs are present at lower cover. The seepage zone was in excellent condition (Bush Forever scales), with sparse cattle tracks and no weeds recorded. At the deepest part of the swamp near the western end, a small area of floating sedge mat was present intermixed and associated with a dense patch of *Eleocharis ochrostachys* sedges.

Waterfall Yard core seepage zone

A dampland–woodland, occurs north east of the core seepage zone (represented by Quadrat 1) and is considered part of the mound spring complex vegetation. This zone comprised moist black to dark brown peaty loam with a woodland of *Eucalyptus houseana, Melaleuca viridifolia, Grevillea pteridifolia*, and *Pandanus spiralis* (total ~20% cover, to 11m high) over a dense grassland (~80% cover). There was evidence of light grazing by cattle, but only a single seedling plant of one weed species (*Sylosanthes ?viscosa*) at very low density and cover was recorded, and removed, and the vegetation was in Excellent condition (Bush Forever scales).

Dampland: woodland at Waterfall Yard

A fernland on black peaty loam occurs downslope (south) of the core seepage zone (Quadrat 3) and comprises part of the mound spring complex vegetation. The quadrat captures a series of assemblages including a woodland over ferns, and a woodland over dense grasses and herbs. The woodlands comprise *Banksia dentata, Grevillea pteridifolia* and *Pandanus spiralis* to 10m high. The site was very moist with a small flowline through the western end. The ferns *Blechnum orientale*, *Cyclosorus interruptus*, *Lindsaea ensifolia* and *Lygodium microphyllum* were present in shaded areas. Many *Banksia dentata* trees were heavily hung with the mistletoe *Decasnina petiolata*, and their trunks mostly with black *Septobasidium* fungus (see below). There was evidence of light grazing and light trampling by cattle, but only three weed species were recorded at very low density and cover, two emerging from cattle dung (*Stylosanthes viscosa* and the fungus *Panaeolus papilionaceus*, the latter is probably restricted to cattle and horse dung), and the herb *Emilia sonchifolia.* The vegetation was in excellent condition (Bush Forever scales).

The fernland at Waterfall Yard is a very unusual assemblage in the north-west Kimberley, combining an overstorey dominated by very old *Banksia dentata* over *Blechnum* and *Lindsaea* ferns, grasses and sedges. The fernland is probably maintained by (1) the shallow water table occasioned by its hydrological setting, with water seeping between the perched mound spring and the adjacent river, and (2) a highly reduced fire frequency, as indicated by very old *Banksia* trees not showing any evidence of fire, and by many large dead *Banksia* trunks in advanced decay and likewise showing no sign of ever having been burnt. Such a long-term fire-free zone is almost unknown for an open woodland in the Kimberley. The fire frequency is no doubt greatly reduced due to the protective barriers afforded by the mound spring on one side, and the Hann River on the other. It is likely that the recent (~50 yr) fire frequency has also been reduced due to the high stocking rate of the holding paddock immediately to the east of the main mound spring (see also discussion on fire threat below). Consequently, fires must either jump one of these barriers, or encroach from the west, in order to impact the fernland. Selective cattle grazing of the damp fernland may also historically have reduced the fuel load by the end of the dry season.

Fernland Waterfall Yard

Fungi in the Waterfall Spring fernland

The core wet seepage zones of mound springs are predicted to have a very low diversity of macrofungi due to the highly waterlogged soil profiles, general lack of woody debris, and few larger angiosperm species. Such sedgelands have few (although potentially unique) macrofungi, mostly growing on culms of graminioids. However the marginal areas of mound spring TECs potentially harbor rich and/or unique elements, due to the increased humidity, decreased fire frequency, and high organic content. The unique fernland described above is a prime example. Seventeen species of fungi were collected from this zone, including several ectomycorrhizal species of *Laccaria* and *Russula*. Of particular interest is the first record from the Australian Monsoon Tropics of the fungal genus *Septobasidium*.

The *Banksia* trees in the fernland, and also along the margins of the Eastern zone of the spring (discussed below) were heavily colonised by a black skin fungus, *Septobasidum* sp., that is probably an undescribed species. *Septobasidium* species are obligate symbionts or parasites of scale insects that feed on their host plant while being parasitised by the fungus. Since the scale insects are simultaneously often protected from predation by the fungus, the relationship can be parasitic or mutualistic depending on the intensity of infection. Despite its conspicuous nature, this fungus has never been noted before, and so may have a restricted distribution. Further surveys are required to determine its distribution, and also the identity and nature of the association with scale insects. However, it is almost certain that at least the high abundance of the fungus (and presumably the scale insect) is associated with the unique hydrological situation and fire regime. This fungus-insect-Banksia association should be further investigated, to determine whether it is restricted in distribution, and whether it is of conservation significance.

Septobasidium* sp. on *Banksia dentata

The introduced fungus *Panaeolus papilionaceus* was recorded from a cow pat in the fernland, and confirmed identical with extra-Australian material using ITS sequences. This is the first definite record of this species from Australia (a single 1927 record from Perth needs to be re-examined using

current species concepts), although it is likely to be common in tropical Australia. The species grows only in dung of introduced mammals and is not an invasive threat.

A fence and track separate two distinct portions of the spring complex vegetation at Waterfall Yard. There were few signs of cattle in the area to the west of the fence that contains all three quadrats, and none were sighted there, as they appear to only be able to access the spring area through damaged portions of the fence. In the eastern portions of the springs where cattle appear to have free access, the grasslands in particular have suffered moderate cattle damage (in places cropped to a turf) and vary from Excellent to Good condition (Bush Forever scales). They are still considered part of the spring complex vegetation however. The grasslands in the area east of the fence contain a similar assemblage to Quadrat 2 (described above). An unusual combination of woodland trees occur on sandy loam adjacent to the grasslands in this zone. No weeds were found in the grassland east of the fence, however some weeds were observed in the woodland adjacent to the river due to high numbers of cattle present.

The core seepage eventually trickles into the Hann River via about five small channels, some forming small waterfalls. About half way along this contact zone is a sandy beach of river bank about 20 m long, with 18 littoral and aquatic species associated with it. Most of these aquatics are not found in the mound spring complex, and so these species are not considered on the species list, however the presence of the spring apparently contributes to the aquatic richness at this point on the river.

A map of the main features in Waterfall Yard spring occurs in Appendix 3. The whole of the spring complex vegetation should be fenced as per the approximate recommended fence alignment depicted in the map (Appendix 3). This recommended fenceline includes the spring complex to the west of the current fenceline as the current fence only bisects the mound spring complex vegetation. Although the area to the west of the fence currently protects the main seepage from the high stocking rate on the east side of the fence, this may not be the case in future. The recommended fenceline runs along the northern edge of the river to avoid damage from large floods.

Gap Spring

Gap Spring consists of diffuse discharge (core seepage zone, Quadrat 4) covered by a sedgeland almost devoid of shrubs and trees, about 150m in diameter with strong microrelief, oozing water across the whole surface. The core sedgeland is composed of the graminoids *Xyris complanata*, *Germainia truncatiglume*, *Sacciolepis indica*, the herb *Gonocarpus chinensis*, and intertwined with the dodder *Cassytha capillaris*. A *Banksia dentata* woodland (over typical mound spring grasses and sedges) occurs upslope (south east) of the core seepage zone, extending into a moderately dense woodland of *Pandanus spiralis*, *Corymbia ptychocarpa*, *Banksia dentata*, *Melaleuca* sp. and *Grevillea pteridifolia*. These woodland elements over sedges and grasses are associated with the same hydrological processes as the mound spring core seepage zone, and should be considered part of the mound spring complex vegetation. A fence separates the cattle yard from the spring complex vegetation, and very little evidence of cattle damage was noted in the core seepage zone. An older fence traversed the southern portion of the core seepage zone that clearly historically encompassed a smaller proportion of the spring vegetation.

Quadrat 4 comprised a dense grassland/herbland (~ 98% cover), situated in the core seepage, and covered in vines. The entire core seepage zone was very moist, with up to 20cm of surface water, and surface flows evident in places. The core seepage zone was in Excellent condition (Bush Forever scales) and had much reduced grazing and trampling since a visit in 1998 (M. Barrett personal observation). Water is now piped pumped via a bore within the spring area to the cattle yards outside the fence, and the exclusion of cattle has facilitated regeneration of the wetlands. Many *Banksia* deaths were evident in the woodlands adjacent to the core seepage zone in the current survey, possibly associated with hydrological issues. This zone was about 50 x 25 m, and an estimated 50% death observed, with many other living trees consisting of mostly dead branches; beyond about 25 m from the core seepage zone margin very few *Banksia* were dead.

Gap Spring: open water in core seepage zone

Gap Spring: dead Banksia zone on southern side.

On the north-west margin of Gap Spring, just inside the fence adjacent to the cattle trough, was a dense patch of weeds (*Emilia sonchifolia*, *Gomphrena celosioides*, *Sida cordifolia*, *Stylosanthes scabra*, and *Triumfetta pentandra*), associated with past disturbance. None of these was found any further into the swamp, however all are potentially invasive especially with increased cattle disturbance.

Mud Spring (Kangaroo Spring)

Mud Spring comprises a central core seepage zone surrounded by a series of woodlands. The central seepage contains a dense grassland to 1.5m high (~ 90% cover) with moderate cover of vines, on dark brown peaty loam. The core zone covered about 100m by 300m, had strong microrelief, and seeped water to 20cm deep across the whole surface. The core seepage is dominated by the grasses *Capillipedium parviflorum*, *Germainia truncatiglume* and *Sacciolepis indica*, and the herbs *Gonocarpus chinensis* and *Xyris complanata*, intertwined with dodder *Cassytha capillaris*. Many herbs and sedges occur at lower cover. A dense woodland of *Melaleuca viridiflora*, *Eucalyptus apodophylla*, *Corymbia ptychocarpa*, and *Pandanus spiralis*, over *Germainia truncatiglume*, *Mnesithea rottboleloides*, *Osbeckia australiana* and *Sorghum plumosaum* var. *teretifolium* occurred adjacent to the east side of the core seepage zone and is considered part of the vegetation of the mound spring complex.

Cattle have largely been fenced out of the spring and water is pumped to the outside of the spring zone to supply stock. There was evidence of some light cattle damage within the springs, however, with cattle probably accessing through damaged portions of the fence that surrounds the core seepage zone. Based on aerial photography it is likely that the grasslands of the core seepage zone extended further downslope but appear to have been heavily grazed and soil churned by stock and are no longer clearly evident (although many sedges and herbs attest to the swampy nature of this area).

The highly invasive weed grader grass (*Themeda quadrivalvis*) occurred to the south within about 20m of the core seepage zone and is of concern. *Emilia sonchifolia* and *Stylosanthes scabra* were also present in the same area.

Mud Spring core seepage zone - Q5

Middle Spring

Middle Spring comprises a central core seepage zone surrounded by a series of woodlands. The central seepage contains a dense stratum of grasses, sedges and herbs to 2m high (~ 98% cover) with vine cover to ~10%, on dark brown to black peaty loam. The core seepage zone was significantly raised above the surrounding landscape and measured about 200m in diameter. The peat layer was more obvious than in any of the other three springs surveyed on Mt Elizabeth Station, and walking caused visible vibration of the layer. The peat layer was black and very fine at the surface, with no visible recent plant matter evident. This may suggest the peat layer is quite old even at the surface.

There was very strong microrelief across the whole surface of the core spring zone, with low *Banksia dentata* present on some mounded areas up to 1.5 m above the average level of the swamp. The core seepage zone was very moist and seeped water to 20cm deep across the whole surface, including some significant drainage channels with water flowing strongly on the eastern edges of the mound. The vegetation was dominated by *Eleocharis ochrostachys*, *Cassytha capillaris*, *Arundinella nepalensis*, *Capillipedium parviflorum*, *Eriocaulon inapertum*, *Fuirena umbellata*, *Gonocarpus chinensis*, *Sacciolepis myosodes*. Many other sedges and herbs were present at lower cover. The high abundance of the sedge *Eleocharis ochrostachys* likely contributes the most biomass to the elevated 'mounds' present in this swamp. A distinctive moss (M.D. Barrett & V. English MDB 5384) was noted in the core seepage zone that may also be linked to peat productivity. A few plants of two weed species, *Hibiscus sabdariffa* and *Stylosanthes ?viscosa* were found on the spring/woodland boundary.

Middle Spring core seepage zone – Q6

A suite of dry eucalypt woodlands occurred adjacent to core seepage zones but were not considered part of the mound spring complex as they were terrestrial assemblages on sands. A single exception is the damp herbfield immediately adjacent to the swamp on the northern margin only, where a small zone c 40 x 10 m harboured conservation-significant herbs (*Lobelia leucotos, Goodenia pumilio*), that are clearly dependent on the existence of the swamp.

Deep erosion gullies occurred on the edges of the core spring zone. These areas appear to have regenerated very well following fencing to prevent stock access since 1999 and 2002, when surveyed by Department of Conservation and Land Management (now Parks and Wildlife) staff (see images below).

1999 Middle Spring erosion channel. Photo Sally Black

2016 Middle Spring regeneration in erosion channels

FLORISTICS

A total of 122 species was recorded across the mound springs and their associated assemblages. Including areas outside quadrats, 29 species were found at Gap Spring, 32 at Mud Spring, 41 at

Middle Spring, and 104 species at Waterfall Yard, highlighting the complexity of assemblages associated with the latter

A total of 79 species was recorded for the quadrats in core seepage zones across the four swamps, with a range of 20-36 species per swamp, while the fernland quadrat 3 at Waterfall Yard contained 46 species. An additional 43 species were found outside of quadrats including assemblages associated with the mound spring complex outside the core seepage zone.

SIGNIFICANT SPECIES

Although the majority of plant species in the mound springs are widespread in other community types across northern Australia, there are several exceptions that are of specific conservation interest, as their persistence in WA is closely associated with the fate of the mound spring TEC.

Indicator species

Seven species were collected that in Western Australia are known only from mound springs (or their margins):

- *Cyperus unioloides*
- *Eleocharis ochrostachys*
- *Eriocaulon inapertum*
- *Lobelia leucotos*
- *Rhynchospora gracillima*
- *Spiranthes* aff*. sinensis*
- *Utricularia circumvoluta.*

Although these species are all known from other habitats elsewhere in Australia, they are candidate indicator species for mound springs in the Kimberley, since they appear to be absent from all other assemblages in WA. All seven species were present at Waterfall Yard, and all except *Cyperus unioloides, Rhynchospora gracillima* and *Spiranthes* at Middle Spring, emphasizing the especially intact nature and ecological significance of these two springs. *Eriocaulon inapertum* was also found at Gap Spring and Mud Spring, and *Lobelia leucotos* has been reported previously from Gap Spring. *Eleocharis ochrostachys* occurs in the deepest, most permanent part of the swamps, and has spongy culm interiors that are probably largely responsible for the ±floating mounds present in the same zones at Hann Spring and Middle Spring, while Gap Spring and Mud Spring lack both *E. ochrostachys* and floating mounds. A distinctive moss (M.D. Barrett & V. English MDB 5384), currently awaiting expert identification, was noted in the core seepage zone at Waterfall Yard and Middle Spring, and may be an additional indicator species.

Rare and indicator species for the mound spring TEC.
Top row: a. *Cyperus unioloides*; b. Unidentified moss; c. *Eleocharis ochrostachys.*
Second row: a, b. *Eriocaulon inapertum*; c. *Lobelia leucotos* (spring margins).
Third row: a. *Limnophula aromatica*; b. *Rhynchospora gracillima*; c. *Rhynchospora rubra.*
Forth row: a. *Spiranthes* aff. *sinensis* – flower; b, c. *Utricularia circumvoluta*, twining plant and flower.

New state records

Three species represent new records for WA, and collections have been submitted to the WA Herbarium, along with Priority 1 recommendations (in each case the fact that they also occur sparsely elsewhere in tropical Australia may result in determination at a Priority 3 status instead).

Cyperus unioloides is newly reported from Western Australia, from collection at Waterfall Yard, where it was present in the core seepage zone of the swamp (eg quadrat 2) but not on the margins, and also at Middle Spring. This species is Pantropical, occurring in Australia in the Northern Territory, Queensland and NSW. In the Northern Territory *C. unioloides* occurs only rarely in similar swamps in the Bradshaw Field Training Area and Nitmiluk NP (Cowie & Stuckey 2008). A conservation ranking of Priority One has been recommended for this species, since its persistence in WA appears to be dependent on the TEC mound springs.

A single specimen of the orchid *Spiranthes* aff. *sinensis* was collected at Waterfall Yard. This is the first collection of *Spiranthes* outside of the eastern states, ie. no collections are known from the Northern Territory or Western Queensland, although the genus occurs through southern Asia. The taxonomy of *Spiranthes* is in flux, but this form may be the same as an apparently undescribed taxon from Cape York and southern PNG (M. Clements pers. comm.). However, other workers take a broad view of species in *Spiranthes*, and then the specimen would be included under a very widely distributed *S. sinensis*. Ongoing molecular work will clarify the taxonomy of this entity. A conservation ranking of Priority One will be recommended for this species.

The bladderwort *Utricularia circumvoluta* is newly reported from Western Australia based on two collections made at Waterfall Yard and Middle Spring, extending its distribution from the Northern Territory and Queensland. A single plant of *U. circumvoluta* had previously been seen at Mud Springs on Charnley River station (R.L. Barrett & M.D. Barrett pers. obs.), but the specimen was lost during the process of expert confirmation, so these collections represent the first extant vouchers from WA, and an addition to the state flora. A conservation ranking of Priority One will be recommended for this species.

Priority Species

Cyperus unioloides, Spiranthes aff. *sinensis* and *Utricularia circumvoluta* are discussed above. Their conservation status is currently being assessed, but is likely to be either P1 or P3 in all cases.

Eleocharis ochrostachys [P3]

Previously known from two locations in the Kimberley, “Plain Creek” mound spring on Drysdale River, and a mound spring on Theda Station. *E. ochrostachys* was a dominant species at Waterfall Yard and Middle Spring on Mt Elizabeth, and is possibly the dominant contributing species to the floating mats present on these two springs, while floating mats are absent from Gap Spring and Mud Spring. *Eleocharis ochrostachys* is considered a Priority Three species in Western Australia, where it is apparently always associated with mound springs, but it is a widespread species from India to the western Pacific, and in Australia also occurs in the Top End of the Northern Territory and Queensland (Cowie et al. 2000).

Eriocaulon inapertum [P1] was located at all four Mound Springs visited on Mt Elizabeth. The species had previously been reported from Middle Spring and Gap Spring by Sally Black in 1999, as well as Fern Pool on Drysdale River from the same survey. The only other record in WA is from Mud Springs on Charnley River Station. *E. inapertum* is now known from six sites in WA, all of them mound springs. The species also occurs in the western Top End of the Northern Territory, where it is also known from few collections, in "open grass or sedge swamps on sandstone".

The herb *Lobelia leucotos* [P1] was described from Queensland, but is also known from the mound springs at Mt Elizabeth, highly disjunct from the Queensland populations. During this survey, *L. leucotos* was found at both Waterfall Yard Spring and Middle Spring, but not Gap Spring or Mud Spring. *L. leucotos* was previously known from Gap Spring (1998 collection), however it was not relocated at the latter during this survey, most likely due to the now much higher sedges and grasses that have established with the improved maintenance of the fence since 1998.

The sedge *Rhynchospora gracillima* was found only at Waterfall Yard Spring. It is known from only one other location in WA, on Theda Station (this site may represent an additional, unlisted mound spring occurrence). Although it is also found in the Northern Territory and Queensland, it is listed as a Priority One species in WA due to its rarity.

The sedge *Rhynchospora rubra* was observed at Middle Spring only, where it had previously been located by Sally Black (although the old specimen collected was unable to be identified at the time). This record is only the third known location for *R. rubra* in Western Australia, and it appears to be highly restricted to sites that remain wet long into the dry season (or are possibly perennially wet). *R. rubra* currently has no conservation status in Western Australia, however a conservation ranking of Priority One will be recommended for this species.

An unusual moss was present at Waterfall Yard Spring and Middle Spring, but has yet to be identified (M.D. Barrett & V. English MDB 5293 and 5384). It is possibly not known elsewhere in the Kimberley.

Range extensions

The Priority One sedge *Rhynchospora gracillima* was found in the core seepage zone at Waterfall Yard. This is only the second known location of this species in Western Australia, the other from an unlisted mound spring on Theda Station. It is also relatively rare in the Top End, where it is only known from about seven locations.

The grass *Capillipedium parviflorum* was found at Hann Spring and Mud Spring. Previously this species had only been collected from the subcoastal north-west Kimberley, although it is widespread in the Top End and Queensland.

The herb *Portulaca* sp. rock pools (K.A. Menkhorst 310) was located on very low outcropping sandstone rocks on the western margin of Waterfall Yard Spring. This species was previously known from only three locations in the Kimberley: Charnley River Station, King Edward River Crossing and Theda Station. The new record lies between the three previous locations. Despite the few

collections, the species is currently not listed as a Priority taxon. It also occurs in the Top End of the Northern Territory.

THREATS

Grazing

Typically cattle will remain where they can access fresh water and so have the tendency to stay at the springs for long periods during hot weather. Unless fences are maintained cattle can cause physical damage to the vegetation of the mound spring complex and the peat based substrates through trampling, resulting in erosion, as well as grazing the regenerating vegetation, altering the species composition by selectively removing edible species. Vegetation removal has the potential to cause an increase in drying of the mound springs, and drying is associated with increasing acidity particularly in peat based wetlands. Water temperatures may also subsequently rise, with potential concomitant effects on aquatic invertebrates.

Cattle have historically been a major threat to the North Kimberly Mound springs on Mt Elizabeth Station and have had adverse effects on their ecological health. In 2012 all the springs with the exception of Waterfall Yard were fenced by the pastoralist utilising funds provided by Parks and Wildlife as a part of the Kimberley Science and Conservation Strategy. Waterfall Yard wasn't fenced due to high likelihood of wet season floods damaging fence line. The existing fence is simply a pastoral fence line. Gibb River Spring was fenced in 2013/14. Personal observations (M. Barrett) and photographic evidence indicate that the core seepage zones have recovered remarkably well where previously highly impacted by stock. The current pastoral lease holder expressed a desire to keep stock out of the springs as they can get injured in them.

There is evidence of low level damage from stock at all of the core spring zones surveyed. Although fences were quite effective at excluding cattle compared to the high adjacent stocking rate, a few cattle had clearly penetrated the fence at nearly all sites, and continued annual maintenance of the fences will be necessary. In addition, *Banksia dentata* deaths upslope of the core seepage zone at Gap Spring may relate to damage associated with hydrological changes (either increasing or decreasing water table). The position of the dead plants on the swamp margin, and lack of an effect on *Banksia* trees in the adjacent woodland argues for a hydrological cause, and against fire or cattle damage as the cause of *Banksia* death at this site.

In addition to physical disturbance, faeces of cattle contaminate the soil and water, particularly in open water, causing nutrient enrichment. This may enhance the introduction of weeds as well as elevate nutrient levels in the groundwater. This adversely affects the aquatic invertebrates that rely on the water supply.

It is understood that the sale of the Mt Elizabeth pastoral lease is currently under negotiation, and that the proposed new leaseholders wish to further develop stock usage, and eco-tourism.

Hydrological changes

There is no information available about the aquifer that supports the ecosystem, or about the ecological water requirements of the mound springs. These are significant knowledge gaps, as the spring ecosystem is completely reliant on a continuous supply of fresh water.

Changes to hydrology are a potential threat to the North Kimberley Mound Springs on Mt Elizabeth Station. At a local scale, groundwater is exploited to provide drinking water for stock. Water is piped out of the core seepage zones for stock usage at Gap Spring, Mud and Middle Spring however (Chemello 2015), and this helps to minimise potential impacts associated with this usage. The extent of impacts of this usage to the mound springs flora and fauna that depend on the constant supply of freshwater is not clear however based on water availability observed in this survey is currently likely to be minimal.

Further development of stock usage of the station has the potential to increase water usage, and has potential to result in an increase in water abstraction and potentially land clearing in the spring areas. The water supply to Mandora mound springs in the western Kimberley has been found to be very localised and associated with very narrow fault lines (J. Rutherford personal communication). In that situation, local abstraction therefore has potential for high level impacts to the springs. A good understanding of the hydrogeology of the springs is therefore very important for management. The impact of hydrological changes on the biota of the mound springs, and other nearby wetlands will also require careful monitoring.

Feral animals

There was evidence of pig grubbing in some of the springs, and other feral animals, such as cats are likely to be present in the mound springs. As with cattle, feral animals cause damage to the vegetation through digging, trampling and grazing, and nutrient enrichment of the water. Carnivorous introduced fauna can also predate on native species and disrupt waterbird breeding.

The first cane toads were recently found at Drysdale River Station and will also almost certainly arrive at the Drysdale springs in the 2016/17 wet season.

Weed invasion

Weeds change the natural diversity and balance of ecological communities and are a risk to the North Kimberley Mound Springs. They displace native plants, particularly following disturbances such as too frequent fire, grazing or partial clearing, and compete with them for light, nutrients and water. Weeds can also prevent recruitment, cause changes to soil nutrients, and affect abundance of native fauna. They can also impact on other conservation values by harbouring pests and diseases, and increasing the fire risk.

Weeds levels are generally very low within the Mound Springs on Mt Elizabeth Station. Some weed invasion has occurred, likely a result of the increase in nutrients and disturbance from cattle. The weeds are mainly located on the edges of the core seepage zones, as the dense vegetation of this zone appears to provide a barrier to reduce the likelihood of weed invasion (see Appendix 2 for weed list). The most common weed recorded in the springs was *Stylosanthes* (*S. scabra* and *S. viscosa*). Grader grass (*Themeda quadrivalvis*) was recorded in close proximity to Mud Spring and should be controlled as a matter of urgency, and reinvasion carefully monitored. One plant of

Passiflora foetida was observed on the south east side of the core seepage area at Waterfall Yard spring (16^0 16' 51.9" S; 126^0 06' 20.8" E), and was removed. This species should be carefully monitored and controlled as it is highly invasive. The patch of several weed species adjacent to the tank and within the fenced zone at Mud Spring should be controlled.

Altered fire regimes

Inappropriate fire regimes are a potential risk to the North Kimberley Mound Springs. Historically, fire within the mound springs was probably only very occasional. It is likely that some of the ecosystems that surround the core seepage zones may be adapted to occasional fire as they contain species that will easily carry fire when vegetation is dry, and some component shrubs would reproduce from seed following fire. The impacts of fire, and fire regeneration response of the mound spring peat substrate and vegetation needs to be determined on an opportunistic basis following bush fire. Mound springs should not be included in routine burning as fires can cause total destruction of peat based systems as it can smoulder for months, totally destroying peat substrate that has accumulated over at least hundreds of years. Fires have been recorded in core seepage zones in areas nearby. In this case fire travelled through the sedges/grasses in the core seepage area and burnt an island of Pandanus in the centre (D. Chemello pers.obs.). It is not known if the peat layer actually burns, however, as it does in mound springs in the southwest of the state but probably depends on the moisture content at the time. The fernland at Waterfall Yard Spring is an exceptional long-unburnt area due to its unique situation between the spring and the Hann River. The fernland area should likewise be excluded from routine burning practices.

Climatic changes

The North Kimberley Mound Springs are at risk from changing climate. Potential effects may include altered surface water and groundwater recharge due to changes in rainfall and more extreme fire behaviour.
An Australian Government website provides the following projections for the Monsoonal North West region, that includes the Kimberley. The following climate change predictions are quoted from: http://www.climatechangeinaustralia.gov.au/en/climate-projections/future-climate/regional-climate-change-explorer/sub-clusters/?current=MNWC&popup=true&tooltip=true

- Rainfall
    - "Changes to rainfall are possible but unclear. For the near future natural variability is projected to dominate any projected changes. The Monsoonal North experienced an overall slight increase in rainfall during the 20th century, which includes prolonged periods of drying as well as above average rainfall. The strongest increases have been across north-western regions during recent decades. Natural climate variability is projected to remain the major driver of rainfall changes in the next few decades. By late in the century, potential summer rainfall changes are approximately -15 to +10 per cent under an intermediate emission scenario (RCP4.5) and approximately -25 to +20 per cent under a high scenario (RCP8.5). Per cent changes are much larger in winter in some models, but these changes are less reliable because average winter rainfall is very low.
    - Impact assessment in this region should consider the risk of both a drier and wetter climate, and the affects of greater variability between seasons.

- Temperature
    - Average temperatures will continue to increase in all seasons (*very high confidence*). There is *very high confidence* in continued substantial increases in projected mean, maximum and minimum temperatures in line with our understanding of the effect of further increases in greenhouse gas concentrations.
    - For the near future (2030), the annually averaged warming across all emission scenarios is projected to be around 0.5 to 1.4 °C above the climate of 1986 – 2005.
    - By late in the century (2090), for a high emission scenario (RCP8.5) the projected range of warming is 2.8 to 5.1 °C. Under an intermediate scenario (RCP4.5) the projected warming is 1.3 to 2.8 °C. More hot days and warm spells are projected with *very high confidence*. Increased intensity of extreme rainfall events is projected, with *high confidence*.
- Extreme weather
    - With *medium confidence*, fewer but more intense tropical cyclones are projected.

- Bushfire behaviour
    - The primary determinant of bushfire in the Monsoonal North West is fuel availability, which varies mainly with rainfall. In regions where abundant rain falls (Top End and the Kimberley), climate change is not expected to change the frequency of fire (*high confidence*). In more southerly locations, changes to future rainfall will be the determining factor of change to fire frequency. When fire does occur, there is *high confidence* that fire behaviour will be more extreme.
- Other
    - Potential evapotranspiration is projected to increase in all seasons as warming progresses (*high confidence*).
    - There is little change projected in relative humidity until later in the century under a high emission scenario (RCP8.5), where a decrease in relative humidity is projected (*medium confidence*).

Addressing climate changes as a threatening process is outside the scope of this report however.

Tourism usage

If new leaseholders seek to develop ecotourism of the mound spring zones, increased visitation has the potential to impact the springs through trampling, and potentially increased fire frequency.

CONCLUSIONS

The most significant ongoing threat to the integrity of the mound springs is grazing and trampling by cattle. Hydrological change is probably the next most significant threat to the future ecological function of the springs. New leaseholders may increase the scale of stock and abstraction of water from the springs. Future proposals therefore have potential to impact the aquifers that maintain the springs and the flora and fauna that rely on the constant water supply.

Despite long term historical grazing by cattle, few significant weeds were noted in the springs during this survey. Weeds have potential to spread and have increased impacts on the springs in future however. Grader grass and *Passiflora foetida* in particular should be controlled as a matter of urgency, and carefully monitored in future.

Impacts of feral animals such as pigs are currently relatively low. There is little evidence that altered fire regimes or climate change are having a significant impact on the springs, but this may change in future.

RECOMMENDATIONS

- Maintain, and repair existing fences where required at all four mounds springs. Repairs were noted as being required at Waterfall Yard during the June 2016 surveys.

- Seek to fence additional areas of the mound spring complex at **Waterfall Yard Spring** including the more degraded areas east of the fenceline/track (see Appendix 3 for map of recommended area for fencing).

- Seek to fenceeroded drainage channels on the south east side near the river, and the north eastern edge of the core seepage zone at **Middle Spring**, that are not currently encompassed by fencing (see Appendix 3 for boundaries of the spring complex - recommended for extension of fencing on SE extremity). Erosion gullies could also be filled with rock to help prevent further degradation.

- Map significant weed/s and control/eradicate them (a small patch of weeds at **Gap Spring**, grader grass adjacent to **Mud Spring,** *Passiflora foetida* at **Waterfall Yard Spring** - a relatively inexpensive action).

- Design and implement a project to determine the hydrological drivers of the mound spring ecosystems. The information should then be employed as a guide to management of abstraction.

- Design and implement a monitoring program that utilises quadrats established during the current survey (more costly and time consuming but essential for management). This will probably require establishment of a more comprehensive network of quadrats. This should be designed to provide information about the success of land management in the sensitive environment of the mound spring ecosystem.

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REFERENCES

Australian Government (2016). Climate change in Australia. Projections for Australia's NRM Regions. Available from URL: http://www.climatechangeinaustralia.gov.au/en/climate-projections/future-climate/regional-climate-change-explorer/sub-clusters/?current=MNWC&popup=true&tooltip=true. Accessed 11 November 2016.

Black, S. (2002). Reassesement of the status of the Organic mound spring sedgeland community of the North Kimberley Bioregion. Nomination form dated 24 May 2002. Department of Conservation and Land Management files.

Black, S. (2004). Mound spring ecosystems in the Western Australian rangelands. In: *Conference Papers, Australian Rangeland Society 13th Biennial Conference. Alice Springs 5-8 July 2004*.

Chemello, D. (2015). Mound Spring Survey August 2015. Department of Parks and Wildlife, Kununurra.

Department of Environment and Conservation (2009) Resource Condition Report for high Conservation Value Aquatic Ecosystem (HCVAE) on mound springs in Western Australia. Prepared for Inland Aquatic Integrity Resource Condition Monitoring (IAI RCM) Project. Department of Environment and Conservation, Perth, Western Australia.

Department of Parks and Wildlife (2015) Conserving Threatened Species and Ecological Communities. Corporate Policy Statement No. 35. Department of Parks and Wildlife, Western Australia.

Government of Western Australia (2000). Bush Forever. Volume 1: Policies, Principles and Processes. Volume 2: Directory of Bush Forever Sites. Perth, W.A.

Halse, S. (2001). Comments on Kimberley Springs sampled by S. Black. Department of Conservation and Land Management files 2 October 2011.

Knott, B and Jasinska, E.J.J. (1998). Mound springs of Australia. In: L. Botonaneanu (ed). *Studies in Crenobology. The biology of springs and springbrooks*. Backhuys Publishers, Leiden.

Williams, A.F. and Holmes, J.W. (1978) A novel method of estimating the discharge of water from mound springs of the Great Artesian Basin, Central Australia. *Journal of Hydrology* 38: 263–272.

Appendix 1a

Flora in mound spring occurrences

Species list (Bold = indicator species)	**Lifeform**	**Introduced**	**Waterfall Yard TOTAL**	**Waterfall Q1**	**Waterfall Q2**	**Waterfall Q3**	**Waterfall Corymbia ptychocarpa Woodland**	**Gap Spring TOTAL**	**Gap Spring Q4**	**Mud Spring TOTAL**	**Mud Spring Q5**	**Middle Spring TOTAL**	**Middle Spring Q6**
Antidesma ghaesembilla	Tree		1				1						
Arundinella nepalensis	Graminoid		1		1	1	1	1	1	1	1	1	1
Banksia dentata	Tree		1	1		1		1	1	1	1		
Blechnum orientale	Fern		1			1							
Brachychiton diversifolius	Tree		1				1						
Brachychiton fitzgeraldianus	Shrub		1				1						
Buchanania aff. obovata	Tree		1				1						
Buchnera urticifolia	Herb							1	1				
Burmannia juncea	Herb							1					
Callitris intratropica	(tree) seedling		1			1							
Canarium australianum	Tree		1				1						
Capillipedium parviflorum	Graminoid		1		1			1	1	1	1	1	1
Cassytha capillaris	Vine		1	1	1	1		1	1	1	1	1	1
Chrysopogon setifolius	Graminoid		1				1						
Corymbia ptychocarpa	Tree		1	1			1			1			
Cyclosorus interruptus	Fern		1			1							
Cyperus haspan subsp. juncoides	Graminoid		1		1	1						1	
Cyperus iria	Graminoid		1										
Cyperus polystachyos	Graminoid		1	1		1							
Cyperus unioloides	Graminoid		1		1							1	1
Decasnina petiolata	Mistletoe		1			1							
Denhamia obscura	Tree		1				1						
Desmodium gangeticum	Herb		1	1									
Drosera aff. paradoxa (swamp form)	Herb		1	1									
Drosera aurantiaca	Herb									1			
Drosera barrettiorum	Herb		1							1		1	
Drosera burmannii	Herb		1		1			1	1	1	1	1	1
Drosera cucullata	Herb		1							1			
Eleocharis ochrostachys	Graminoid		1		1	1						1	1
Emilia sonchifolia var. sonchifolia	Herb	*	1			1		1					
Eragrostis potamophila	Graminoid		1	1	1	1				1		1	1
Eriachne sulcata	Graminoid		1	1	1					1			
Eriocaulon inapertum	Graminoid		1	1	1	1		1	1	1	1	1	1
Eriocaulon odontospermum	Graminoid											1	
Eucalyptus apodophylla	Tree									1		1	
Eucalyptus houseana	Tree		1	1		1	1	1					
Ficus aculeata var. aculeata	Tree		1			1	1						
Ficus platypoda	(Tree) seedling		1			1							
Fimbristylis cephalophora	Graminoid		1	1	1	1		1	1	1	1	1	1
Fimbristylis cinnamometorum	Graminoid		1	1				1	1				
Fimbristylis lanceolata	Graminoid		1	1									
Fimbristylis aff.dichotoma/depauperata (M.D. Barrett 5336)	Graminoid		1			1							
Fimbristylis nutans	Graminoid		1	1	1			1	1			1	1
Fimbristylis pauciflora	Graminoid		1			1						1	
Fimbristylis sp. B Kimberley Flora (K.A. Menkhorst 767)	Graminoid						1						
Fimbristylis tetragona	Graminoid		1	1	1	1		1	1	1	1	1	1
Fuirena umbellata	Graminoid		1		1	1						1	1
Germainia truncatiglume	Graminoid		1	1	1	1		1	1	1	1	1	1
Glycine tomentella	Shrub		1				1						
Gomphrena celosioides	Herb	*						1					
Gonocarpus chinensis	Herb		1	1	1	1		1	1	1	1	1	1
Goodenia bicolor	Herb		1	1									
Goodenia pumilio	Herb											1	
Grevillea pteridifolia	Tree		1	1		1						1	
Grewia retusifolia	Shrub		1				1						
Hibiscus sabdariffa	Shrub	*										1	
Hypericum gramineum	Herb											1	
Limnophila aromatica	Herb		1	1	1	1						1	1
Limnophila fragrans	Herb		1										
Lindernia aff. tectanthera	Herb		1										
Lindsaea ensifolia	Fern		1			1							

Species list (Bold = indicator species)	**Lifeform**	**Introduced**	**Waterfall Yard TOTAL**	**Waterfall Q1**	**Waterfall Q2**	**Waterfall Q3**	**Waterfall Corymbia ptychocarpa Woodland**	**Gap Spring TOTAL**	**Gap Spring Q4**	**Mud Spring TOTAL**	**Mud Spring Q5**	**Middle Spring TOTAL**	**Middle Spring Q6**
Lobelia leucotos	Herb		1					(previous record)				1	
Ludwigia octovalvis	Herb											1	1
Lycopodiella cernua	Fern		1	1									
Lygodium microphyllum	Fern		1			1							
Melaleuca leucadendra	Tree		1			1							
Melaleuca ?nervosa (sterile)	Tree							1					
Melaleuca viridiflora	Tree		1	1						1			
Mimulus uvedaliae Benth. var. uvedaliae	Herb		1										
Mitrasacme foliosa	Herb		1										
Mitrasacme nummularia	Herb		1	1						1	1		
Mitrasacme subvolubilis	Herb		1		1	1		1	1	1	1	1	1
Mnesithea rottboelloides	Graminoid		1	1			1			1			
Moss (M.D. Barrett & V. English MDB 5384)	Moss		1									1	1
Nelsonia campestris	Herb		1			1						1	
Ophioglossum reticulatum	Fern		1	1									
Osbeckia australiana	Shrub		1	1						1	1		
Pandanus spiralis	Tree		1	1		1				1			
Paspalum scrobicularum	Graminoid		1	1	1	1							
Phragmites karka	Graminoid		1			1							
Philydrum lanuginosum	Shrub		1		1	1							
Phyllanthus baccatus	Shrub		1			1	1						
Planchonia carya	Tree		1				1			1			
Plectranthus scutellarioides	Herb		1	1	1	1	1			1	1	1	1
Portulaca sp. rock pools (K.A. Menkhorst 310)	Herb		1										
Premna herbacea	Shrub (dwarf)		1				1						
Pseudopogonatherum irritans	Graminoid		1		1							1	
Rhynchospora gracillima	Graminoid		1		1								
Rhynchospora rubra	Graminoid											1	1
Sacciolepis indica	Graminoid		1	1	1	1		1	1	1	1	1	1
Sacciolepis myosuroides	Graminoid		1		1							1	1
Santalum lanceolatum	Shrub		1				1						
Schoenoplectus mucronatus	Graminoid		1			1						1	1
Scleria rugosa	Graminoid		1			1							
Sida cordifolia	Shrub	*						1					
Sorghum plumosum var. teretifolium	Graminoid		1	1	1	1		1		1			
Spermacoce sp.	Herb		1										
Spiranthes aff. sinensis	Herb		1		1								
Stylidium dunlopianum	Herb		1	1	1	1		1	1	1	1	1	1
Stylidium floribundum	Herb		1										
Stylidium irriguum	Herb		1										
Stylosanthes scabra	Shrub							1					
Stylosanthes viscosa	Shrub	*	1	1		1						1	
Syzygium eucalyptoides subsp. eucalyptoides			1										
Terminalia ?hadleyana	Tree		1				1						
Terminalia eucalyptoides subsp. eucalyptoides	Tree		1										
Themeda quadrivalvis	Graminoid	*								(near)			
Thysanotus chinensis	Herb		1	1									
Timonius timon	Tree		1	1		1	1						
Triumfetta pentandra	Herb	*						1					
Utricularia caerulea	Herb		1										
Utricularia chrysantha	Herb							1	1	1	1	1	1
Utricularia circumvoluta	Herb		1		(outside quadrat)							1	1
Utricularia gibba	Herb		1		1	1		1	1				
Utricularia kimberleyensis	Herb		1		1					1	1		
Utricularia uliginosa	Herb		1										
Vigna lanceolata var. filiformis	Shrub		1	1									
Vigna lanceolata var. lanceolata	Shrub		1			1							
Wahlenbergia queenslandica	Herb		1	1									
Xyris cheumatophila	Graminoid		1			1							
Xyris complanata	Graminoid		1	1	1			1	1	1	1	1	1
Xyris indica	Graminoid		1	1	1			1	1	1	1	1	1
Total			**53**	**19**	**15**	**20**	**8**	**12**	**7**	**15**	**10**	**17**	**13**

Appendix 1b

Quadrat species, heights and cover values

Species list (Bold = indicator species)	Lifeform	Introduced	Waterfall Q1		Waterfall Q2		Waterfall Q3		Gap Spring Q4		Mud Spring Q5		Middle Spring Q6	
			Height (m)	cover	Height	cover	Height	cover	Height	cover	Height	cover	Height	cover
Arundinella nepalensis	Graminoid				1.3	<1	1.8	5	1.6	5	1.8	1	2	5
Banksia dentata	Tree		4 (1-5) m	1			4	5	3	<1	3	7		
Blechnum orientale	Fern						0.8	5						
Buchnera urticifolia	Herb								1	<1				
Callitris intratropica	(tree) seedling						1	<1						
Capillipedium parviflorum	Graminoid				1.2	7			1	1	1.5	40	1.2	2
Cassytha capillaris	Vine		0.5	5	1	15	1	5	0.4	20	0.5	10	1.5	5
Corymbia ptychocarpa	Tree		8	<1										
Cyclosorus interruptus	Fern						1	10						
Cyperus haspan subsp. juncoides	Graminoid				0.5	<1	0.3	<1						
Cyperus iria	Graminoid													
Cyperus polystachyos	Graminoid		0.7	<1			0.4	<1						
Cyperus unioloides	Graminoid				0.7	<1							0.8	<1
Decasnina petiolata	Mistletoe						4	<1						
Desmodium gangeticum	Herb		0.5	<1										
Drosera aff. paradoxa (swamp form)	Herb		0.02	<1										
Drosera burmannii	Herb				0.1	<1			0.02	<1	0.01	<1	0.2	<1
Drosera cucullata	Herb													
Eleocharis ochrostachys	Graminoid				0.7	2	0.3	3					1	20
Emilia sonchifolia var. sonchifolia	Herb	*					0.05	<1						
Eragrostis potamophila	Graminoid		1	2	1.3	7	1.5	3					1	<1
Eriachne sulcata	Graminoid		0.7	2	0.4	5								
Eriocaulon inapertum	Graminoid		0.3	<1	0.5	2	0.3	<1	0.3	<1	0.5	<1	0.4	2
Eucalyptus houseana	Tree		8	1			0.5	<1						
Ficus aculeata var. aculeata	Tree						0.3	<1						
Ficus platypoda	(Tree) seedling						0.7	<1						
Fimbristylis cephalophora	Graminoid		0.3	<1	0.7	2	0.3	<1	0.3	<1	0.6	<1	0.7	<1
Fimbristylis cinnamometorum	Graminoid		1	<1					1	<1				
Fimbristylis lanceolata	Graminoid		1	<1										
Fimbristylis aff.dichotoma/depauperata (M.D. Barrett 5336)	Graminoid						1	<1						
Fimbristylis nutans	Graminoid		0.3	<1	0.7	<1			0.3	<1			0.6	<1
Fimbristylis pauciflora	Graminoid						0.15	<1						
Fimbristylis tetragona	Graminoid		0.3	2	0.4	30	0.3	<1	0.3	<1	0.2	<1	0.5	1
Fuirena umbellata	Graminoid				1	25	1.5	<1					1.5	2
Germainia truncatiglume	Graminoid		1.2	40	1.2	20	1.2	5	1.2	20	1.3	20	1.2	30
Gonocarpus chinensis	Herb		0.3	2	0.3	2	0.2	20	0.4	15	0.6	<1	0.5	2
Goodenia bicolor	Herb		0.5	<1										
Grevillea pteridifolia	Tree		5	1			10	7						
Limnophila aromatica	Herb		0.2	<1	0.8	1	0.2	<1					0.6	<1
Lindsaea ensifolia	Fern						0.5	5						
Ludwigia octovalvis	Herb												1.7	0.5
Lycopodiella cernua	Fern		0.3	<1										
Lygodium microphyllum	Fern						1	10						
Melaleuca leucadendra	Tree						3	<1						
Melaleuca viridiflora	Tree		10 (0.3-1.5 seedlings)	10 (+15 seedlings)										
Mitrasacme foliosa	Herb													
Mitrasacme nummularia	Herb		0.4	<1							0.2	<1		
Mitrasacme subvolubilis	Herb				0.3	<1	0.4	<1	0.3	<1	0.1	<1	0.4	<1
Mnesithea rottboelloides	Graminoid		0.2	<1										
Moss (M.D. Barrett & V. English MDB 5384)	Moss												0.1	<1
Nelsonia campestris	Herb						0.05	<1						
Ophioglossum reticulatum	Fern		0.06	<1										
Osbeckia australiana	Shrub		0.6(0.5-1.6)	2							1.3	<1		
Pandanus spiralis	Tree		4	1			5	7						
Paspalum scrobicularum	Graminoid		1.2	<1	1.2	<1	0.1	<1						
Phragmites karka	Graminoid						4	<1						
Philydrum lanuginosum	Shrub				0.9	<1	1.3	<1						
Phyllanthus baccatus	Shrub						0.2 (seedling)	<1						
Plectranthus scutellarioides	Herb		0.8	<1	0.7	<1	0.5	<1			0.6	<1	1	<1
Pseudopogonatherum irritans	Graminoid				1.5	1								
Rhynchospora gracillima	Graminoid				0.6	<1								
Rhynchospora rubra	Graminoid												1.5	<1
Sacciolepis indica	Graminoid		0.7	<1	1.1	<1	0.8	<1	1	10	0.4	5	1.2	2
Sacciolepis myosuroides	Graminoid				0.2	<1							1.3	2

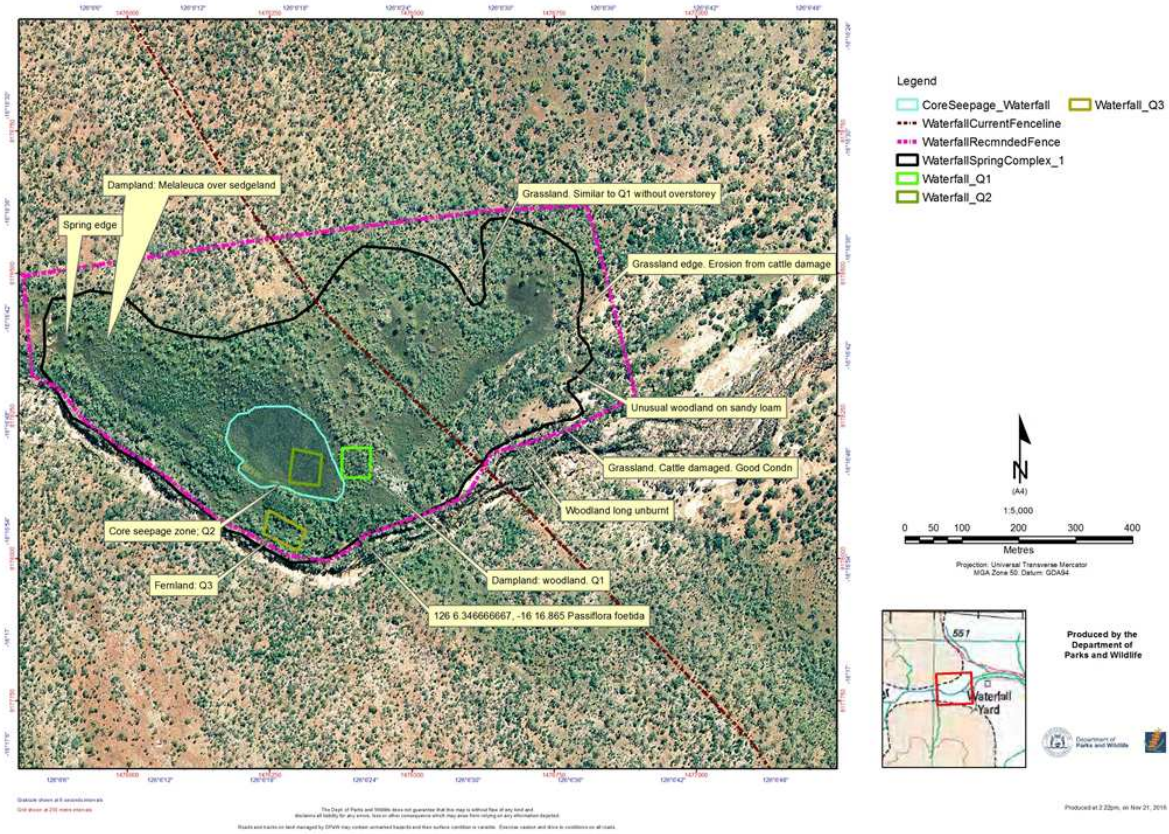
Species list (Bold = indicator species)	Lifeform	Introduced	Waterfall Q1		Waterfall Q2		Waterfall Q3		Gap Spring Q4		Mud Spring Q5		Middle Spring Q6	
			Height (m)	cover	Height	cover	Height	cover	Height	cover	Height	cover	Height	cover
Schoenoplectus mucronatus	Graminoid						0.3	<1					1.2	1
Scleria rugosa	Graminoid						0.1	<1						
Sorghum plumosum var. teretifolium	Graminoid		1	50	1.3	<1	1.2	<1						
Spiranthes aff. sinensis	Herb				0.4	<1 (1 plant)								
Stylidium dunlopianum	Herb		0.3	<1	0.1	<1	0.2	<1	0.05	<1	0.2	<1	0.2	<1
Stylosanthes viscosa	Shrub	*	0.02	<1 (removed)			0.1 (seedlings)	1						
Thysanotus chinensis	Herb		0.6	<1										
Timonius timon	Tree		3	<1			3	3						
Utricularia chrysantha	Herb								0.4	<1	0.3	<1	0.4	<1
Utricularia circumvoluta	Herb												0.3	0.25
Utricularia gibba	Herb				0.01	<1	0.02	<1	0.02	<1				
Utricularia kimberleyensis	Herb				0.3	<1					0.1	<1		
Vigna lanceolata var. filiformis	Shrub		0.2	<1										
Vigna lanceolata var. lanceolata	Shrub						0.05	<1						
Wahlenbergia queenslandica	Herb		0.7	<1										
Xyris cheumatophila	Graminoid						0.3	<1						
Xyris complanata	Graminoid		0.3	<1	0.3	<1			0.8	60	0.7	5	1	<1
Xyris indica	Graminoid		0.6	<1	0.5	<1			0.8	1	0.2	<1	0.5	<1

Appendix 2

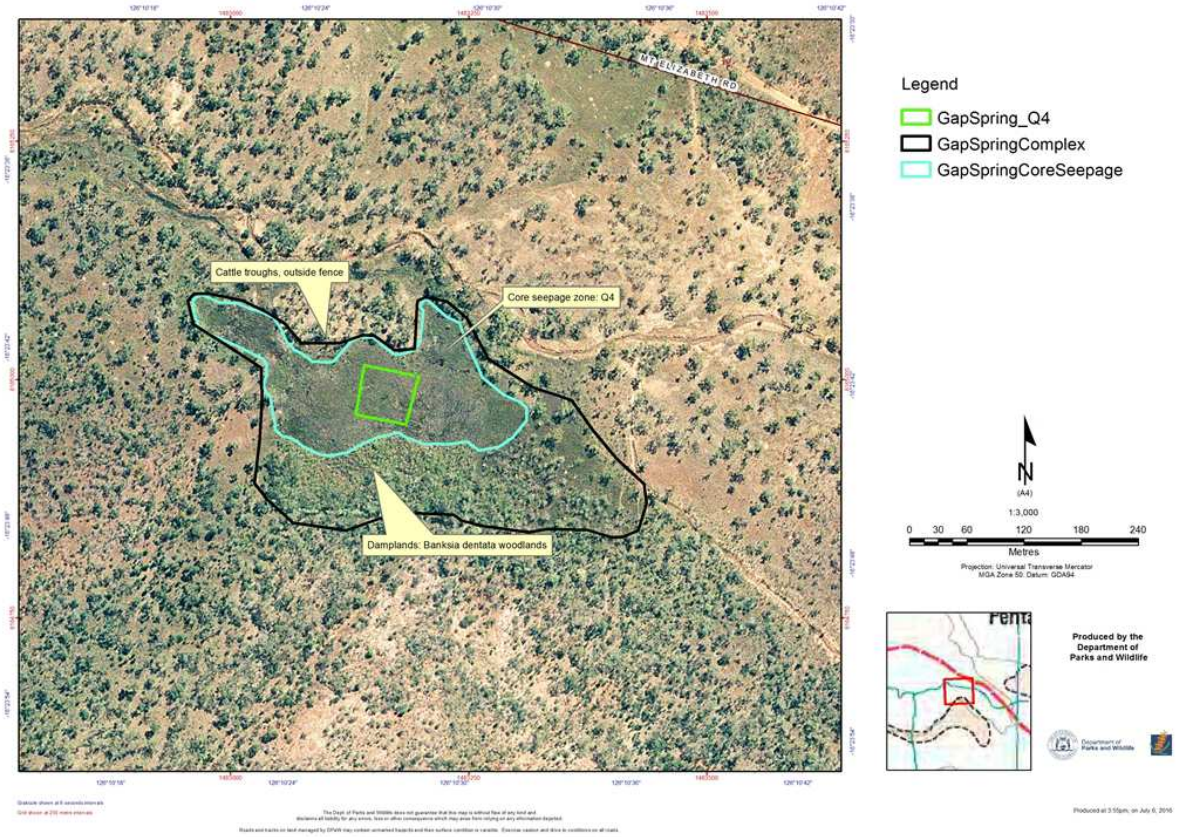
Weed taxa located in mound spring occurrences

Species	Waterfall Yard Spring	Gap Spring	Mud Spring (Kangaroo Spring)	Middle Spring
Emilia sonchifolia	**1**	**1**	**1**	
Gomphrena celosioides		**1**		
Hibiscus sabdariffa				**1**
Panaeolus papilionaceus (fungus in cow dung)	**1**			
Passiflora foetida	**1**			
Sida cordifolia		**1**		
Stylosanthes scabra		**1**	**1**	
Stylosanthes viscosa	**1**			**1**
Themeda triandra			**1**	
Triumfetta pentandra		**1**		

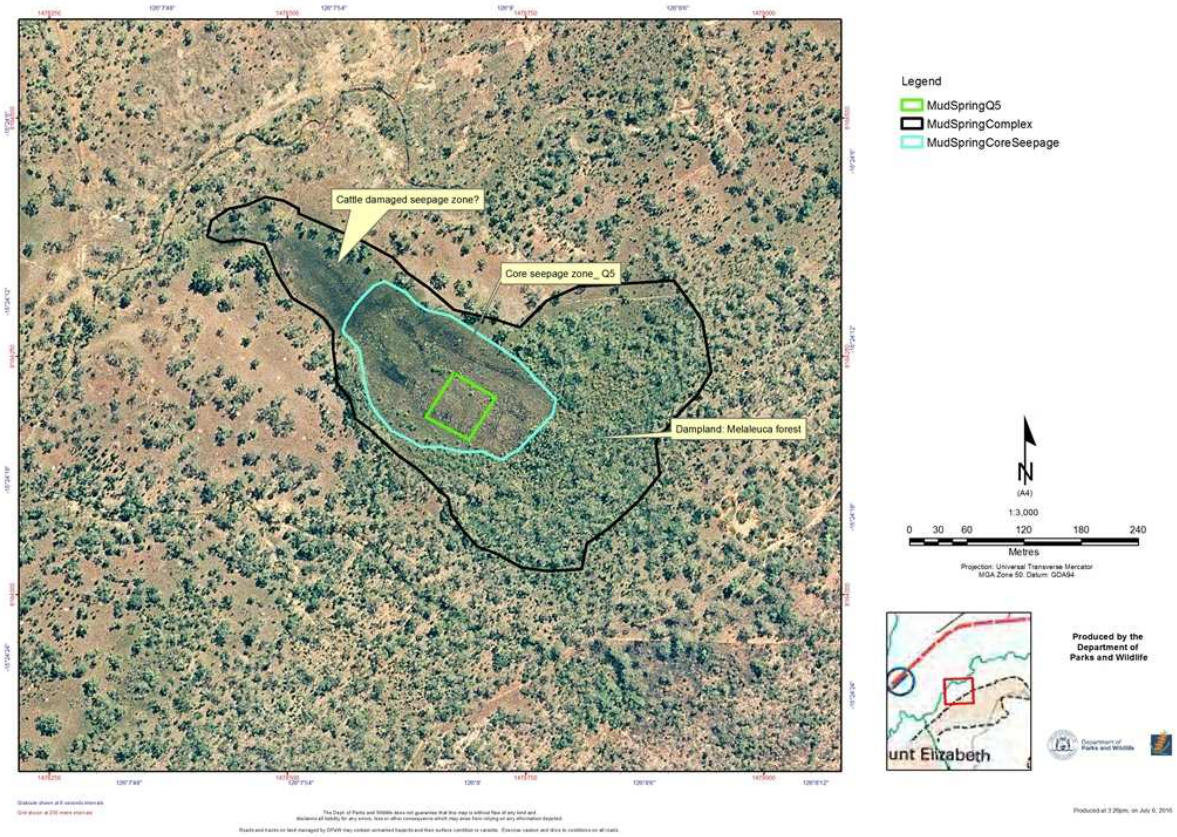
Appendix 3 – detailed maps



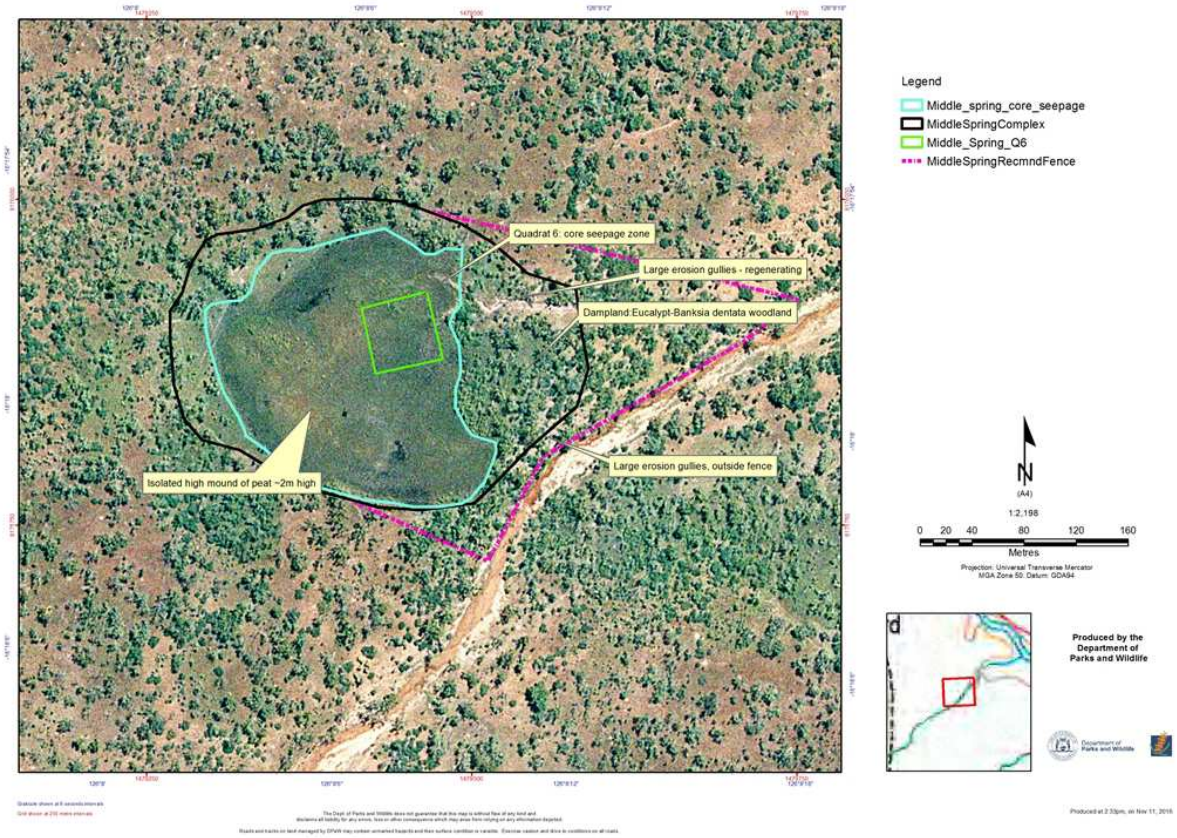
Waterfall Yard spring main features



Gap Spring main features



Mud Spring main features



Middle Spring main features