Government of **Western Australia**
Department of **Water and Environmental Regulation**

EAST GNANGARA MOUND SPRINGS INVERTEBRATE MONITORING

SPRING 2019 SURVEY
Final Report

Wetland Research & Management

May 2020



East Gnangara Mound Springs: Invertebrate Monitoring Spring 2019 Survey

Prepared for:

DEPARTMENT OF WATER & ENVIRONMENTAL REGULATION

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Frontispiece (left to right): Water quality sampling at Edgecombe Spring; *Cherax quinquecarinatus* at Edgecombe Spring; and the excavated pool at the source of Barnard Spring.

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Disclaimer

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1 INTRODUCTION

1.1 Project Background

The ongoing monitoring of springs on the East Gnangara Mound is part of the key commitments outlined in Ministerial Statement No. 819 (Published 4th December 2009). Key commitment 7-1 states:

"*The proponent shall ensure that the integrity of all groundwater-dependent ecosystems located on the Gnangara Mound that may be impacted as a result of groundwater abstraction are protected*".

The aim of ongoing monitoring is to determine the impact of altered groundwater regimes (primarily related to public and private groundwater abstraction, land use and climate) on the ecological condition of groundwater-dependent ecosystems on the Gnangara groundwater mound. Additionally, key commitment 10-1 states:

"The proponent shall participate in and undertake research and monitoring on the Gnangara Mound which includes:

- *Clarification of the relationship between groundwater level and wetland water levels and wetland water quality;*
- *Improvement in the understanding of the conservation value of wetlands and other groundwater-dependent ecosystems on the Gnangara Mound".*

Monitoring provides valuable information which can be used by the Department of Water & Environmental Regulation (DWER) for ongoing management, with data being used to influence annual, interim and longer-term management decisions, and for inclusion in the annual and triennial reports to the Office of the Environmental Protection Authority (OEPA).

This current work represents a one-year contract for environmental monitoring (aquatic invertebrate and water quality) and investigations for the East Gnangara Mound (EGM) Springs, managed by DWER. Five nominated springs; Barnard Spring, Edgecombe Spring, Egerton Spring, Gaston Road Spring and Sue's Spring South, on the eastern edge of the Gnangara Mound are sampled as part of this monitoring contract, when water levels are expected to be the highest (generally mid spring).

1.2 Study Objectives

The objectives of the present study were to:

I. Systematically sample water quality (*in situ*, ions, nutrients, total iron, turbidity, colour) and aquatic fauna (micro- and macro-invertebrates) as close as possible to the source of five nominated springs (Barnard Spring, Edgecombe Spring, Egerton Spring, Gaston Road Spring and Sue's Spring South) on the eastern edge of the Gnangara Mound;

II. Report water quality against the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018) guidelines for the protection of aquatic ecosystems;

III. Describe the impact of altered groundwater regimes on the ecological condition of these groundwater-dependent ecosystems; and

IV. Compare data collected in October 2019 with historical data (November 2000, September 2001, January 2002, September 2002, September 2003, October 2004 and November 2005, October 2007, December 2008, November 2009, October 2010, September 2011, October

2012, October 2013, November 2014, November 2015, November 2016, November 2017, November 18).

This study was conducted under Department of Biodiversity, Conservation and Attractions; Parks and Wildlife Service (formerly the Department of Parks and Wildlife, DPaW) permit no. BA27000163 (Fauna taking (biological assessment) licence).

2 METHODS

2.1 Study Area

The Gnangara Mound is located to the north of Perth, Western Australia, and extends across an area of approximately 2,200 km^2 surrounded by Gingin Brook to the north, the Gingin Scarp to the east, the coastline to the west and the Swan River to the south. This shallow groundwater resource provides a significant proportion of water requirements for the Perth region (residential, agriculture and commercial uses). The crest of the Gnangara Mound is located between Muchea and Lake Pinjar, where the water table level is as high as 75 m AHD above sea level. Water flows away from this high point towards the Indian Ocean, the Swan River, Ellenbrook and Gingin Brook. The Gnangara Superficial aquifer is recharged by rainfall, primarily in winter and spring. The aquifer sustains valuable groundwater dependent ecosystems, including mound springs. Changes in groundwater levels can directly impact on the health of these ecosystems, especially if levels fall below the ecological water requirements of the system.

The climate of the Perth region is Mediterranean, characterised by hot, dry summers and mild, wet winters. The average daily temperature ranged from 25.4 – 33.7°C during summer (December to February) and 17.4 – 20.8°C during winter (June to August) (BOM, 2019). Rainfall patterns are highly seasonal (Figure 1) and rates of evaporation are typically high.

Total rainfall recorded in 2019 was 580.2 mm (BOM gauging station no. 009225), 145.2 mm lower than the long term historical mean (1993–2018) of 731.3 mm. Of particular note, May in 2019 recorded 70 mm less rainfall than the overall May average. Similarly, July, August, September and October all recorded below average rainfall in 2019. Total rainfall recorded in 2019 (580.2mm) was the lowest recorded since 2010 (503.8mm) (BOM, 2017).

The rainfall in 2019 was much lower than in the two previous years. In 2017 and 2018, rainfall was 854.0 mm and 741.6 mm respectively and included unseasonal high rainfall events in the summer of each year (Figure 2). The unusual summer rainfall events in 2017 and 2018 contributed to minimum groundwater levels in the superficial aquifer, falling less than usual over the summer/autumn period of these years. This, together with relatively good rainfall through winter and spring in both of those years, led to increases in groundwater levels in the superficial aquifer in some parts of the Gnangara system, including at some of the spring sites monitored.

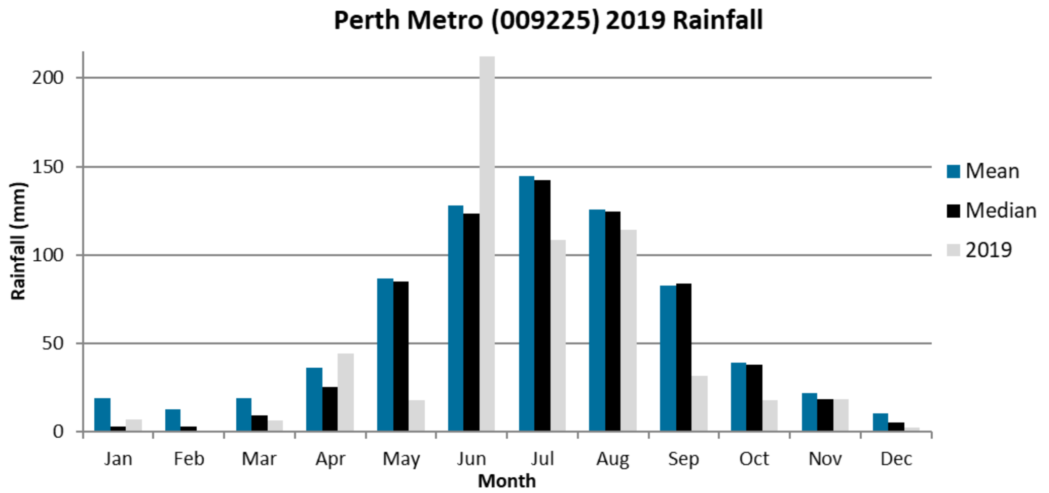


Figure 1. Long term (1995-2019) mean and median monthly rainfall at BOM gauging station no. 009225, showing total monthly rainfall for 2019.

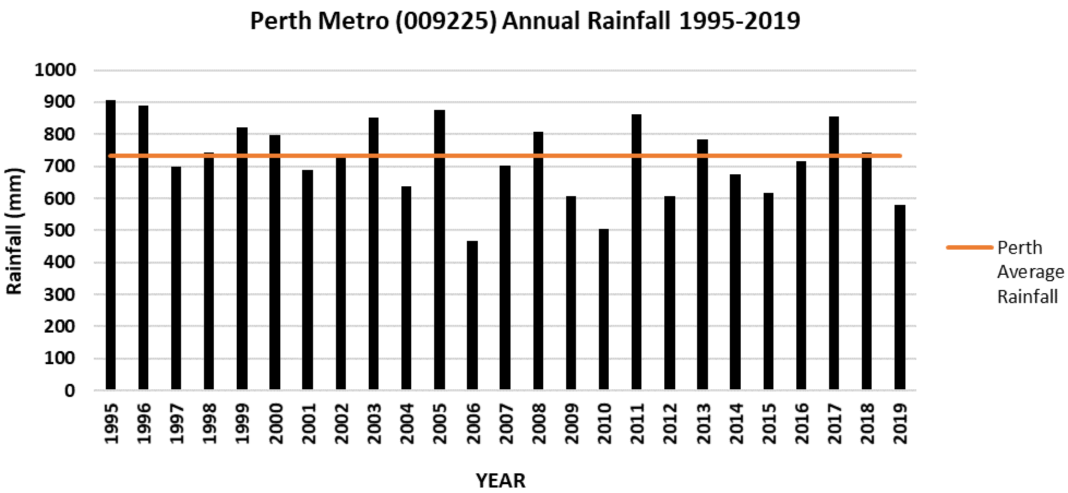


Figure 2. Annual rainfall total at BOM gauging station no. 009225 from 1995 to 2019.

Wetlands in Mediterranean climate regions are highly susceptible to degradation following shifts in land use (Cooper *et al.,* 2013; Sirami *et al*., 2010; Underwood *et al*., 2009), with naturally high climatic and topographic variability amplifying the detrimental effects of urbanisation and agricultural development (Cowling *et al*., 1996; Shrestha *et al*., 2017). Such effects include, but are not limited to, decreased surface permeability leading to narrowed discharge peaks of surface water flows following rainfall (Ackerman & Schiff, 2003); decreased recharge and upwelling of groundwater, and consequently longer no-flow periods (Walsh *et al*., 2005); as well as the contamination of surface and ground waters by a range of pollutants (Ackerman & Schiff, 2003; Cooper *et al*., 2013; Kløve *et al*., 2011). Furthermore, Mediterranean climate regions such as South Western Australia typically exhibit a high level of biodiversity and endemism (Myers *et al*., 2000), highlighting the need for vigilant monitoring and conservation strategies for the regions sensitive wetland ecosystems. To implement successful monitoring programs and management strategies however, an in-depth knowledge of ecosystem composition and function is required to inform the conservation of unique taxa endemic to the region.

2.2 East Gnangara Mound Springs

Groundwater-dependent ecosystems such as springs play an important role in linking groundwater, surface water and terrestrial habitats (Boulton, 2005; Barquin & Scarsbrook, 2008). Springs provide a buffer against drought and extreme temperatures (Kløve *et al*., 2011) and are therefore considered to be keystone ecosystems due to their disproportionately large role in landscape ecology (Perla & Stevens, 2008; Springer *et al*., 2015). Spring-fed tumulus mound wetlands in particular have been found to provide important habitat for rare or endemic taxa and as a result, are widely recognised as biodiversity hot spots in both arid and mesic regions (Cowling *et al*., 1996; Hershler *et al*., 2014; Horowitz *et al*., 2009; Minckley & Unmack, 2000; Shepard, 1993; Tang & Knott, 2009; Williams & Danks, 1991). Within the Gnangara Mound region of South Western Australia, such springs provide stable habitats for both spatially continuous and disjunct populations of a range of flora and fauna, including several known endemic taxa, within a largely xeric environment (Tang & Knott, 2009).

Despite their intrinsic value, springs are highly threatened by anthropogenic impacts on a global scale and face drastic impairment or loss in some areas (Springer *et al*., 2015). Locally, spring ecosystems supplied by the Gnangara Mound are similarly vulnerable. A combination of decreased annual rainfall and over-abstraction of groundwater has led to a markedly lowered groundwater table in recent years, threatening the very existence of spring ecosystems that depend on the positive head of the aquifer to provide upwelling of groundwater. Additionally, the increased prominence of urban, agricultural and public infrastructural developments in areas immediately adjacent to known Gnangara Mound springs is likely to result in changes to catchment hydrology (paving and compaction), increased pollutant runoff, nutrification and growth of invasive vegetation.

As part of an ongoing annual sampling program to assess the health of Gnangara Mound spring ecosystems, five groundwater springs on the eastern edge of the Gnangara Mound were sampled on the 30th October 2019. The 2019 monitoring program represents ongoing monitoring of three spring sites; Egerton Spring, Gaston Road Spring, and Sue's Spring South, the fifth consecutive year of sampling at Edgecombe Spring since the site was reinstated in 2015, and the second sampling event of a new spring, Barnard Spring[1] The heritage listed spring was included in the current study following visual observation of water emanating from the source of the spring, together with a documented similar *In situ* water quality to nearby tumulus springs (pers. comm. D. Romiti, Chittering Landcare).. The GPS coordinates of each site are provided in Table 1, and site photographs are shown in Appendix 1. Site locations are represented visually in Figure 3.

Table 1. GPS locations of each mound spring sampled, and groundwater monitoring bores within the Superficial Aquifer used to infer groundwater recharge.

	Site	Corresponding Bore	Zone	Easting	Northing
Mound springs	Egerton Spring	B25	50J	403508	6484428
	Edgecombe Spring	B10	50J	404893	6481948
	Gaston Road Spring	GN24	50J	402812	6499003
	Sue's Spring South	GN24	50J	402481	6498461
	Barnard Spring	LC160C	50J	404457	6487995
Groundwater monitoring	B10		50J	404832	6481802
	B25		50J	403389	6484444
	GN24		50J	402152	6498916
	LC160C		50J	404681	6487723

[1] Barnard Spring has been sampled previously by Jasinka & Knott, 1994.

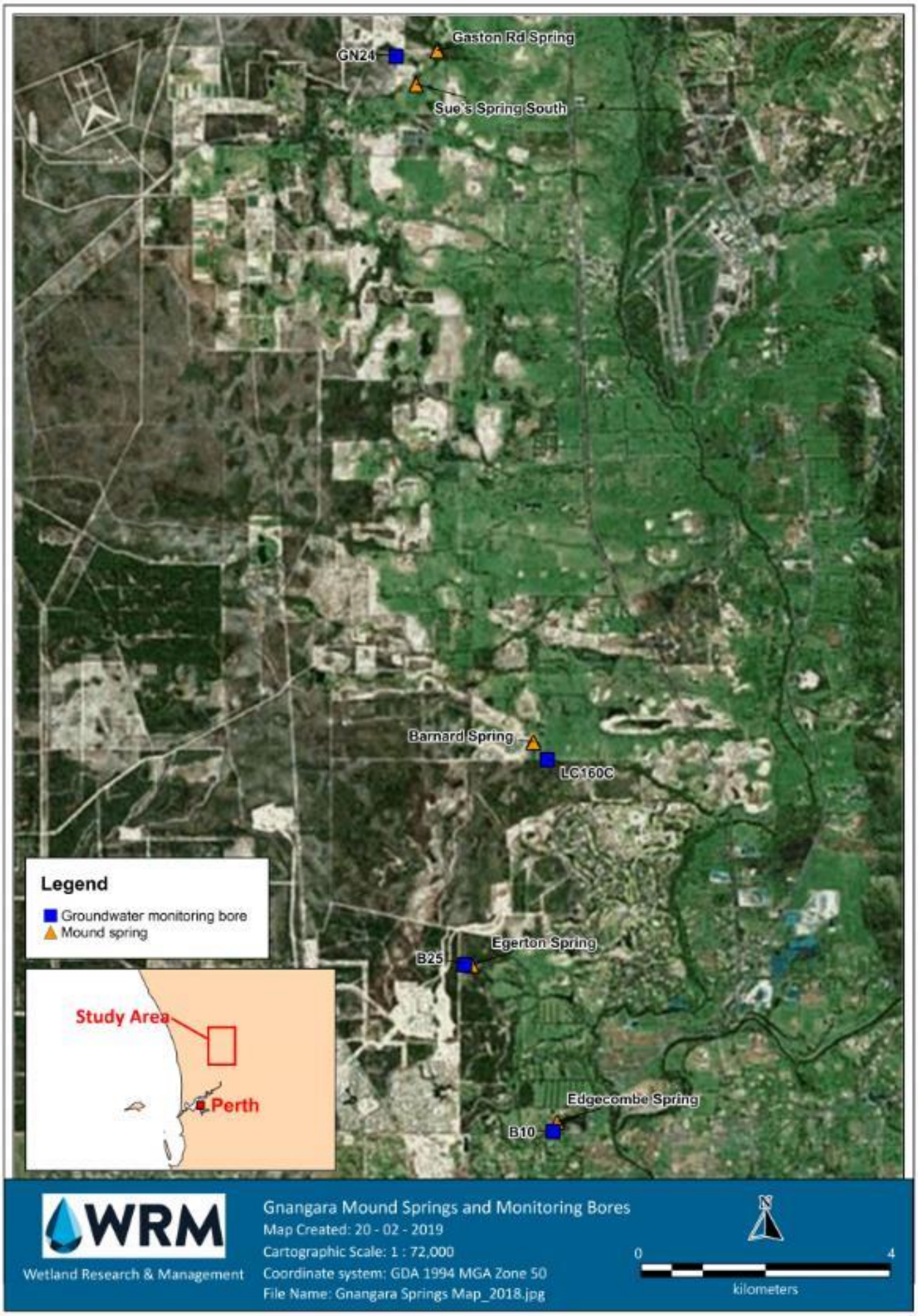


Figure 3. Map of Gnangara Springs Sampling locations and associated monitoring bores in October 2019.

Edgecombe Spring, located approximately 500 m west-northwest of the junction of Gnangara Rd and West Swan Rd, was sampled for the fifth consecutive year in 2019 (2015 - current), following a cease in sampling since 2008 (Knott *et al*., 2008). This site is a permanent rheocrene spring *sensu* Williams (1983), with water flowing along an epiphreatic conduit formed in quartz sand under approximately 0.15 m of dark organic soil. Knott *et al*. (2008) noted that since monitoring in 2003, the area immediately west of the spring to within a few metres has been cleared for suburban development. Those authors further noted that such shifts in land use would undoubtedly cause major hydrogeological changes to, and possibly the destruction of the spring. However, similar to previous observations (WRM 2016, 2017, 2018) there has been limited residential development of land immediately west of the spring since 2010 (see Appendix 2).

Egerton Spring is located in the northwest section of what was formerly Egerton Stud, Ellenbrook. Hydrogeological cross-sections of flow paths in the surrounding area suggest that Egerton Spring is a surface expression of shallow-depth groundwater originating in the Bassendean sands of the Superficial Aquifer, which has a saturated depth of approximately 50 m, rather than an upwelling from the base of the Superficial Aquifer (McHugh *et al*., 2011). This perennial source of surface water seepage is ecologically significant, providing a moist, humid microhabitat within dry surrounds, and facilitating the localised growth of low reeds, rushes, liverworts and mosses (Department of Water, 2011). The surrounding area has been extensively cleared and developed for residential and light commercial purposes (Aveley Estate). Only a small buffer zone of native coastal woodland remains around the spring. Aerial photographs depicting the encroachment of the urban zone from 2004 to 2018 are shown in Appendix 3. Urban development has largely been complete since 2015, however, it is unknown how this development will affect local hydrology through the increased prevalence of impermeable surfaces and increased abstraction from local bores.

Both Gaston Road Spring and Sue's Spring South are mound-fed surface expressions of groundwater and occur on privately owned land north of Neaves Road, less than 3 km west-northwest of the junction of Muchea South Road and Rutland Road in Bullsbrook (Figure 3). Whilst Gaston Road Spring sustains a shallow swamp with isolated, disconnected pools, Sue's Spring South feeds a defined creek. Native vegetation has been extensively cleared, save stands of rushes and trees including a variety of *Melaleuca* species immediately surrounding the springs. Herbaceous weeds, brambles (*Rubus fruticosus*), and duck weed (*Lemna* sp.) are prolific at Sue's Spring South. Land use in the surrounding area is primarily agricultural, including strawberry farms and an alpaca stud. Construction of the northern section (Ellenbrook to Muchea) of Northlink WA adjacent to, and approx. 300m to the east of Gaston Road Spring and Sue's Spring South will likely result in changes to local groundwater levels and watershed hydrology. Proximity of Northlink to the springs is shown in Appendix 4. Like Egerton Spring, both Gaston Road Spring and Sue's Spring South are ecologically significant due to their peaty substrate with high levels of organic content, and provision of a moist, humid microhabitat within a largely dry landscape.

The current study represents the second sampling record for Barnard Spring, previously documented by WRM (2019) and Jasinka & Knott (1994). The wetland is in the northern extension of the Lexia Wetlands, although much of the land surrounding the spring has been cleared of its original vegetation presumably for pasture use. The spring has been materially altered from its natural state, having been excavated (~early 1900s), with the source of the spring approximately 1.2m below the surface. This has resulted in a pool forming (approx. 5 x 3 m) in which water flows into a feeder (water) pipe into a receiving trough and then downstream into a series of wetland channels and pools. Both structures have been heritage listed by the National Trust. The channel from the pool is lined with a mix of pithy sword-sedge (*Lepidosperma longitudinale*), bracken fern (*Pteridium esculentum*), and sword fern (*Nephrolepis exaltata*). The downstream channel from the pool is dominated by organic material (peat and leaf litter/detritus) and sandy substrate, with riparian vegetation providing canopy cover for the spring. Other vegetation surrounding the spring includes a variety of large native Melaleuca, Marri and Eucalyptus trees, some of which have been covered in the non-native elephant creeper (*Argyreia nervosa*). Sampling of water quality and aquatic invertebrates of Barnard Spring in the current study will provide insight into conservation value of the system, relative to nearby tumulus springs, and inform further management and protection actions.

Permission to access private property was obtained from relevant property owners in consultation with the Department of Water & Environmental Regulation prior to undertaking fieldwork.

2.3 Bore levels and water quality

Levels of groundwater recharge at each mound spring were inferred from water levels in corresponding groundwater monitoring bores (B10, B25, GN24 and LC160C) within the Superficial Aquifer, and in close vicinity to the springs. GPS locations of these bores are given in Table 1 and locations presented in Figure 3. Bore B10 was used as a reference for Edgecombe Spring; B25 for Egerton Spring; GN24 for both Gaston Road Spring and Sue's Spring South; and LC160C for Barnard Spring. Water levels in each bore were plotted as metres relative to the Australian Height Datum (m AHD) over time to examine historic patterns.

At each mound spring, a number of water quality variables were recorded *in situ* using portable Wissenschaftlich-Technische-Werkstätten (WTW) field meters, including pH, dissolved oxygen (% saturation and mg/L), and water temperature (°C). Undisturbed water samples were taken at each spring using pre-cleaned 500 ml, 125 ml and 50 ml bottles for laboratory analyses of electrical conductivity (µs/cm), TDS, major ion, nutrient, colour (PCU), total iron and turbidity concentrations. Samples were kept chilled in an esky until they were delivered to the laboratory within 8 hours of sampling. All laboratory analyses were conducted by Australian Laboratory Services (ALS), a NATA accredited laboratory. Water quality variables measured are summarised in Table 2. Water quality data were compared against ANZG (2018) default guideline values (DGVs) water quality guidelines for the protection of aquatic ecosystems for 99% species protection in wetlands of South West Australia (Appendix 4).

Table 2. *In situ* and laboratory-determined water quality parameters measured at each mound spring in November 2017.

In situ	Laboratory (mg L^{-1} unless otherwise indicated)	
Dissolved Oxygen (mg L^{-1})	EC (µS cm^{-1} @ 25 ˚C)	Magnesium (Mg^{2+})
Dissolved Oxygen (% saturation)	TDS	N_NO_3^-
pH	Turbidity (NTU)	N_NOx
Water Temperature (˚C)	Calcium (Ca^{2+})	N_NO_2^-
	Chloride (Cl^-)	Total reactive phosphorus
	Colour (PCU)	Sodium (Na^+)
	Total Iron	Sulphate (SO_4_S)
	Potassium (K^+)	

2.4 Aquatic Invertebrate Fauna

Invertebrate fauna at each mound spring were sampled using a small (~10 cm diameter), custom-made fine-mesh hand net (110 µm mesh aperture). Samples were collected as close to the point of the spring discharge as possible and, if not accessible, along the runnels as they exited from the mound[2]. Access to the actual point of discharge of each spring was not possible in all cases. Sampling at the source of Sue's Spring South was impeded by dense riparian fringing vegetation, therefore samples were collected from the downstream runnels (approx. 3 m from the source of the spring). As Barnard Spring has been excavated, and the source of the spring lies 1.2m below the water surface in the resultant ponding, invertebrates were collected from a range of habitats within the pool environment. (see Appendix 1 for site photos). Bulk sediment and detritus were sampled at the source of each spring for aquatic invertebrates. Each sample was placed in a sealed, labelled plastic bag covered with water from the site, and stored in a 1 L polyethylene tub, and returned to the laboratory for sorting of live specimens under a dissecting microscope. Samples were picked live for total abundances, with collected specimens then identified to the lowest possible level (genus or species level). In-house expertise was used to identify invertebrate taxa using available published keys and through reference to the established voucher collections held by WRM. External specialist taxonomic expertise was sub-contracted to assist with microinvertebrate fauna (Dr Russ Shiel, The University of Adelaide). Taxa that could not be identified to species level generally were assigned a voucher number and lodged in the WRM voucher collection.

[2] The aim of sampling is to collect aquatic fauna with subterranean origins (i.e. stygofauna and cavernicole taxa), present in each spring. It is acknowledged that a diverse aquatic fauna characteristic of Swan Coastal Plain wetlands will be present in the wetlands generated by each of the springs, but this fauna was NOT targeted in the current program.

3 RESULTS AND DISCUSSION

3.1 Bore levels

Water levels in monitoring bore B10, which reflect water levels at Edgecombe Spring, have been relatively stable over time and exhibit a clear annual cycle with minima and maxima broadly corresponding to summer drawdown and winter recharge respectively (Figure 4). Winter maxima decreased between 2000 and 2002, subsequently increased between 2003 and 2008 and has since remained relatively constant from 2009 onwards. Summer minima followed a similar trend, having decreased between 2000 and 2004, although water levels have remained similar, albeit higher since the summer of 2005 (variation ≤ 0.30m AHD). In 2019, B10 exhibited a summer minima (14.23 m AHD 02/05/2018) similar to 2018 (14.29 m AHD 08/06/2017) and consistent with the water levels recorded at the bore in 2009. Recharge to groundwater in 2018 following relatively good winter rainfall resulted in the second highest (maxima) water level on record since 2008 (15.32 m AHD 06/08/2008). The high peak level in 2018 relate to the unusual summer rainfall event in January of that year, together with relatively good winter and spring rainfall which led to higher than usual annual recharge to groundwater (Figure 4). Due to low rainfall in 2019, the water level maxima in 2019 was lower than in 2018, although higher than the average (14.92m AHD 3/09/2019) possibly due to the high amount of recharge following above average June rainfall. Successive years of observed seepage (viz. flow) from Edgecombe Spring suggests that current groundwater conditions are sufficient to maintain this spring ecosystem.

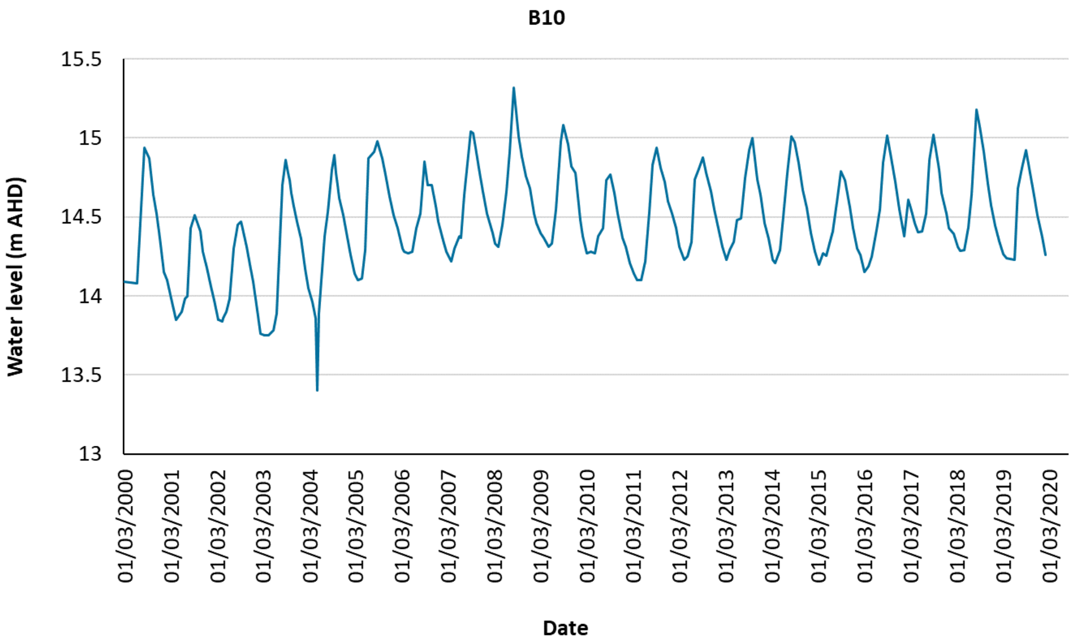


Figure 4. Groundwater levels (m AHD) at DWER groundwater monitoring bore B10 since records began in 2000.

Water levels in monitoring bore B25, used to relate to flows at Egerton Spring, appeared relatively constant for the four years preceding 2015, following a steady increase in water levels between 2002 and 2009 (Figure 5). More recently (2016 to current), water levels in B25 have shown a steady increase in summer minima and to a lesser degree winter maxima since 2016. There was a notable decline in summer minima water level at B25 in 2016 (39.58m AHD, 08/03/2016), however, to a much lesser degree than observed in 2003 (39.26 m AHD, 13/03/2003) and 2011 (39.49 m AHD, 06/05/2011). This was followed by the highest summer minima on record at B25 in 2017 (39.86 m AHD, 03/05/2017). The maximum water level recorded in 2018 of 40.255 m AHD (06/09/2018) represents the highest peak level at B25 since water monitoring commenced at the spring by DWER in 2000. Despite the below average rainfall in 2019, maxima and minima remained similar to the previous three years (Figure 1; Figure 5).

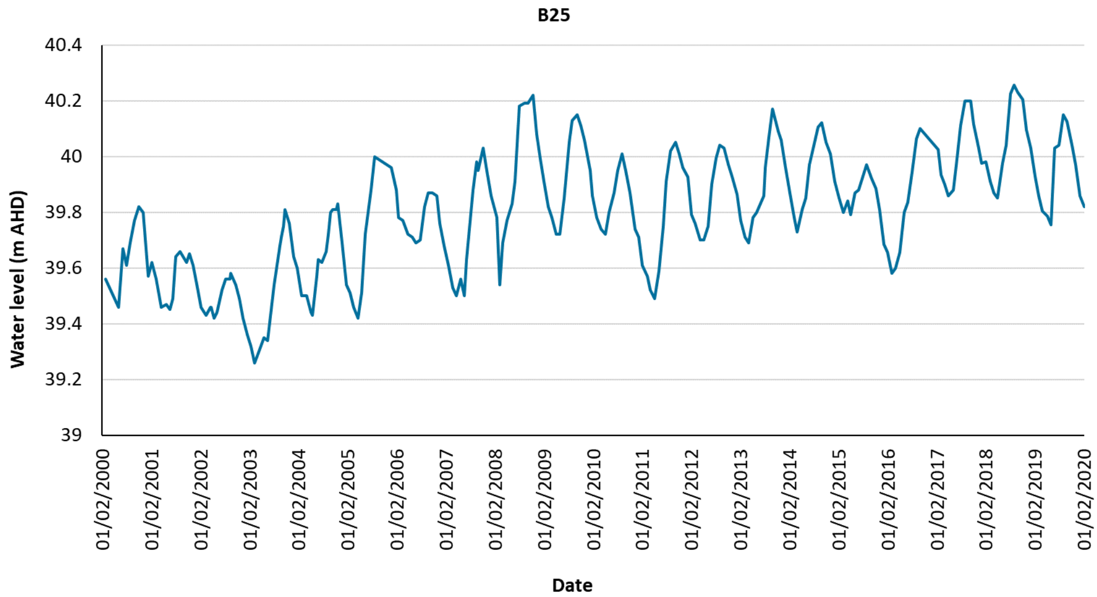


Figure 5. Groundwater levels (m AHD) at DWER groundwater monitoring bore B25 since records began in 2000.

Assessment of groundwater levels at bores B10 and B25, coupled with field observations of increased surface flows from 2016 at Edgecombe and Egerton Springs, show that that current groundwater levels are adequate to maintain these two spring ecosystems.

Urbanisation within the vicinity of Edgecombe and Egerton Springs appears to have enhanced localised recharge, as evidenced in groundwater level trends since 2000 (Appendix 2 and 3). It is important to consider that the response times of groundwater and catchments to changes in land use vary greatly depending on topography, geology, vegetation and climate (Beverly & Hocking, 2012). Therefore, ongoing monitoring of water levels at Edgecombe Spring, Egerton Spring and in the corresponding bores will be vital to identify the possible implications of altered hydrology.

Water levels in bore GN24, reflecting water levels in Sue's Spring South and Gaston Road Spring, have steadily declined for nearly two decades (1990's to 2010's) with the trend appearing to have reached equilibrium between the period 2014 – 2016 (Figure 6). However, there was a notable (staged) decline in water levels from the winter maxima in 2016 (60.38m AHD, 01/09/2016) to summer minima in 2017 (58.95m AHD, 01/06/2017) (Figure 6). This may reflect rapid development of the agricultural land surrounding Sue's Spring South and Gaston Road Springs, which has likely resulted in increased groundwater abstraction to support the expansion of commercial operations including, but not limited to, Plantrite and Berry Sweet Strawberry Farm. A similar (staged) decline was observed from the 2017 maxima (60.41m AHD, 01/09/2017) to February 2018 (58.96m AHD, 01/02/2018), from the 2018 maxima (60.32m AHD, 01/10/2018) to February 2019 (59.05m AHD, 01/02/2019) and the 2019 maxima (60.26 m AHD, 05/08/2019) to February 2020 (58.77 AHD, 03/02/2019) (Figure 6). The most recent minima recorded in Feb 2020 was the lowest ever recorded at GN24 (58.77m AHD, 03/02/2020). Major construction works associated with development of the northern section (Ellenbrook to Muchea) of NorthLink WA commenced in November 2017. Localised abstraction of groundwater by CPB Contractors Pty Ltd for dust suppression and to facilitate pavement construction works for the dual carriageway and Neaves Road Interchange may account for this notable decline in the water table. The irregular and atypical fluctuations in declining groundwater levels since 2016 are of particular concern and suggest episodic extraction, possibly due to intermittent pumping by a licensed self-supply bore very close to GN24 (M. Hammond pers. comm.). The decline in water table below 59.0m AHD between 2017 (01/06/2017) and 2020 (03/02/2020) is extremely concerning (Figure 6 and 7). The hydrology of the springs is not fully understood, but their flows likely rely on levels in the Superficial aquifer and it is not known at what point declines in levels in the aquifer will reach a 'threshold', below which the springs cease to flow. Following completion of Northlink WA there may be further changes to the local groundwater table.

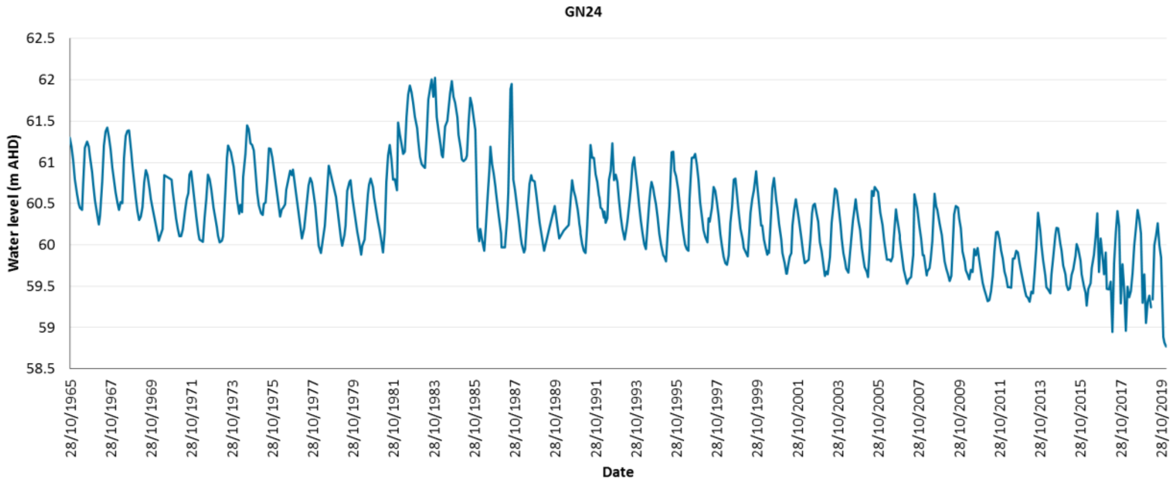


Figure 6. Groundwater levels (m AHD) at DoW groundwater monitoring bore GN24 since 1965.

In contrast to that observed in 2017 and 2018 which included unusual rainfall events in both summers, the below average summer rainfall in 2019 did not offset the magnitude of groundwater level drawdown at GN24 (i.e. extent of summer minima, Figure 6). Despite the below average rainfall in summer 2019, WRM observed surface water expression and flow at both Gaston Road Spring and Sue's Spring South in 2019 comparable to previous years (E. Thillainath pers. comm). Of particular interest was the below average rainfall recorded in summer of 2020, which coupled with the extraction pressure, has resulted in the lowest summer minima recorded at GN24 since records commenced (Figure 6; Figure 7). Ongoing monitoring of groundwater levels at GN24 at an increased frequency, particularly under the scenario of a drying climate, is required to determine the cause of irregular fluctuations in groundwater level since 2016, and ensure protection of TEC listed springs in close proximity.

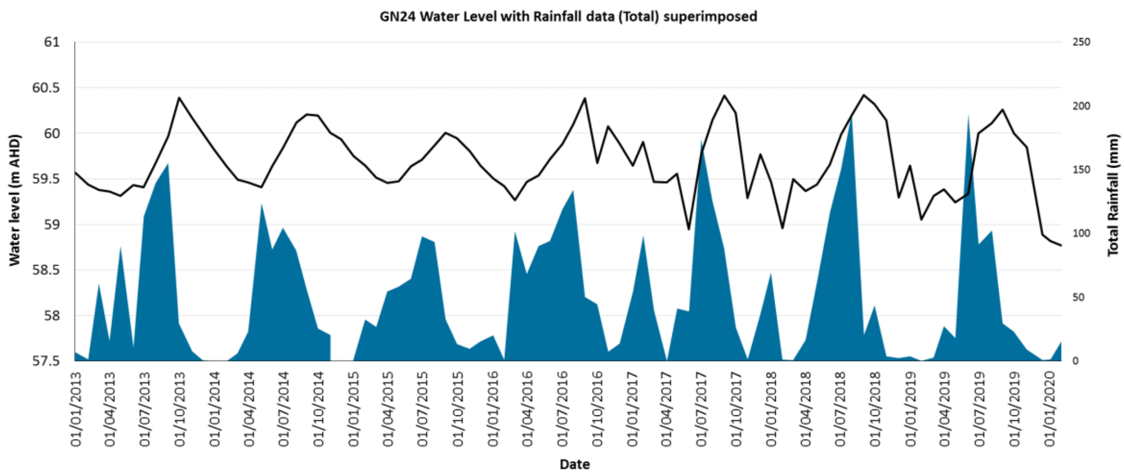


Figure 7. Groundwater levels (m AHD) at DWER groundwater monitoring bore GN24 from 2013 to January 2020 (solid line), with superimposed total rainfall (mm) taken from the Pearce RAAF base (station 009053) (shaded area).

Gaston Road Spring continues to sustain a series of shallow expressions, with a maximum depth of 5 – 7 cm, with slight flow evident in some expressions. This may reflect the increased water levels in the corresponding GN24 bore at the time of sampling (Oct 2019) (Figure 1; Figure 6). It remains unknown if these two springs have different groundwater threshold levels below which surface expression ceases. Nonetheless, levels at bore GN24 appears to be a reliable indicator of flow at Sue's Spring South and Gaston Road Spring. It appears that the successive summer rainfall events in 2017 and 2018, together with relatively good rainfall through winter and spring of these years maintained groundwater levels over this time, but the low rainfall in 2019 resulted in low spring peak level and summer minima in 2020.

Groundwater levels at monitoring bore LC160C, reflect water levels in nearby Barnard Spring LC160C has shown relatively stable summer minima water level since monitoring commenced in 1984. There was a clear annual cycle with minima and maxima broadly corresponding to summer drawdown and winter recharge from 1984 to 1998 (Figure 8). Following this period, there were erratic fluctuations in water level from the winter maxima in October 1999 to the summer minima in May 2001 and then a notable decline in summer minima to below 31.5m AHD in May 2011. In recent years, there has been a notable increase in annual recharge, which has led to levels increasing to a level (33.5m) similar to historic levels (1984 to 1998) (Figure 8).

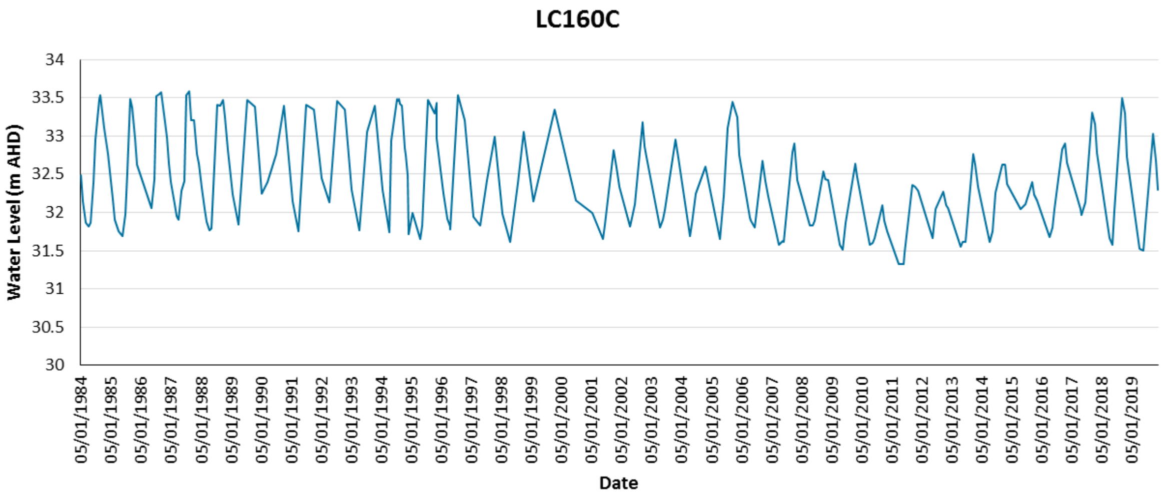


Figure 8. Groundwater levels (m AHD) at DWER groundwater monitoring bore LC160C from 1984 to November 2019.

3.2 Water quality

Surface water quality at each mound spring were compared to ANZG (2018) DGVs for physical and chemical stressors as well as toxicants for South West Australia for slightly disturbed ecosystems (Table 3, Appendix 5).

Dissolved oxygen (DO) saturation (%) was below the recommended DGV (90-120%) at all mound springs (Appendix 5, Table 3). While values lower than the guidelines were recorded at all springs, DO saturation was considered moderate at four of the five springs (68.7% at Edgecombe, 57.3% at Gaston Road Spring, 42.8% at Egerton and 31.3% at Sue's Spring) and low at the remaining Barnard Spring (6.7%). DO saturation below 20% is considered likely to represent conditions of environmental stress to resident fauna. However, it should be noted DO undergoes diel fluctuations and recorded values could represent minima levels within the natural daily cycle. DO saturation was notably lower at Sue's Spring South than in previous sampling rounds (31.3% in 2019 compared to site average of 69.3%), which could be attributed to increased density of introduced blackberry reducing photosynthetic activity of algae and macrophytes close to the source of the spring (Figure 6). Gaston Road and Edgecombe Springs recorded similar DO levels to previous years, however Egerton Spring was notably below average (42.8% compared to an average of 79.7%). The DO levels at Egerton Spring are known to greatly fluctuate, recording 100.1% DO in 2011 and then just 35% the following year in 2012. Barnard Spring recorded very low DO (6.7%) similar to the previously recorded low DO in 2018 (16.1%). The excavation of Barnard Spring restricted water quality sampling at the source of the spring outlet (water quality sampling conducted downstream of outlet), therefore the oxygen concentration of the heavily vegetated, detritus dominated spring trough and associated pool could have contributed to this low oxygenation value. The decomposition of large loads of accumulated detritus and vegetative cover at these sites is a process driven by respiration and reduces levels of dissolved oxygen. Dissolved oxygen largely exhibits a diel pattern, reflecting the flux between respiration and photosynthesis, thereby infrequent measurements of DO provide only a snapshot of typical daily conditions. It should be noted however that Egerton, Edgecombe and Gaston Road Springs were all inundated with sedge vegetation, more so than in 2018.

With respect to acidity levels, Edgecombe Spring (pH 7.42) and Egerton Spring (pH 7.35) were circum-neutral, and Sue's Spring (pH 5.94) and Barnard Spring (pH 5.03) were both weakly acidic, with Gaston Road Spring being strongly acidic (pH 3.75) (Figure 11; Table 3). Minimal variation in pH from historical readings were observed across the five surveyed springs, with only Egerton Spring shifting from slightly acidic in 2018 (pH 6.15) to circum-neutral in 2019 (pH 7.35). Acidity readings at Edgecombe and Egerton Spring were within ANZG (2018) water quality guidelines (Figure 11; Table 3). At all other sites however, recorded pH values were below ANZG (2018) guidelines, but remained comparable to acidity levels recorded in recent years (Figure 11). A number of factors may contribute to the slightly acidic conditions at Sue's Spring and to the strongly acidic conditions at both Gaston Road Spring and Barnard Spring. The acidity of aquatic environments can be regulated by the concentration of humus (i.e. organic matter), nearby agricultural practices or by underlying geology and groundwater chemistry. Tumulus mound springs in particular, which are dominated by organic matter and humic substances, are naturally acidic environments, which accounts for the high acidity and low pH values recorded at the EGM springs annually. Some areas of the Gnangara Superficial aquifer and associated surface waters are mildly acidic due to a combination of excessive drawdown and disturbance from surrounding land use (i.e. agricultural land clearing), two key factors which have been linked to the acidification of groundwater (Appleyard & Cook, 2009). The notable initial decline in pH at Egerton Spring (2000–2008) may reflect exposure and oxidation of acid sulphate soils during clearing for development, with subsequent recovery of pH once development commenced and any acid-generating materials were buried/managed.

Electrical conductivity (EC) was within ANZG (2018) guidelines at all springs (Figure 11; Table 3). Although close to the lower ANZG (2018) default guideline value, all values recorded constitute freshwater as defined by the DoE (2003)[3] (Appendix 5). There is a general acceptance that freshwater ecosystems do not experience significant ecological stress below 1,500 µS cm^{-1} (Hart *et al*., 1991), and whilst growth and emergence rates in some freshwater invertebrates are optimised at intermediate rather than low salinities (Kefford *et al*., 2006; Hassell *et al*., 2006), EC at Sue's Spring South is not likely to be of ecological concern.

Ionic compositions at each spring were:

- Egerton Spring $Cl^- > Na^+ > SO_4^{2-} > Ca^{2+} > Mg^{2+} > K^+$
- Edgecombe Spring $Cl^- > Na^+ > SO_4^{2-} > Ca^{2+} > Mg^{2+} > K^+$
- Sue's Spring South $Cl^- > SO4^{2-} > Na^+ > Ca^{2+} > K^+ > Mg^{2+}$
- Gaston Road Spring $Cl^- > Na^+ > SO_4^{2-} > Mg^{2+} > Ca^{2+}, K^+$
- Barnard Spring $Cl^- > Na^+ > SO_4^{2-} > K^+ > Ca^{2+} > Mg^{2+}$

Ionic composition at Egerton and Edgecombe Springs followed a similar hierarchy to the previous year's data. Sue's Spring South exhibited reduced chloride (Cl^-) concentrations than in previous years and compared to the other springs in the sampling program. Similar to previous sampling, sulphates were detected at all five mound springs. Sue's Spring South recorded a large increase in concentration of sulphates from <1 mg L^{-1} in 2018 to 38 mg L^{-1} in 2019 (Table 3).

[3] Fresh defined as < 1500 µS/cm, Brackish = 1500 – 4500 µS/cm, Saline = 4500 – 50,000 µS/cm, Hypersaline > 50,000 µS/cm (DoE 2003). Classifications were presented as TDS (mg/L) in DoE (2003) so a conversion factor of 0.68 was used to convert to conductivity µS/cm as recommended by ANZG (2018).

Table 3. Water quality variables recorded from the Gnangara Mound springs in October 2019, compared to default ANZG (2018) default guideline values for alternative levels (95%, 90% and 80%) of species protection. Values that exceeded DGVs are highlighted as per; > 95% TV, > 90% TV, > 80% TV.

Parameter	Units	Range of TV's	95%	90%	80%	Edgecombe Spring	Egerton Spring	Barnard Spring	Gaston Road Spring	Sue's Spring South
In situ										
DO	% saturation	90-120	<90	-	-	68.7	42.8	6.7	57.3	31.3
DO	mg L^{-1}		-	-	-	6.42	4.06	0.63	5.21	2.91
pH		7 to 8*	<7, >8	-	-	7.42	7.35	5.03	3.75	5.94
Temp	°C		-	-	-	18.1	17.9	19.8	18.4	18.8
Laboratory determined										
EC	µS cm^{-1} @ 25°C	300-1500	<300	-	-	436	445	344	365	312
TDS	mg L^{-1} @ 180°C		-	-	-	270	282	302	430	233
Turbidity	NTU	10-100	>100	-	-	7.8	292	1	33.1	1.4
Calcium (Ca^{2+})	mg L^{-1}		-	-	-	40	30	11	3	22
Chloride (Cl^{-})	mg L^{-1}		-	-	-	66	86	77	87	49
Colour	PCU		-	-	-	20	50	500	1500	300
Total Iron (Fe)	mg L^{-1}		-	-	-	1.47	3.26	0.42	2.56	0.22
Potassium (K^{+})	mg L^{-1}		-	-	-	7	6	10	2	8
Magnesium (Mg^{2+})	mg L^{-1}		-	-	-	7	8	6	5	4
N_NOx (eutrophication)	mg L^{-1}		>0.1	-	-	3.03	0.76	0.11	0.06	2.93
N_NO_3-(toxicant)	mg L^{-1}	0.7-17	0.7	3.4	17	13.42	3.37	0.49	0.27	12.98
N_NO_2^-	mg L^{-1}		-	-	-	<0.01	0.02	<0.01	<0.01	<0.01
Total reactive phosphorus	mg L^{-1}		>0.03	-	-	<0.01	<0.01	0.55	0.02	0.57
Sodium (Na^{+})	mg L^{-1}		-	-	-	41	50	43	50	29
Sulphate (SO_4^{2-})	mg L^{-1}		-	-	-	40	43	33	32	38

*= in highly coloured wetlands pH typically ranges from 4.5-6.5.

Nitrogen oxide (NO_x) levels were below the 95% ANZG (2018) DGV at Gaston Road Spring, however, Egerton Spring, Edgecombe Spring, Barnard Spring and Sue's Spring South recorded NO_x concentrations exceeding the default eutrophication DGV (0.1 mg L^{-1}; Appendix 5) (Figure 11; Table 3). In previous years, there has been a trend of increasing NO_x at Egerton Spring and Sue's Spring South (since 2010/11, up to 2016). This trend continued for Egerton Spring in 2018, which exhibited a spike in NO_x concentration to levels not previously recorded for the spring before falling to levels below the 90% species protection DGV in 2019 (Figure 11). Edgecombe Spring NO_x concentrations have steadily been falling the last 3 years (Figure 11). The composition of NO_x was dominated by nitrate (NO_3^-) (Figure 9; Table 3), with nitrite (NO_2^-) concentrations below or equal to the limit of detection at all sites.

Concentrations of NO_3^- (Figure 9; Table 3) were below levels of the ANZG (2018) toxicant DGV for the protection of 80% of species (17 mg/L; Appendix 5) but exceeded the toxicant DGV for the protection of 90% of species (3.4 mg/L; Appendix 5) at Edgecombe Spring (13.42 mg/L) and Sue's Spring South (12.98 mg/L). Nitrate levels at Egerton Spring (3.37 mg/L) exceeded the 95% level of protection (0.7mg/L; Appendix 5) but were below the 90% DGV (3.4 mg/L, Appendix 5). Gaston Road Spring (0.27 mg/L) and Barnard Spring (0.49 mg/L) exhibited the lowest nitrate concentrations of the five mound springs, however, both exceeded the 99% level of protection (0.017 mg/L; Appendix 5). Although elevated above default toxicant guidelines, concentrations were lower than those recorded in 2018 at Egerton Spring and Edgecombe Spring (Figure 9). It should be noted that the current ANZG (2018) default 95% DGV for NO_3 as a toxicant of 0.7 mg/L (= 0.16 mg L^1 N-NO_3) is currently under review as being too conservative. The new ANZG DGV for NO_3 (95% species protection) is likely to be around 11 mg L^{-1} (2 - 2.5 mg L^{-1} N-NO_3) (R. van Dam, ***eriss***, pers. com.) and will incorporate the most recent data from acute and chronic toxicity testing in New Zealand (Hickey, 2013). Recently published guidelines for Canada also recommend a higher NO_3 guideline of 13 mg/L (= 2.9 mg/L N-NO_3,) for freshwaters (CCME 2014). Therefore, the high nitrate concentrations at Sue's Spring South and Edgecombe Spring are only likely to exceed 95% species protection, following revision of default guidelines.

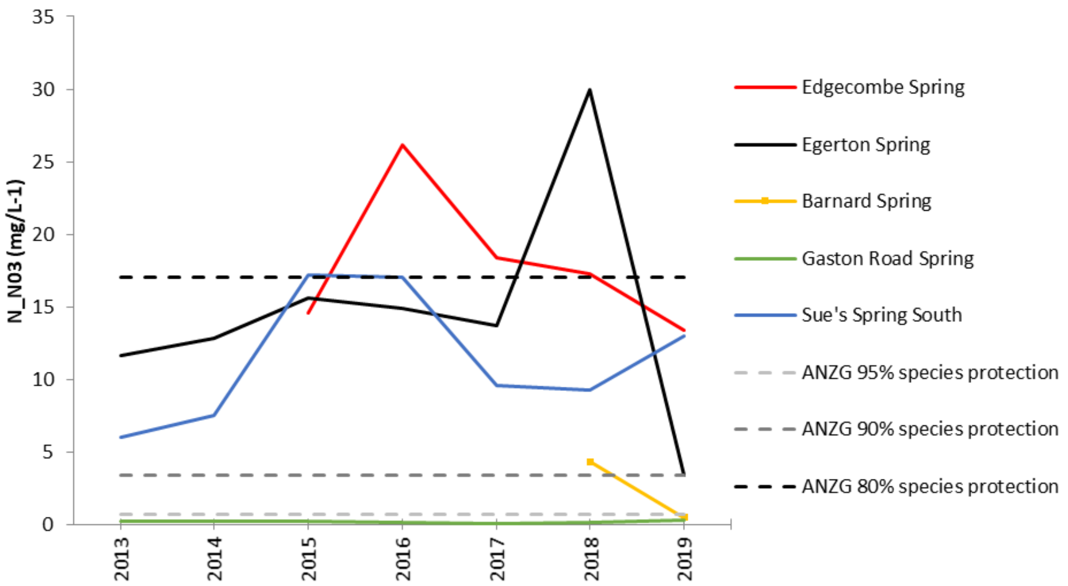


Figure 9. Nitrate (N_NO3$^-$) recorded at five Gnangara springs since 2013. Note that sampling did not occur at Edgecombe Spring during 2013 and 2014. ANZG (2018) guidelines for species protection in Western Australian wetlands are shown as dashed lines.

Total reactive phosphorous (TRP) was below the LOD (<0.01 mg/L) at both Egerton Spring and Edgecombe Spring consistent with all previous sampling occasions (Table 3). TRP levels at Gaston Road Spring in 2018 were below the DGV and consistent with all previous records at this site (WRM, 2019). At Sue's Spring South, the concentration of total reactive phosphorous was slightly higher than 2018 (Figure 10), with the concentration still exceeding the relevant ANZG (2018) DGV (0.06 mg L^{-1}; Table 3; Appendix 5). Sue's Spring South has historically recorded high levels of TRP (Figure 10) yet continues to sustain a diverse suite of macro and micro invertebrates and an overall productive spring, hence the exceedance of the DGV for the spring appears to be of minimal ecological concern. In 2018, the newly added Barnard Spring recorded the highest total reactive phosphorous of the five springs (0.73 mg L^{-1}; Figure 10; Table 3), however these levels dropped during the 2019 survey (0.55 mg/L^{-1}) to be slightly lower than levels at Sue's Spring South, though still exceeding the DGV for TRP. Ongoing monitoring of this spring is required to develop a baseline and to gauge whether this high TRP concentration at the spring is naturally occurring.

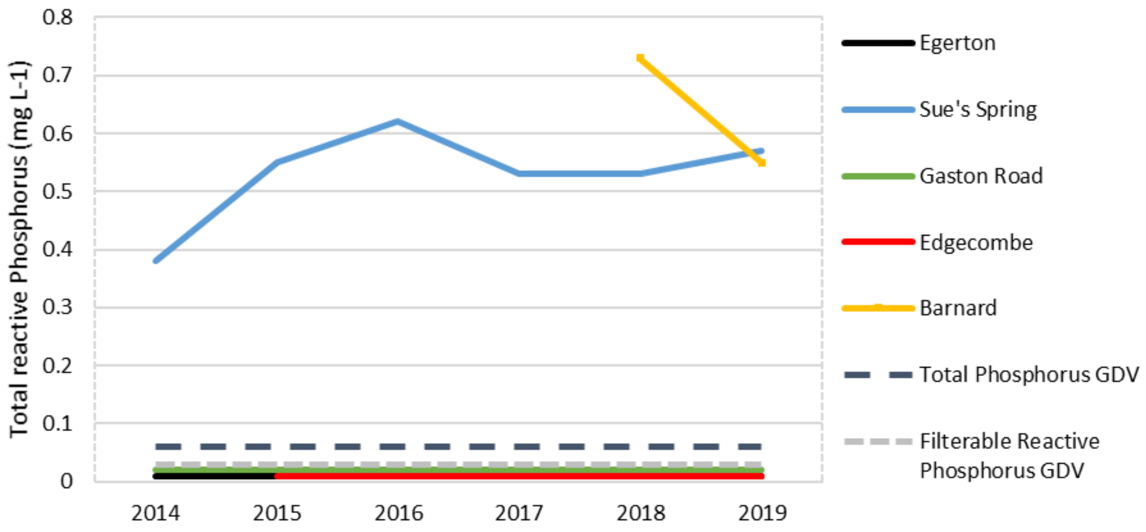


Figure 10. Total reactive Phosphorus (TP) at five Gnangara springs since 2014. Note that sampling did not occur at Edgecombe Spring during 2014. ANZG (2018) guidelines for species protection in Western Australian wetlands are shown as dashed lines.

Turbidity measures at Edgecombe, Barnard and Sue's Spring South were considered low to moderate and were below the ANZG (2018) upper limit trigger value of 100 NTU for South Western Australian wetlands (Table 3). A high turbidity reading of 292 NTU was recorded at Egerton Spring, which is an increase from 2.6 NTU in 2018. The high turbidity reading from Egerton Spring is unlikely to reflect ambient conditions at the site, but rather reflects the difficulty of collecting surface water samples in such shallow bodies of water, with substrates likely to have been disturbed during the collection process. Turbidity readings from Egerton Spring have always been highly variable, ranging from 0.9 NTU in 2017 to 185 NTU in 2005 (WRM 2018, Knott *et al*. 2009). Turbidity is a measure of the amount of suspended particulate matter (SPM) such as silt, phytoplankton and detritus in the water. Turbidity can be an ecological stressor in aquatic environments by directly smothering benthic organisms (Hogg & Norris, 1991), clogging feeding apparatuses in suspension feeding taxa (Newcombe & MacDonald, 1991), or through the reduction and simplification of habitat (Campbell & Doeg, 1989). Turbidity levels are not of particular ecological concern at four of the five springs sampled, with readings mostly under the upper limit trigger value of 100 NTU for South Western Australian wetlands as recommended by ANZG (2018) (Table 3).

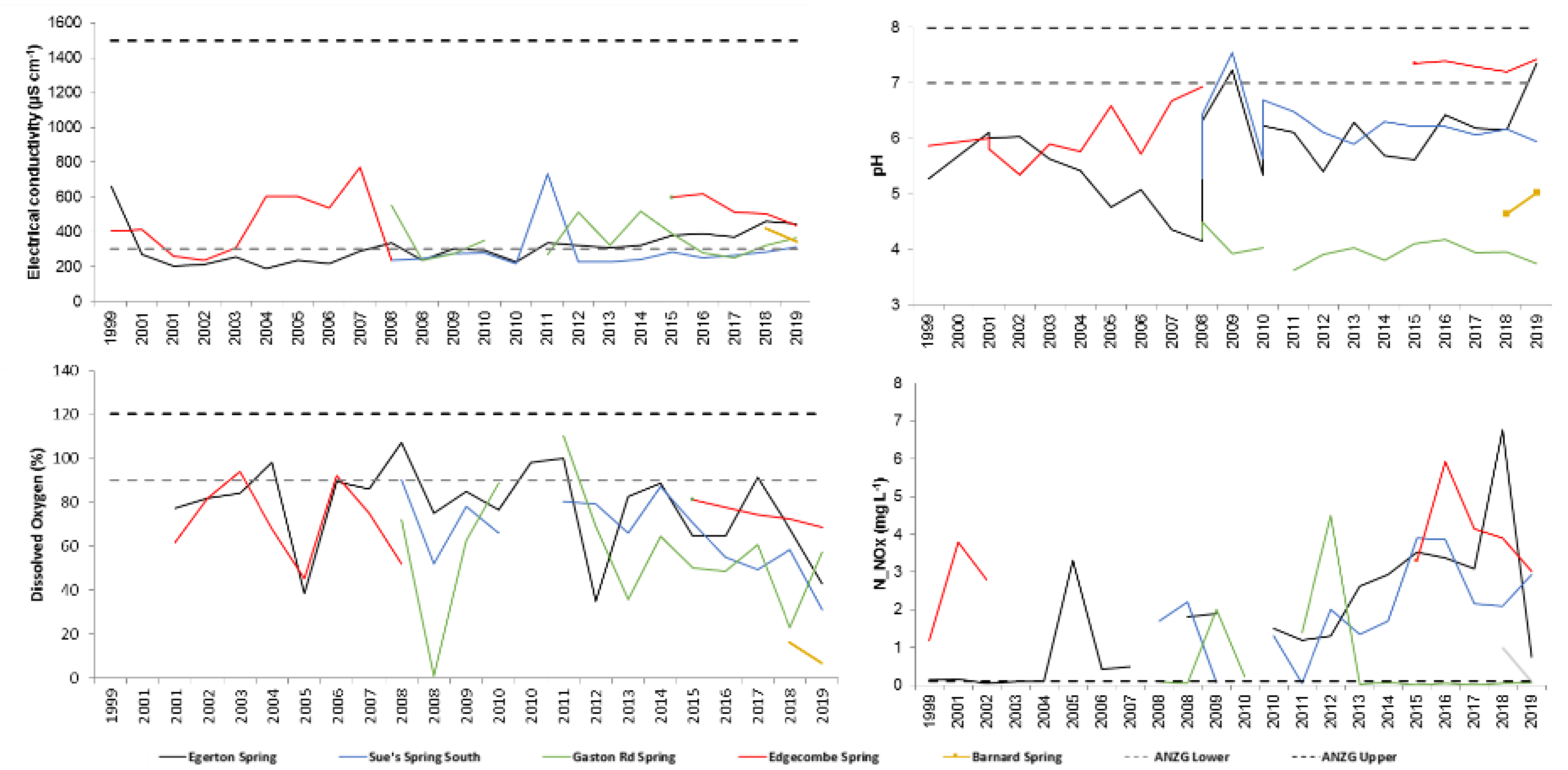


Figure 11. (Clockwise from top left) Electrical conductivity (µS cm-1), pH, dissolved oxygen (% saturation) and N_NOx (mg L-1) recorded at the five sampled Gnangara Springs. Note that sampling occurred twice in some years and that sampling did not occur every year at all sites. ANZG (2018) guidelines for Western Australian wetlands are shown as dashed lines.

Measurements of colour ranged from 20 PCU at Edgecombe Spring to 1500 PCU at Gaston Road Spring (Table 3). High water colour (i.e. tannin stained) at Gaston Road Spring is unsurprising and reflects the standing nature of shallow depressions (i.e. little flow, lentic) and large loads of organic material observed. Water colour is indicative of the tannic and humic content, generally resulting from the decomposition of organic material. Studies on 250 wetlands throughout the Swan Coastal Plain showed the majority of colour levels to be below 600 PCU, but values as high as 18,300 PCU (Sandringham Rd Swamp, Gingin) have been recorded in highly tannin-stained wetlands (Storey *et al*., 1993). Thereby, all five mound springs surveyed possess similar colour levels to that of other springs throughout the region with colour readings under 1500 PCU. The mound spring sites in the current study are small, shallow and have high accumulated loads of organic material, accounting for the variation in colour levels recorded. Water colour does not have a toxic effect on the majority of aquatic fauna but can be a factor affecting assemblages by altering plant species composition and, in turn, dependent fauna (Samways *et al.,* 1996). Water colour at these sites is considered consistent with recent years and is of little ecological concern.

Total iron concentration at EGM springs has remained relatively constant since 2010, with the 2019 Fe levels conforming to this trend (Figure 12). In 2019, Egerton, Edgecombe and Gaston Road Spring all showed slight increases in total iron concentrations compared to 2018, whilst Sue's Spring South and Barnard Spring concentrations were very similar to previous years (2017/2018). There is currently insufficient data to derive a reliable trigger value for iron in Australia (ANZG, 2018). Elsewhere, Crane *et al*. (2007) proposed a water quality criterion for dissolved iron (effectively the same as a DGV) for aquatic ecosystems in the UK of between 0.043 and 0.25 mg L^{-1}, whilst in the USA, Linton *et al*. (2007) proposed a value of 1.74 mg L^{-1} for overall community protection but acknowledged that critical iron concentrations for individual species may be lower. It is currently unknown whether iron levels at EGM spring sites are of ecological concern, however, they remain relatively consistent over the last seven-year period, apart from an upward trend apparent from Egerton, Gaston Road and Edgecombe Spring in 2019 (Figure 12). This trend is to be monitored in years to come.

4 INVERTEBRATE FAUNA

4.1 Composition and Richness

A total of 53 aquatic and semi-aquatic invertebrate taxa were recorded from the five EGM springs sampled in October 2019. These included taxa that could not be identified to species level due to specimens being damaged or immature, or because of taxonomic limitations, so the actual number of species present is likely to be greater than the figure reported. A full taxa list is provided in Appendix 6. Taxonomic composition between sites was variable (Table 4), although copepods (Copepoda), aquatic mites/ticks (Arachnida), beetles (Coleoptera), and the larvae of true flies (Diptera) were recorded at all five mound springs. Similar to previous sampling rounds (see WRM 2014, 2015, 2016, 2017, 2018, 2019), the mound springs continue to be dominated by insects (44% of taxa) with almost all of those taxa (88% of insects) having aquatic larvae and flying adult life stages (Figure 13). Of the 53 taxa recorded, just over half of those taxa (27 taxa or 51% of overall taxa) occurred at only a single mound spring, suggesting that invertebrate assemblages at EGM springs are typified by a high degree of spatial heterogeneity. The percent taxa restricted to a single mound spring location has been consistent in recent years, ranging from 51% to 65% (2015-current). In terms of groundwater ecology, the greatest proportion of taxa were categorised as surface water-dependent (22+ taxa), followed by groundwater-dependent (19+), possibly groundwater-dependent (11+) and unknown (2+). All surface water-dependent taxa were insects, while groundwater-dependent taxa comprised 17+ crustaceans and 2+ types of springtail (Hexapoda: Collembola). Taxa categorised as possibly dependent on groundwater included oligochaetes, freshwater hydra, aquatic mites, the protista *Arcella discoides* and scirtid beetle larvae (Coleoptera: Scirtidae).

It should be noted that species-level identification for Chironomidae (midges), particularly within the sub-family Chironominae, were reduced to family level where species could not be definitively validated using taxonomic literature (e.g. Cranston 1990) or coded voucher records (i.e. slide mounts) for species not formally identified.

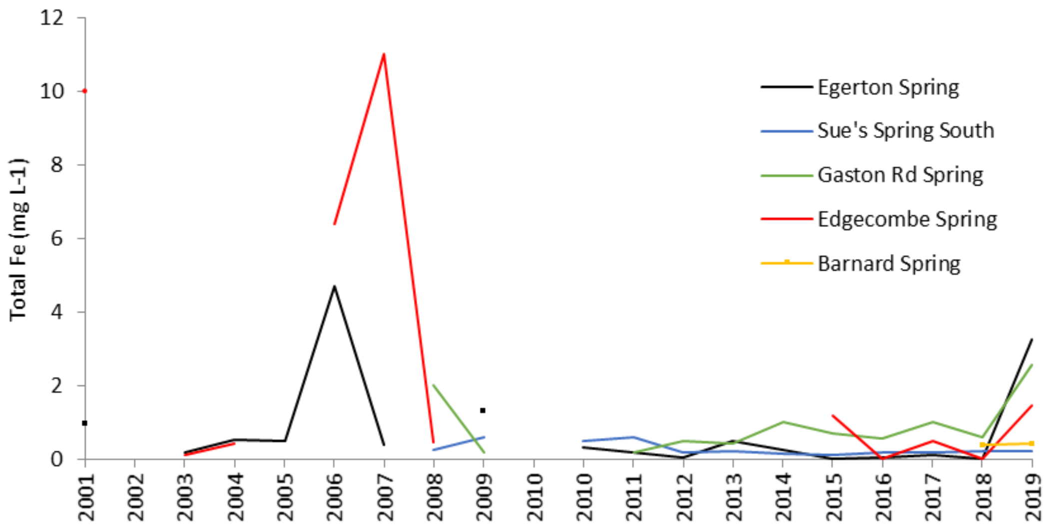
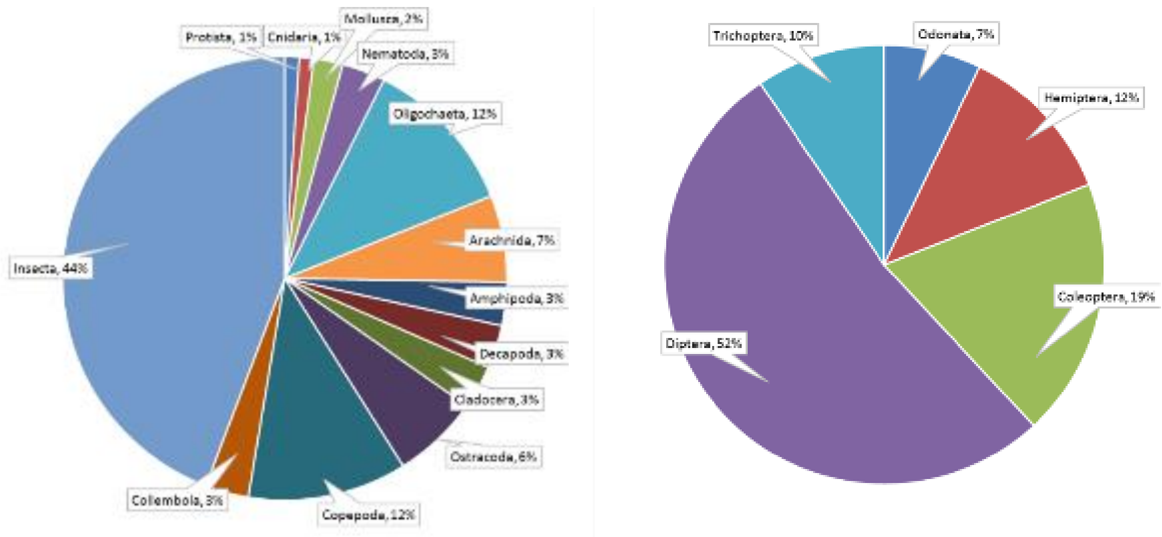


Figure 12. Total iron content (Fe mg L-1) at Gnangara Mound springs since 2001. Note that sampling occurred twice in some years and that sampling did not occur every year at all sites.



2018: All groups **2018: Insecta**

Figure 13. Pie graphs showing overall taxonomic composition (percentage of macroinvertebrate fauna) from all five Gnangara Mound springs sampled in October 2019.

Table 4. Taxonomic composition of invertebrate assemblages at four Gnangara Mound springs sampled in October 2019 according to current taxonomic resolution. Counts that in reality may be higher than reported due to the presence of indeterminate specimens are denoted by '+'.

Taxa	Sue's Spring South	Barnard Spring	Edgecombe Spring	Egerton Spring	Gaston Road
Protista	0	0	0	0	1
Cnidaria	1+	0	0	0	0
Mollusca	1+	0	0	1+	0
Nematoda	1+	0	0	1+	1+
Oligochaeta	3+	0	2+	3+	3+
Arachnida	1+	1+	1+	1+	2+
Amphipoda	0	1+	0	2+	0
Decapoda	0	1	1	0	1
Cladocera	1	0	0	0	2
Ostracoda	0	2	1	3	0
Copepoda	2	2+	1	4+	2
Collembola	1+	0	1+	0	1+
Odonata	0	0	1+	1+	1+
Thysanoptera	1+	0	0	0	0
Hemiptera	0	2+	1+	1+	1+
Coleoptera	1+	2+	1+	2+	2+
Diptera	7+	6+	4+	8+	5+
Trichoptera	0+	0	0	1+	0
Richness	**20+**	**17+**	**14+**	**28+**	**22+**

Three sites recorded over 20+ taxa in 2019; Sue's Spring South, Gaston Rd spring and Egerton Spring. Richness was slightly lower at Barnard Spring and Edgecombe Springs in 2019 where only 17+ and 15+ taxa were recorded respectively. A summary of species composition for each spring is provided below:

Taxa richness at Sue's Spring South in 2019 (20+ taxa) was lower than in 2018 (26+ taxa) but comparable to richness observed at the spring in 2017 (20+ taxa recorded in 2017). Similar to previous years, Sue's Spring South was heavily dominated by surface water-dependent taxa in 2019 (eleven taxa, 45% overall), likely reflecting the difficulty in accessing the exact source of the spring. Of the surface water-dependent species present, one new species, a dipteran (fly) larve, Forcipomyiinae sp. was recorded. Two possible groundwater dependant species were recorded; an oligochaete, *Pristina longiseta*, and a single freshwater Hydra. With respect to groundwater-dependent taxa; four taxa were recorded (20% overall), but no species were new records for Sue's Spring South. A previously unrecorded species of freshwater snail, *Gyraulus* spp. was also recorded, but it is unknown if the species is groundwater dependent.

With respect to taxa richness, Gaston Road Spring in 2019 recorded an increase in richness (22+ taxa) compared to 2018 (19+ taxa) returning to similar levels as previous sampling years, 2016 and 2017 (22+ taxa respectively). Gaston Road Spring supported a high proportion of both surface water-dependent (8+ taxa, 36%) and groundwater dependent taxa (7+ taxa, 32%). Of the surface water-dependent species, a chironomidae (midge fly) family, Aphroteniinae sp. was recorded for the first time at Gaston Road. In contrast, three species of groundwater dependent taxa were recorded from Gaston Road Spring for the first time in 2019, including *Parastenocaris jane* (copepod)*, Ilyocryptus smirnovi* (cladocera), and Entomobryoidea spp. (collembola). Of particular interest is the record of *Parastenocaris jane* (copepod) and Ilyocryptus smirnovi (cladocera) which represent the first records of these species at any of the previously surveyed EGM springs. *Parastenocaris jane* is a copepod species in the family Parastenocarididae. *Parastenocaris* contains around 220 species and subspecies (Galassi and Laurentiis 2004). Representatives of this genus are distributed over all continents and are found in the Pilbara, Kimberley and South-west regions of Western Austraila. The taxonomic impediments surrounding the genus *Parastenocaris* were recently discussed by Galassi and De Laurentiis (2004) and Karanovic (2005) and are generally due to the morphological differences between male and female specimens. A gilgie (*C. quinquecarinatus)* was also recorded at Gaston Road, the third record at this site, previously being recorded in both 2016 and 2018.

Egerton Spring saw an increase in taxa richness in 2019, with 28+ overall taxa, two more taxa recorded compared to 2018 (26+ taxa) (Table 5). Similar to 2018, Egerton Spring had a high proportion of groundwater-dependent taxa (nine taxa, 32% overall) and surface water dependent taxa (12 taxa, 43% overall). Two new groundwater-dependent taxa which had not previously been recorded from the spring included the ostracod species *cf. Cypricercus sp.* and *Alboa woora. Alboa woora* is known from wetlands on the swan coastal plain (Woodhouse 2004, Pennifold 2012), however this is the first instance of the species recorded during the EGM springs surveys. Copepoda species *Attheyella hirsute* and *Paracyclops chiltoni* continue to be consistently recorded at Egerton Spring. A second instance of the ostracoda species, *Vestalenula* cf. *marmonieri*, was recorded in 2019, following a new record of this species at Egerton Spring, as well as at the Gnangara Mound in 2018. In addition to the newly recorded groundwater dependent fauna, Egerton Spring continues to provide important habitat for groundwater-dependent taxa, most notably for the amphipod *Wesniphargus* sp. which has been recorded annually at the spring since 2009 (see WRM 2019). The majority of surface water fauna were insects with flying adult life stages that are able to aerially migrate to colonise suitable habitats (Bogan & Boersma 2012). In 2018, two south-west endemic surface water macroinvertebrate taxa species (the mayfly *Bibulmena kadjina* and the dragonfly larvae *Zephyrogomphus lateralis*) were identified for the first time at Egerton Spring, however, were absent from the current 2019 sampling survey.

A decline in taxa richness was observed at Edgecombe Spring between 2018 (19+ taxa) and 2019 (14+ taxa). The majority of taxa at Edgecombe Spring were classified as surface water dependent (six taxa, 42.9% overall) followed by groundwater-dependent taxa (four taxa, 28.6% overall) and possible groundwater-dependent taxa (four taxa, 28.6% overall) (Table 5). Only one groundwater-dependent taxa collected in 2019 had not been previously identified at Edgecombe Spring, the Gilgie, *Cherax quinquecarinatus*. Of the possible groundwater-dependent taxa at Edgecombe Spring, one new taxon was identified as not having been previously recorded from the spring, the oligochaete *Nais communis*. The current round of sampling shows a return to 2017 taxa richness which documented a decline in overall richness from 2015 and 2016 levels at Edgecombe Spring. Despite this decline in taxa richness at Edgecombe Spring in 2019, the spring continues to persist with strong water flow and comparable surface water expression to previous sampling seasons (i.e. 2016 and 2017).

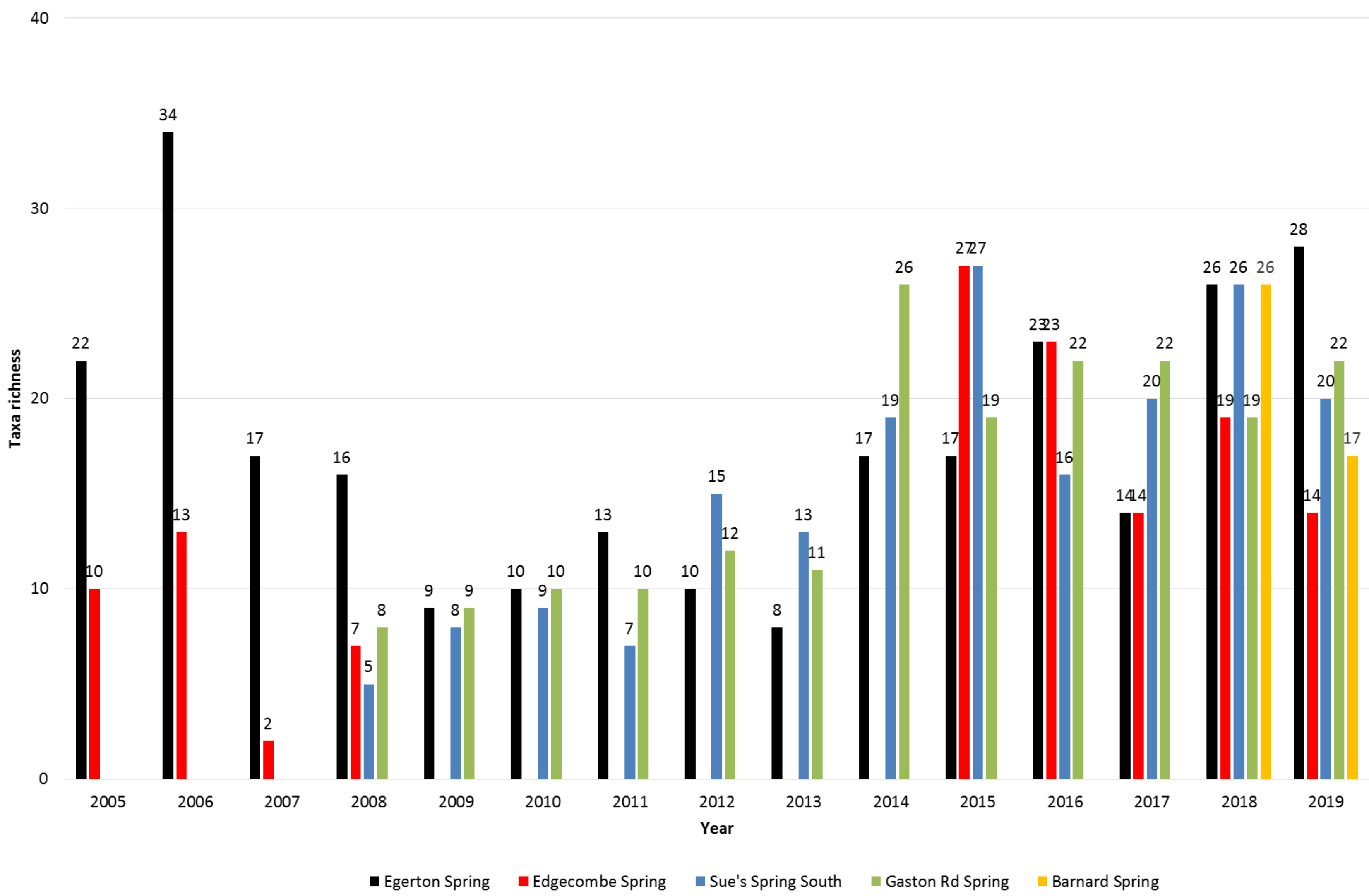


Figure 14. Invertebrate taxa richness at Gnangara Mound spring sites recorded since 2005. Data were standardised according to the taxonomic resolution of 2005. Note that sampling began at Sue's Spring South and Gaston Road Spring in 2010, and that Edgecombe Spring was not sampled from 2009 to 2014. 2018 was the first year Barnard Spring was included in the sampling program.

Table 5. Summary of groundwater dependency[4] amongst invertebrate taxa recorded at Gnangara Mound since 2005. Data were standardised according to the taxonomic resolution of 2005. Note that sampling began at Sue's Spring South and Gaston Road Spring in 2010, and that Edgecombe Spring was not sampled from 2009 to 2014. 2018 was the first year Barnard Spring was included in the sampling program.

	Year	Groundwater-dependent	Possible groundwater-dependent	Surface water	Unknown	Total no. of taxa
Egerton Spring	2005	5	5	10	2	22
	2006	7	9	16	2	34
	2007	6	3	6	2	17
	2008	4	4	6	2	16
	2009	3	2	4	0	9
	2010	3	2	5	0	10
	2011	4	1	8	0	13
	2012	4	1	4	1	10
	2013	2	3	3	0	8
	2014	5	3	8	1	17
	2015	4	8	4	1	17
	2016	7	6	10	0	23
	2017	4	3	7	0	14
	2018	10	2	13	1	26
	2019	9	5	12	2	28
Edgecombe Spring	2005	3	3	3	1	10
	2006	2	4	5	2	13
	2007	1	1	0	0	2
	2008	2	2	1	2	7
	2015	6	8	11	2	27
	2016	6	4	13	0	23
	2017	1	4	9	0	14
	2018	6	5	7	1	19
	2019	4	4	6	0	14
Sue's Spring South	2010	3	1	4	1	9
	2011	2	1	4	0	7
	2012	3	3	7	2	15
	2013	4	1	7	1	13
	2014	6	6	4	3	19
	2015	8	8	9	2	27
	2016	4	7	4	1	16
	2017	6	3	8	3	20
	2018	6	6	11	3	26
	2019	4	6	8	2	20
Gaston Road Spring	2010	3	2	4	1	10
	2011	3	3	4	0	10
	2012	2	3	7	0	12
	2013	3	0	7	1	11
	2014	2	5	18	1	26
	2015	5	5	8	1	19
	2016	4	3	15	0	22
	2017	6	3	13	0	22
	2018	7	4	7	1	19
	2019	7	6	8	1	22
Barnard Spring	2018	7	6	12	1	26
	2019	6	2	9	0	17

[4] Groundwater dependent species are categorised as relying on the maintenance of groundwater presence and quality to survive, likely subterranean in origin and unable to relocate or recolonise areas. Species often occur in highly localised distributions and spend part or most of their lives below ground. Surface water species are generally opportunistic, cosmopolitan inhabitants that may re-colonize the surface water expressions via adult aerial stages rather than originate from groundwater.

Barnard Spring was added to the sampling program in 2018 and recorded a similar overall diversity and composition of water dependent taxa to other TEC listed mound springs. In 2019, Barnard Spring recorded a decrease from the previous year in taxa richness (from 26+ to 17+ taxa). Over half of the taxa present at Barnard Spring were surface water-dependent taxa (9+ taxa, 53% overall), with approximately a third of the taxa being groundwater-dependent (6+ taxa, 35%). Of the surface water-dependent species present, the veliid waterbug, *Microvelia oceanica* was recorded in 2018 and again in 2019 at Barnard Spring. Previously this species had not been recorded at any of the EGM springs. A diving water beetle, *Limbodessus inornatus*, was also recorded at Barnard Spring in 2019, having been recorded once from Edgecombe Spring in 2015. With respect to groundwater-dependent taxa, three species of note were recorded; the ostracod, *Vestalenula* cf. *marmonieri*, the crayfish, *Cherax quinquecarinatus* (gilgie), and an immature Amphipoda specimen. *Vestalenula* cf. *marmonieri* has only been recorded from Egerton Spring in recent years (2018 and 2019). In 2018, the South West regionally endemic amphipod species *Perthia acutitelson* was recorded from Barnard Spring, thereby it is likely the immature amphipod specimens collected from the spring in 2019 could be representative of this species. *P. acutitelson* are commonly collected from permanent pool habitats (CENRM 2004), however the amphipod species has also been previously identified in cave habitats and root mats of the Leeuwin-Naturaliste region (DEC 2008). Of particular note was the detection of a gilgie (*C. quinquecarinatus*) at Barnard Spring. Gilgies have previously been observed at the site by the current landowners (E. Thillainath pers. comm), with the confirmed presence of the species suggesting that the spring supports a local population of *C. quinquecarinatus*. Other groundwater-dependent ostracod and copepod species which were collected from Barnard Spring (*Eucyclops edytae*, *Candonopsis cf. tenuis*) have been previously identified at the other intact springs, thereby supporting the comparable nature and ecological importance of the spring to the current study.

Broadly, the categories of taxa recorded from the mound springs in 2019 are consistent with previous years sampling records, with Barnard Springs expressing similar taxonomic characteristics to the other springs sampled, albeit with some taxa differences due to its excavated outlet. Egerton Spring and Gaston Road Spring increased in richness, whilst Edgecombe, Sue’s Spring South and Barnard Spring exhibited decreases in taxa richness.

Generically, the diversity of invertebrate groups and overall community composition across all five EGM springs was comparable in October 2019 (Figure 14; Table 4). This illustrates the importance of these springs to local ecosystems in several ways. Across all sites, 23+ taxa classed as surface water-dependent were recorded, thereby representing almost half (41%) of all taxa at the springs. The majority of these are insects with flying adult life stages, suggesting that aerial colonisation is an important contributor to invertebrate diversity at the EGM springs. The springs, being perennial, also provide source populations to colonise adjacent seasonal wetlands and watercourses. It is likely that groundwater springs and the surrounding vegetation provide important breeding habitats for surface water-dependent taxa such as flies, aquatic beetles, caddis flies and dragonflies. A total of 18+ groundwater-dependent taxa and 11+ possible groundwater-dependent taxa were also recorded in the present study. Although some of these taxa are likely to be common regionally, most have limited dispersal capabilities and are probably restricted locally to perennial surface waters such as springs. Several potentially range-restricted, endemic, groundwater-dependent species were also recorded. This illustrates the importance of groundwater-fed springs as permanent, moist refuges within a seasonally dry landscape such as the Swan Coastal Plain.

4.2 Invertebrate taxa of conservation significance

A number of invertebrate species collected from EGM Springs in October 2019 were noteworthy due to their rarity, endemism and/or novelty to science. These included the amphipod *Wesniphargus* sp., and the cladocerans; *Alona rigidicaudis*, *Ilyocryptus spinifer* and *Ilyocryptus smirnovi*. The Western Australian Museum's (WAM) three-tiered classification system for SRE species was used in this study to better elucidate faunal conservation significance at the springs (WAM, 2013). Additionally, the importance of the widespread but ecologically important *C. quinquecarinatus* is discussed in section 5.2.

The 2019 sampling round recorded the amphipod *Wesniphargus* sp. (Neoniphargidae) (Plate 1) at Egerton Spring. Having been found at Egerton Spring since 2015, this taxon is likely to constitute a hitherto undescribed species and has only been recorded by WRM at Egerton Spring (each year since 2009) and once at Sue's Spring South (2008), suggesting that it is likely to be a short-range-endemic (SRE) restricted to the Gnangara Mound system. SRE species typically have low dispersal capabilities and ranges of distribution smaller than 10,000 km^2 (EPA, 2009; Harvey, 2002). Specimens of the genus *Wesniphargus* are uncommon (WRM, unpublished data), but it appears that Egerton Spring supports a healthy population, with 18 individuals recorded in 2017, 13 individuals recorded in 2018, and 25 individuals recorded in 2019. There is a distinct lack of data (both taxonomic and geographic) available for these amphipods, and so we cannot confirm the fauna as true SRE's, however it is apparent they have a limited geographical distribution. Limited available information results in classification of these fauna as potential SRE's based on the WAM (2013) and EPA (2009) frameworks.

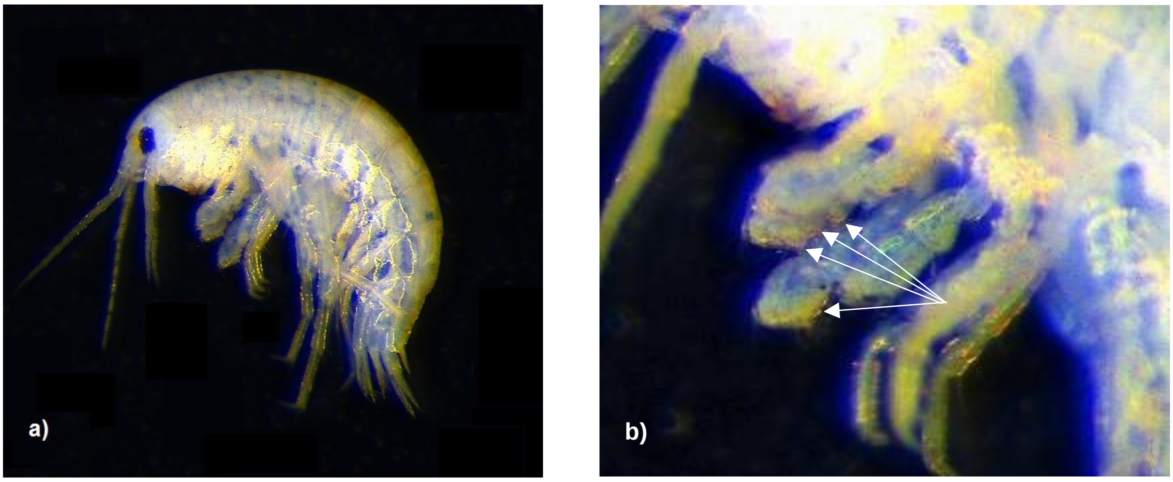


PLATE 1 a) The amphipod *Wesniphargus* spp. (Neoniphargidae) collected from Egerton Spring. Note the small bumps (denoted by arrows) on the underside of the gnathopods (b) which are characteristic of the Neoniphargidae family.

Of particular interest in 2018 was the collection of the south-west regionally endemic amphipod *Perthia acutitelson* from Barnard Spring, of which four individuals were collected. In 2019, this species was not recorded at Barnard Spring, although three immature Amphipoda specimens were collected. The species is known to be restricted to creeks and swamps west of the Darling Scarp and has previously been found prolifically in the south-west (Halse & Blyth, 1992) and as far north as Chittering in close proximity to Barnard Spring (Knott, 1975). The presence of the regionally endemic amphipod at the spring warrants the ongoing inclusion of the spring in the study so as to confirm whether the spring supports a local population of the conservation significant *Wesniphargus* species. However, it is noted the spring is highly modified from its natural state and already has a degree of protection being listed under the National Heritage Trust.

The discovery of a number of new water flea (cladocera) species has been evident at the Gnangara Mound Springs in recent years (2017, 2018 and 2019), notably from Gaston Road Spring, Egerton

Spring and Sue's Spring South. Prior to 2017, only low densities of three species of water flea had been collected and identified from the Gnangara Mound Springs. In contrast, five new species of Cladocera were identified at the springs in 2018, with an additional new species recorded in 2019. Cladocerans produce diapausing, extremely tolerant eggs (Forró et al., 2008) which could have been present at the springs previously, although changes in groundwater level, climate, and ground disruption from surrounding land use changes could be resulting in the increased detection of these species at the springs in the past three years. Cladocerans have the potential in high densities to alter species composition of an ecosystem by grazing on resident algae, as well as by attracting more diverse predators. Continued monitoring is thereby necessary to detect changes in species composition of the Gnangara Mound Springs, most notably Gaston Road.

The Cladocera genus, *Ilyocryptus,* is globally widespread, but different continents have shown that this genus has both cosmopolitan and non-cosmopolitan species. Specimens from this genus can also display vastly different morphological characteristics between life stages and gender, and as such, taxonomy has been historically contentious (Kotov and Timms 1998, Kotov and Dumont 2000). *Ilyocryptus spinifer* was recorded from Sue's Spring South for the first time in 2018 and for a second time in 2019. This species is globally cosmopolitan and found in both temperate and tropical environments. *Ilyocryptus smirnovi* was recorded from Gaston Road Spring for the first time in 2019. This species appears to be widespread across western and northern Australia, with records from Queensland and Western Australia (Kotov and Timms 1998). *Ilyocryptus* is a floc-burrower, ploughing through the surficial sediments, and is a detritivore, eating bacteria and dead or decaying organic material (Dr. Russ Shiel pers comm.)

Alona rigidicaudis has been recorded from Gaston Road Spring previously (2017 and 2018) and was collected in high abundances in 2019. Prior to 2017, there were no records of this species at any of the four spring sites sampled by WRM between 2010 and 2016. *Alona rigidicaudis* is an Australia-wide species existing in diverse freshwater environments. The colonisation of the species at Gaston Road is possibly a result of ephippia (eggs) being vectored into the spring by birds or feral pigs (attached to feathers or mud on trotters respectively); feral pigs have become a significant issue at Gaston Rd swamp in recent years. Conversely, given the coinciding timing of the construction of the Northlink highway and dates of first appearance (late 2017), is the possible that either clay or other road construction material for the nearby Northlink contained foreign ephippia, which could have washed into the spring and hatched. Both theories document methods of translocating ephippia or dormant resting eggs (Dr. Russ Shiel pers. comm.). It should be noted however, that Gaston Road Spring has become inundated with stagnant, disconnected pools with variable flow in recent years, with sampling difficulties (sampling within close proximity to the spring outlet) potentially resulting in contrasting faunal assemblages since sampling at the Gnangara Springs commenced.

In 2019, *Eucyclops edytae* was identified at two of the spring sites (Barnard Spring and Gaston Road Spring). Formally described in 2009, this species is endemic to the Gnangara Mound, where it occurs primarily in surface springs and rarely in subterranean waters (Tang & Knott, 2009). Given its highly restricted distribution (<10,000 km^2) and requirement for specific habitats (shallow, perennial surface springs of the Gnangara Mound), this species is a strong candidate for confirmed SRE status. However, currently this species can only be classified as a potential SRE, as the available research and expertise on the species is limited with notable gaps in knowledge on the fauna (WAM, 2013). Tang & Knott (2009) noted that maintaining groundwater flow in caves and minimising residential development near Gnangara Mound springs are essential to protecting this species. This species has previously been recorded by WRM at Gaston Road Spring in 2010, 2011, 2013, 2014, 2016, 2017 and 2018 and was recorded for the first time at Egerton Spring in 2015 and Barnard Spring in 2018.

5 SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Water levels and quality

Edgecombe Spring was sampled for the fifth successive year in October 2019, following the cease in sampling of the mound spring after 2008, having been deemed too degraded for ongoing monitoring. Water levels remain sufficient to allow the collection of aquatic invertebrates, and it appears that the spring has either recovered from its previously degraded state, or that it was premature to remove this site from the sampling regime in 2009. Groundwater levels in both B10 and B25 monitoring bores (pertaining to Edgecombe Spring and Egerton Spring, respectively) have been relatively stable since 2008. Unseasonal summer rainfall as well as above average winter rainfall during 2018 and above average May rainfall in 2019 contributed to groundwater level trends over the period at bores B10 and B25. Surface water flow at Edgecombe Spring and Egerton Spring in 2019 was very similar to recent years, suggesting that groundwater levels are currently adequate to maintain these spring ecosystems. In 2019, the groundwater level maxima was lower than in 2018 at B25, although higher than the average, possibly due to recharge following above average May rainfall. Successive years of observed seepage from Edgecombe Spring suggests that current groundwater conditions are sufficient to maintain this spring ecosystem. Despite the below average rainfall in 2019, maxima and minima remained similar to the previous three years at B10 and B25. Continued monitoring of Edgecombe Spring and Egerton Spring is essential for comparison against groundwater levels, particularly under the scenario of a drying climate.

Water levels in bore GN24, reflecting water levels in Sue's Spring South and Gaston Road Spring, have steadily declined for nearly two decades (1990's to 2010's) with the trend appearing to have reached equilibrium between the period 2014 – 2016. However, there was a notable (staged) decline in water levels from the winter maxima in 2016 to summer minima in 2017. A similar (staged) decline was observed from the 2017 maxima to February 2018, from the 2018 maxima to February 2019 and the 2019 maxima to February 2020. This may reflect rapid development of the agricultural land surrounding Sue's Spring South and Gaston Road Springs, which has likely resulted in increased groundwater abstraction to support the expansion of commercial operations including, but not limited to, Plantrite and Berry Sweet Strawberry Farm. Major construction works associated with development of the northern section (Ellenbrook to Muchea) of NorthLink WA commenced in November 2017. Localised abstraction of groundwater by CPB Contractors Pty Ltd for dust suppression and to facilitate pavement construction works for the dual carriageway and Neaves Road Interchange may also account for this notable decline in the water table. Despite the below average rainfall in summer 2019, WRM observed surface water expression and flow at both Gaston Road Spring and Sue's Spring South in 2019 comparable to previous years (E. Thillainath pers. comm). Ongoing monitoring of groundwater levels at GN24, at an increased frequency, particularly under the scenario of a drying climate, is required to determine the effects of irregular fluctuations in groundwater level (possibly due to sporadic abstraction from a nearby self-supply licensed bore), and provide sufficient protection of TEC listed springs in close proximity. The decline in water table levels between 2017 and 2020 is concerning. If the current climatic regime continues, a below average rainfall year appears insufficient to offset increased water use, and if winter 2020 result in below average rainfall, the aquifer will undoubtedly be placed under greater stress, and require tighter management and monitoring around water abstraction.

Gaston Road Spring continues to sustain a series of shallow expressions, with a maximum depth of 5 – 7 cm, with slight flow evident in some expressions. The flows observed during the monitoring in October reflect the water levels at bore GN24 at the time, which were only slightly lower than the peak levels in 2018It remains unknown if these two springs have different groundwater threshold levels below which surface expression ceases. Nonetheless, levels at bore GN24 appear to a reliable indicator of flow at both Sue's Spring South and Gaston Road Spring.

Barnard Spring was sampled for the second successive year in 2019, and from the resulting data, it is apparent that water levels in the corresponding bore (LC160C) are sufficiently sustaining the spring, with bore levels stabilising/ increasing since 2016/17. Water flow at Barnard Spring was comparable to the other springs surveyed in October 2019. With respect to spring conditions, the water flow from the pool via the feeder and trough was substantial, with a significant amount of water flowing to the downstream wetland community. In recent years, there has been a notable increase in annual recharge back in line with historic levels (1984 to 1998).

In terms of water quality, the EGM springs were generally characterised by fresh electrical conductivity, low to moderate dissolved oxygen saturation, and tannin stained water. Waters were generally acidic (strongly so at Gaston Road Spring, Barnard Spring and Sue's Spring South), with the exception of Edgecombe Spring and Egerton Spring, where pH was circum-neutral. Current water quality conditions are consistent with previous sampling events and likely reflect heavy accumulation of organic matter and possibly the acidification of underlying groundwater. Other than at Gaston Road Spring, where levels of nitrogen oxide were below detection limits, N_NOx levels were high and in excess of relevant ANZG (2018) trigger values for the protection of aquatic fauna in wetlands of South Western Australia. Nitrate (NO3-) levels recorded at Sue's Spring South, Edgecombe Spring and Egerton Spring represent eutrophication stress to resident fauna and pose increased risk of nitrate toxicity. However, it should be emphasised that current default guidelines for nitrate toxicity to freshwater invertebrates are conservative and require revision. It is likely resident fauna of the springs have adapted to historically high nitrate concentrations. Ongoing monitoring will further characterise any temporal trends in nitrate levels, and the potential for toxicity to resident fauna.

Water quality data (sulphate and pH concentrations) indicate Gaston Road Spring is susceptible to acidification, most likely associated with sediment desiccation (i.e. acid sulphate soils) during periods of low groundwater level. Development of NorthLink WA and expansion of nearby agricultural commercial operations has resulted in localised abstraction from the aquifer, as evidenced by bore data (GN24) for the periods 01/09/2016 to 01/06/2017, 01/09/2017 to 01/02/2018, 03/09/2018 to 01/02/2019 and from 02/09/2019 to current. These fluctuations demonstrate sizable drops in water level over the course of these abstractions (approximately 1.5m drop in AHD water level from winter maxima to summer minima). The low pH at Gaston Road Spring could also be a result of increased oxidation of accumulated airborne sulfur arising from ground and surface water as a result of increased sulphate (SO_4^{2-}) deposition from surrounding land use (Lamers *et al*., 1998). Desiccation of wetlands as a result of falling groundwater levels has become a concern for wetland conservation worldwide, especially with the prospect of global climate change enhancing the negative impact of a drying climate and ecosystems (Lamers *et al*., 1998). Ongoing monitoring of Gaston Road Spring is therefore necessary, as any possible desiccation of the spring with potential future drawdown and abstraction from ongoing nearby development could expose acid sulphate soils and in turn result in acidification of groundwater, which could threaten the conservation significant EGM springs. Similar impacts may also be observed at nearby Sue's Spring South if groundwater extractions continue to put pressure on the aquifer.

5.2 Invertebrate fauna

A total of 53 taxa were recorded from the five springs sampled on the East Gnangara Mound in October 2019, with approximately 51% of the fauna occurring at only a single mound spring. This illustrates the high degree of diversity and spatial heterogeneity of aquatic and semi-aquatic invertebrate fauna at the EGM springs. The most speciose site was Egerton Spring recording 28+

taxa, followed by Gaston Road (22+ taxa), Sue's Spring South (20+ taxa), Barnard Spring (17+ taxa) and Edgecombe Spring (14+ taxa). There was a notable overall decrease in richness at the mound springs in 2019 compared to 2018, however richness was higher than the low richness recorded in 2017 (taxa in 2017: n=44, taxa in 2018: n=64). The most notable reduction was at Barnard Spring (26+ taxa in 2018 to 17+ taxa in 2019), however as there have only been two sampling occasions for this spring continued monitoring is needed to determine if this reduction was significant. It was not possible to identify all taxa to species level due to damaged and/or immature specimens or taxonomic restraints, so actual species richness at individual sites, and overall, is likely to be greater than reported.

In terms of groundwater ecology, the majority of recorded taxa were categorised as surface water dependent fauna. These taxa were all insects with aquatic larvae and flying adult life stages. The high diversity of surface water invertebrates indicates that aerial colonisation is a major contributing factor to diversity at EGM springs. It also suggests that the springs, which constitute moist buffers against climatic extremes, provide important refuges and breeding sites for a range of insects. In 2019 there was a decrease in groundwater-dependent taxa from 2018 at Sue's Spring South, Barnard Spring and Edgecombe Spring. Gaston Road and Egerton Spring, however, maintained the same number of groundwater dependent taxa across years. Taxa considered to be groundwater-dependent or possibly so, were represented by a diverse suite of crustaceans, aquatic mites, oligochaete worms and springtails (i.e. Collembola). The degree of groundwater dependency among the invertebrate assemblages of Gnangara Mound springs clearly demonstrates the ecological importance of these habitats as refuges for aquatic invertebrates with limited dispersal capabilities. After the re-introduction of Edgecombe Spring into the sampling program in 2015, it is clear that the spring continues to support a diverse array of groundwater-dependent species, including aquatic mites and oligochaetes as well as a range of surface water species. The mound spring can be considered of high ecological value, and it is recommended that it is retained as part of any ongoing invertebrate and water quality monitoring regime of the East Gnangara Mound. In addition, Barnard Spring should remain in the sampling program for the foreseeable future as a result of its variable species diversity (n=26 in 2018, n=17 in 2019 taxa recorded from the spring) and due to the presence of South West WA endemic species at the spring (*Cherax quinquecarinatus, Perthia acutitelson* (recorded in 2018) and *Eucyclops edytae*). All amphipod specimens collected were too immature to identify to species at Barnard Spring in 2019 and it remains unknown if *Wesniphargus* amphipods also occur at this location, as their distribution is highly restricted, but the presence of the regionally endemic amphipod *Perthia acutitelson* suggests it is possible.

Several rare, endemic and/or novel taxa were recorded at Gnangara Mound springs in 2019. Egerton Spring continued to support the WA endemic amphipod *Wesniphargus* spp. which have been recorded at this spring since 2009. Specimens of this type have only been recorded at two sites by WRM since 2009[5], Egerton Spring and Sue's Spring South, suggesting that this species is restricted to the Gnangara Mound and therefore is classified a potential SRE. These crustaceans are evidence of the evolution of life forms which existed when Australia was part of Gondwanaland and are therefore important to science (Hopper *et al*., 1996). Another potential SRE species that was recorded in 2018 at Egerton Spring, Gaston Road Spring and Barnard Spring was the cyclopoid copepod *Eucyclops edytae,* which is known to be confined to the Gnangara Mound. Although *E. edytae* has predominantly been recorded from springs, previous specimens which have been collected from the Yanchep Caves system. However, all known populations in caves are now presumed extinct since all known cave streams have dried due to declining groundwater levels. Inherently, this places greater conservation value on spring systems where *E. edytae* has been recorded, including Barnard Spring.

[5] Specimens recorded in 2006 were reported as Paramelitidae sp. gen nov., but may have been *Wesniphargus* sp.

Four new species of Crustacea were collected from the Gnangara Mound Springs in 2019, including one new species of Cladocera (*Ilyocryptus smirnovi*), one new species of Copepoda (*Parastenocaris jane*) from the Gaston Road Spring and two new Ostracoda (*Alboa wooroa*, cf. *Cypricercus* sp.) from the Egerton Spring. Prior to 2017, only three species of water flea (Cladocera) had been collected from the springs in low densities. Since 2017 however, several new cladoceran species have been collected from the springs (2018 = five new species, 2019 = one new species) notably from Gaston Road Spring, Egerton Spring and Sue's Spring South.

Some of these species have not previously been identified from the southwest region of WA, although sampling, identification and data availability constraints are likely factors for the knowledge gap of this diverse group. Further research on the range (i.e. distribution) of these water flea species is required to either confirm or deny the species apparent range extension, as well as to investigate the potential origin of these cladocerans (i.e. introduced by natural or anthropogenic factors). There is no doubt however that the new records of these species at the spring emphasises the protection of the Gnangara Mound springs to protect and manage these associated habitats and species.

The freshwater crayfish *Cherax quinquecarinatus* was recorded at Edgecombe, Gaston Road Spring and Barnard Spring in 2019, and as a result we can infer that all mound springs sampled are likely to support local, potentially genetically diverse populations of the endemic crayfish, as the species has previously been encountered at each spring in separate sampling seasons. This highlights the importance of ongoing monitoring of the Gnangara Mound to develop a better understanding of these populations in context to local and/or regional wetlands.

5.3 Conclusion

Springs associated with the East Gnangara Mound provide refuges for highly diverse and heterogeneous assemblages of aquatic and semi-aquatic invertebrates, including several rare, SRE, regionally endemic and/ or undescribed groundwater-dependent species. The crustacean fauna is of particular significance, with some taxa likely to be restricted to not only South Western Australia, but also to the Gnangara Mound. Further, several of the recorded microcrustacean species are potential (i.e. notably data deficient) short-range endemics (SRE's) (WAM, 2013), which reinforces the importance of continued research of tumulus mound springs which are known to support a distinct fauna with limited dispersal capabilities. The occurrence of groundwater dependent fauna in mound springs is variable interannually, and between springs, and likely reflects site-specific hydrological regime (i.e. discharge, surface water availability) at the time of sampling.

Annual rainfall in 2019 was below average, however discharge and surface water expression at each of the mound springs in 2019 were similar to previous years, due to the time of sampling coinciding with peak groundwater levels. Increased and sustained local abstraction of groundwater has resulted in severe fluctuations in water level over the past 3 and a half years at bore GN24. This is of most concern and presents a threat to the long-term future of TEC listed Gaston Road Spring and Sue's Spring South. There is the potential that local abstraction could result in short term drying events of these springs. Potential for increased acidification of TEC listed springs is of concern, as a result of increased local abstraction of groundwater, particularly under the scenario of a drying climate and reduced winter recharge regime. Current frequency of groundwater level monitoring at local bores does not appear sufficient to detect the short spatial scale of abstraction of large volumes of water, which may drawdown the hydrostatic head of the system below the AHD of the springs, and result in temporary loss of flow, or even drying of mound springs. It is currently unknown whether Gaston Rd Spring and Sue's Spring South dry/are heavily reduced over the summer months. In order to investigate this further, it would be beneficial to incorporate an autumn sampling round of the springs on an annual basis to detect what is present during periods of drying.

Water quality at each of the mound springs was similar to recent years, with concentrations of EC, DO, pH, and water temperature appearing relatively stable, and of little ecological concern. Nutrient levels (N-NOx) continue to pose eutrophication stress, whilst nitrate concentrations also exceed default trigger values for toxicants at alternative levels of protection for each of the mound springs. Although there is potential for toxicity to fauna at nitrate concentrations recorded in the current study, it is noted default toxicant guidelines are inherently conservative and require revision. Therefore, it is likely current nitrate concentrations, which are slightly elevated compared to recent years, pose a small risk to the resident fauna, and that this fauna are likely adapted to these conditions. Barnard Springs recorded similar water quality results to the other four mound springs despite its historical excavation, and should remain in the ongoing sampling program to create a baseline for the spring as well as for future comparisons to anthropogenically altered springs as a result of changing land uses (i.e. ecological alteration of Gaston Road Spring and Sue's Spring south in the coming years due to encroaching development).

Construction of the northern section of NorthLink to the east of Sue's Spring South and Gaston Road Spring commenced in 2017 along the Neaves Road intersection, concomitant with increased groundwater abstraction from nearby agricultural land uses and expansions (i.e. Plantrite native plant nursery expansion and Berry Sweet Strawberry Farm), is likely to continue to alter surface flows and groundwater levels (and potentially quality) in proximity to mound springs. Continued monitoring of Gnangara Mound springs, notably Gaston Road Spring and Sue's Spring South, is therefore critical to identify any future changes and fluctuations in water levels, water quality and assemblages of aquatic fauna, to understand the relationships between these factors, and to assist future management plans for the protection of resident fauna.

5.4 Recommendations

A number of recommendations for 2019 sampling/monitoring efforts are presented below for consideration, and include:

- Effort should be made to implement a monitoring program for Gaston Road Spring and Sue's Spring South, with increased sampling frequency (i.e. incorporate an autumn sampling round at a minimum), particularly during and post-development of the northern section of Northlink WA. In addition, the bore (GN24) should be monitored at increased frequency (i.e. weekly / fortnightly), or ideally have continuous logging to better capture drawdown / abstraction effects from local users. This is critical in identifying periods where TEC listed mound springs are under increased risk of drying and acidification.

- Water level loggers should be installed at GN24 to provide daily groundwater level readings. This would allow DWER to assess the impact local abstraction is having on the water table as opposed to local/regional rainfall events. The irregularity and uncertainty of water level drawdown at GN24 warrants routine (i.e. quarterly) water quality testing at GN24. Water quality data should be compared against relevant ANZG (2018) guidelines for ecosystem protection.

- Environmental groundwater requirements for each spring in the study should be investigated to ensure maintenance of flow and protect against any future drawdown impacts. To develop an EWR for each spring based on groundwater level it is necessary to gain a better understanding of seasonal changes in discharge from each spring and how this varies relative to groundwater levels. This will require at least monthly monitoring of discharge from each spring over at minimum a 12 month period, but ideally 24 – 36 months to encompass inter-annual variability, and relate flows to groundwater levels and characterise seasonal relationships relative to maximum and minimum groundwater levels.

- Edgecombe Spring, which was reinstated to the monitoring program in 2008, should continue to be included in future monitoring as it could support valuable groundwater-dependent fauna, with possible SRE (at the least regionally endemic) microcrustaceans being recorded previously at the site (2016). Further monitoring will be critical to see if these previously collected specimens remain at the site.

- Barnard Spring should continue to be included as part of the East Gnangara Mound Springs Sampling Program, in order to better characterise groundwater dependent fauna and establish further conservation significance, as well as to develop baseline environmental values for the spring (i.e. water quality, fauna assemblages etc.).

- Funding should be sourced for relevant experts to conduct formal descriptions and DNA analysis of novel species, namely the the amphipod *Wesniphargus* sp. (Neoniphargidae), and specimens lodged with the Western Australian Museum.

- Feral pigs remain an issue at Gaston Road Spring, not only with regards to accessing the spring safely but also due to the destruction of habitat at the site, which was highly evident in 2019. WRM recommend an eradication program of the feral pigs so as to improve the quality of the spring and to establish safe site access at Gaston Road Spring for future sampling.

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APPENDICES

APPENDIX 1. Photographs of EGM spring sites at the time of sampling in October 2019.

Sue' Spring South:

Edgecombe Spring:

Egerton Spring:

Gaston Road Spring:

Barnard Spring:

Downstream trough

Upstream trough

Excavated pool

Submerged outlet

APPENDIX 2. Aerial photos showing the growth of the urban zone around and encroaching onto Edgecombe Spring (yellow marker) for the 2004, 2010, 2017 and 2018.

November 2004

January 2010

December 2017

October 2018

October 2019

APPENDIX 3. Aerial photos showing the growth of the urban zone around and encroaching onto Egerton Spring (yellow marker) for the period 2004 – 2019.

March 2004

May 2005

March 2007

February 2010

November 2011

February 2013

June 2015

November 2016

December 2017

October 2018

October 2019

APPENDIX 4. Aerial photos showing the development of the Northlink WA to the east of the Gaston Road Spring and Sue's Spring South from 2010 (top) to 2019 (bottom).

APPENDIX 5. ANZG (2018) DGV for the protection of aquatic systems in South West Australia.

Table A2-1. Range of default DGV for conductivity (EC, salinity), turbidity and suspended particulate matter (SPM) indicative of slightly disturbed ecosystems in South West Australia. Ranges for turbidity and SPM are similar and only turbidity is reported here. Values reflect high site-specific and regional variability. Explanatory notes provide detail on specific variability issues for ecosystem types.

Ecosystem type	Salinity (µs/cm)	Explanatory notes
Upland & lowland rivers	120-300	Conductivity in upland streams will vary depending on catchment geology. Values at the lower end of the range are typically found in upland rivers, with higher values found in lowland rivers. Lower conductivity values are often observed following seasonal rainfall.
Lakes, reservoirs & wetlands	300-1500	Values at the lower end of the range are observed during seasonal rainfall events. Values even higher than1500 µs/cm are often in saltwater lakes and marshes. Wetlands typically have conductivity values in the range 500-1500 µs/cm over winter. Higher values (>3000 µs/cm) are often measured in wetlands in summer due to evaporative water loss.

Table A2-2. Default DGV for physical and chemical stressors for South West Australia for slightly disturbed ecosystems. Trigger values are used to assess risk of adverse effects due to nutrients, biodegradable organic matter and ph in various ecosystem types. Data derived from trigger values supplied by Western Australia. TP = total phosphorus, FRP = filterable reactive phosphorus, TN = total nitrogen, NOx = oxides of nitrogen, NH_4^+ = ammonium, DO = dissolved oxygen.

	TP ($\mu g\ L^{-1}$)	*FRP* ($\mu g\ L^{-1}$)	*TN* ($\mu g\ L^{-1}$)	*NOx* ($\mu g\ L^{-1}$)	*NH_4^+* ($\mu g\ L^{-1}$)	*DO* % saturation[a]	*pH*
Aquatic Ecosystem							
Lowland River[b]	65	40	1200	150	80	80-120	6.5-8.0
Lakes & Reservoirs	10	5	350	10	10	90-nd	6.5-8.0
Wetlands[c]	60	30	1500	100	40	90-120	7.0-8.5[d]

a = dissolved oxygen values were derived from daytime measurements. Dissolved oxygen concentrations may vary diurnally and with depth. Monitoring programs should assess this potential variability;
b = all values derived during base river flow conditions not storm events;
c = elevated nutrient concentrations in highly coloured wetlands do not appear to stimulate algal growth.
d = in highly coloured wetlands pH typically ranges 4.5-6.5.

Table A2-3. Guideline trigger values for toxicants at alternative levels of protection. Values are in µg L^{-1}.

Compound	Trigger values for freshwater Level of protection (% species) 99%	95%	90%	80%
METALS & METALLOIDS				
Aluminium pH > 6.5	27	55	80	150
Aluminium pH < 6.5	ID	ID	ID	ID
Arsenic (As III)	1	24	94	360
Arsenic (As IV)	0.9	13	42	140
Boron	90	370	680	1300
Cadmium	0.06	0.2	0.4	0.8
Cobalt	ID	ID	ID	ID
Chromium (Cr III)	ID	ID	ID	ID
Chromium (Cr VI)	0.01	1	6	40
Copper	1	1.4	1.8	2.5
Iron	ID	ID	ID	ID
Manganese	1200	1900	2500	3600
Molybdenum	ID	ID	ID	ID
Nickel	8	11	13	17
Lead	1	3.4	5.6	9.4
Selenium (Se total)	5	11	18	34
Selenium (Se IV)	ID	ID	ID	ID
Uranium	ID	ID	ID	ID
Vanadium	ID	ID	ID	ID
Zinc	2.4	8	15	31
NON-METALLIC INORGANICS				
Ammonia	320	900	1430	2300
Chlorine	0.4	3	6	13
Nitrate	17	700	3400	17000

APPENDIX 6. Records of aquatic and semi-aquatic invertebrates at Egerton Spring, Edgecombe Spring, Sue's Spring South, Gaston Road Spring, Barnard Spring in October, 2019, based on current taxonomic resolution. Values are actual counts. Groundwater ecology categories are: surface water-dependent (SW); groundwater-dependent (GD); possible groundwater-dependent (P); and unknown (U).

Kingdom/Phylum/Class/Order	Family	Lowest taxon	Groundwater ecology	Sue's Spring South	Barnard Spring	Edgecombe Spring	Egerton Spring	Gaston Rd
PROTISTA								
AMOEBOZOA								
TUBULINEA								
ARCELLINIDA	**Arcellidae**	*Arcella discoides*	**P**	0	0	0	0	7
ANIMALIA								
CNIDARIA								
Hydrozoa		Hydra sp.	**P**	1	0	0	0	0
NEMATODA		Nematoda spp.	**U**	3	0	0	8	5
MOLLUSCA								
GASTROPODA								
Hygrophila	**Planorbidae**	*Gyraulus* spp.	**U**	1	0	0	1	0
ANNELIDA								
OLIGOCHAETA		Oligochaeta spp. (imm./dam.)	**P**	12	0	0	2	2
Tubificida	**Enchytraeidae**	Enchytraeidae spp.	**P**	0	0	0	0	1
	Naididae	*Nais communis*	**P**	0	0	1	0	0
		Pristina leidyi	**P**	6	0	0	17	2
		Pristina longiseta	**P**	3	0	0	21	0
	Phreodrilidae	Phreodrilidae spp.	**P**	0	0	1	0	0
ARTHROPODA								
CRUSTACEA								
MAXILLOPODA								
Cladocera	**Chydoridae**	*Alona rigidicaudis*	**GD**	0	0	0	0	63

Kingdom/Phylum/Class/Order	Family	Lowest taxon	Groundwater ecology	Sue's Spring South	Barnard Spring	Edgecombe Spring	Egerton Spring	Gaston Rd
	Ilyocryptidae	*Ilyocryptus spinifer*	**GD**	1	0	0	0	0
		Ilyocryptus smirnovi	**GD**	0	0	0	0	1
Copepoda								
Cyclopoida		Cyclopoid copepodites	**GD**	0	1	0	3	0
	Eucyclopinae	*Eucyclops edytae*	**GD**	0	4	0	0	300
		Paracyclops chiltoni	**GD**	206	0	13	4	0
Harpacticoida		*Harpacticoida copepodites*	**GD**	0	0	0	22	0
	Parastenocarididae	*Parastenocaris jane*	**GD**	0	0	0	0	4
	Canthocamptidae	*Attheyella hirsuta*	**GD**	40	0	0	26	0
Ostracoda								
	Darwinulidae	*Vestalenula* cf. *marmonieri*	**GD**	0	1	0	19	0
	Candonidae	*Candonopsis* cf. *tenuis*	**GD**	0	2	12	0	0
	Cypridinae	*Alboa wooroa*	**GD**	0	0	0	2	0
		cf. Cypricercus sp.	**GD**	0	0	0	2	0
MALACOSTRACA								
Amphipoda		Amphipoda spp. (imm./dam.)	**GD**	0	1	0	3	0
	Neoniphargidae	*Wesniphargus* spp.	**GD**	0	0	0	25	0
Decapoda	**Parastacidae**	*Cherax quinquecarinatus*	**GD**	0	1	1	0	1
CHELICERATA								
ARACHNIDA								
Trombidiformes		Acarina spp.	**P**	3	0	4	60	8
Sarcoptiformes		Oribatida spp.	**P**	0	1	0	0	3
HEXAPODA								
ENTOGNATHA								
COLLEMBOLA								
Entomobryomorpha		Entomobryoidea spp.	**GD**	0	0	4	0	1
Poduromorpha		Poduroidea spp.	**GD**	3	0	0	0	0

Kingdom/Phylum/Class/Order	Family	Lowest taxon	Groundwater ecology	Sue's Spring South	Barnard Spring	Edgecombe Spring	Egerton Spring	Gaston Rd
INSECTA								
Coleoptera	**Dytiscidae**	*Limbodessus inornatus*	**SW**	0	2	0	0	0
		Sternopriscus sp.	**SW**	0	0	0	0	1
	Hydrophilidae	*Enochrus* spp. (L)	**SW**	0	0	0	2	0
	Scirtidae	Scirtidae spp. (L)	**P**	3	2	5	16	7
Diptera	**Chironomidae**	Chironomidae spp. (P)	**SW**	1	0	0	1	0
	Aphroteniinae	Aphroteniinae spp.	**SW**	0	0	0	0	2
	Chironominae	Chironominae spp.	**SW**	7	32	3	60	16
	Orthocladinae	Orthocladinae spp.	**SW**	5	8	0	19	51
	Tanypodinae	Tanypodinae spp.	**SW**	5	4	39	37	35
	Ceratopogonidae	Ceratopogonidae sp. (P)	**SW**	0	0	0	6	0
		Ceratopogoninae spp.	**SW**	0	0	17	3	0
		Dasyheleinae sp.	**SW**	0	0	0	1	0
		Forcipomyiinae spp.	**SW**	3	0	0	0	0
	Culicidae	*Aedes* spp.	**SW**	0	11	0	0	0
		Anopheles spp.	**SW**	0	1	0	3	0
		Culex spp.	**SW**	1	7	0	0	26
	Sciaridae	Sciaridae spp.	**SW**	0	0	5	0	0
	Tipulidae	Tipulidae spp.	**SW**	2	0	0	0	0
Thysanoptera		Thysanoptera sp.	**SW**	1	0	0	0	0
Odonata								
Anisoptera								
	Synthemistidae	Synthemistidae spp.	**SW**	0	0	2	10	2
Trichoptera	**Hydroptilidae**	*Oxyethira* sp.	**SW**	0	0	0	1	0

Kingdom/Phylum/Class/Order	Family	Lowest taxon	Groundwater ecology	Sue's Spring South	Barnard Spring	Edgecombe Spring	Egerton Spring	Gaston Rd
Hemiptera	**Veliidae**	Veliidae spp. (imm./dam.)	**SW**	0	13	1	3	1
		Microvelia oceanica	**SW**	0	2	0	0	0
		Taxa richness		**20**	**17**	**14**	**28**	**22**
			GD	**4**	**6**	**4**	**9**	**6**
			P	**5**	**1**	**3**	**4**	**6**
			SW	**9**	**10**	**7**	**13**	**9**
			U	**2**	**0**	**0**	**2**	**1**