Department of Science, Information Technology and Innovation

Barcaldine Springs Supergroup

Hydrogeology and ecology

2016

Queensland Government

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Excerpt from

Fensham, R.J., Silcock, J.L., Laffineur, B., MacDermott, H.J. 2016, Lake Eyre Basin Springs Assessment Project: Hydrogeology, cultural history and biological values of springs in the Barcaldine, Springvale and Flinders River supergroups, Galilee Basin springs and Tertiary springs of western Queensland. Report to Office of Water Science, Department of Science, Information Technology and Innovation, Brisbane.

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Citation

Queensland Herbarium 2017, Hydrogeology and ecology of the Barcaldine Springs Supergroup. Department of Science, Information Technology and Innovation, Brisbane.

Front Cover: Edgbaston Springs and a spring (imaginatively) called “New Big”. There is Spinifex in the foreground, free water in the mid-ground, with some scalding in front and the far right rear. Photo: Queensland Herbarium.

March 2017

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Overview

Springs comprising the Barcaldine supergroup occur over a 330 x 100 km area (Figure 1) and include 287 active spring wetlands, and 50 inactive springs. Thirteen percent of the outcrop springs and 15% of the discharge springs are inactive (Table 1). The springs are concentrated in two lines: a western line of predominantly discharge springs and an eastern line comprising outcrop springs (Figure 1).

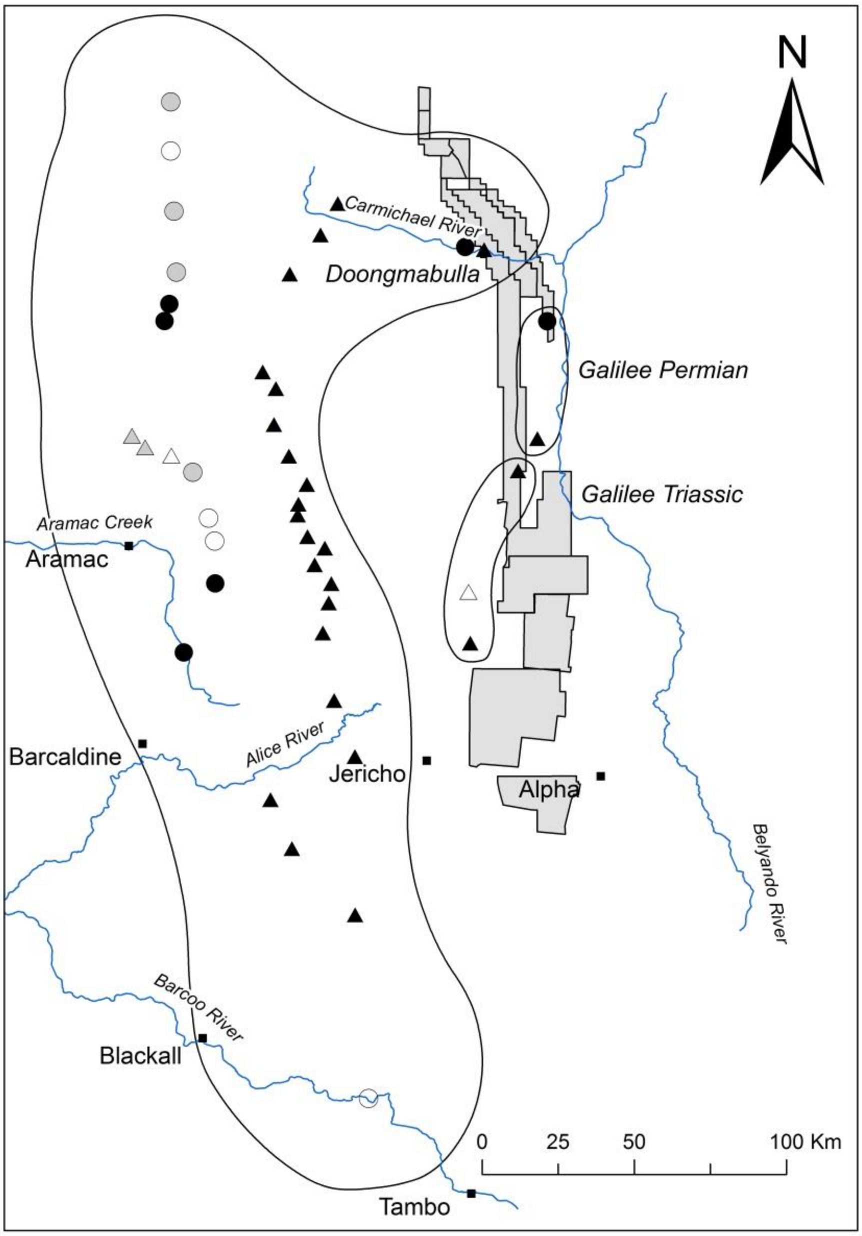

Figure 1. Spring complexes within the Barcaldine supergroup with the Doongmabulla, Galilee Permian and Galilee Triassic spring groups identified. Spring complexes showing 100% active springs (solid), partially (1%-99%) active (grey) and 100% inactive (open symbols). Outcrop springs (triangles) are distinguished from discharge springs (circles). The leases for the proposed coal mining developments in the Galilee Basin are shown (grey polygons).

Table 1. Summary of the status of the springs in the Barcaldine supergroup (excluding Doongmabulla) at the complex, wetland and vent scale.

	Complex			Spring		Vent	
	Active	Partially active	Inactive	Active	Inactive	Active	Inactive
Outcrop	21	3	1	71	11	78	11
Discharge	4	4	4	216	39	218	39

The outcrop springs within the Barcaldine supergroup occur towards the eastern margin of the Eromanga Basin where the sediments comprising aquifer units are outcropping (Figure 2). The springs typically occur in relatively flat terrain where there is outcropping sandstone. Most of these springs have been excavated and for some the water level is below the rim of the excavated sandstone (Figure 3).

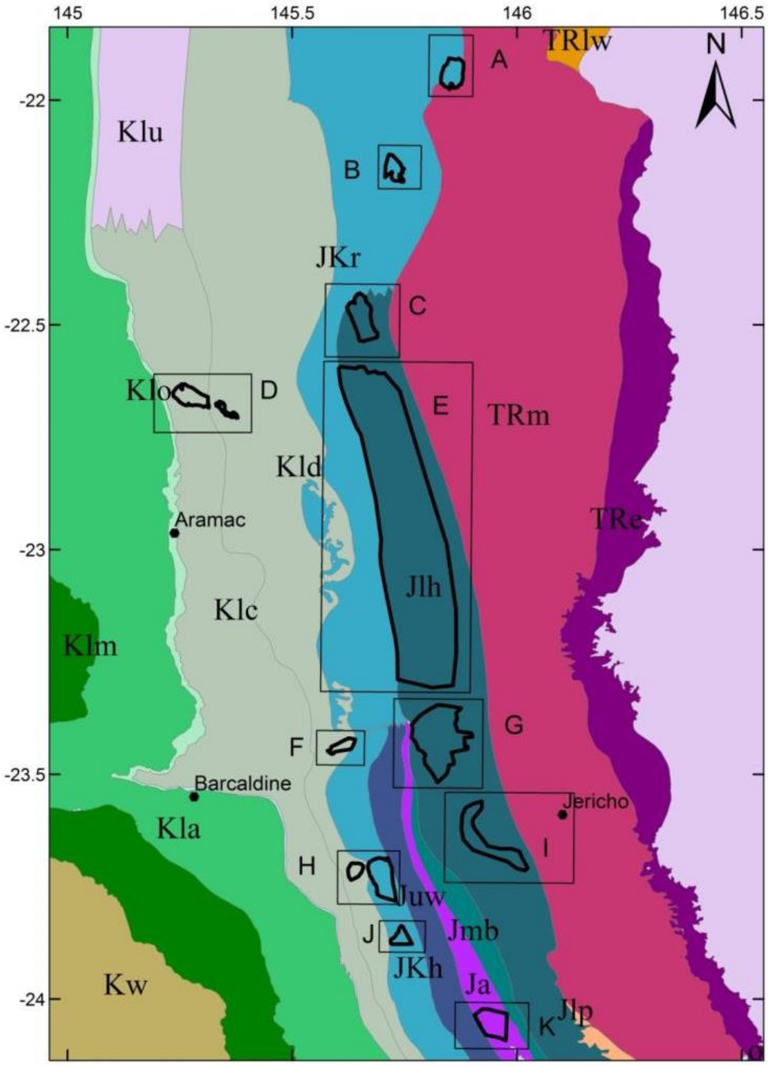

Figure 2. Outcrop springs (labelled polygons) in the eastern Barcaldine supergroup with the consolidated sedimentary geology of the Great Artesian Basin (i.e. Cainozoic units) removed. Tre: Clematis Sandstone; Trlw: Warrang Sandstone; Trm: Moolayember Formation; Jlp: Precipice Sandstone; Jlh: Hutton Sandstone; Jkr: Ronlow Beds; Jmb: Birkhead Formation; Ja, Adori Sandstone, Juw, Westbourne Formation; Jkh, Hooray Sandstone; Kld, Doncaster Member, Klc, Coreena Member; Klo: Toolebuc Formation; Kla: Allaru Mudstone; Klo: Mockunda Formation; Kw: Winton Formation (Data source: Hydrogeology of the Great Artesian Basin-boundaries of the hydrogeological units, GeoSciences Australia, 2014, catalogue no. 72665).

Figure 3. Box Flat Spring is typical of the springs in the eastern Barcaldine supergroup, occurring in flat terrain with sandstone outcropping and having been excavated.

The discharge springs extend in a north-south line. In the middle section this line of springs is associated with the floodplains of the tributaries of Aramac Creek, and in the northern section by the floodplain of Thunderbolt Creek. These sections are intersected by a residual plateau (Figure 4). In the far south almost 200 km from the other discharge springs in this supergroup are the Northampton Hotel springs to the east-south-east of Blackall.

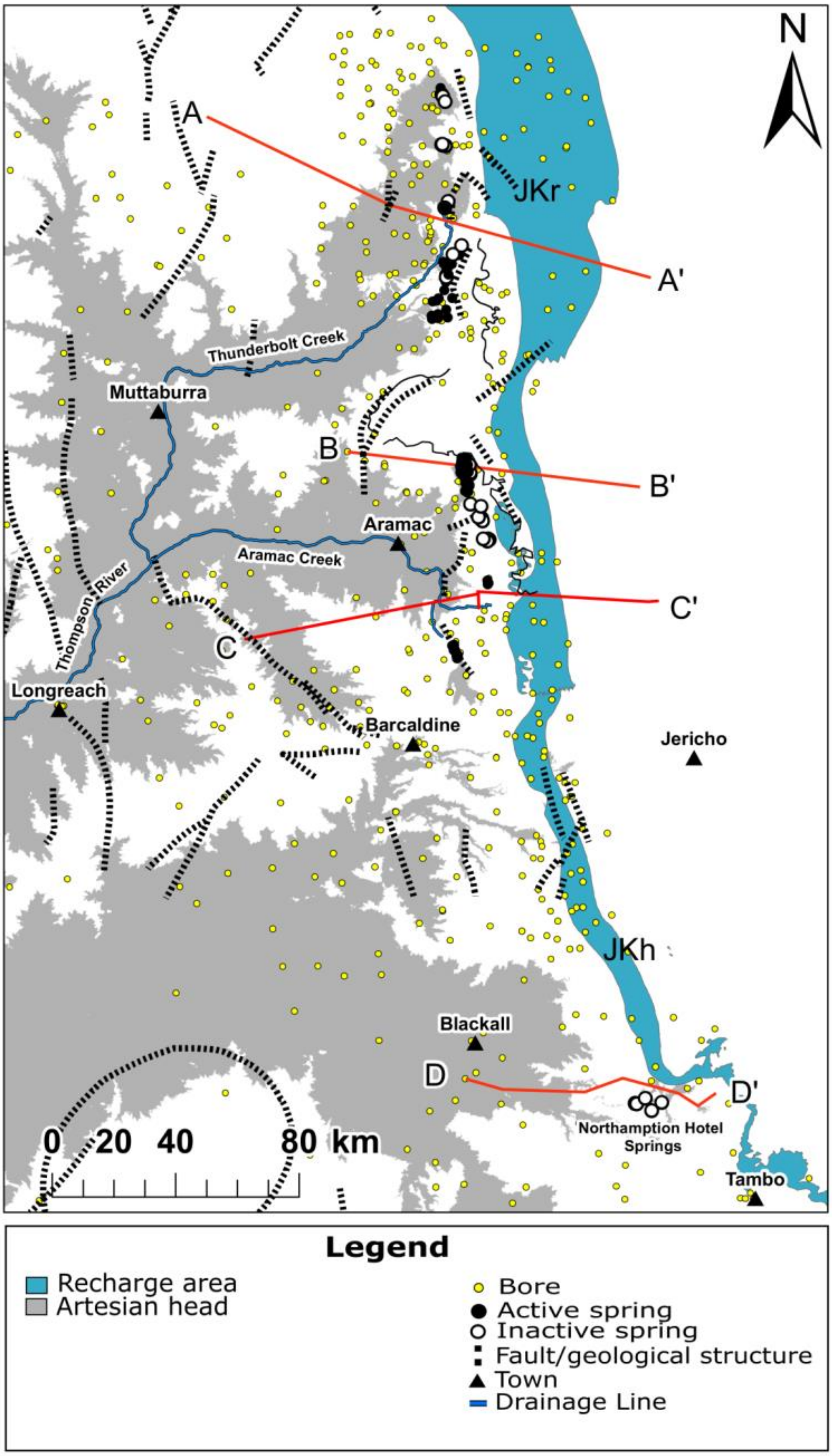

Figure 4. The Barcaldine supergroup discharge springs. The outcropping Ronlow Beds (Jkr)/Hooray sandstone (Jkh) that provide the water source for the springs is identified in blue. Bores are identified in yellow. Stratigraphies presented below are identified.

Hydrogeology

Regional geology

The stratigraphic relations between the sedimentary units in the vicinity of the Barcaldine supergroup outcrop springs is presented in Figure 2C. The base of this sequence is formed by the water-bearing Hutton Sandstone which is overlain by the Injune Creek group of sediments (including interbedded units mostly forming non-porous aquicludes and aquitards). These are overlain by the Hooray Sandstone, often identified as Ronlow Beds forming an equivalent in this region. The Hooray Sandstone is the most important aquifer for groundwater exploitation throughout the GAB. The Hooray Sandstone is overlain by generally fine-grained sediments of the Wallumbilla Formation including the Doncaster and Coreena Members. These units can include water-bearing facies but generally act as an aquitard in this region.

In practice, the sandstone units in this area represent transitional facies with a gradual eastward reduction in the amount of argillaceous sediment accompanied by a thinning of the Hooray Sandstone and Injune Creek Group (Burger and Senior, 1979) such that the Ronlow Beds are dominantly equivalent to the Hutton Sandstone (Figure 2).

Hydrology of the springs

Barcaldine outcrop springs

These springs mostly overlie the Hutton Sandstone, but there are some springs overlying the Hooray Sandstone, Ronlow Beds, Adori Sandstone, Doncaster Member and Coreena Member (Figure 2).

The Doncaster and Coreena Members are generally fine-grained and are not usually considered aquifer-bearing units, but some springs overlying these units (Figure 2D) are included here because they have a similar character to the other Barcaldine supergroup outcrop springs and are assumed to have a similar mechanism of discharge (see below). If our interpretation is correct the source of these springs is from permeable beds within the Doncaster and Coreena Members.

The observations of The Vagabond, who travelled to “The Springs” 13 miles west of Jericho in 1885 when the railway line was under construction, verifies that many of the ‘springs’ were actually holes dug through to the shallow rocky watertable, as described in his article ‘A winter tour in Queensland’, published in *The Australasian Supplement*,:

> *This is called The Springs because any railway navvy armed with a crowbar can here successfully imitate Moses's feat at Horeb, and striking the reef of solid limestone rock which runs across the plain water will gush therefrom (19 September 1885, p.1).*

A contemporaneous reporter from The Maitland Mercury and Hunter River General Advertiser referred to springs in the general vicinity;

> *In the same desert country at Green Tree there are fine springs. Then west of Green Tree you come on the native wells. Then there are the mud springs at Coreena station…(May 22 1890, p.6)*

It is probable that the ‘native wells’ included some of the springs in this group, and this suggests that some of the excavations were initiated by Aboriginal people.

There are very few springs in this area that have not been excavated, the Yellow Water Springs being the prime example (Figure 5). The ‘weeping rock’ discharge of this spring reveals the likely appearance of the other springs before excavation.

Figure 5. The Yellow Water Spring, one of the few springs in the eastern Barcaldine supergroup that has not been excavated. This spring provides a rare insight into the original character of these springs.

The potentiometric surface in these sandstone units is mostly below ground level (Table 2) suggesting either a deep source or local recharge source and a gravity-fed discharge. A potential deep aquifer source is the Clematis Sandstone, but this is unlikely given the potentiometric surface in this aquifer is insufficient to generate discharge for these springs. Furthermore there is no evidence of either fracturing or faulting through the confining sediments of the Moolayember Formation, which is about 200m thick through this area (Vine et al., 1972b).

The evidence suggests that these springs are fed by gravity from local recharge. They all occur in geological units that are sufficiently porous to contain and transmit groundwater, with the exception of group D on Figure 2 which occurs in sediments that are generally fine-grained. The terrain is generally flat but a detailed examination of the elevation indicates that they all occur in areas where there is outcrop at higher elevation which could provide recharge (Figure 7).

Likely recharge areas for each cluster of these springs have been inferred from the position of the spring and breaks in slope of the surrounding topography. Assuming that these areas receive 500mm of rainfall per annum and using the discharge rates inferred from field inspection (Table 2), the proportion of recharge required to supply this discharge can be calculated. The proportion of recharge required is less than 0.016% in all cases except the Maryvale Springs where the estimate of the proportion of recharge water required to provide discharge to the spring is 1.18%.

There is little evidence that these springs have diminished in flow during European settlement, and this would be in keeping with a local groundwater source rather than a regional aquifer. The exceptions are the springs at Sandy Creek (site 342) which were described by Griffiths:

> *The Sandy Creek springs are close to the west boundary and about 3 miles south of the NW corner. The water issues from the desert formation and fills pools about a mile in extent running north into Sandy Creek. The water suits stock but is not considered good for human consumption. During the 1897 drought (Nov) 9 to 10 000 sheep with 70% of lambs were regularly watered here, taking about 24 000 gallons per day.*

In 1999, the main spring at Sandy Creek was active, excavated and dammed, with free water covering 250m^2 but was not flowing the creek (Figure 6). Clearly these springs have diminished in flow, which is atypical for outcrop springs fed by gravity. The modelled surface of the Ronlow Beds aquifer (Hooray Sandstone equivalent) is 26m below the ground surface. The groundwater surface decline as a result of regional drawdown impacts is substantially less in this region. This suggests the decline in this spring is the result of interception of local groundwater sources, probably by the bore adjacent to the spring (Figure 6).

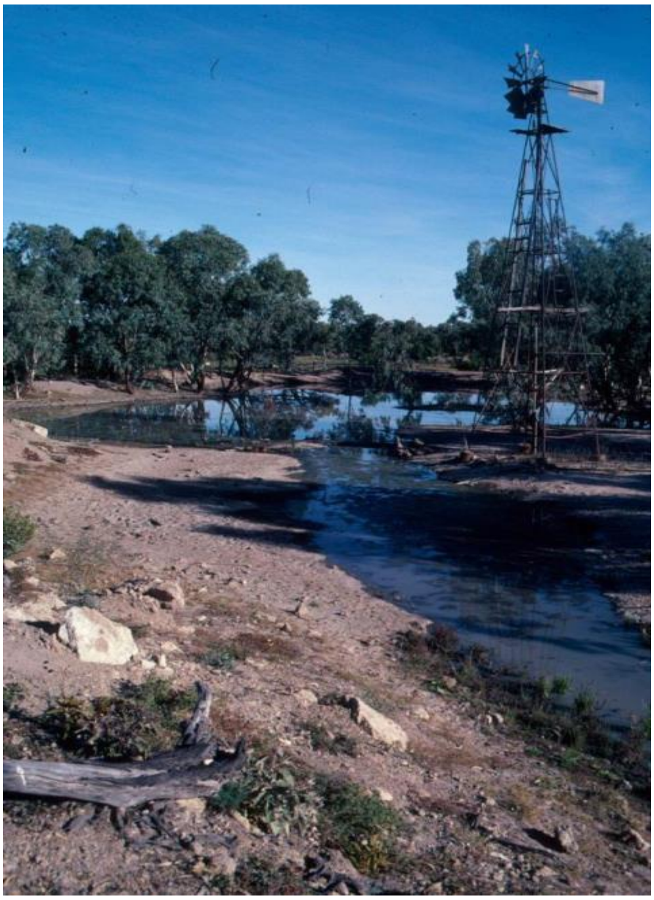

Figure 6. Sandy Creek Spring in 1999

Table 2. Spring clusters as identified on Figure 6 with source geology, mean elevation, assumed recharge area, assumed recharge volumes (assuming 500mm rainfall per year), discharge and the proportion of assumed recharge required to supply discharge to the springs. The modelled head was supplied by Geosciences Australia.

Cluster	Name	Geology	Average modelled potentiometric head (m)	Elevation of lowest spring	Presumed recharge area (km2)	Recharge ML/yr	Discharge ML/yr	Discharge/ recharge (%)
A	Scott, Kyong	Ronlow Beds (JKr)	-46.01	327	29.77	14883.6	1.242	0.008
B	Marion	Ronlow Beds (JKr)	-115.94	395	18.10	9052.2	0.001	0.000
C	Black Swamp, Yellow waterhole	Hutton Sandstone (Jlh)	-27.56	289	46.03	23015.8	1.382	0.006
D	Budgerry West	Coreena Member (Klc)	NA	267	28.18	14091.0	37.752	0.268
D	Budgerry East	Doncaster Member (Kld)	NA	281	5.31	2656.6	14.763	0.556
E	Barcaldine Core Spring	Hutton Sandstone (Jlh)	-50.68	294	1053.38	526691.0	10.289	0.002
F	Valley Downs	Doncaster Member (Kld)	NA	325	11.80	5898.4	0.906	0.015
G	Heart	Hutton Sandstone (Jlh)	-15.45	326	145.35	72673.6	3.719	0.005
H	North Delta West	Doncaster Member (Kld)	NA	292	10.27	5137.5	0.738	0.014
H	North Delta East	Hooray Sandstone (JKh)	-2.67	305	44.02	22010.0	3.110	0.014
I	Jericho	Hutton Sandstone (Jlh)	-11.05	336	68.17	34082.7	0.622	0.002
J	Alls Well	Hooray Sandstone (JKh)	1.39	323	11.91	5952.6	0.001	0.000
K	Maryvale	Adori Sandstone (Ja)	NA	386	38.80	19398.4	229.211	1.182

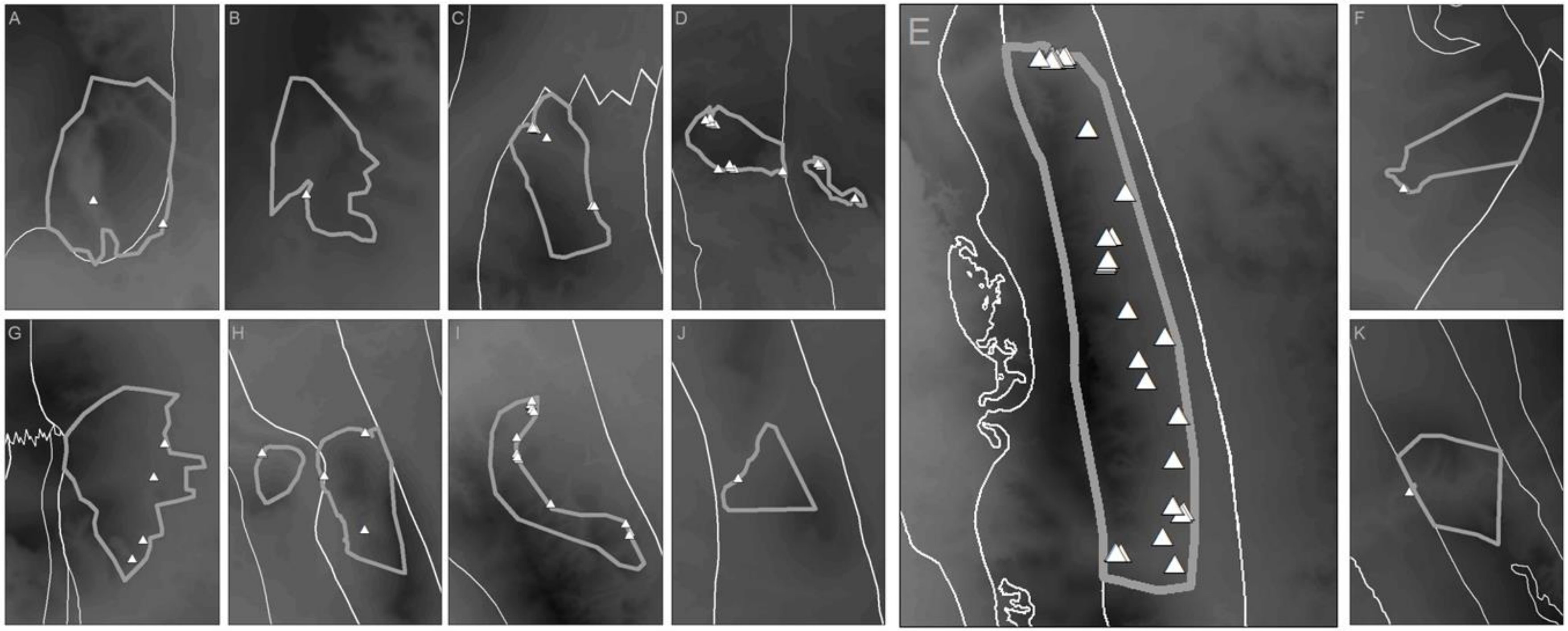

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Figure 7. Individual spring clusters identified on Figure 2 with geological boundaries represented as narrow white lines, estimated recharge areas grey lines, and springs identified as white triangles. The digital terrain model is represented as dark (high elevation) to light (low elevation), and is scaled appropriately to demonstrate the extent of upslope terrain for each spring cluster.

Barcaldine discharge springs

These springs (with the exception of the Northhampton Hotel Springs) almost certainly emanate from the Ronlow Beds/Hooray Sandstone where erosion has thinned or bisected the overlying Wallumbilla Formation. The springs occur along the margin of where the potentiometric surface in the Hooray Sandstone becomes artesian (Figure 4) and an intersection of the springs with a modelled surface of potentiometric head suggests pressure relative to ground surface in the vicinity of –24.5 m and +7.8 m.

Stratigraphic sections bisecting this line of springs suggest that they occur where there is a coincidence of a relatively thin confining layer and artesian pressure. To the east of this line there is insufficient aquifer pressure to provide artesian flow, and west of this line the aquitard may be too thick for a flow path to form. Where the springs occur the Wallumbilla formation is generally between 40 and 100m m deep (Figure 8, Figure 9, Figure 10, Figure 11), but it may be considerably reduced where current streams enhance erosion. The Wallumbilla Formation may include permeable beds sufficient to transmit discharge from the underlying sandstone over such distances.

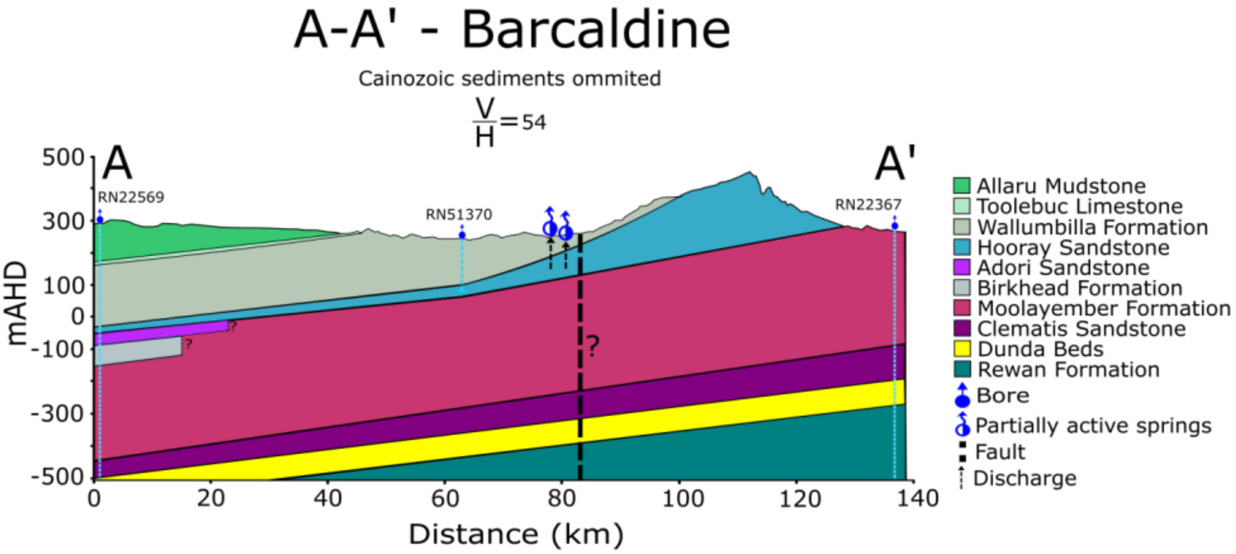

Figure 8. Stratigraphy at Corinda (see Figure 4). Figure 11 indicates the position of the Barcaldine discharge springs and position of a fault structure that may provide a weakness in the Wallumbilla Formation permitting discharge.

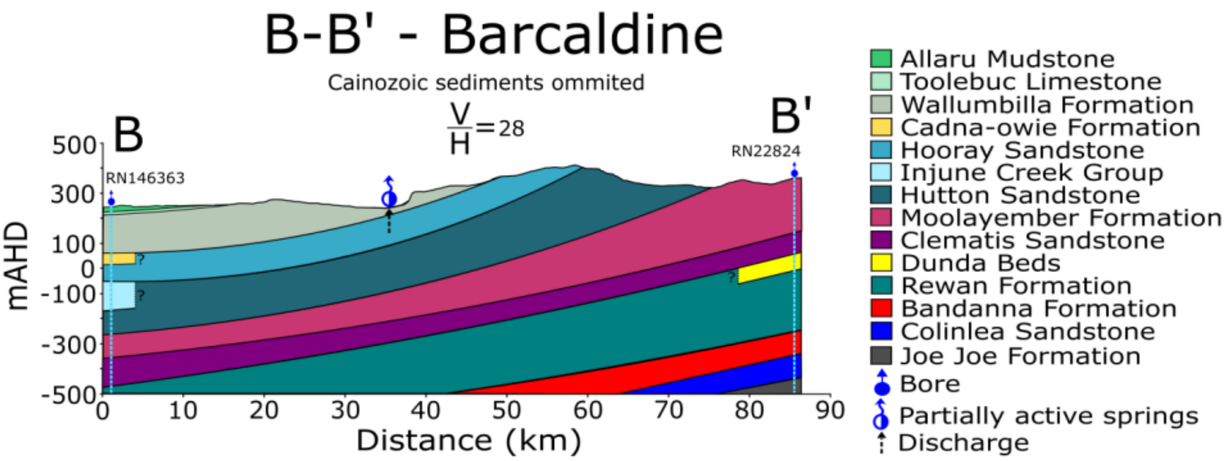

Figure 9. Stratigraphy at Edgbaston (see Figure 4) indicating the position of the Barcaldine discharge springs where the Wallumbilla Formation has been thinned by Pelican Creek.

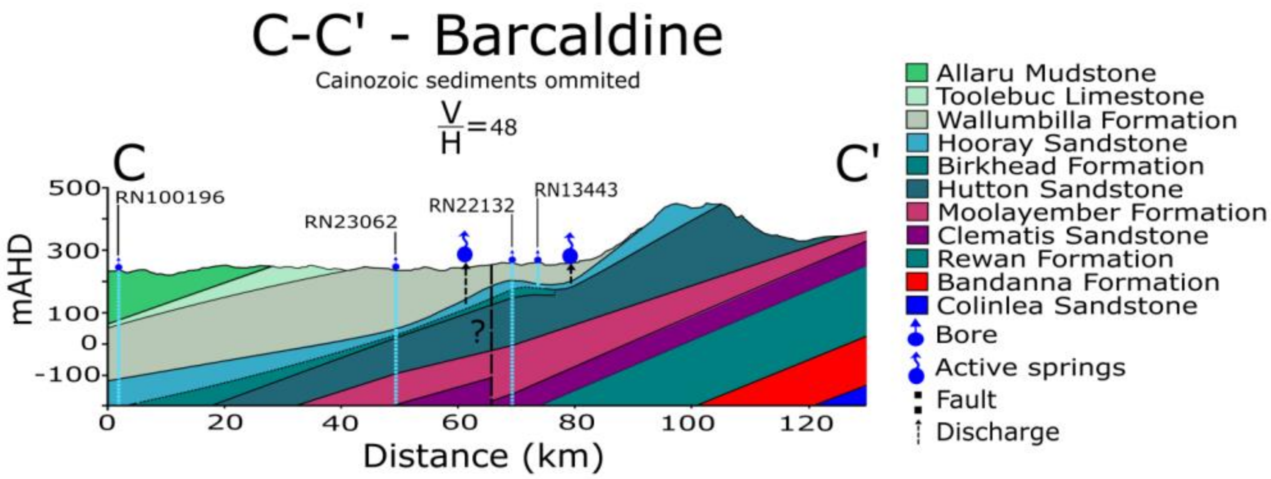

Figure 10. Stratigraphy at Coreena (see Figure 4) indicating the position of the Barcaldine discharge springs. The Coreena Springs in the west may be associated with a fault structure that may provide a weakness in the Wallumbilla Formation permitting discharge, and the Jersey Springs in the east where the Wallumbilla Formation has been thinned by erosion associated with Sandy Creek.

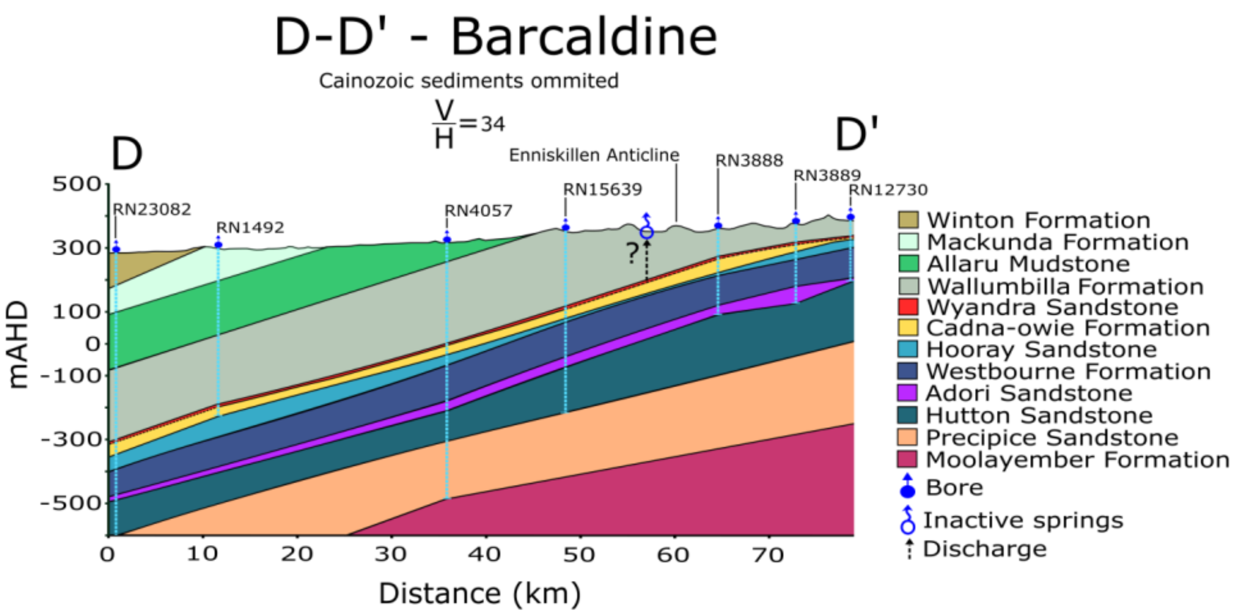

Figure 11. Stratigraphy at Northampton Hotel (see Figure 4) indicating the position of the Barcaldine discharge springs. There is no evidence of thinning or faulting in the Wallumbilla Formation that would allow discharge.

There is also evidence of fault structures in some locations, such as at Corinda and Coreena (Figure 8, Figure 10) that may be allowing discharge through fractures in the aquitard.

The source of the outlying Northampton Hotel Springs in the far south of the Barcaldine supergroup is difficult to explain. These currently inactive springs were never very substantial, described by Griffiths in 1898-9 as supplying a waterhole ‘sufficient for the local stock’. The aquitard formed by the Walumbilla Formation is approximately 150m thick (Figure 11), and while the Mt Enniskillen anticline trends northeast through the springs it is not apparent for a stratigraphy prepared from nearby bores (Figure 11). The source of these springs is either through permeable beds in the Walumbilla Formation or from a local aquifer within the Walumbilla Formation. The extinction of the springs in coincidence with extensive extraction through bores into the main aquifer in the Hooray Sandstone lend weight toward the former interpretation.

The discharge springs, particularly those in the Pelican Creek area, are associated with calcium carbonate precipitated from the groundwater as travertine deposits. Calcium carbonate is generally held in solution where pH is lowered, usually by carbonic acid derived from a source of carbon-dioxide. The interpretation presented here suggests that these springs have their source in the outcropping Ronlow Beds 30 km to the east at an elevation about 40m above the springs. This suggests intermediate residence times for the groundwater, but this is sufficient to accumulate calcium carbonate for the formation of the travertine around spring discharge areas.

Around Pelican Creek there are large areas of travertine that are not associated with current springs indicating considerable dynamism in spring locations over long time frames. Fossilised spring-dependent snails occur in the travertine. There is some evidence that travertine accumulations can block spring discharge resulting in emergence at new locations. An area in upper Pelican Creek known locally as the Bald Ring may be an example of a travertine shield with springs emerging from its expanding edge (Figure 12).

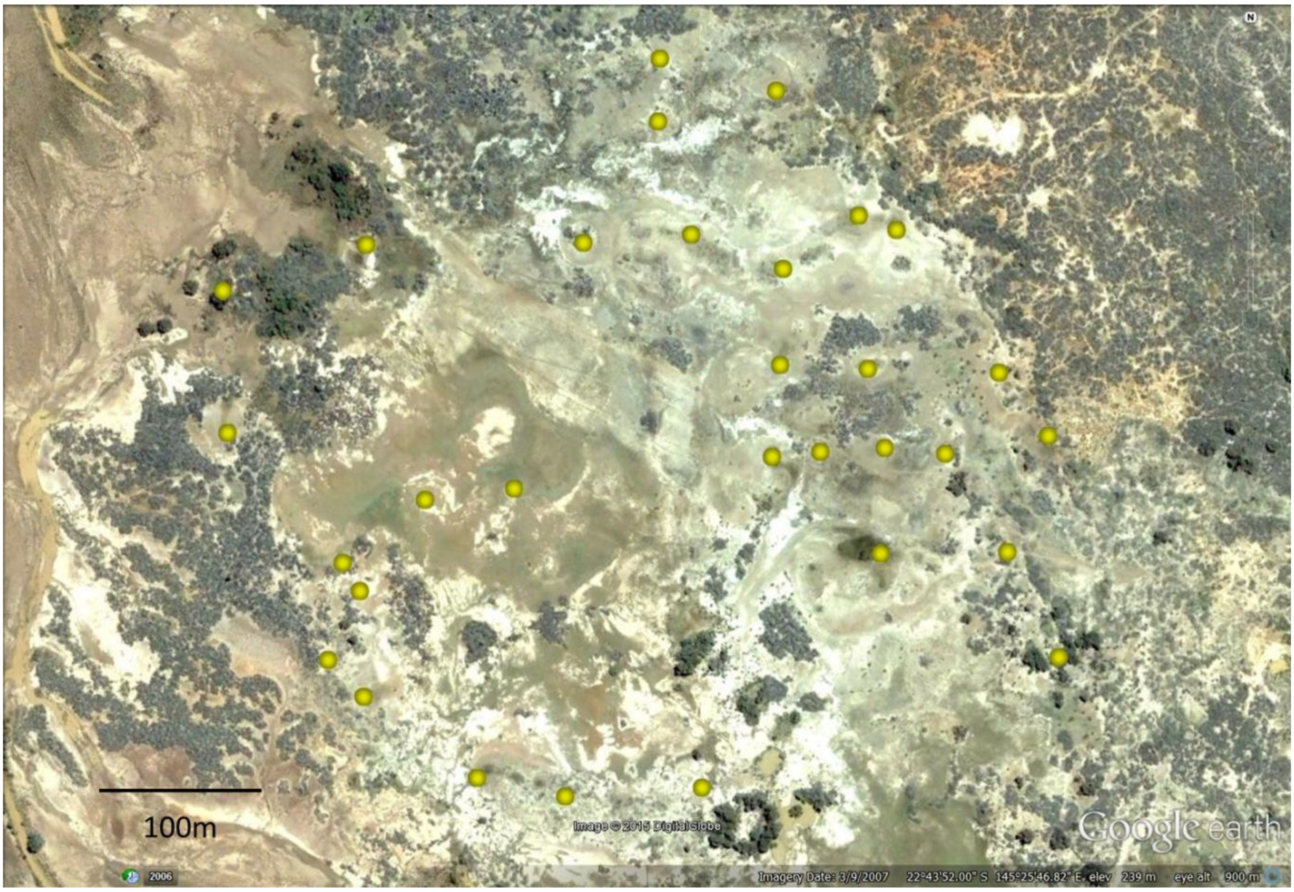

Figure 12. The Bald Ring at Edgbaston appears to be a travertine shield with springs (yellow circles) emerging around its margin; satellite image captured 2007.

There are also Pleistocene megafauna deposits adjacent to Pelican Creek which probably represent a spring-fed swamp that is no longer active. Many springs in the region have become inactive presumably because of depression cones in the potentiometric surface around groundwater bores.

Springs occur along Pelican Creek and its flood-out lakes on Edgbaston. The highest of these springs is not far from the break of slope at the base of the retreating scarp. In this location erosion is presumably reducing the thickness of the aquitard to the point where springs can emerge. The springs of the western Barcaldine Supergroup seem to be dynamic, with new springs emerging as erosion allows release of groundwater through the aquitard and closure of springs as they become cemented by travertine deposition. Despite this dynamism the concentration of endemic species (particularly in the headwaters of Pelican Creek) suggests considerable antiquity for the springs in their general geomorphological setting.

Biological values

Outcrop springs

Most Barcaldine outcrop springs are small and dominated by generalist wetland species, mostly grasses, sedges and annual forbs, both native and exotic. River red gums (*Eucalyptus camaldulensis*), the characteristic tree of inland wetlands and Australia's most widely-distributed eucalypt, occur around most springs. No endemic species have been recorded from outcrop springs in the Barcaldine supergroup, although some support geographically isolated populations of plants otherwise restricted to wetter areas. Four springs in The Lake group support *Myriophyllum implicatum*, representing a disjunct population of this aquatic species, while *Fimbristylis* sp. (Lake Buchanan V.J.Neldner+ 3362) is only known from one spring in this group and the shores of ephemeral Lakes Buchanan and Constant 100 km to the north.

More than three-quarters of outcrop springs have been excavated and/or contained in the Barcaldine group, destroying their spring wetlands (Figure 13) and making it difficult to judge whether they would have contained endemic species prior to modification. However the fact that even relatively unmodified outcrop springs do not contain specialised species suggest it is unlikely that any endemic species have been lost. Rather, the more neutral water chemistry and greater temporal fluctuations of outcrop springs compared to discharge springs seem to have limited the evolution of specialised endemics (Fensham et al., 2011).

Figure 13. Outcrop spring on The Lake: one of the few of the Barcaldine outcrop springs that has not been excavated.

Discharge springs

The Barcaldine supergroup stands out even amongst the exceptional endemism of GAB discharge springs (see Section 1). Nine spring groups contain endemic species, with Pelican Creek containing by far the highest concentration of endemic species in the GAB and indeed inland Australia (38 spring endemic species, including 24 that occur nowhere else). Coreena and Thunderbolt Creek have four endemic species each. Smoky, Coreena and Thunderbolt Creek each contain an endemic snail that is restricted to these springs (Table 3).

Plants

Four plant species are endemic to the Barcaldine supergroup: *Eriocaulon aloefolium, Eriocaulon giganteum*, *Eryngium fontanum* and *Peplidium* sp. (Edgbaston R.J. Fensham 3341) (Figure 14). The two *Eriocaulon* species are each restricted to a single population on Edgbaston in the Pelican Creek spring group. Both are perennial tussock-forming herbs, the former with fleshy aloevera-like leaves to 10cm long, the latter growing to 40cm high (see (Davies et al., 2007) for full morphological descriptions). *E. aloefolium* occurs across 0.005km^2 over two adjacent spring wetlands. In 2010, 1274 clumps were counted; this had almost doubled to 2588 in June 2013 but plants were smaller, suggesting a recent recruitment event (Paul Foreman, unpublished data). It is selectively dug up by pigs at certain times, however seems to recover well from this disturbance. The spring containing *Eriocaulon giganteum* lies on the ephemeral Lake Mueller and is surrounded by *Melaleuca bracteata.* Its area of occupancy is <0.001 ha, with 263 individuals counted in 2013, down from 480 in 2010, apparently due to flooding mortality amongst smaller plants in lower lying areas (Paul Foreman, unpublished data).

Table 3: Occurrence of spring endemics by spring complex, Barcaldine supergroup.

	Archers	Coreena	Thunderbolt Creek	Pelican Creek	Smoky	Kennedy	Old Lake Huffer	McKenzie's	Total springs, Barcaldine (all GAB)
Plants									
Chloris sp. (Edgbaston R.J. Fensham 5694)				4					
Eriocaulon aloefolium	-	-	-	2	-	-	-	-	2 (2)
Eriocaulon carsonii	-	-	2	70	-	-	-	-	89 (140)
Eriocaulon gigantium	-	-	-	1	-	-	-	-	1 (1)
Eryngium fontanum	-	1	-	54	-	-	-	-	60 (60)
Hydrocotyle dipleura	1	-	-	51	1	1	1	-	65 (75)
Isotoma sp. (Myross R.J. Fensham 3883)	-	-	-	12	-	-	-	-	15 (16)
Myriophyllum artesium	1	1	9	61	1		-	-	89 (130)
Peplidium sp. (Edgbaston R.J. Fensham 3341)	-	-	-	25	-	-	-	-	25 (25)
Sporobolus pamelae	1	1	-	108	-	1	-	1	126 (130)
Fish									
Scaturiginichthys vermeilipinnis	-	-	-	3	-	-	-	-	3 (3)
Chlamydogobius micropterus	-	-	-	29	-	-	-	-	29 (30)
Molluscs							-		
Gabbia davisi	-	-	-	-	1	-	-	-	1 (1)
G. fontana	-	-	-	13	-	-	-	-	13 (13)
G. pallidula	-	-			-	-	-	-	
Glyptophysa n.sp.	-	-	-	11	-	-	-	-	11 (11)
Gyraulus edgbastonensis	-	-	-	16	-	-	-	-	16 (16)
Jardinella colmani	-	-	2	-	-	-	-	-	2 (2)
Jardinella coreena	-	1	-	-	-	-	-	-	1 (1)
J. aff. accum smooth	-	-	-	4	-	-	-	-	4 (4)
J. edgbastonensis	-	-	-	38	-	-	-	-	38 (38)
J. aff. edgbastonensis	-	-	-	15	-	-	-	-	15 (15)
J. corrugata	-	-	-	17	-	-	-	-	17 (17)
J. accuminata	-	-	-	12	-	-	-	-	12 (12)
J. jesswiseae	-	-	-	31	-	-	-	-	31 (31)
J. pallida	-	-	-	18	-	-	-	-	18 (18)
J. Myross A aff pallida	-	-	-	5	-	-	-	-	5 (5)
J. Myross B tall keeled	-	-	-	5	-	-	-	-	5 (5)
J. Myross C aff accum ribbed	-	-	-	1	-	-	-	-	1 (1)
J. Myross D (fat) aff corrugata	-	-	-	13	-	-	-	-	13 (13)
J. zeidlerorum	-	-	-	10	-	-	-	-	10 (10)
Edgbastonia alanwillsi	-	-		16	-	-	-	-	16 (16)
Other invertebrates									
Dugesia artesiana (flatworm)	-	-	-	2	-	-	-	-	2 (2)
TOTAL ENDEMIC SPECIES	3	4	4	31	3	2	1	1	

Figure 14. Plant species endemic to the Barcladine supergroup (clockwise from top left: *Eriocaulon aloefolium, Eriocaulon giganteum, Peplidium* sp. (Edgbaston R.J. Fensham 3341), *Eryngium fontanum*)

Peplidium sp. (Edgbaston R.J. Fensham 3341), a slender prostrate forb with round leaves and dark-pink flowers, is also restricted to the Pelican Creek springs where it is known from 25 springs, mostly north and east of the Edgbaston homestead. It can be locally abundant within its extremely restricted range, with a conservative population estimate of 2500 plants. *Eryngium fontanum* is a distinctive upright perennial herb with a circular cluster of fleshy leaves at its base, a solid fleshy taproot and flowering stems 40-80 cm long producing elongated blue flowerheads. It occurs at Doongmabulla (four adjacent spring wetlands), Pelican Creek (recorded from 54 spring wetlands) and Coreena (one small population of 20 plants), and the total number of individuals is probably <6000 plants.

A further three species are known only from the Barcaldine and Eulo supergroups, and in all cases Barcaldine represents their stronghold. *Isotoma* sp. (Myross R.J. Fensham 3883), a tiny mat-forming aquatic to <3cm high with white flowers, is mostly restricted to the Barcaldine supergroup, but also occurs in one spring at Yowah Creek west of Eulo.

It has been recorded in 12 spring wetlands at Pelican Creek and three at Moses Springs on Doongmabulla. Its mat-forming habit and inconspicuous nature when not flowering render it very difficult to estimate population size, but a conservation estimate would be 200 plants per population * 15 springs = 3000 plants in total.

The robust perennial grass *Sporobolus pamelae* only occurs at four spring wetlands west of Eulo outside the Barcaldine supergroup. It is a characteristic and often dominant grass in >80 spring wetlands at Pelican Creek and 15 at Doongmabulla, with scattered tussocks at four other springs. *Hydrocotyle dipleura*, a distinctive ground-hugging forb forming small carpets across patches on permanent groundwater soakage areas, occurs at four spring groups at Eulo and six at Barcaldine, where it has been recorded from 65 individual springs. Most (51) of these populations are at Pelican Creek. The tall perennial grass *Chloris* sp. (Edgbaston R.J. Fensham 5694) is extensive around the damp edges of springs at Doongmabulla and is patchily common over small areas at Edgbaston. It is often heavily grazed by macropods and has been recommended for listing as Endangered (Silcock et al., 2014). *Utricularia fenshamii* is almost an endemic known from Barcaldine supergroup discharge springs and also the Eulo Bourke and Mitchell-Staaten supergroups. However, it is also known from a swamp near Wee Waa in New South Wales (Jobson, 2013). The Barcaldine supergroup contains more than half the known populations of *Eriocaulon carsonii* and *Myriophyllum artesium*

Some springs also contain disjunct populations of some plant species, notably belah (*Casuarina cristata*) at Smoky Spring on Lake Huffer; *Cenchrus purpurascens* and *Utricularia caerulea* at Edgbaston and Doongmabulla; *Leersia hexandra* at Thunderbolt Spring on Corinda; and black tea-tree (*Melaleuca bracteata*) and bore-drain sedge (*Cyperus laevigatus*), both of which characterise many springs. *Baumea rubiginosa, Isachne globsa, Ischaemum australe* and *Sacciolepis indica* at Doongmabulla also represent isolated inland occurrences of primarily higher-rainfall mesic species.

Fish

Fish species known from the Barcaldine group comprise endemic spring species, riverine vagrants that access springs opportunistically and the widespread invasive species gambusia, *Gambusia holbrooki*. Two of the three fish species endemic to Great Artesian Basin springs in Queensland occur in – and only in – the Barcaldine group (Figure 15); the red-finned blue-eye, *Scaturiginichthys vermeilipinnis,* and the Edgbaston goby, *Chlamydogobius squamigenus*)(Figure 15). Both species are listed as endangered under Queensland legislation (NCA 1992) and critically endangered by the IUCN (2015). Under federal legislation (EPBC 1999), the blue-eye is endangered and the goby vulnerable.

Figure 15. Endemic fish from the Barcladine supergroup: red-finned blue-eye (top) and Edgbaston goby (bottom) (photos: Adam Kerezsy).

Red-finned blue-eye was discovered in 1990 by Australian fish ecologist Peter Unmack at Edgbaston Station north-east of Aramac. The species is the only member of its family (Pseudomugilidae) from Australia’s interior, and is rarely larger than three centimetres long. The springs at Edgbaston remain the only habitats where red-finned blue-eye have been found, however the spring complex is also inhabited by gambusia and observations from 2009 have demonstrated that gambusia colonisation leads to extirpation of the endemic species at individual spring scale (Kerezsy and Fensham, 2013).

Edgbaston was purchased by the not-for-profit conservation group Bush Heritage Australia in 2008 and a recovery project was initiated in 2009 to ameliorate red-finned blue-eye decline. Techniques that have been used to-date at Edgbaston Reserve have included application of the piscicide rotenone (to control gambusia), relocation of red-finned blue-eye to springs that are gambusia-free and the installation of barriers around these springs to reduce the chance of subsequent gambusia colonisation (Kerezsy and Fensham, 2013). A captive breeding project was also initiated in 2014 by Bush Heritage Australia, although initial results indicate that maintaining and breeding the species in captivity is difficult (A. Kerezsy, pers. comm.). Similar results were reported in the 1990s by fish hobbyists, and no captive populations have endured from these attempts (Fairfax et al., 2007).

Red-finned blue-eye occurred in four springs at the commencement of the recovery project. They currently occur in eight, although six are relocated populations established between 2009 and 2014 (Kerezsy and Fensham, 2013; Kerezsy, 2015).The continuing decline of naturally-occurring populations of the species as well as the unpredictable success or failure of relocated populations suggest that the future of the species remains precarious and that on-going management is crucial to maintaining populations in the short to medium term (Kerezsy and Fensham, 2013).

The Edgbaston goby is a benthic species that grows to a maximum length of five to six centimetres (Allen et al., 2002). There are related species at Elizabeth Springs in the Diamantina catchment in western Queensland (*Chlamydogobius micropterus*), at Dalhousie Springs in northern South Australia (*Chlamydogobius dalhousiensis*), in the Finke River in the Northern Territory (*Chlamydogobius japalpa*) and in the southern Lake Eyre Basin (*Chlamydogobius eremius*). Speciation within the genus is likely to be a result of isolation and Australia’s drying climate over a long time period: as permanent water in the arid zone became more scarce, the small gobies were probably forced to retreat to spring complexes (at Edgbaston, Elizabeth Springs and Dalhousie) and isolated riverine water sources in the Finke and southern Lake Eyre regions.

Though not generally considered as imperilled as red-finned blue-eye, populations of Edgbaston goby have remained low: the species was found in eight springs at Edgbaston in 1994 (Wager, 1999), at nine in 2009 (Kerezsy, 2009) and nine in 2014 (Kerezsy, 2014c). In addition, Edgbaston goby is also present in at least one spring on Myross (a property adjoining Edgbaston) and in its outflow in Pelican Creek, and a population was recently found in a bore drain on Ravenswood, some 30 kilometres to the south-west (Kerezsy, 2014b). A population recorded from a bore drain at Crossmoor Station can be considered extinct as this bore has been capped.

Although Edgbaston goby has a wider distribution than red-finned blue-eye and can demonstrably co-habit with gambusia and survive in non-spring environments, evidence from Edgbaston suggests that increasing gambusia abundance may have a deleterious impact on the species (Kerezsy, 2014b). In the first instance, management of the species would benefit from additional survey of all permanent waters in the Aramac/Muttaburra/Longreach areas in order to accurately establish the distribution of the species. However, a recovery project similar to that in place for red-finned blue-eye is also worthy of consideration, particularly as populations of Edgbaston goby are often small (<50 individuals).

Riverine fish species present in catchments of the Lake Eyre Basin migrate to and colonise new areas following flooding: it is not surprising that these species occasionally access springs (Kerezsy et al., 2013). In the Barcaldine group, spangled perch, *Leiopotherapon unicolor*, glassfish, *Ambassis* sp., desert rainbowfish, *Melanotaenia splendida tatei* and hardyhead, *Craterocephalus stercusmuscarum* have been observed either opportunistically or as part of routine sampling (P. Unmack, S. Brooks, R. Fairfax, R. Fensham, A. Kerezsy pers. obs.).

These observations suggest that any small-bodied riverine fish species may access spring environments when conditions are favourable, however due to the shallowness of the springs, the high temperatures some springs reach in summer and the clarity of the water, these species can correctly be considered vagrants. Although hardyhead (*Craterocephalus stercusmuscarum*) from Big Moon Spring on Myross were once considered a possible separate spring species (Wager and Unmack, 2000), recent observations suggest that the fish is more widespread in the Aramac Creek catchment (D. Sternberg pers. com.), and genetically it is closely related to other populations elsewhere in the Lake Eyre Basin (Unmack and Dowling, 2010).

Invertebrates

The Barcaldine supergroup is home to the highest proportion of endemic invertebrate taxa in GAB springs nationally, many of which are restricted to particular regions. The invertebrate fauna can be broadly divided based on the way they use the habitat: transient and widely dispersing species (e.g. dragonflies) are common across numerous spring groups with little regional specialisation, whilst obligate aquatic groups such as molluscs tend to be endemic to a particular complex. Endemic taxa are particularly valuable and of primary conservation concern as they occupy very narrow ranges (i.e. most have a full range <50km radius) and rely solely on a particular set of springs. Current levels of endemism within the supergroup are likely to be an underestimate as numerous taxa found in Barcaldine that are represented in other areas (e.g. the amphipod genus *Austrochiltonia*, the shrimp species *Caridina thermophila*, flatworms *Dugesia artesiana*) have been ear-marked as potential endemics yet to be confirmed (Ponder et al., 2010).

Of confirmed endemic taxa the Barcaldine supergroup is particularly rich in molluscs: at least 15 species of gastropods are endemic to the supergroup. These comprise ten described and several undescribed species of *Jardinella* (Hydrobiidae), three species of spring endemic *Gabbia* (Bithyniidae) and two endemic Planorbidae (Ponder et al., 2010). Pelican Creek contains the highest concentration of endemics with nine species, while Smoky, Coreena and the Thunderbolt Creek springs (Winter and Thunderbolt Springs) are home to one endemic snail each. The species of Edgbaston are highly variable in shape and size, ranging from the tiny (<3mm) sand-coloured *Jardinella pallida* to the largest and most distinctive undescribed species of *Glyptophysa*, with a surprising amount of morphological variability arising in this local radiation of the Hydrobiidae.

Endemic gastropods rarely occupy all springs within a complex, which is likely the product of the interplay between limits on dispersal and environmental limits created by the variability of the spring environment. Snails are only able to move to new springs if there is a wetted area for them to traverse (e.g. connected spring tails), and most colonisation events are likely to be the product of transport on floodwaters or incidental transport on large mammals or birds. Most species within the Edgbaston complex are unable to survive more than two hours out of water, and most perish within six hours of being exposed to the highest natural levels of salinity (>6ppm) or extreme temperatures (>45°C), including *Jardinella acuminata*, *Jardinella jesswisea*, *Glyptophysa* n.sp. and *Gyraulus edgbastonensis* (Renee Rossini, unpub. data). This restricts many species to those springs that remain stable throughout daily and seasonal fluctuations, and to the permanent and deepest parts of those springs. More tolerant species (e.g. *Gabbia fontana, Jardinella corrugata*) can persevere up to 24 hours out of water and extreme salinities and are often found at spring edges or in shallow edges or tails.

Though spatially restricted to permanent and stable areas, many species are numerically common. Population estimates for two species based on their habitat associations predict that, in a large spring (E509) there could be up to 5,000 individuals of the large *Glyptophysa* n. sp. and between 13,000 and 26,000 individuals of *Jardinella corrugata* (Renee Rossini, unpublished data). It is likely that these numbers fluctuate markedly between seasons as extensive mortality occurs following winter when the spring tails begin to dry due to increase evaporation, leaving hundreds of individuals trapped and exposed to extreme conditions.

Groundwater scald plants

Sodic and salty groundwater scalds (Figure 16) are often associated with discharge springs, and these areas have a specialised non-aquatic flora (Figure 17; Table 4). Two species are endemic to this habitat and occur only on Edgbaston Reserve: *Gunniopsis* sp. (R.J. Fensham 5094) is known from three populations within a 2 km^2 area, totalling 80 plants, while the recently-described *Pluchea alata* (Bean, 2013b) can be locally common over small areas of scalded habitat adjacent to springs. The Near Threatened *Sporobolus partimpatens* is known from groundwater scalds within the Barcaldine, Bourke, Springsure, Eulo and Mulligan River supergroups, while undescribed *Calocephalus*, *Sclerolaena* and *Dissocarpos* species are restricted to groundwater scalds in the Aramac-Barcaldine area. *Trianthema* sp. (Coorabulka R.W. Purdie 1404) occurs on groundwater scalds throughout the GAB. *Eremophea spinosa* and the recently-described *Sphaeromorphaea major* (Bean, 2013a) are restricted to groundwater scalds in the Barcaldine supergroup in inland Queensland, but occur in other habitats elsewhere.

Figure 16. Scalded area in the vicinity of discharge springs provide habitat for endemic plant species.

Figure 17. Endemic plant species associated with scalded areas around discharge springs (clockwise from top left): *Gunniopsis* sp. (Edgbaston R.J. Fensham 5094); undescribed dioecious *Sclerolaena*; *Trianthema* sp. (Coorabulka R.W. Purdie 1404) and undescribed *Calocephalus* sp. (Edgbaston J.Silcock JLS800)

Table 4. Plants species endemic to GAB groundwater scalds, Barcaldine supergroup

Spring or complex	**Scald endemics**
Archer's	*Calocephalus* sp. (Edgbaston J.Silcock JLS800), *Sclerolaena "dioecia", Sporobolus partimpatens,Trianthema* sp. (Coorabulka R.W. Purdie 1404)
Edgbaston/Myross	*Gunniopsis* sp. (Edgbaston R.J. Fensham 5694), *Pluchea alata, Calocephalus* sp. (Edgbaston J.Silcock JLS800), *Trianthema* sp. (Coorabulka R.W. Purdie 1404), *Dissocarpos* sp. (Doongmabulla E.J. Thompson+GAL21), *Sclerolaena "dioecia", Sporobolus partimpatens, Dactyloctenium buchananensis,*
Smokey	*Calocephalus* sp. (Edgbaston J.Silcock JLS800), *Sporobolus partimpatens, Trianthema* sp. (Coorabulka R.W. Purdie 1404)
Coreena (including Maranda)	*Calocephalus* sp. (Edgbaston J.Silcock JLS800), *Trianthema* sp. (Coorabulka R.W. Purdie 1404), *Dissocarpos* sp. (Doongmabulla E.J. Thompson+GAL21), *Sclerolaena "dioecia", Sporobolus partimpatens, Dactyloctenium buchananensis*
Thunderbolt Creek (Corinda/Lake Huffer)	*Calocephalus* sp. (Edgbaston J.Silcock JLS800), *Dactyloctenium buchananensis, Eremophea spinosa, Sclerolaena "dioecia", Sporobolus partimpatens, Trianthema* sp. (Coorabulka R.W. Purdie 1404)
Old Lake Huffer	*Eremophea spinosa, Sclerolaena "dioecia", Trianthema* sp. (Coorabulka R.W. Purdie 1404)

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