THE UNIVERSITY OF WESTERN AUSTRALIA
FACULTY OF
Natural and
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Dear Andrew

I response to your request for comment on the likelihood of having to consider the impact on stygofauna stemming from the ***Beenyup Groundwater Replenishment Trial***, I am pleased to attach my arguments that conclude that no stygofauna will occur in the Leederville aquifer. I will send out in tomorrow's mail a hard copy.

I would be happy to elaborate if required.

Kind regards

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Background

The Water Corporation, in consultation with the Department of Water, the Health Department, the Department of Environment and Conservation and the Environmental Protection Authority, is planning to conduct a trial to inject high quality water produced at the Beenyup Wastewater Treatment Plant into the Leederville aquifer. The high quality water will be produced from advanced treatment technologies involving a combination of microfiltration, reverse osmosis and UV disinfection. To assist in progressing with the project, the Water Corporation has sought advice on the likelihood of the presence of stygofauna in the target aquifer, and if present, the likely impacts upon them.

To the first relevant question "*What is the likelihood of stygofauna being present?*", for reasons discussed below, the answer has to be "*Very highly unlikely*", leaving aside the issue of whether interstitial spaces in the aquifer sediments are sufficiently large to contain minute invertebrates. To the second (" *the likely impacts...*"), therefore, I think it irrelevant to consider the likely impact on a non-existent fauna.

From information in Water Corporation, (2007: Table 1, Hydro stratigraphic summary for BNYP 1/07), the Leederville aquifer underlying the Beenyup site being considered is 106.6 m thick lies within the Wanneroo member between depths 117.3 – 223.9 m below ground level. Above it lies 21.8 m (95.5 – 117.3 m) of the Pinjar member, an aquitard comprising siltstone and sandstone. There are three pertinent sub-questions to consider in elucidating the likelihood of the occurrence of a stygofauna in the Leederville aquifer:

1. What is the likelihood that the Leederville aquifer has been accessible for colonization by a stygofauna?
2. Does the water chemistry of the aquifer preclude habitation by stygofauna?

3. Is sufficient food available?

1. Palaeogeographic history

The Pinjar and Wanneroo Member components of the Leederville Formation date from late Neocomian (Hauterivan) to Aptian ages of the Cretaceous Era (Davidson 1995). Although Davidson (1995: Table 7, p. 28) indicates that the Leederville aquifer occurs between the Kardinya Shale member and the South Perth Shale, i.e. predominantly within the Warnbro Group (as such there is minor variation with information in Water Corporation 2007), and is older than 114 million years, the significant information is that overlying the Leederville aquifer is the sequence (in order of decreasing depth from the ground surface): **a confining bed**, the Mirrabooka aquifer, **a confining bed**, minor aquifers, **a confining bed**, Rockingham and superficial aquifers of the Gnangara Mound, uppermost. The stygofauna from the Perth Basin has been recorded from superficial, unconfined aquifers and, as hypothesized by Jasinska (1997), probably represent a number of origins. The marine forms likely invaded the habitats of the unconfined superficial aquifers directly, and much more recently than did the Gondwanic fresh water relicts which have a history extending from the pre-fragmentation of the super-continent. The Gondwanic aquatic fauna is a surface-based assemblage of forms and, where habitats are suitable, some elements have invaded subterranean aquatic zones that have maintained a connection with surface waters. The Leederville aquifer is separated from surface-based influences by a series of aquitards which, based on anecdotal comments from geologists, maintain total separation between the Leederville aquifer and those both overlying and underlying it. The difference in water salinity between the Leederville aquifer (250 mg L-1) and the overlying Mirrabooka aquifer(<500) (see next section) is strong evidence of a lack of connection between the two aquifers.

Consequently, there are two possible routes into the ground water. There may have been the opportunity for surface forms to colonise and adapt to the sediments of the Wanneroo Member as the formation developed 110+ million years ago, but if there was any colonization, descendents are unlikely to have survived to the present times. The lack of connectivity between the aquifer and surface for considerable time would have precluded the transfer of food on which any stygofauna would have depended. The alternative possibility, of colonization by forms *via* the superficial aquifers of the Gnangara Mound would be made highly unlikely for the very limited connections, if any, around the barriers of the intervening confining beds, and the lack of food supply. Hence, even if a stygofauna had, in the long distant past, ever become established in the early stages of formation of the Leederville aquifer, the chances of it persisting to the present time are vanishingly remote.

2. Water chemistry

The water chemistry data presented in Water Corporation 2007 (Table 2: p. 7) presumably refers to water at WT45 from the top of the Leederville aquifer: a chloride concentration of 120 mg L^{-1} is consistent with the salinity of 250 mg L^{-1} cited for the top of the Leederville aquifer. Since the salinity of the overlying Mirrabooka aquifer is "fresh and less than 500 mg L^{-1} ", it is reasonable to interpret the salinity of the Mirrabooka aquifer as being higher than at the top of the Leederville aquifer. Hence, the aquitard is providing an effective barrier to exchange of water between the two aquifers – and hence also exchange of stygofauna and food.

The water temperature and water chemistry data of ground waters in caves at Yanchep, and from Egerton Spring discharging into Ellenbrook, summarized in Table 1, provide a physico-chemical context of conditions inhabitable by the local stygofauna. The temperature of the WT 45 sample (25 °C) generally is about 6 °C higher than the temperature of the superficial aquifers of the Gnangara Mound, and this is not likely to exceed critical thresholds for survival. (The low temperatures, for example from Boomerang and Cabaret caves, likely reflect the effect of cold air temperatures on low volumes of ground water.)

Despite major declines in water levels in caves at Yanchep, a fauna of markedly reduced diversity has been recorded from all caves through the period of monitoring. (The decline in abundance and diversity is due to the diminishing availability of water, not to changes in water quality (Knott *et al.* 2006.) The water chemistry data from WT 45 for nitrogen, phosphorus and sulphur fall within the ranges recorded from the Yanchep and Egerton Spring sites.

The fresh/salt water boundary traditionally is considered to be the detectable limit by humans to taste salt, namely 3 g L^{-1}, and the osmotic concentration is 3 mOsm kg^{-1} (Bayly and Williams 1974). The water from WT 45 is <1 g L^{-1} so any resident fauna must function as a fresh rather than marine form. The osmotic concentration of body fluids of freshwater invertebrates ranges from 50-350 mOsm kg^{-1} (Bayly and Williams 1974). Hence, freshwater invertebrates need to expend substantial energy to osmoregulate; the body will require the uptake of ions by active, energy-requiring processes to offset ions lost by diffusion.

The WT 45 salinity (Cl^{-1} = 120 mg L^{-1}) is higher than for the other sites listed in Table 1 with the exception of the Na^{-1} concentration of 323 mg L^{-1} recorded from YN555 in November 2005. At that time, 9 taxa were recorded from the cave compared with 8 in the three previous sampling occasions, 3 of forms with adults capable of aerial dispersal, and 6 obligatorily aquatic. Fresh water invertebrates typically tolerate a limited range of salinities, but the salinity at the top of the Leederville aquifer probably is not high enough to exclude such invertebrates, given that any inhabitants had access to a sufficient and reliable food supply. Crustaceans typically concentrate trace metals, including heavy metals, from their environments (White and Rainbow 1987). In an isopod studied by Migliore and de Nicola Giudici (1990) and a crustacean likely to be a reliable analogue of stygofauna of the Gnangara Mound, the tolerance to Fe, measured in terms of ST50, the time of survival from the beginning of a test to the death of 50% of the test specimens, was lower than to Hg, Cd, Cr, Cu, with juveniles more sensitive than adults (<20 days at 0.5 mg L^{-1}), 15 days at the Fe concentration in WT 45. This would preclude development of specimens to adult status, and therefore preclude reproduction.

Table 1: Water quality: Comparison between data from bore WT 45 and summary of data from cave waters and springs on the Gnangara Mound sampled as part of the monitoring programme for DEC, 1998-2005 (Knott *et al.* 2006)

	WT 45	Boomerang 00-05	Carpark 00-05	Water 00-05	Twilight 00-05	Cabaret 98-05	YN61 02-05	Orpheus 02-05	YN555 02-05	Egerton 99-05
Na^+ mg L^{-1}	120*	61.1-79	51-109	39.3-56	67-94	44.6-55	48.2-54.3	61.7-79	98-323	46-93*
Fe_total mg L^{-1}	5.42									0.18-0.97
P_SR mg L^{-1}	0.16**	0.01-0.08	<0.01-0.01	0.01-0.01	<0.01-0.01	0.01-0.01	<0.05-0.05	<0.01-0.01	<0.01-0.1	<0.01-0.03
N_NO_3 mg L^{-1}	<0.002	0.01-0.56	0.04-0.12	0.04-0.11	0.75-4.2	<0.01-0.19	0.01-0.08	0.03-0.09	0.88-1.6	0.05-3.3
SO_4_S mg L^{-1}	7.9	9-11.7	8-18.3	6-11.1	25-33	8-15.8	11.6-19.8	17-23.2	21-99.3	5.5-18
DO mg L^{-1}	0.71	3.2-12.6	2.8-9.1	2.8-6.2	2.7-7.6	3.7-8.9	2-11.1	2.7-4.9	1.5-7.9	3.9-9.6
DO % saturation	0.43	32-100	29.7-91	30.2-66.7	27.2-75.6	36.6-90.7	22.1-100	28.5-67.4	15-77	38.3-94
EC @ 25 °C µS cm^{-1}	60	507-769	451-1125	413-576	755-936	397-512	598-769	734-846	875-2582	192-662
Temp	25.4	12.3-23.3	15.9-19.3	18.5-21.6	14.9-16	13.4-17.9	17.6-18.8	17.7-19.0	13.5-16.6	14.9-20.8
pH	6.59	7.09-9.43	6.66-9.24	7.26-9.42	7.51-9.49	7.11-9.49	7.14-7.96	7.54-8.26	6.65-7.86	4.76-6.11

- chloride in WT 45 and Egerton Spring; **, total phosphorus (mg L)

Another factor likely to preclude the maintenance of populations of stygofauna in the Leederville aquifer relate to the very low oxygen presence (0.71 mg L^{-1}; 0.43% saturation) in WT45 compared with values ranging from 1.5-9.6 mg L^{-1}; saturation 15-100%) at all other sites listed in Table 1. Stygofauna can tolerate water with low oxygen concentration present, but whether there would be sufficient to drive the base physiological requirements let alone an increased demand for osmoregulation is unlikely. A diverse fauna comprising crustaceans and a fish, the blind gudgeon *Milyeringa veritas* Whitely occurs at depths below 16 m, i.e. below the second sulphide layer in Bundera sinkhole, an anchialine system on the Cape Range peninsula in north-western Australia, in water of about sea water salinity (Humphreys 1999). One element of the Bundera sinkhole stygofauna is the remipede *Lasionectes exleyi* Yager and Humphreys; remipede crustaceans have always been collected from water with a low oxygen concentration of 0.1-0.22 mg L^{-1} (Yager 1994; Yager *et al.* 1994). This is not a useful comparison when predicting the likelihood of the existence of a stygofauna in the Leederville aquifer: the Bundera stygofauna is of marine derivation inhabiting water of sea water salinity and with a reliable food supply accessible.

3. Food supply

It is widely acknowledged that a major constraint on the evolution and persistence through time of a stygofauna is the dependence on surface-based food supplies: there is no subterranean photosynthetic-based productivity (Barr 1967; Culver 1982). The remarkable diversity and abundance of stygofauna in cave stream at Yanchep (until the rapid lowering of the watertable at the beginning of this century (Knott *et al.*, 2006)) resulted from the reliable supply of nutrients delivered *via* the tuart (*Eucalyptus gomphocephala*)tree root mats lining the small streams(Jasinska *et al.* 1996; Jasinska and Knott 2000). The caves at the junction between the Tamala limestone and the Bassendean sands are shallow, 8 m below ground level in the best studied system in Cabaret cave, for example. The maximum recorded depth of tree roots is 68 m (i.e. substantially less than the 117 m depth to the top of the Leederville aquifer (pers. com from Prof H Lambers, 08 December 2007, who cited from a textbook that currently he