SUSTAINABLE CHOICES IN GEOTECHNICS: A CASE STUDY OF QUARRY TO PARKLAND CONVERSION

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ABSTRACT

Sustainability and sustainable development are broad concepts, and there is a growing imperative to both define sustainability, as per the 17 goals of the United Nations Division of Sustainable Development Goals (DSDG), and to regulate compliance with sustainable practice, such as the European Union's Corporate Sustainability Reporting Directive. The geotechnics practice, which is literally at the ground level of design and construction, has many opportunities to consider, develop and drive sustainability within our industry. This paper presents a case study of a quarry to parkland conversion project in suburban Sydney where sustainable practice was considered at every stage, from material reuse of existing fill to alternative means to reducing rock fall risk without installing support structures. The case study demonstrates how elements of sustainable practice in geotechnical engineering and engineering geology were achieved through comparison with select goals as published by the DSDG. Comparisons and contrasts are also made with other projects where perhaps a sustainable outcome could not be achieved due to factors such as existing Standards or time constraints. The paper summarises some of the difficulty of taking sustainable theory into practice and highlights how sustainable construction is often linked to the most economically viable design and maintenance solution. It is hoped that this paper will add to the growing industry knowledge of sustainable geotechnics in practice and provoke discussion of how to incorporate sustainability within the context of our current framework of Standards and standard industry good practice for design.

1 INTRODUCTION

Sustainability and sustainable development are broad concepts – sustainability itself represents the ability of a system to continue to function over time without loss of effectiveness; where supply meets or exceeds demand over a given timeframe (Basu, et al., 2015). Sustainable development is considered to have been best defined by the Brundtland report produced in 1987, which noted that sustainable development was "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Basu, et al., 2015; Lagesse, et al., 2022). This lead to the formation of a United Nations programme for sustainable development, now represented by the Division for Sustainable Development Goals (DSDG) (Lagesse, et al., 2022; United Nations, 2023). In 2015, the DSDG formulated the 2030 Agenda for Sustainable Development, with 17 Sustainable Development Goals that attempt to address the core ideals behind sustainable development – i.e., allowing for development that does not compromise future generations (United Nations, 2023).

All member nations of the UN have signed up to these 17 goals (and their 169 targets split across the goals) (United Nations, 2023), and thus many government authorities have introduced or developed regulations to measure compliance with sustainability targets. An example of this is the European Union's Corporate Sustainability Reporting Directive which requires companies of a certain size to disclose information on risks and opportunities related to social and environmental issues within their areas of working (European Comission, 2023). Another example is the increasingly common field of Environmental, Social and Governance (ESG) consulting, as corporations and regulators look to improve their internal and external alignment with sustainable activities (UN Environment Programme - Finance Initiative, 2004).

The geotechnics practice is literally and figuratively at the ground level of design and construction and is often most heavily involved at the early stages of a project. This position gives geotechnics a high level of impact on the overall sustainability of a project (Basu, et al., 2015; Clayton & Smith, 2015; Gill, 2017; Lagesse, et al., 2022; Pantelidou, et al., 2012; Purdy, et al., 2022). Prior to the release of the 17 SDGs in 2015, multiple studies were undertaken to identify how sustainable development could be embedded in civil engineering, both in construction and consultancy, some with a focus on environmental sustainability and the reduction of greenhouse gas emissions (Pantelidou, et al., 2012; Costigane & Guthrie, 2013; MacAskill & Guthrie, 2013). Other publications looked at the role of geotechnical engineering within the context of sustainable development (with social and economic sustainability also forming part of the discussion) (Basu, et al., 2015) including site investigation impacts (Clayton & Smith, 2015).

In 2017, the role of geology in achieving the 17 SDGs was explored, presented as a matrix to identify the broad contributions to each individual goal by relevant disciplines including hydrogeology and engineering geology (Gill, 2017). This was later refined specifically for engineering geology in a detailed mapping exercise by Lagesse, et al. (2022) to demonstrate how engineering geologists could support all 17 SDGs, and the majority of the individual targets within those goals, though some were indirect contributions. The role of engineering geological practice in achieving goals such as SDG 1 No Poverty and SDG 2 Zero Hunger (as examples) was demonstrable, but indirect. By comparison, arguably the strongest contributions of engineering geological practice were to SDG 7 Affordable and Clean Energy, SDG 9 Industry, Innovation and Infrastructure, and SDG 11 Sustainable Cities and Communities (Lagesse, et al., 2022).

Based on the above, one of the largest impacts that geotechnics has on sustainable development is through construction, from project inception to design to construction to operations. Sustainability is often driven by geotechnics through effective site investigations which provide ground information to de-risk design and construction (Clayton & Smith, 2015) and by considered design that reduces movement of material, makes use of existing ground conditions (Chen & McIlquham, 2023), and minimises built infrastructure and construction impact on communities (Basu, et al., 2015). These activities also contribute to improving the resilience of a project, which represents the ability of the system to withstand or adapt to outside stresses or environmental changes (most often considered for climate change). Therefore, it can be seen that many opportunities existing within the geotechnics profession to drive sustainability within many industries. However, there are many challenges which must be considered and overcome to balance reliable and robust designs that meet risk mitigation requirements with sustainable practices.

2 THE QUARRY

The site is a former road-base aggregate quarry situated within a volcanic breccia/basalt intrusion, hosted within sandstone. The quarry was operated intermittently for several decades, and developed such that the base was over 120 metres below the original surface. After quarrying ceased, the site was acquired by the local government, which then allowed it to be used as a storage for spoil from a nearby, significant tunnelling project. This filled the void up with nearly 55 vertical metres of crushed sandstone and shale, which was placed via conveyor belt and pushed into place by front end loaders.

In order to make use of the land, the local government council developed a proposal to convert the site into a parkland for the benefit of the local community, to remediate the natural environment, preserve the cultural, geological and industrial heritage of the area, and to create a drawcard for tourism. This parkland conversion presented a challenging geotechnical and engineering geological puzzle; what could be done to treat the rock fall risk associated with the still exposed quarry walls, the long-term settlement of the spoil within the quarry void, and the slope stability of the adjacent waste dumps and infrastructure pads, which had since become heavily vegetated. This case study will focus on the work undertaken for addressing geotechnical risks associated with the highest wall within the quarry, and how the choices aligned with a sustainability perspective, and also presents (at a higher level) those choices made for the deep quarry spoil and the other quarry high walls and surrounding slopes.

The aforementioned highest wall within the quarry is approximately 70 metres high, and is comprised of a relatively fresh, medium to high strength rock for the lower two-thirds, with a highly weathered, near soil-strength weathered rock within the upper third. The lower, fresh rock zone is comprised of three faces (with two benches in between) with a face angle of approximately 80° from horizontal. The upper face has no benches, and has either been laid back to approximately 50° or has "fretted" back to this profile over time. The high wall appears to have weathered noticeably and been subject to slopewash since exposure, as inferred from built up colluvium on the lower benches, and small rocks at the toe that are surmised to have fallen from above.

3 GEOTECHNICS DESIGN CHOICES

A key component of the parkland conversion was to allow public access to the quarry void, and thus the presence of the public at the toe of each high wall and slope had to be considered. A typical methodology for treating geotechnical risk of this kind would be to cut back the upper, weathered material to a shallower profile, and potentially consider a shotcrete facing and/or soil nails. For the lower, fresher rock mass, the methodology might be to introduce draped or anchored mesh, secured with rock bolts in a systematic pattern, and individual blocks further secured with additional rock bolts. Such works would entail a significant financial cost, but also require consumption of manufactured materials like cement and steel. These two elements alone carry a large environmental burden; a tonne of steel produces 1.83 tonnes of CO_2 emissions (Pandit, et al., 2020), while a tonne of cement produces at least a tonne of CO_2 (United Nations Environment Programme, 2010). Such systems introduce a potentially onerous maintenance regime, depending on constructability, access and scale, and there is often minimal resilience in these systems.

For the highest wall in the quarry, it was not considered economically viable nor aesthetically pleasing to install slope stabilisation treatment. However, the risk to the public had to be considered. Therefore, rock fall trials were conducted, whereby "adverse case" boulders were dropped from the crest of the high wall (via excavator) and the distance to which the boulders rolled from the toe recorded. The findings of these trials supported the concept of an exclusion zone at the toe of the wall, that would negate the requirement for built infrastructure. Council had planned a wetland area within the parkland to serve as a natural water filtration system for the man-made lake planned in the quarry. The opportunity to combine the exclusion zone with the wetland system was thereby proposed, as the wetland would be excluded to public access while also serving to capture incidental rock fall.

Some of the benefits of using a wetland as an exclusion zone are:

- The ground is muddy, thickly vegetated and has numerous small waterbodies, which make traversing it less appealing to the general public.
- Maintenance of such a feature is much lower than many other types of exclusion zone (for example, any incidental rock fall does not need to be cleared as frequently).
- The coefficient of restitution is lower in such an environment than for cleared ground, talus or gravel (Hoek, 2023). This significantly reduces runout distance (and bounce height) of falling material, which can lead to a thinner exclusion zone, if needed.

The stability of the upper, weathered portion of the high wall was improved through diverting surface water run-off and retaining the vegetation at the crest (largely comprised of well-established, endemic native plants), with a view to increase the amount of native ground cover established on the face, as well. This had a positive environmental impact as well as improving the resilience of the design (i.e., a design solution that is more tolerant of climate change and that does not introduce built infrastructure with a fixed design life). It is important to note that limited devegetation was undertaken on the lower, fresh rock zone so as to reduce the risk of root jacking (i.e., the vegetation was not considered to be stabilising the face).

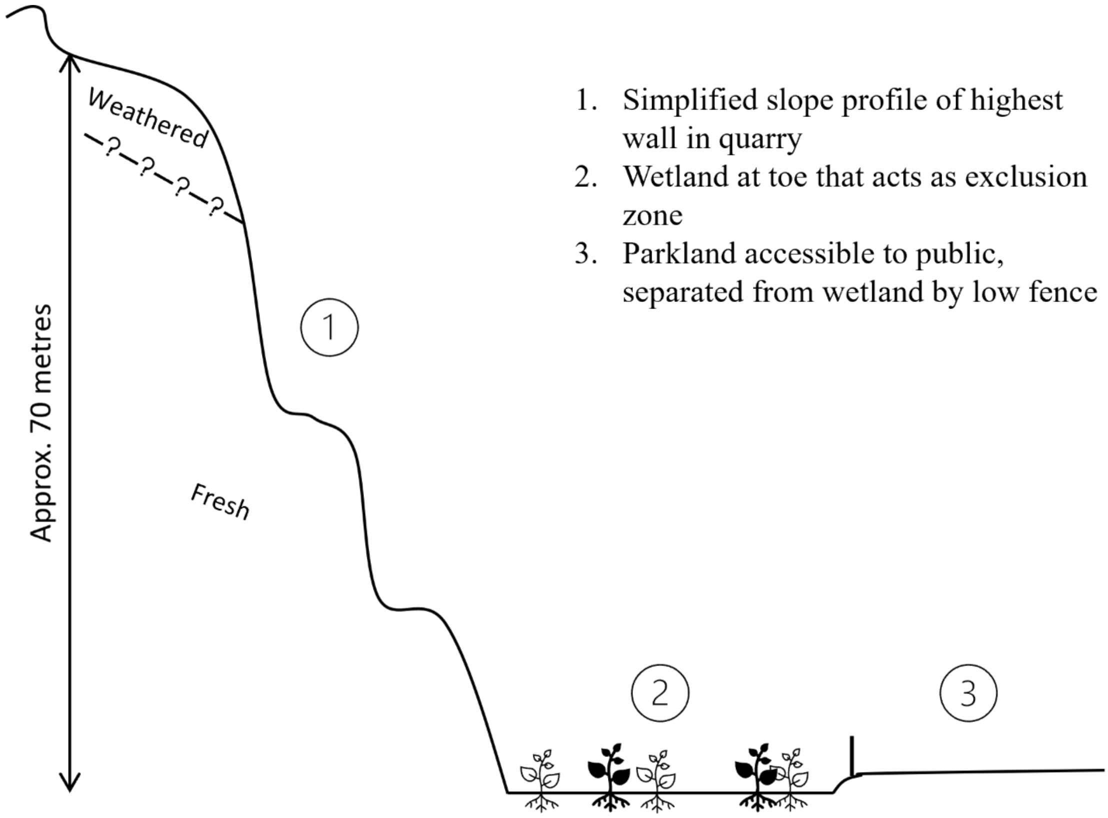

Figure 1: Indicative illustration of the risk mitigation measure of the high wall

Elsewhere in the quarry void, more typical slope stabilisation treatments were applied. This included selected rock bolts to retain individual blocks, and systematic draped mesh or anchored mesh. The decision to undertake slope treatment in these areas was based on a combination of the assessed risk requiring some form of rock fall hazard mitigation, and a lack of space at the toe for an exclusion zone. Modifications to the design, over time, introduced potential exclusion zones (such as where a road embankment created an elevation difference between the public and the toe of the wall, to allow for a "catch ditch"), and these were generally adopted to negate the requirement for mesh installation. Indeed, catch ditches are noted as being an effective method of reducing rock fall risk (Hoek, 2023).

The slopes around the quarry are generally waste material from quarry operations or overburden, dumped out on top of the residual soil and colluvium of the original valley. These slopes have become overgrown with native and non-native trees in the time since quarry operations ceased, but do not have established ground cover, indicating the lack of soil within the waste material. Quantitative and Qualitative Risk Assessments (collectively known as QRAs)were undertaken in accordance with the guidelines presented by the Australian Geomechanics Society Landslide Taskforce, often referred to as AGS 2007c (Walker, et al., 2007), using anecdotal evidence from Council employees and observations of slope failure such as talus and scour to determine likelihood. These QRAs determined that the overall slope risk was within the acceptable risk level suggested in AGS 2007c for existing slopes (i.e., less than 1×10^{-4}), though the potential for large failures to occur during adverse rain fall was identified.

Noting this, it was identified that slope risk would increase further if vegetation were removed, as the trees were beneficial to slope stabilisation by binding together the loose boulders that formed the “skeleton” of the dumped spoil. Administrative and isolation controls were put in place to mitigate the risk of large slope failures based on rain fall (i.e., trigger levels for rain fall in a certain period that would require complete closure of the parkland, and follow-up inspections prior to re-opening). These controls negated the requirement for potentially extensive clearance and retaining structures adjacent to access roads and walking tracks within the site.

The quarry void “backfill”, as previously mentioned, was some 50 metres of crushed tunnel spoil, which had been loosely placed via conveyor belt and front-end loader. No specified compaction method had been undertaken to improve the backfill as it was placed. In addition to this, the material had been subject to several cycles of inundation by surface and groundwater (the quarry being below the water table). The parkland conversion involved creating a new landform that would reshape this backfill and incorporate cut material from elsewhere in the scheme. The final landform would also feature several single-story buildings and other lightly loaded structures and pavement, though exact placement was not yet determined. Therefore, a traditional “structural fill” capable of providing adequate bearing capacity with minimal risk of differential settlement was required.

Tunnel spoil in the Sydney basin is noted as being a suitable fill material for construction (Chen & McIlquham, 2023) and was therefore planned to be structural fill. A specification for structural fill based on the engineering parameters of this material was created, to inform re-use of site won material elsewhere as well. However, the desire was to have less suitable material (such as oversize boulders, broken concrete slabs, and clayey material) won on site placed within the void as well, to avoid transporting these less suitable materials off site. In order to achieve this cut-fill balance, a pragmatic approach was undertaken whereby these less suitable materials were placed as basal fill, to a maximum compacted depth and with a minimum thickness of structural fill above. Boulders (up to 0.6 m) were to be placed such that they were kept from forming vertical stacks, but otherwise allowed to be used in the basal fill. This reduced the material handling, processing and transport of the landscaping aspect of the parkland conversion. The basal fill / structural fill arrangement was subject to successful field trials to demonstrate its viability as a design solution.

A limited site investigation was undertaken to inform design elements as well as assess the physical characteristics of the tunnel spoil within the quarry void. The term limited is used here specifically as the decision was made to gather as much information as possible while having a cost-effective geotechnical investigation. To achieve this, specifically targeted intrusive investigations (boreholes, test pits and Cone Penetrometer Tests) were undertaken to inform the most important design elements, in consultation with Council. These important design elements were generally those that presented the largest risk to construction (based on delays or material costs) unless geotechnical uncertainty was reduced. Other design elements were inferred from nearby or relevant geotechnical and geological observations and testing.

4 DISCUSSION

2.1 DESIGN ELEMENTS IN CONTEXT OF SUSTAINABILITY

The below table (Table 1) demonstrates how the design elements of this case study map to the SDG targets, with additional commentary on where the measures sit on the Hierarchy of Controls, similar to the work presented in Lagesse, et. al. (2022). It can be seen that **SDG 11 Sustainable cities and communities** is not specifically demonstrated in Table 1. Rather, the work performed generally aligns with 11.4 Protect and safeguard cultural and natural heritage, demonstrated by the role that geotechnics played in facilitating the parkland conversion in a constructible and economically viable manner.

Table 1: Mapping of design elements to SDG targets and their Hierarchy of Control types

Design Element	Relevant SDG Targets	Evidence of sustainable choices	Hierarchy of Control Type(s)
High wall stabilisation / geotechnical risk mitigation	**9 Industry, innovation, and infrastructure** 9.1 Sustainable and resilient infrastructure. 9.4 Upgrade and retrofit infrastructure and industry to enhance sustainability. **12 Responsible consumption and production** 12.5 Reduce waste generation through prevention, reduction, recycling and reuse.	Establish exclusion zone at toe of the high wall to negate installing slope stabilization. Resilience is achieved through the system remaining valid even if rock fall occurs.	Isolation, Engineering Controls
Basal fill	**9 Industry, innovation, and infrastructure** 9.1 Sustainable and resilient infrastructure. **12 Responsible consumption and production** 12.5 Reduce waste generation through prevention, reduction, recycling and reuse.	Reduction in vehicle movements and haulage of fill material, thereby reducing fuel consumption, potential dust escaping to atmosphere, and noise. Reuse of existing fill material and potentially less desirable, site-won fill to achieve cut-fill balance.	Engineering Controls
Surrounding slope stabilization	**9 Industry, innovation, and infrastructure** 9.1 Sustainable and resilient infrastructure. **12 Responsible consumption and production** 12.5 Reduce waste generation through prevention, reduction, recycling and reuse.	Utilise stabilising effect of existing vegetation and introduce park closure regimes to isolate the public from potential hazards based on rainfall trigger levels.	Isolation, Administrative Controls
Limited site investigation	**12 Responsible consumption and production** 12.4 Environmentally sound management of chemical and all wastes throughout their life cycle. 12.5 Reduce waste generation through prevention, reduction, recycling and reuse.	Specifically targeted boreholes and test pits, with intent to inform most critical design elements as well as tangentially inform other elements, thus reducing fuel consumption. Remove all drilling consumables and wastewater from site.	Engineering Controls (though this does not directly translate to the Hierarchy of Control as it relates to *design risk* rather than *slope risk*).

The design solutions presented above were often the most cost-effective means for addressing the risk associated with the individual items. They were also in general accordance with current industry practice for treating geotechnical or civil engineering risks, though with some departures to reduce both cost and environmental impacts. This was a fortunate case in which the geotechnical design solutions were demonstrably aligning with both a sustainable outcome and current industry practice for risk assessment and risk mitigation. However, there are some difficulties aligning sustainability, resilience and industry standards for risk management / geotechnical design (Basu, et al., 2015), as is explored in the following sections.

2.2 HIERARCHY OF CONTROLS AND RESILIENCE

As noted previously, resilience in design refers to the ability for the design intent to be remain valid during stresses or in the event of failure, as measured through robustness and redundancy (being tolerant of breakage or damage), resourcefulness (identification of or adaptability to disruption) and rapidity (the speed of recovery of the design to stresses or failures) (Das, et al., 2018).

When viewed from the perspective of applying the hierarchy of controls then, in the author's opinion, resilience may therefore best be achieved via elimination, isolation or administrative controls for slope stabilisation / risk mitigation. For example: elimination may be achieved through regarding the slope to a more stable profile; isolation may be achieved through development of exclusion zones, and administrative controls can take the form of trigger levels, procedures, and signage. These mitigation measures can be designed to "bounce back" and remain just as effective in the event of failure (MacAskill & Guthrie, 2013).

However, elimination (i.e., removal of the hazard) can often be more expensive and environmentally impactful than isolation or administrative controls. The benefit of elimination is that it offers the greatest possible risk mitigation, hence its position at the top of the Hierarchy of Controls, which ranks risk mitigation types from most to least effective (Worksafe Victoria, 2023). However, a sustainable outcome might be best achieved by isolation or administrative controls, when consideration is given to the mitigated risk level, and whether this reduced risk (without elimination) is broadly acceptable to the asset owner, in line with their own risk management regime and any relevant standards.

2.3 CONSIDERING RESILIENCE AND SUSTAINABILITY WITH RISK MANAGEMENT

The overall goal of any risk management is to reduce the risk to nil, or at least to a 'tolerable level' depending on the risk appetite of the asset owner or vulnerable parties (Walker, et al., 2007). The AGS 2007c Practice Notes for Landslide Risk Assessment (Walker, et al., 2007) define As Low As Reasonably Practicable (ALARP) as being a pragmatic approach for achieving a tolerable level of risk mitigation, with further reduction no longer being practical in cost to an individual or asset owner. The "test" for what is reasonably practicable is therefore linked to economic viability of further risk reduction, but does not have a direct link to "sustainability", that is to say, at which point is the proposed overall solution or design at odds with the sustainability targets of the SDG or even those of the asset owner.

As a high level example, a theoretical scenario is as follows: a popular walking track sits below a steep slope with a risk of rock fall and translational slide. A quantitative risk assessment finds the most vulnerable person (hikers stopping to take photographs for 30 minutes) as having a risk to loss of life (LoL) of 1×10^{-3} without control measures. A qualitative risk assessment on damage to property finds that the risk of the walking track infrastructure being lost due to translational slide as 1×10^{-4} (i.e., 1 in 10,000) without control measures.

- Individual block removal via hand tools brings LoL risk down slightly to 5×10^{-4}.
- Rock bolting blocks that cannot be removed brings LoL risk down to 1×10^{-4}.
- Widescale scaling of crest to reduce slope angle, and remove non-native trees causing root jacking, brings the slope risk level down to 5×10^{-5}.
- It is within the budget of the asset owner to undertake these activities, as the location is near the start of the walking track, and the track's carpark provides a suitable staging ground.
- However, these last two measures add to the carbon footprint of the risk reduction, via factors such as grouting, fuel usage, additional spoil removal, etc. Tree removal also impacts both environmental and community sustainability. In addition, community is impacted further by closing the walking track for a longer construction programme.
- In this instance, ALARP could allow for this impact to overall sustainability of the walking track, but if the sustainability is considered, it may be more "practicable" to undertake individual block removal, and place signage indicating the risk of rock fall and slope failure, and not to pause to take photographs. Allowing trees to grow up to block the view may help. In addition, the asset owner may wish to close the hiking track during inclement weather which may trigger the failure.
- Note that, if the slope were further down the walking track, it may be economically unfeasible to undertake the remediation; an example of how economics can be linked to sustainable choices.

Although hypothetical, the above example happens across the industry on a regular basis. Risk assessments are generally quantitative or at least provide a numerical outcome (based on a risk matrix) once probability and consequence have been assigned (in the case of qualitative analysis). Therefore, the inclusion of sustainability and resilience factors may not seem readily achievable. Previous work by others (Das, et al., 2018; MacAskill & Guthrie, 2013) has identified the value in conducting Multi-Criteria Analysis (MCA) as a means to embed sustainable and resilient design outcomes in a typical risk management workflow. In the realm of slope stabilisation, with respect to the guidelines provided in AGS 2007c, a potential workflow might look like Figure 2 below.

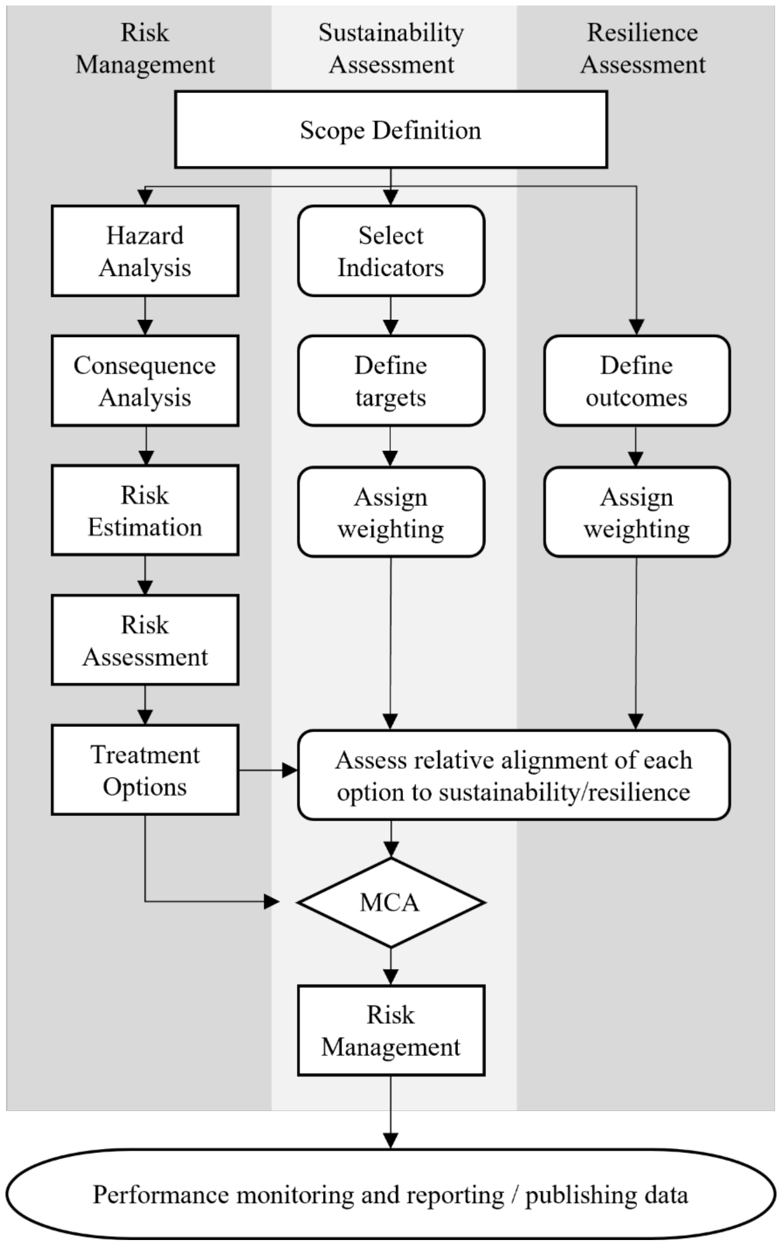

Figure 2: Potential workflow for considering sustainability and resilience in design along with appropriate risk estimation and mitigation, adapted from (Walker, et al., 2007) and (MacAskill & Guthrie, 2013)

Guidance on the selection of sustainability and resilience outcomes, and appropriate weighting, are beyond the scope of this paper, though other publications provide examples, such as (Das, et al., 2018) and (MacAskill & Guthrie, 2013). The monitoring of performance of the risk mitigation measures, resilience over time, and the conformance to sustainability targets, is a vital step in iteratively improving the embedment of sustainability in geotechnics. Although the above flowchart refers to improving the sustainability of a slope stabilisation solution, there is another area where the geotechnics practice can significantly contribute to a better outcome for sustainability and resilience in design in general (Clayton & Smith, 2015).

2.4 SITE INVESTIGATIONS AND IMPACTS ON PROJECT SUSTAINABILITY

Site investigations have arguably the greatest impact on sustainability of all the activities that are carried out by the geotechnics practice. In addition, many projects require regular intrusive investigation locations to meet the specifications of a given type of built infrastructure. The intent behind a comprehensive intrusive investigation is to de-risk the design, which theoretically will reduce construction time or material consumption (Clayton & Smith, 2015). Therefore, such regular investigations may also be more sustainable when reviewing the potential impacts of a project across its lifecycle (known as an LCA or Life Cycle Assessment), despite the initial impact on the sustainability profile (Purdy, et al., 2022).

This places some onus on the consulting engineering geologists and geotechnical engineers to design site investigations that provide as much information as possible from the fewest individual investigations, or to gather data through more sustainable methods (such as geophysical surveys which use less fuel and consumables like cement than traditional borehole drilling (Clayton & Smith, 2015; Purdy, et al., 2022). However, there is also a need for engagement with, and by, the asset owner or end client on where geotechnics can improve the project's sustainability (or resilience), either in design, construction or operation (Pantelidou, et al., 2012). As an example (in the author's experience) there is often a requirement to design "one size fits all" solution which accounts for the potential adverse case, independent of the level of knowledge of the ground that has been achieved. Early collaboration may lead to outcomes which de-risk the design while also positively impacting the sustainability of the project overall, such as the aforementioned case for improving the knowledge of the ground and thus reducing the construction materials. Initiatives such as the comprehensive and sustainable GIS database for Australia (Och, 2023), similar to those seen in other countries, will improve the knowledge of ground conditions without undertaking comprehensive site investigations. However, support from asset owners to allow reliance on these data (gathered by third parties) is a necessary step to reducing the sustainability impact of site investigations.

5 CONCLUSIONS

This paper summarises how select choices to address geotechnics challenges improved the sustainability and resilience in of the design outcomes, partly by mapping the solutions against the UN Sustainable Development Goals. It also highlights some of the difficulties with taking a "sustainable approach" while also applying current industry practice for risk mitigation. It notes the importance of early engagement between geotechnics professionals and asset owners or clients to improve overall sustainability of a project throughout its lifecycle. As government regulation of compliance to sustainable targets is progressively rolled out, the need to consider resilience and sustainable development in design (through MCA or options assessment) will become both commonplace and critical. Therefore, it is important for the geotechnics practice to develop workflows to balance the need for robust and reliable design with resilient and sustainable development.

6 REFERENCES

Basu, D., Misra, A. & Puppala, A. J. (2015). Sustainability and geotechnical engineering: perspectives and review. Canadian Geotechnical Journal, Volume 52, pp. 96-113.

Chen, K. & McIlquham, J. (2023). Sustainable re-use of conventionally unsuitable material in the construction of Moorebank Intermodal Precinct. Cairns, Proceedings of the 14th Australia and New Zealand Conference on Geomechanics (ANZ2023).

Clayton, C. & Smith, D. (2015). Effective Site Investigation. 2nd ed. s.l.: ICE Publishing.

Costigane, B. & Guthrie, P. (2013). Mired in the meaning: sustainability in consultancy. Engineering Sustainability, 166 (6), pp. 330-336.

Das, J. et al. (2018). Sustainability and resilience analyses in slope stabilisation. Engineering Sustainability, 171(1), pp. 25-36.

European Comission (2023). Corporate sustainability reporting. [Online] Available at: https://finance.ec.europa.eu/capital-markets-union-and-financial-markets/company-reporting-and-auditing/company-reporting/corporate-sustainability-reporting_en [Accessed 30 August 2023].

Gill, J. C. (2017). Geology and the Sustainable Development Goals. Journal of International Geoscience - Episodes, March, 40(1), pp. 70-76.

Hoek, E. (2023). Practical Rock Engineering, s.l.: Rocscience.

Lagesse, R.H., Hambling, J., Gill J., Dobbs, M., Lim, C. and Ingvorsen, P. (2022). The role of engineering geology in delivering the United Nations Sustainable Development Goals. Quarterly Journal of Engineering Geology and

Hydrogeology, Volume 55, (https://doi.org/10.1144/qjegh2021-127).

MacAskill, K. & Guthrie, P. (2013). Risk-based approaches to sustainability in civil engineering. Engineering Sustainability, 166(4), pp. 181-190.

Och, D. (2023). To develop a national sustainable GIS geotechnical database to capture present data for the future: Assessment of International Geological Surveys and their open-data sources, s.l.: Winston Churchill Memorial Trust.

Pandit, J., Watson, M. & Qader, A. (2020). Reduction of Greenhouse Gas Emission in Steel Production Final Report, Melbourne: C02CRC Ltd Publication Number RPT20-6205.

Pantelidou, H. et al., 2012. Earthworks emissions in construction of a highway. Geological Society, London, Engineering Geology Special Publications, Volume 26, pp. 175-180.

Purdy, C. M. et al. (2022). Life-cycle sustainability assessment of geotechnical site investigation. Canadian Geotechnical Journal, Volume 59, pp. 863-877.

UN Environment Programme - Finance Initiative, (2004). Who Cares Wins - The Global Compact Connecting Financial Markets to a Changing World. [Online]
Available at: https://www.unepfi.org/fileadmin/events/2004/stocks/who_cares_wins_global_compact_2004.pdf [Accessed 30 August 2023].

United Nations Environment Programme, (2010). Greening Cement Production has a Big Role to Play in Reducing Greenhouse Gas Emissions. [Online]
Available at: https://www.unep.org/resources/report/greening-cement-production-has-big-role-play-reducing-greenhouse-gas-emissions [Accessed 13 September 2023].

United Nations Sustainable Development Goals (2023). The 17 Goals. [Online] Available at: https://sdgs.un.org/goals [Accessed 01 September 2023].

Walker, B., Davies, D. & Wilson, G. (2007). Practice Note Guidlines for Landslide Risk Management 2007. Australian Geomechanics, 42(1), pp. 63-114.

Worksafe Victoria (2023). The Hierarchy of Control. [Online]
Available at: https://www.worksafe.vic.gov.au/hierarchy-control [Accessed 1 September 2023].