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REPORT

Review and Considerations - Aspects of Potential Groundwater Contamination and Related Matters Concerning Flooding

Proposed Development of a General Cemetery (Wallacia Memorial Park), Wallacia, NSW

Engagement and Purpose

Following a recent public hearing by the Independent Planning Commission, the Catholic Metropolitan Cemeteries Trust (the Client) engaged Dr Boyd Dent trading as Red Earth Geosciences (REG) to examine aspects of the hydrogeological setting and geoscientific aspects of the operation of the proposed cemetery on land currently functioning as the Wallacia Golf Course. Dr Dent has particular expertise in these matters which has been recognised Worldwide (Appendix 1).

It is anticipated that the advice herein will provide learned information and opinion to the Commission and community on several of the matters raised in the public forum and elsewhere, and specifically address notable concerns regarding groundwater and flooding.

Present Investigation

The Client provided a number of documents for review (listed in Appendix 2); these have been considered together with some other related materials. An inspection of the site and surrounds was made on 1 April 2019 in the accompaniment of representatives of the Client and Mr Stephen Gray of GRC Hydro Pty Ltd, Hydrologist/Water Engineer consultant for the Client.

Review of Documentation and Other Matters

A study of the documentation considered with related experience, has allowed a detailed understanding of the site. This understanding relates to the subsurface features, drainage aspects and general context, and likely operations to be developed.

The proposed site currently functions as a golf course with associated club house and maintenance facilities thereon. There is nothing remarkable about the current development and it reflects the small modifications to the landscape – e.g. flattening, banking and pitting, associated with making access tracks, tees, greens and bunkers, and sheds as seen on most golf courses. The course hosts several small artificial pond structures on pre-existing drainage lines. There has been some small modification of the drainage pathways, if compared to the 1947 aerial photography (see Douglas Partners, 2017, "Contamination and Hazardous Materials Assessment", Drawing 5), but these appear to have been to enhance course function, or accommodate boundary roadways, than for other purposes.

The primary physiographical features of note are Jerrys Creek, a small tributary to the Nepean River, and other surrounding and hosted streams. Jerrys Creek bisects the site in its western third, and is marked by a sinuous course (currently partially restrained by stream control works) and a small, flattish floodplain area in a noticeable small valley structure. In addition, other lower order streams either arise on the site, or generally traverse the majority of the northern boundary. The site lies within two catchment areas (see Travers, 2017, "Watercourse Assessment", Figure 3) the boundary of which roughly traverses the NW-E length of the site via a small ridge-like structure in the southern third.

Jerrys Creek, the Nepean River, and some nearby streams flood in certain major rainfall events. The likely impact of storm flooding on the site has been reported by GRC Hydro, 2017 ("Wallacia Golf Course Redevelopment – Flood Assessment"). The modelling presented, and subsequent discussions, indicate that parts of the site will be affected. The local Jerrys Creek flood event is regarded as critical owing to its relatively high scour potential. The flood study work also shows that parts of the site are specifically affected in a 1%AEP event including a very small part adjacent to the south-eastern road boundary which is affected by impeded flow. The site can also be affected by backwater flooding via a major event in the Nepean River rising from the confluence with Jerrys Creek to the north west of the site.

It is understood that the Client has focussed their proposed cemetery design to be above a flood exclusion zone developed in recognition of working limits developed from modelling of the local flood event. The zone developed (Grave Exclusion Zone - GEZ) incorporates an allowance for the likely maximum invert (base) levels of graves. The design has also allowed other buffer zones adjacent to this level as appropriate. The matters of riparian corridor development are well covered in the Travers report and elsewhere.

As a direct consequence, there is a low potential that any of the proposed burial areas will be covered by flood waters during a 1%AEP event. Many of the adjacent areas are likely to experience heightened, overland flow and puddling during such events. It was also noted that landforms along several drainage lines, especially in boundary areas, are often quite steep and this aspect is likely to exacerbate storm flow concentration and speed, with potential for scouring to proceed backward from the headward reaches.

The site subsurface aspects have been documented by Martens, 2017 ("Preliminary Geotechnical, Groundwater and Salinity Assessment: Proposed Wallacia Cemetery, Wallacia, NSW") and further groundwater information made available in an interim report of groundwater monitoring (Martens, 14 January 2019). In addition, REG has extensive related experience in the engineering and hydrogeological aspects of the same geological formation (the Bringelly Shale) as comprises the site.

<u>General Aspects – Groundwater and Decomposition Products</u>

Two groups of primary concerns have been expressed by the community:

> (1) generally, does the groundwater of cemeteries pollute in so far as decomposition products can contaminate waterways?
>
> (2) when flooded, do graves contribute decomposition products to floodwaters which subsequently recede with these?

There is, in addition, a concomitant idea to (2), namely: do flood waters infiltrate the burial spaces at flood level, thus contributing to groundwater such that decomposition products are mobilised and continue within the groundwater system?

These primary concerns are commonly raised in discussions of cemetery development and are valid for most sites. They are especially true in scenarios where major drainage lines are associated with the development, there are nearby groundwater wells or works, water supply systems occur nearby, and generally in temperate or potentially wetter climate areas.

Several studies in various geological/physiographic/climate settings throughout the World have shown that cemeteries produce 4 main types of decomposition products which can sometimes be measurable in associated groundwater. These comprise: microbiological components e.g. bacteria and viruses; nutrients e.g. nitrogen as ammonium and its associated compounds; organic acids and complex saturated and unsaturated chain molecules; inorganic salts and metals. These chemicals derive from (a) the decomposing remains due to decomposition and decay reactions; or from (b) the funereal aspects themselves, comprising – clothing, coffin, buried artefacts, the grave; or from (c) concentrations of cremated remains (ashes); or from disturbance of the ground during burial e.g. the oxidation of arsenic- or sulfur- containing minerals. There are other minor potential sources – which have not been widely reported, but include radiological chemicals and pharmaceuticals.

All of these chemical and biological components are normal in cemetery operations as they derive from the deceased human body or the burial processes. The act of burial, at say 1.4 – 2.3 m depth in a coffin is a means of dealing with the public health aspects of decomposing remains. Additional matters are introduced by common funeral practices and include the use of wooden or metal coffins and their hardware; plastic coffin liners and bodybags; fabric used in burial clothing and coffin linings; and small amounts by the immediate past history of the deceased e.g. due to medical treatments, and including embalming. Embalming is not widely practised in Australia, but introduces organic compounds to the deceased and then to the environment.

<u>Decomposition Products in Groundwater</u>

The general case of burial in a coffin creates a micro environment of decomposition. When buried and available oxygen (in coffin, soils and grave fill) has been consumed, the decomposition proceeds anaerobically. This overall process takes a long time. The time varies very much depending on the nature of the cadaver, the environment of burial, the nature and composition of soils in particular, but also the other aspects of the funeral, the burial, the physiography and the climate.

Ultimately, body fluids and decomposition products will move from the coffin into the surrounding soil, or be highly associated with the grave infill soil at the grave invert level. In these locations further degradation of the various organic compounds continues by soil microflora and chemical reactivity. Some chemicals e.g. metals and inert salts, deposit directly in the soils, and some are permanently incorporated (mineralised).

If groundwater seepage through the grave infill occurs and/or these decomposition products are in contact with the groundwater system, perhaps by means of a fluctuating watertable, then they may be mobilised from the immediate grave area.

To guard against the outcomes of this mobilisation, cemeteries are properly developed so that groundwater pathways are sufficiently long to enable decomposition product degradation (including diffusion) with time and soil processes. In addition, burial occurs well above any fluctuating watertable level. General guidelines, developed and supported internationally, are used to assist in this design process but are largely not prescriptive.

<u>Site Conditions and Groundwater</u>

The site conditions at Wallacia are extremely favourable for restricting the flow of groundwater. The cemetery will be developed in soil and weathered rock which is mostly argillaceous (clayey) in nature with sandy and silty components, and which is somewhat variable. The soil matrix is best described as of low permeability.

The soil conditions do not easily permit connected flows of groundwater. Thus, at shallow depths, groundwater is unevenly dispersed, very small sub-surface flows occur and are diffuse; most flows are perched (i.e. restricted to small disconnected bands/layers/lenses); and ephemeral (not permanent).

There is no watertable at the site; the soil conditions are too clayey to facilitate the development of this feature. Consequently, any groundwater flows are limited spatially and temporally. It can generally be said that groundwater flow velocities through the soil are likely to be of the order of a few cm/annum*. Infiltration and percolation rates (vertical and horizontal) will vary considerably over the site and will likely increase in the short term after disturbance in burial areas. Even if sub-surface discontinuities favourable to groundwater movement are present in the weathered rock, or at the soil/rock interface, groundwater flows will be slow, mostly non-uniform and short lived: the nature of the subsurface is such that these flow paths are quickly ended, blocked by essentially impermeable clay deposits.

Consequently, with long travel times, groundwater is acted on continuously by soil and microbial processes, that taken together, effectively ‘clean it’ and change its chemical and biological constitution. Except for the most resistant inorganic salts, nutrients and some metals, the filtration process generally produces an acceptable groundwater chemistry within a few metres of travel for sites like the present one. This would apply only if groundwater is mobilised away from the graves. Boundary buffer zones, of the order of 5 m in clayey soils, and wider, specified riparian zones will have the general impact of improving groundwater quality.

The effects in changed hydrogeochemistry are not necessarily uniform in time or space. This attribute is also influenced by the design of the cemetery and *where and when* burials take place in relation to groundwater flow paths. Cemetery development is typically dynamic; it varies substantially in spatial and temporal aspects, including depth, construction and occupancy of graves, and consequently sub-surface outcomes.

> * groundwater flow velocities in the unsaturated zone are rarely measured in general practice for standard development activities: the process to do so is very difficult and the results need to reflect a high number of parameters. Even in highly saturated conditions (e.g. after flooding), the determination is difficult and is still affected by temperature, type of soil and soil minerals, soil pore sizes and connectivity, height of the saturated soil column, continuing rainfall, entrapment of gases and other factors.

<u>Groundwater and Flooding</u>

A consideration of flow dynamics is needed to answer the issues noted above.

If graves are inundated by floodwater, which for the worst case scenario is assumed to dissipate slowly, then it can be expected that excess infiltration will occur into some graves. Those graves most recently established and where the grave in-fill soils have not had time to compact, may be especially impacted. Current understandings of this phenomenon in similar soils in Sydney cemeteries, suggest that a few 'normal' years of weather and cemetery operations will be sufficient to restore much of the lower grave space to have highly impermeable attributes. The grave space then progressively begins to function much like the surrounding soil.

The normal soil function is as described previously. In the flooded case, the potentially extra, wetted-up, in-grave soils will dissipate their water content non-uniformly and slowly at the level below which evaporative conditions apply. The additional flood-derived groundwater then behaves like any other groundwater already present. A small variation can occur with a potential increase in the height of the saturated soil-water column: if many of the relevant parameters are ignored, it might be possible for flow paths to commence at a higher level (i.e. not as deep in the soil profile) than usual, with some shorter flow paths emerging at the surface. These flow paths, however, are unlikely to have engaged with decomposing remains so that in the majority of cases, they are unlikely to be hazardous or otherwise reflect the usual groundwater.

The matter of whether the actual flood waters, while elevated in the landscape, can readily add to the groundwater flow systems also needs to be considered. For this to occur, the floodwater would need to seep laterally into an already fully saturated soil. Usually this can't occur unless there is a pressure head on the floodwater lake, e.g. a further raising of flood lake height. Consequently, if the floodwaters' highest point is taken for reference, then groundwater systems above this should behave as outlined previously. The matter is in most respects inconsequential provided that the cemetery design and operations have taken this potential risk into account. The proposed design incorporates the GEZ developed from flood reference levels and takes into account grave invert levels. No graves will be established in this zone. Further, the permanent inundation of graves will not occur.

While floodwater persists to any extent in the landscape, the groundwater flow paths are also disrupted. Functionally, this is similar to a lake or pond being present. However, in this scenario, groundwater flow may be further retarded as the groundwaters' hydraulic parameters need to rapidly adjust to a sudden new exit regime (the lake/flood waters, as well as likely reduced evapotranspiration) and, a reduced driving potential from above. If the surrounding soils still have some holding capacity, i.e. they are not totally saturated, then further diffusion of the groundwater can occur, probably with favourable implications for improved water quality. If the converse applies - fully saturated soils everywhere, then new, ephemeral, seepage points might emerge higher in the landscape.

In the less likely event that the flooding occurs without total soil saturation being present, there is a very low potential for a limited (short distance), lateral migration of some stilled floodwater into the soil profile. But this occurrence would be subject to all the soil attributes outlined previously, and is likely to occur below the invert of affected graves thus not directly engaging decomposition products.

A final consequence of flooding, and significant storm events is the potential for increased surface scour in small parts of some burial areas. In the headward ends of steeper streamlines especially, soils are typically thinner and potentially less cohesive if the uppermost slope is also steep. Potential scour, which might in the ultimate event engage graves or cause soil instability, can be reduced by design and/or engineering works to slow or disrupt flows generally and retard them without permanent ponding.

Groundwater Control and Management

The groundwater-related issues are managed by a number of processes.

Firstly, the selection of a site that is essentially suitable from a geoscientific perspective: the present site complies.

Secondly, the provision of suitable buffer zones to prevent any burials or ashes emplacement or ashes scattering lying close to the cemetery boundaries. The specified buffer width will vary depending on the hydrogeological setting. 5 m is a minimum width for sites like Wallacia Golf Course, but this should be increased where other factors are evident.

Thirdly, the judicious use of deep rooting, locally adapted, native vegetation plantings in buffer zones will assist in entrapping and consuming groundwater. The same phytoremediation ideas can be used adjacent to stream lines.

Fourthly, the provision of buffer zones along natural drainage lines. In this regard, the requirements of the Water Management Act 2000 (see Travers report) are adequate.

Fifthly, suitable cemetery design to take account of imposed risks like flooding: the proposed site design does this.

Conclusions

On the basis of the considerations outlined above, it is concluded that:

1. the site is suitable for the proposed cemetery development;

2. the proposed design incorporating the concept of a GEZ to exclude certain areas from burial, together with suitable other riparian buffering, will not introduce an additional groundwater quality risk, beyond that of any typical cemetery;

3. there is a low risk of grave sites being inundated by flood waters. If this were to occur it will not significantly increase the risk of derived decomposition products leaving the cemetery boundaries; except if inappropriate scour was to occur.

Recommendations

1. In order to reduce the risk of surface scour from flooding or major storm events, it is suggested that some further attention be paid to providing soil bunding in steeper parts of the site connected to drainage lines, at locations topographically below the designated burial zones. Further, on the longer, steeper slopes, that disruptor structures or design components be introduced.

2. Design components or structures or surface grading should be used to prevent permanent ponding from storm events.

3. Consideration should be given to additional dense planting of deep-rooting, locally adapted, native vegetation in connection with the under-road drain line on the south-east boundary; as well as generally on the steeper section of the eastern half of the north boundary adjacent to streams.

Appendix1 – Expertise

Dr Boyd B. Dent

Boyd Dent completed a B.Sc. degree in Applied Geology in 1973 and commenced his professional career as an engineering geologist initially working in the Quality Control Laboratory of Pioneer Concrete (NSW) where he was responsible for special aggregate investigations and statistical control of concrete components and mixes. Following that, for the then NSW Main Roads Department in charge of major fill investigations for extensions of the freeway system Sydney-Newcastle and investigated other road deviations in coastal and highland swamps.

This was followed by employment as a consultant engineering geologist by a small Sydney-based company with principal work focussed on foundation investigations for buildings and hillside domestic dwellings, land drainage, landslip studies and sympathetic development. Boyd joined the NSW Public Works Department where he was responsible for grout curtain and finalisation reports on the Mangrove Creek Dam project. He also investigated a number of water supply augmentation schemes including Bermagui, Coonabarabran, Parkes, Maclean Reservoir, and strengthening or raising of dams in country NSW. Other projects: rock slope stability for Woy Woy Sewage Works, land stabilisation for Wyong TAFE and definition of breakwater armour stone quarries at Ballina.

In 1994 Boyd completed an M.Sc. degree in Hydrogeology and Groundwater Management at the University of Technology, Sydney, with a thesis component related to groundwater supply for Eastern Suburbs Memorial Park. In February 1995 was appointed as Lecturer in the UTS Department of Applied Geology (later Environmental Sciences) and commenced PhD studies. Responsible for coordination and teaching of first year Earth Science and other core undergraduate subjects, studies in environmental and groundwater geology and supervision of senior project (thesis) undergraduates, and postgraduates. Boyd developed research interests in environmental geological areas including the emerging field of medical geology; documented former municipal landfill sites (in Greater Sydney), the rehabilitation of abandoned mines (particularly oil shale), and groundwater protection.

In 2002 he completed a seminal research project (for PhD degree) on the hydrogeochemistry and microbiological attributes of cemetery groundwaters by virtue of an Australia-wide study funded by industry and government research grants (the National Study of Cemetery Groundwaters). In this Study he developed proposals for the proper siting, management and function of cemeteries from a geoscientific perspective. Boyd has been recognised by the World Health Organisation and practitioners in the USA, UK, Germany, Netherlands, Brazil and Jamaica, as a specialist in cemetery processes and geological factors. The data and evidence-based conclusions have been widely presented at conferences and seminars; invited lectures given to the industry in Australia and the UK, and in the UK at University of East Anglia, Sheffield University, and in Brazil at University of

São Paulo, and in the USA at Yale University. He has contributed to forensic science studies and cases in Australia and the USA.

At various times since 2007 Boyd has undertaken a wide range of consulting projects trading under the entity name *Red Earth Geosciences*. Projects have included review of proposals for the development of an abandoned quarry as a landfill (western Sydney); relocation of graves from a valley cemetery to be inundated by a new dam and development of a new cemetery (Munni Munni); a flood-affected new cemetery – Centenary Memorial Park at Sumner, Qld; a study of rainfall infiltration affecting a residential development (Nelson Bay); background contributions to numerical groundwater modelling for a black coal mine; review of a coal mine development on behalf of community objectors at Scone; review of the NSW State Groundwater bore records; project management for the development of updating tools for the NSW State's groundwater models; and geoscientific assessment of a number of public and private cemetery proposals.

In August 2010 Boyd accepted the position of Senior Research Fellow in the Geotechnical and Hydrogeological Engineering Research Group at Monash University (Gippsland) with a special focus on brown coal mining. He returned to Sydney and in 2015 was engaged by the NSW Department of Primary Industries (initially Office of Water) to assess major infrastructure projects and aquifer interference developments.

Boyd was approached by Rookwood Cemetery to devise and conduct a major research project targeting an understanding of decomposition and management of cemetery soils; this 6 year program commenced in February 2017.

Boyd's advice is sought on a Worldwide basis in respect of the location and development of cemeteries and their planning and operational issues regarding groundwater. Some examples of field-based studies in this respect have been conducted in Victoria (Anderson's Creek Cemetery Trust); Sydney (Eastern Suburbs Memorial Park); Jamaica – at Burnt Ground; South Australia – natural burial ground at Hahndorf. His opinions are accepted by State and Local Government agencies in respect of cemetery development and groundwater management. In 2006 he was part of an international team that has developed the revised Manual for Management of Dead Bodies After Disasters, an initiative of PAHO, WHO and others. He advised the NSW Solicitor General regarding past land practices for a municipal cemetery and adjacent lands. In 2018 he provided advice to the NSW Parliamentary Enquiry for the State's new interment system.

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Appendix 2 – Documents and Sources

Australian Government, Bureau of Meteorology

* Data sources were accessed for official weather stations – 067027, 067029, 067108 via http://www.bom.gov.au/climate/data-services/

Douglas Partners Pty Ltd

* Report on Preliminary Site Investigation - Contamination, Proposed Cemetery Wallacia Golf Course, Wallacia, NSW, Project 76652.02, June 2017

Geological Survey of NSW, Department of Minerals and Energy

*Penrith, Geological Series Sheet 9030 at 1:100,000 (Ed1), 1991

GRC Hydro Pty Ltd

* Wallacia Golf Course Redevelopment – Flood Assessment, Final Report, Project 170038, October 2017

Martens & Associates Pty Ltd

* Preliminary Geotechnical, Groundwater and Salinity Assessment: Proposed Wallacia Cemetery, Wallacia, NSW, October, 2017

* Letter report: Proposed Cemetery – Wallacia Memorial Park at Wallacia Golf Course, 13-15 Park Road, Wallacia, NSW, dated 14 January 2019

NSW Government, Environment, Climate Change & Water

* Penrith, Soil Landscape Series – Sheet 9030 at 1:100,000 (Ed 1, reprint), 2010

NSW Government, Spatial Services

* cadastral, lot, DP and base topographic data accessed at: https://six.nsw.gov.au/v

NSW Government, Water NSW

* All Groundwater Data – datasets accessed at: https://realtimedata.waternsw.com.au/water.stm

Travers bushfire & ecology

* Watercourse Assessment, Proposed Cemetery Lot 2 DP 1108408, 13 Park Road, Wallacia, File A17162W, October 2017