Tonkin & Taylor

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Greater Wellington Regional Council
PO Box 11646
Wellington 6142

Attention: Bruce Geden

Dear Bruce

Wairarapa Water Use Project (WWUP): Geotechnical Investigations of Possible Storage Sites

1 Introduction

This letter summarises the key findings from the geotechnical assessment of possible storage sites (Task 2A), which have implications for Review Point 2 (Task 2B). The letter comprises one of the key outputs from Workstream 2. The findings from the geotechnical assessment of storage sites will be presented in further detail in the Engineering Report as an outcome of Workstream 6 when further technical investigations have been conducted and the derived information is collated.

The task and workstream descriptions are based on Tonkin & Taylor's (T&T's) Offer of Service to Greater Wellington Regional Council (GWRC) (T&T 28063.103/V01 February 2014). Review Point 2 is described in T&T's Offer as "an opportunity for GWRC to review any findings from Task 2A that could compromise further consideration of any of the 5 priority storage sites, and endorse/revise the scope for the tasks still to come based on findings". This letter is described in T&T's Offer as "a brief memo collating findings from Task 2A … largely based on the 'fatal flaws' review undertaken during Task 2A".

2 Summary of Findings for Each Storage Site

2.1 Introduction

The site investigations for Task 2A comprised a range of methods depending on site characteristics and access. The investigations included digger pits, shovel samples, and walkover inspections of surface materials and features. The purpose was to identify and understand any geotechnical/geological issues, constraints or risks that may affect whether a storage site is appropriate to continue being investigated for the WWUP. Construction cost estimates will be reported upon separately following further development of design concepts for the schemes.

The assessment has considered issues, constraints or risks that could potentially lead to threats to technical and/or economic viability. The primary focus has been on geotechnical / geological aspects, but some comments on other aspects noted during the visits are also included. The significance of the identified issues, constraints and risks has been assessed to a preliminary level based on site observations and engineering judgement rather than full analysis. Ground conditions away from direct observations in test pits and surface exposures have been inferred based on judgement.

The Task 2A site visits were undertaken by T&T's team, comprising B Hegan (Principal Engineering Geologist), N Peters (Senior Engineering Geologist) and D Knappstein (Senior Water Resources and Geotechnical Engineer), assisted by G Ordish of GWRC. The visits were completed in two tranches, the first undertaken over 1.5 weeks from the 7 April 2014 to 16 April 2014, and the second undertaken over 2.5 weeks from the 13 May 2014 to 28 May 2014. Feedback and commentary was provided verbally by GWRC's Peer Reviewer, G Pickens, who visited all five shortlisted storage sites with B Hegan, D Knappstein and G Ordish on 27 May 2014 and 28 May 2014.

Findings for each of the storage sites are summarised in Sections 2.2 to 2.6.

2.2 Site 10 Tividale

2.2.1 Site Appreciation

The proposed dam and reservoir sites at Tividale would be located in Cretacecous (K) and Miocene (Mi) aged sediments and sedimentary rock. Geological contacts between materials are yet to be determined, but are likely to be faulted. Based on observations on site, the Cretaceous/Miocene boundary may be close to the left abutment. Geological boundaries shown in GNS' QMap generally appear inaccurate in this area.

T&T's geological mapping indicates that the possible dam wall site is located in Miocene (Mi) aged, extremely weak to weak sandstone, dipping downstream at 10° approximately. Cemented, calcareous beds outcrop upstream of the possible dam wall location, which will dip under the possible dam site.

The potential for transmission of reservoir pressures under the possible dam wall site, particularly through the cemented, calcareous beds will need to be considered, but is not expected to be significant since the sandstone appears massive with few defects (except stress relief joints) and because the cemented, calcareous beds are anticipated to be relatively deep under the possible dam wall site, especially at a possible revised dam location[1]. During the previous phase of the WWUP, the potential for relaxed joints in the sandstone at the possible dam site to require grouting to manage leakage was highlighted as a risk / area of uncertainty. The information gathered during the 2014 site visits indicates that the relatively open joints are related to local stress relief, and unlikely to provide a persistent seepage path under the proposed dam.

Landslides in the proposed reservoir will need to be considered in terms of road realignments and dead storage to be set aside for sedimentation. The landslides are generally shallow, except where crushed, fissile mudstone (K) alternates with strong sandstone (also K). During the previous phase of the WWUP, the risk of landslide-generated seiches was identified. However, observations during the

[1] The proposed dam wall may be shifted slightly downstream from the location indicated in the previous phase of work (Options Refinement) in order to simplify diversion arrangements, though noting that additional earthworks would be required at the revised location.

2014 site visits indicate that the landslides immediately upstream of the possible dam site are generally shallow and unlikely to generate seiches of substantial size.

The stream has an unusually contorted shape, likely due to defects / lineations or changes in material. At some time in the past, there may have been a landslide blocking the gorge immediately upstream of the confluence of Tauweru River and Mangapurupuru Stream, which the Tauweru River has cut back through.

Observations of the stream in the vicinity of the possible dam wall indicate that local stream banks are prone to slumping, and tree falls. Flood debris was observed caught in trees in the order of 5-10m above the stream bed.

2.2.2 Issues, Constraints and Risks

The main issues, constraints and risks identified at Tividale were:

- Realignment of Mangapurupuru Road. Several large earthflows were observed along the realignment route considered during the previous phase of the WWUP. A number of alternative routes along relatively stable terrain were inspected, but are likely to entail an increase in the length of realignment / upgrade, which has implications for construction cost and travel time for road users. Achieving appropriate longitudinal grades on the realignment is also expected to be challenging.
- Sedimentation due to landsliding in the proposed reservoir and catchment, local stream bank collapse and tree falls. These issues will also require management of debris risk to intakes.

Several minor issues, constraints and risks were also identified:

- Uncertainty in relation to depth of subexcavation in the valley floor[2] beneath the possible dam wall, which is currently inferred based on the shape of the valley and general observations in the wider area (rather than direct evidence from subsurface investigations).
- Value engineering for the proposed dam is likely to be limited to dam types that utilise the extremely weak sandstone and very weak to weak siltstone, which were the only materials observed in abundance close to the possible dam wall. However, this material appears suitable for construction based on current observations, subject to laboratory testing.
- Leakage and transmission of water pressures along the cemented, calcareous bands dipping downstream under the proposed dam, though noting this is not expected to be an issue at the possible revised dam site.
- Additional cost of stabilisation measures at a local area of instability along the potential Coopers Road realignment.

2.3 Site 135 White Rock Road

2.3.1 Site Appreciation

The proposed dam and reservoir at White Rock Road would be located in an Upper Miocene-Pleistocene sequence of materials, generally comprising limestones and siltstones. Torlesse greywacke outcrops on the Makara River in the upper part of the proposed reservoir.

[2] The uncertainty regarding subexcavation is related to the valley floor primarily. The depth of subexcavation on the right bank terrace has been proven by test pits. The left side of the valley (cliff) appears relatively favourable and is expected to require only minimal subexcavation.

The area is highly regarded by the geological community and contains many Type locations for New Zealand stratigraphy and observations for magnetic reversals. The site has been subject to detailed mapping by Victoria University.

The upper slopes / gorge walls at the possible dam site[3] comprise slightly shelly, coarse sandstone beds with thin, discontinuous coquina limestone interbeds. The lower slopes comprise extremely weak, massive, slightly shelly siltstone with minor sand. The floor of the valley is infilled with Holocene-aged alluvium and large, toppled, limestone boulders, likely to require blasting to remove, though the blasted limestone may then be suitable for use in construction of the proposed dam (armour). The thickness of alluvium in the valley floor, which will need to be subexcavated due to permeability, is expected to be relatively shallow (less than 5m) based on observations in the gorge downstream and the driller's log at the groundwater bore located upstream.

Landslides in the proposed reservoir generally appear relatively shallow, but widespread, and will need to be considered for the road realignment and dead storage allowance for sedimentation.

One particular area of instability was noted along the road realignment. The lateral extent of the instability has been defined by test pits, and one test pit indicated that the depth of sliding was less than 5m, though noting that the depth is likely to be a few meters greater in other locations. Defect mapping indicates that sliding is controlled by joints orthogonal to bedding with no evidence of sliding on bedding planes.

Two landslips on the true right of the Makara River upstream of the homestead appear to be controlled by weaker interbeds within the siltstone. The southern of these two landslips is already evacuated and mostly above proposed reservoir level, and considered unlikely to release further substantial volumes of slip material into the proposed reservoir. The northern landslip may require some buttressing works at its northern end.

The proposed dam and reservoir are located on the limb of an actively deforming anticline. Faulting in the general area will need to be investigated further.

2.3.2 Issues, Constraints and Risks

The main issues, constraints and risks identified at White Rock Road were:

- Leakage risk through the slightly shelly, coarse sandstone beds between the thin, discontinuous limestone interbeds at the possible dam abutments. The significance of this risk could be determined by Lugeon testing in drillholes on site. The risk relates to both the consentability and potential construction cost of measures to manage leakage. (Consentability is relevant if such measures extend upstream to the QEII covenanted area.) Further commentary on this risk is provided in Section 3.2.
- Construction and ongoing maintenance cost of realigning White Rock Road, especially with respect to the treatment of the landslip.

Several minor issues, constraints and risks were also identified:

- Leakage through the Clay Creek limestone in the upper part of the proposed reservoir will need to be considered as it has some Karstic development. However, this is considered unlikely to prove a significant issue because the reservoir depth would be shallow at this location and there appears to be no clear leakage path out of the proposed reservoir.

[3] The proposed dam wall could be shifted slightly upstream from the location indicated in the previous phase of work (Options Refinement) in order to straighten the alignment of the diversion culvert and minimise the risk of seepage around abutments, though noting that additional earthworks would be required at the revised location.

- Sedimentation due to slips in the proposed reservoir, though this is only expected to prove a minor issue as the slips generally appear relatively shallow.
- Additional cost of blasting large, toppled limestone blocks beneath the possible dam wall site.
- Transmission of water pressures under the possible dam site along bedding. This was also identified as a risk during previous phases of the WWUP, though is now considered a lesser risk since the siltstone under the possible dam site appeared relatively massive where observed.
- Leakage through sandstone (identified as 'Bridge Member' Sandstone) outcropping within the proposed reservoir. This is not expected to be a significant risk since the sandstone is heavily overconsolidated and not considered to have a substantial leakage potential.

2.4 Site 197 Te Mara

2.4.1 Site Appreciation

Torlesse greywacke forms the basement rock at the proposed dam and reservoir sites for Te Mara, unconformably overlain by Miocene-aged sediments, including extremely weak, massive sandstone grading up to extremely weak to very weak, massive siltstone, and conglomerate at some locations. These materials are, in turn, unconformably overlain by greywacke-derived, eroded/dissected marine and alluvial terrace deposits of various ages.

The regional geological structure is strongly influenced by local faults in the general area. Miocene-aged sediments are folded into a series of anticlines and synclines, with the proposed reservoir basin located in a probable syncline.

The valley slopes at the possible dam wall site itself comprise massive greywacke sandstone with negligible shearing or crushed zones and negligible argillite. The shape of the slopes is controlled by joints and bedding. Solifluction deposits infill the local U-shaped gullies on the valley sides, with seepage emerging at the interface between the solifluction and underlying greywacke. A thin colluvium / scree mantle is also locally present. The floor of the valley at the possible dam wall is infilled with alluvium that will need to be subexcavated / 'cut off' due to permeability and organics content.

Provided suitable subexcavation is undertaken, no significant, specific leakage or stability issues were noted at the location of the possible dam wall site based on current observations. Furthermore, no significant landslides were observed in the wider reservoir.

2.4.2 Issues, Constraints and Risks

No significant issues, constraints or risks were identified at Te Mara. The only minor risk identified was the depth of subexcavation required at the possible dam wall to remove unsuitable material in the valley floor (alluvium) and on the true right slope (solifluction).

The information gathered during the 2014 site visits has allayed some of the potential risks / areas of uncertainty highlighted during previous phases of investigation, specifically:

- Potential seepage through possible paleovalleys in left side of proposed reservoir - test pits and observations of surface exposures indicate that the reservoir rim in the area of concern comprises massive, extremely weak Miocene-aged sandstone. Seepage through this material is not expected to be an issue.
- Possible crushed zone in the right abutment of the proposed dam wall site associated with springs - the seepage appears to be associated with solifluction deposits rather than any lineation or defect in the greywacke. The solifluction deposits would be removed during

preparation for dam construction and the seepage would be intercepted by a surface drain at the interface between the proposed dam and existing ground.

- Potential for terrace gravels in the proposed reservoir to slide at the interface with underlying rock during earthquake shaking – no existing instability was observed at the interface of the alluvial terrace material and Miocene-aged rock. This is thought to be because the Miocene-aged rock comprises sandstone rather than siltstone, and does not provide a substantial permeability contrast with the alluvium that could make the interface prone to instability.

2.5 Site 210 Black Creek

2.5.1 Site Appreciation

Torlesse greywacke forms the basement rock at the proposed dam and reservoir site for Black Creek. In the eastern side of the proposed reservoir, an old erosional surface in the greywacke dips at 10° approximately to the west, unconformably overlain by Miocene-aged, extremely weak, massive sandstone. The western side of the valley comprises uplifted steep greywacke slopes. A non-active fault is likely down the middle of the valley.

At the main proposed dam site on Black Creek, greywacke is exposed in the true left slope and partway up the right slope. The valley floor is infilled with alluvium, possibly in the order of 20-25m thick, which would need to be 'cut off' or subexcavated due to permeability and possible liquefaction risk. On the right abutment terrace, the greywacke is overlain by presumed (not directly observed) Miocene-aged sediments, in turn unconformably overlain by alluvial / marine terrace (Plio-Pleistocene) material. The alluvial/marine terrace deposits are involved in large scale, active, landslippage to the west of the right abutment in the main valley, possibly occurring on permeability contrasts in the underlying material and exacerbated by undercutting of the toe by the Waingawa River.

The possible dam wall site on Wakamoekau Creek (option at upstream end of gorge) is located in greywacke rock. Alluvium is present in the valley floor, but is expected to be of limited thickness and require minor subexcavation based on test pit investigations and intermittent outcrops of greywacke rock in the stream bed. No significant, specific leakage or stability issues were observed at this proposed dam site, though a sheared, argillite-dominated zone was observed downstream of the left abutment.

Instability of the terrace gravels sliding on less permeable underlying rock has been observed in some locations within the proposed reservoir, but is generally not expected to be widespread based on current observations.

2.5.2 Issues, Constraints and Risks

The main issues, constraints and risks identified at Black Creek were:

- Depth of subexcavation required beneath the main proposed dam wall site on Black Creek.
- Seepage through the reservoir rim on the true right of the main proposed dam wall site on Black Creek into the large scale, active landslide. This seepage may have implications for stability of the landslide, which is located upslope of Upper Waingawa Road and a homestead, and may also have implications for stability of the right abutment of the possible dam.
- Complexity and variability of materials on the true right of the main proposed dam on Black Creek, including uncertainty around the depth of terrace gravels and subexcavation required.

The main issues, constraints and risks identified above all relate to the main proposed dam wall site on Black Creek. A smaller option at this site based on a possible main dam wall site at Wakamoekau

Creek and saddle dam between the Black Creek and Wakamoekau Creek catchments would avoid these issues, constraints and risks (described in previous phase of the WWUP as Scheme 206 Wakamoekau).

Several minor issues, constraints and risks were also identified:

- Potential for terrace gravels in the proposed reservoir to slide at the interface with underlying rock during earthquake shaking.
- In the vicinity of the possible dam wall site on Wakamoekau Creek (option at upstream end of gorge), white veining was observed in test pits and exposures. The vein material will need to be identified via laboratory testing, to confirm it is not a zeolite prone to shrink-swell, which can impact on the quality of rockfill that can be derived from the greywacke. If present, mitigation measures such as installing drainage zones could be considered.
- Cost of the seepage control zone for the possible dam on Wakamoekau Creek. Current thinking would be to use the moderately to highly weathered greywacke rock present to the north of the left abutment. However, there is uncertainty about how the material would break down upon compaction, and how wide an area would need to be opened up to provide sufficient quantity. Nevertheless, this is regarded as a minor risk since alternative dam types or sources of material for a seepage control zone could be considered.

2.6 Site 215 Mangatarere

2.6.1 Site Access

Visits to the proposed reservoir and dam site at Mangatarere were limited by landowner permissions to a few properties within the proposed reservoir upstream of the possible dam wall site, and detailed lithology and defect mapping along an 800m long section of the road cutting up the centre of the valley, ranging from 500m upstream of the possible dam wall site to 300m downstream of the possible dam wall site. Inspections of surface exposures of possible borrow materials located downstream of the gorge were also undertaken.

2.6.2 Site Appreciation

At the proposed reservoir and dam sites, Mangatarere Stream is deeply incised into Torlesse greywacke, with alluvium in the valley floor, and discontinuous alluvial terraces up to a few meters above the floor of the valley. Thin deposits of scree and thicker deposits of colluvium are locally present on the valley slopes. The greywacke comprises alternating bands of sandstone and bands of siltstone / argillite. The possible dam wall site is located in a relatively massive, sandstone dominated band of greywacke, which is well exposed in road cuttings and the road surface itself.

Low angle joints were noted dipping under the possible dam wall site, and will need to be assessed with respect to transmission of water pressures, though joints appeared relatively tight and not persistent where observed. No other significant, specific, stability or leakage issues were observed at the proposed dam wall site or in the proposed reservoir during the site visit. Based on observations to date, the road realignment is expected to be relatively straightforward, and similar to the current road bench, but located further upslope.

The main structural trend within the greywacke is controlled by bedding, which strikes NNE-SSW and dips very steeply. The location of streams and side gullies are related to the locations of the siltstone/argillite bands. A major NNE-SSW aligned band of contorted, fissile argillite crosses the valley approximately 500m upstream of the possible dam wall site – Mangatarere Stream turns locally to follow the strike of this feature. An active fault, parallel to the range front, is mapped 1.5km downstream at the mouth of the gorge.

Downstream of the gorge, the Pliocene-aged "Mangatarere Mudstone" outcrops in the banks of the Mangatarere Stream near Tea Creek Road. The low hills to the east of Tea Creek Road are formed by old, high level terrace, moderately to highly weathered, greywacke-derived gravels.

2.6.3 Issues, Constraints and Risks

No significant issues, constraints or risks were identified at Mangatarere. However, a number of minor issues, constraints and risks were identified:

- Uncertainty in relation to depth of subexcavation to remove alluvium in the valley floor at the possible dam site (considered too permeable to leave in place), though not expected to be a significant thickness based on the valley shape.
- The potential for transmission of water pressures via low angle joints under the possible dam wall site may require primary grouting. This was also highlighted as a potential risk during previous phases of the WWUP. However, the detailed defect mapping in 2014 indicates that the low angle joints are relatively tight and not persistent.
- Cost of the seepage control zone. Current thinking is to use the highly weathered greywacke gravel in low hills to the east of Tea Creek Road, which will entail a higher than typical haul cost (3-4km away from possible dam site). Alternative materials for the seepage control zone or alternative dam types that do not require a seepage control zone could be considered. For instance, greywacke at site could be crushed to provide aggregate for concrete for a concrete faced rockfill dam or other dam type.

3 Overall Findings

3.1 Revised Comparison of Storage Sites

Table 3-1 presents the comparative scores for each site based on the issues, constraints and risks presented in Section 2. The scores range from 1 to 5, with 1 being the least favourable and 5 being the most favourable. The scores are comparative i.e. a score of 1 indicates the site that is considered less favourable than the other shortlisted sites in terms of the identified issues, constraints and risks. It does not necessarily imply an unacceptably high level of risk or geotechnical issues. As discussed above, the assessment focusses primarily on geotechnical aspects and considers the storage sites only (rather than distribution aspects).

Table 3-1

Storage Site	Comparative Geotechnical Issues/Risks Scores		Comment
	During previous Options Refinement Phase	Revised based on Task 2A findings	
Tividale (Site 10)	3	4	
White Rock Road (Site 135)	1	1	Low score due primarily to leakage risk around proposed dam abutments
Te Mara (Site 197)	4	5	
Black Creek (Site 210)	2 (4 for alternative smaller option or 'subset')	1 (4 for alternative smaller option at Black Creek i.e. an arrangement with a possible dam on Wakamoekau Creek and a saddle dam between the Black Creek and Wakamoekau Creek catchments)	Low score due primarily to risk of very deep subexcavation/cut off at proposed main dam wall site on Black Creek
Mangatarere (Site 215)	3	4	

3.2 Comment on Fatal Flaws

For the purpose of this assessment, a 'fatal flaw' has been interpreted as an issue that would entail clearly unreasonable technical challenges and/or be clearly uneconomic to address, such that further investigation of a possible site should be abandoned.

Based on the current knowledge of the sites, there are no clear 'fatal flaws' for any of the sites.

However, a number of issues that could potentially prove to be 'fatal flaws' with further investigation are flagged as follows:

- Black Creek (Site 210): Extent of subexcavation required in the valley floor beneath the main proposed dam wall site on Black Creek.

Test pit 210A was undertaken in the valley floor at this location, and was excavated to a depth of 4.2m before stopping due to high inflows into the pit from the nearby Black Creek. The materials observed in the pit appeared unsuitable (too leaky and possibly prone to liquefaction) to leave in place beneath the possible dam footprint, and would likely need to be subexcavated prior to commencing placement of fill material for the proposed dam. Based on the shape of the valley, and observations of greywacke levels in the stream further down the valley, it is considered possible that the depth of unsuitable material to be subexcavated could be up to 25m deep. If this is the case, it would add significant construction cost (previously 5m subexcavation has been assumed in the valley floor), possibly to the extent that this scheme is no longer financially viable. Alternative measures other than subexcavation should be considered but are also likely to increase construction cost. A drill hole would be required to confirm the extent of the gravels and hence the significance of this risk.

- White Rock Road (Site 135): Leakage around the abutments of the proposed dam.

  The upper portion of the possible dam abutments are expected to comprise slightly shelly, coarse sandstone with thin coquina limestone interbeds. The leakage risk is considered to be through the shelly sandstone, in between the thin limestone interbeds. The measures required to manage the leakage risk may increase construction cost so that the scheme is not financially viable. A drill hole with Lugeon testing would be required to assess the permeability of these materials together with an assessment of potential seepage through the abutments.

Black Creek (Site 210) and White Rock Road (Site 135) have been given the least favourable comparative scores in Table 3-1 recognising the potential for the 'fatal flaws' above to eventuate with further investigation.

The possible 'fatal flaws' have been identified based only on inferences from surface exposures and relatively shallow test pits rather than direct evidence. We strongly recommend further investigation to prove these fatal flaws are real before eliminating a site on this basis alone. The investigation into the possible fatal flaws could be undertaken during prefeasibility, or deferred to a later phase in the project, at which point these sites may have been eliminated for other reasons.

4 Acknowledgements

T&T is grateful to a range of organisations and individuals who have provided information, assistance and/or input for this phase of the project. We specifically acknowledge A Pickens of Pickens Consulting Ltd for providing feedback in his capacity as GWRC's peer reviewer. We also acknowledge staff at GWRC (Wellington and Wairarapa), including G Ordish, for arranging access with landowners, reinstatement, 4WD and digger hire, and storage of samples collected.

We are especially grateful to those landowners who gave permission for our team members to enter their properties during the site walk-over and investigative work.

5 Applicability

This report has been prepared for the benefit of Greater Wellington Regional Council with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.

Tonkin & Taylor Ltd

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