Tonkin+Taylor

Memo

To:	**Natalia Ford**	**Job No:**	**51344.0120**
From:	**Tonkin & Taylor Ltd.**	**Date:**	**7 March 2018**
Subject:	**Review of resource consent application to dam water in a large water storage facility and modify a canal**		

1 Introduction

This memo is provided to Canterbury Regional Council/Environment Canterbury (ECan) by Tonkin & Taylor Ltd. (T+T) and outlines our assessment of aspects of an application for resource consent to dam water in a large water storage facility and modify a canal. The work has been undertaken for ECan as our client.

This memo contains the following sections as listed in Table 1 following.

Table 1 Memo sections

Section	Title
1	Introduction
2	Qualifications and experience
3	Scope of the review
3.1	Scope of work
3.2	Relevant documents
4	Project nature and scale
5	Dam breach assessment
5.1	Proposed Klondyke Storage Dam
5.2	Canal upgrade
6	Dam potential impact classification
6.1	General
6.2	Dam
6.3	Canal upgrade
7	Design standards proposed by the applicant for the dam and canal upgrade works
8	Site specific seismic hazard assessment
9	Identification of credible Potential Failure Modes
10	Construction methodology proposed by the applicant for the dam and canal upgrade as relates to dam safety matters
10.1	KSD construction
10.2	Canal upgrade
10.3	Commissioning

Section	Title
11	Dam Safety Management
12	Emergency preparedness
13	Submissions
13.1	General concerns raised by submitters
13.2	Submission of the Early Family Trust
13.3	Submission of Rangitata Water Limited
13.4	Submission of Mr John McGregor Simpson
14	Consent conditions
15	Overall conclusion
16	Applicability

2 Qualifications and experience

Tim Morris is a Senior Civil Engineer and Project Director, with twenty years industry experience. In addition to numerous dam safety inspection roles, Tim has managed or contributed to investigation stages as well as detailed design and construction of many hydroelectric and irrigation projects. Projects often involve complex water storage and distribution infrastructure; including schemes featuring intakes, canals, pipelines and dams of various types.

Tim is a Chartered Professional Engineer (CPEng.) and a member of the New Zealand Society On Large Dams (NZSOLD). Prior to discontinuation of the register, he was a Category A Recognised Engineer. Tim has led or contributed to numerous dam inspections and safety review projects for Low to High or equivalent Potential Impact Category (PIC) dams.

In addition, Tim has substantial review experience with input into many major projects involving multifaceted water storage and transmission infrastructure. Some examples include various stages of the Central Plains Water scheme, Deep Stream hydroelectric project and the Akarana Pond presently under construction. Tim has also acted as expert witness for the EPA board of inquiry considering the application for resource consent for the Ruataniwha Water Storage project.

Tim has led and undertaken the majority of the assessment outlined in this memo.

3 Scope of this review

3.1 Scope of work

The scope of work is as set out in our letter of engagement to Environment Canterbury of 3 June 2016 and related correspondence. The scope includes review of the information provided to T+T in relation to the following aspects of the prosed storage facility and canal upgrade:

- The dam breach assessment.
- The PIC proposed by the applicant.
- Design standards proposed by the applicant for the dam and canal upgrade works.
- The Construction methodology proposed by the applicant for the dam and canal upgrade as relates to dam safety matters.

The scope of this memo is limited to the effects associated with the scope described above. We understand the purpose of these review services is to provide ECan additional assurance regarding expectations for the approach to the project. Our services do not constitute a means by which principal design responsibility can be passed onto T+T.

The scope also included an initial site visit. This was undertaken on 24 June 2016 in conjunction with Rangitata Diversion Race Management Limited (RDRML) and ECan staff. The visit comprised a walkover of some areas in close proximity to the proposed storage, including the inlet and outlet area locations, as well as viewing areas within the zone of potential inundation.

Issues related to sediment transport, accumulation and flushing are not dam safety matters and outside the scope of this assessment.

3.2 Relevant documents

The New Zealand Dam Safety Guidelines[1] (the NZSOLD guidelines) published by NZSOLD have been prepared by NZSOLD from technical bulletins published by the International Commission on Large Dams (ICOLD) and other internationally recognised references on dam engineering. As stated by NZSOLD, the NZSOLD guidelines outline appropriate practices that should be considered during the investigation, design, construction, commissioning, assessment, rehabilitation and operation of dams and canals in New Zealand. We consider the NZSOLD guidelines to be an appropriate reference and basis to inform assessment of aspects of the project within the scope of this memo. We have prepared this memo on this basis.

A range of key documents (as provided to us) and related correspondence are the basis of our work. Document of relevance are:

- Assessment of Environmental Effects Report and Resource Consent Application prepared for Rangitata Diversion Race Management Limited dated July 2016[2].
- Klondyke Storage Proposal Engineering Report prepared by MWH and dated August 2016[3].
- Klondyke Storage Proposal Dam Break Assessment prepared by MWH and dated August 2016[4].
- Klondyke Storage Proposal Construction Methodology Report prepared by MWH and dated August 2016[5].
- A spread sheet summarising uncertainties and information gaps from initial discussions with the applicant[6].
- Letter from MWH/Stantec "RDR Klondyke Storage - Dam Safety S92 Responses (Dam Break and Engineering)", 26 August and 1 September 2016.
- Email correspondence regarding potential loss of life and related matters[7].
- Letter from MWH/Stantec "RDR Klondyke Storage - Dam Safety S92 Responses", 8 March 2017.
- Klondyke Pond – Potential Failure Modes Assessment – spreadsheet produced and provided by Stantec[8].

[1] New Zealand Society on Large Dams; New Zealand Dam Safety Guidelines; May 2015.
[2] Ryder Consulting; Lake Klondyke: A Proposed Water Storage Facility, Assessment of Environmental Effects Report & Resource Consent Application, Prepared for the Rangitata Diversion Race Management Limited; July 2016.
[3] MWH; Klondyke Storage Proposal Engineering Report, Prepared for HOBEC on behalf of the Rangitata Diversion Race Management Ltd, Revision 4; August 2016.
[4] MWH; Klondyke Storage Proposal Dam Break Assessment, Prepared for HOBEC on behalf of the Rangitata Diversion Race Management Ltd, Revision 4; August 2016.
[5] MWH; Klondyke Storage Proposal Construction Methodology Report, Prepared for HOBEC on behalf of the Rangitata Diversion Race Management Ltd, Revision 5; August 2016.
[6] T+T Pers. Comm. Morris/Ford; FW: KLONDYKE; 24 February 2017. T+T Pers. Comm. Morris/Ball; 51344.012 RDR Klondyke; 2 August 2016. T+T Pers. Comm. Morris/Curry; 51344.012 RDR Klondyke; 2 August 2016.
[7] T+T Pers. Comm. Morris/Ball; FW: MWH Response; 1 September 2016.
[8] Stantec Pers. Comm. Woods/Morris; Klondyke Storage Potential Failure Modes Workshop; 8 November 2017.

- Draft Klondyke Water Storage Facility Dam Safety Management System completed by MWH/Stantec, Revision 4 issued as "Consultation Draft"; March 2017[9].
- Draft Klondyke Water Emergency Action Plan completed by MWH/Stantec, Revision 5 issued as "Consultation Draft"; March 2017[10].
- Draft Klondyke Water Storage Commissioning Plan completed by MWH/Stantec, Revision 4 issued as "Consultation Draft"; March 2017[11].
- Site specific seismic hazard assessment undertaken by GNS Science[12].
- Submissions on the consent application that ECan advise are relevant to the T+T scope of work. The submissions provided to T+T are from Early Family Trust, Mr J M Simpson and Rangitata Water Limited[13].
- Report prepared by Riley Consultants (Riley) regarding the proposed canal upgrade[14].

4 Project nature and scale

The project that the resource consent application relates to involves construction and operation of a High Potential Impact Category (PIC) dam adjacent to the Rangitata Diversion Race (RDR) and the Rangitata River. The proposal also involves work to upgrade the RDR canal from the existing Rangitata River Klondyke intake to the proposed dam in order to convey additional flow from the Rangitata River to the proposed reservoir. The canal subject to the proposed upgrade is assessed by the applicant as having a Low PIC.

The NZSOLD guidelines define PIC as the system of classifying dams according to the incremental consequences of dam failure, so that appropriate dam safety criteria can be applied. The term is described further in Section 6.1.

The proposed dam site is at the location where water for the Mayfield Hinds Irrigation Scheme is diverted from the RDR. The proposed dam is substantial. For example, the application states that it will store up to 53 Mm^3 (million cubic metres) of water to full supply (normal top water) level and feature earth embankments up to 6.25 km long and up to 30.50 m high. The reservoir foot print illustrated in the application is 286 ha.

Given the location of the proposed dam, potential effects arising from the proposal are proportional to the nature and scale, including the size, of the proposed dam storage. This section assesses the size of the proposed dam in comparison to other reservoirs in order to assist understanding potential effects.

By way of comparison, and in order to provide some context to the nature and scale of the proposed High PIC dam, the nearby Rangitata Water Limited (RWL) storage is reported to store 16.5 Mm^3 of water and have a maximum water depth of 8 m. The RWL storage is a very large irrigation dam, yet the proposed Klondyke dam will be three times deeper and store over three times the water volume.

[9] Stantec/MWH; Klondyke Water Storage Facility Dam Safety Management System, Prepared for Rangitata Diversion Race Management Limited, Revision 4 issued as "Consultation Draft"; March 2017.
[10] Stantec/MWH; Klondyke Water Emergency Action Plan completed by MWH/Stantec, Revision 5 issued as "Consultation Draft"; March 2017.
[11] Stantec/MWH; Klondyke Water Storage Commissioning Plan completed by MWH/Stantec, Revision 4 issued as "Consultation Draft"; March 2017.
[12] GNS Science; Seismic Hazard Assessment for the Klondyke Storage Pond, GNS Science Consultancy Report 2017/160; August 2017.
[13] T+T Pers. Comm. Todd/Morris; RDR consent review; 16 March 2017.
[14] Riley Consultants; Klondyke Water Storage Proposal - Canal Modification, Engineering report, Reference 11835/2-A, Revision 2.0; 14 July 2016.

The Opuha Water Limited web site indicates that Opuha Dam stores over 74 Mm^3, the same order of magnitude as the proposed 53 Mm^3 dam.

We consider that the references to the proposed dam as "Klondyke Pond" are a little misleading and has the potential for the scale of the proposal to be underestimated. For example, the international Ramsar wetland convention sets the upper limit for pond size as eight hectares, two orders of magnitude less than the area advised by the applicant.

The National Policy Statement (NPS) For Freshwater Management 2014, provides a definition for "Large Rivers and Lakes". In the case of a lake, the stated definition for a large lake is a body of water having a perimeter larger than 1.5 km. We are advised that the perimeter/embankment length of the proposed dam is 6.25 km, over four times that of the NPS definition of a large lake. We consider a lake to be larger than a pond.

We consider that in an international context, the KSD is a significant off river water storage dam (i.e. not directly filled by a natural water course/river). For example, Queen Mary reservoir near London is a very large well-known reservoir formed by earth embankments on all sides and filled by a diversion from the Thames River. This large dam has a capacity of 30.6 Mm^3, just over half that of the proposed dam.

In our opinion the very large size of the proposed dam, including in an international context, warrants that a complete and thorough application and assessment of potential effects be provided.

Accordingly, and in order to provide the correct project perspective, for the purposes of this memo the planned storage is referred to as the Klondyke Storage Dam (KSD).

5 Dam breach assessment

5.1 Proposed Klondyke Storage Dam

A dam breach assessment is a hypothetical assessment undertaken to inform understanding of the potential consequences of various dam break scenarios. A dam breach assessment is undertaken to:

- Identify the Potential Impact Category (PIC) to be assigned to a large dam.
- Inform emergency action planning.
- Identify potential effects on the environment arising from an uncontrolled release of a reservoir's stored contents.

The level of detail appropriate to a dam breach assessment should be appropriate to the nature and scale of the dam and the potential consequences downstream of the storage. A dam breach assessment identifies three parameters that may be subsequently used to select the PIC appropriate to a particular dam, inform emergency action planning and identify potential effects on the environment. The three parameters comprise:

- Population at Risk (PAR)
- Potential Loss of Life (PLL).
- Assessed damage level - generally taking account of damage to residential houses, damage to critical or major infrastructure, damage to the environment and community recovery time.

This section considers the applicant's assessment of these matters. The subsequent sections considers selection of the PIC using these data for the KSD and proposed canal upgrade.

The KSD dam breach assessment undertaken by the applicant is mostly described in the dam break assessment report produced by MWH[15].

We have considered this document and we have found that:

1 We consider that the applicant has mostly undertaken what NZSOLD refer to as a "*comprehensive assessment*" albeit that the suitability of the reported level of detail associated with the damage and loss estimate is open to debate as discussed below. We do not consider that a comprehensive assessment of PLL and downstream damages has been completed and we consider that this is normally part of a comprehensive assessment. We consider that a comprehensive level assessment, as described by NZSOLD, is appropriate in this instance given the very large size of the KSD.

2 Initial conditions adopted by the applicant for the analysis appear appropriate. The applicant initially considered two potential locations for hypothetical failure positions, referred to as the Southeast and West breach locations. Subsequently, following discussions with the applicant and further to the dam break report, a further scenario, referred to as the "East Embankment" case has been undertaken by the applicant. Other scenarios may also develop albeit that the cases reported may be considered adverse circumstances.

3 The applicant has considered sunny and rainy day cases. Estimates of breach parameters reported by the applicant, for example outflow hydrographs are stated to be in accordance with recognised references.

4 The applicant has undertaken two dimensional hydraulic modelling using proprietary Innovyze ICM software. Topographical data adopted for the assessment is described. Sensitivity analyses (see below) could be more complete albeit that further sensitivity analyses would not alter the adopted High PIC for the 53 Mm^3 reservoir described.

5 There is considerable uncertainty in PAR estimates described by MWH/Stantec. We consider it normal practice and in accordance with the NZSOLD guidelines to consider itinerants that may be in the area at the time of the hypothetical failure scenario. The dam break report does not appear to consider estimates of itinerant populations or individuals beyond dwellings within the estimated zone of potential inundation. For example, as indicated by MWH, there could also be contributions to the PAR from itinerants at locations outside of dwellings (farms, other businesses, road users, river users, etc.). Inclusion of an itinerant population would not alter the adopted High PIC. However, estimates of other potential effects, such as the potential loss of life, may rise from that reported if the PAR is increased to accommodate itinerants. Riley have considered itinerants for their PIC assessment of the canal upgrade. The canal upgrade works are of a much lesser scale than the KSD.

6 The dam break report does not consider numerical estimates for potential loss of life. The matter is addressed in qualitative terms only. The report merely states that consideration of PLL would not alter the adopted High PIC. While this point is agreed, we consider it appropriate to have a reasonable understanding of estimates of PLL in order to understand the scale of effects arising from the proposal and to inform emergency action planning.

7 Clarification of appropriate PLL estimates were sought from June 2016[16]. Subsequent to the dam break report MWH/Stantec have provided some high level advice in response to the request for this matter to be clarified. We would expect this to be to the extent recommended by the NZSOLD guidelines.

[15] MWH; Klondyke Storage Proposal Dam Break Assessment, Prepared for HOBEC on behalf of the Rangitata Diversion Race Management Ltd, Revision 4; August 2016.

[16] T+T Pers. Comm. Morris/Ford; FW: KLONDYKE; 24 February 2017. T+T Pers. Comm. Morris/Ball; 51344.012 RDR Klondyke; 2 August 2016. T+T Pers. Comm. Morris/Curry; 51344.012 RDR Klondyke; 2 August 2016.

8 The MWH/Stantec letters of 26 August and 2 September 2016 outline some estimates of PLL as follows:

- Southeast scenario: PLL approximately two individuals.
- West scenario: PLL approximately one individual.
- East scenario: PLL estimated by MWH/Stantec to be less than one individual.

We understand that the MWH/Stantec assessment is based on their assessment of individuals in dwellings, and does not consider the itinerant population at risk. We do not agree that this approach is in accordance with the NZSOLD Guidelines insofar as estimating the number of people at risk is concerned.

9 MWH/Stantec have estimated depth velocity (DV) parameters and used these estimates to assess PLL albeit that only individuals in dwellings have been considered. Other comments as outlined in our email of 1 September 2016[17] follow.

10 There has been some correspondence with MWH/Stantec regarding the hydraulic roughness of ground subject to potential inundation downstream of the dam used for the model. In this instance this is represented by the Manning's "n" value parameter. Lower n values may result in higher velocity flows. MWH/Stantec have adopted n = 0.06 as a base case and also looked at cases with n values of 0.03 and 0.09. We do not agree that n = 0.06 is necessarily an accurate middle estimate of this parameter. A slightly lower value may be prudent. For example, Chow[18] advises the following n values for different ground surfaces:

- Pasture n = 0.035.
- Field crops n = 0.040.
- Gravel bottom n = 0.033.
- Dense brush n = 0.070.

Others report similar values to Chow. MWH/Stantec advise that n = 0.090 is a more conservative assumption and provide comment on this basis. Based on Table 4-5 of the dam break report, indications are that n = 0.030 is actually a more conservative assumption in regard to DV. This is because the higher velocity estimates result in DV estimates increasing when the lower n value is used. MWH also advise "*In summary the area of inundation and assessment of population at risk and damage are substantially the same regardless of the assumed roughness value*". While we agree with this statement insofar PIC is concerned, this statement does not refer to PLL or mention uncertainty in DV associated with n values. PLL is related to DV, and DV appears to increase, at least in some locations for lower n values. The fatality rate adopted by MWH/Stantec is quite sensitive to DV at low DV values. We consider that this matter is cause for further uncertainty in the MWH/Stantec PLL estimates.

11 The DV estimates have been overlaid by MWH/Stantec on aerial photographs albeit at a very coarse scale. We consider that the scale of the figures illustrating the DV assessment to be too coarse at locations of interest where the DV infers a higher fatality rate (e.g. area shown in orange, area north west of mentioned Cracroft Maron Road, location where DV = 70 ft^2/s (or 6.6 m^2/s), 33 locations of interest associated with the south east scenario). We consider that this scale is not fine enough at key locations to enable a reasonable interpretation of the DV risk arising from the scenarios modelled. In other words, due to the scale of the DV map, it is harder for a downstream landowner or occupier to identify whether and/or how they could be affected and what impact a potential dam break might have on them and/or their property. than if the mapping in key areas was at a finer scale.

[17] T+T Pers. Comm. Morris/Ball; FW: MWH Response; 1 September 2016.
[18] Chow et. al.; Applied Hydrology; McGraw Hill 1980.

12 It is not possible to readily reconcile the locations of interest with the associated PLL estimate. For example, with the south east scenario, the PLL estimate of 2 cannot be easily reconciled to specific locations (at one location inferred PLL estimate = 0.3 x 2.5 = 0.75 compared to average fatality rate of 2/80 = 0.025). It would be useful for a table that sets out at each of the 33 locations the address, DV, PAR, fatality rate as a function of DV and contribution to PLL. Also, mention of the overall limit in the context of a sensitivity analysis would be useful.

13 The PLL estimate excludes itinerants within the zone of potential inundation - the assessment of PLL may therefore be optimistic. Consideration of itinerants does not necessarily require detailed modelling. It is our view that good practice would include appropriate and reasonable consideration of these individuals. Subject to the circumstances it could be misleading to exclude this group. For example, NZSOLD 2015 indicates that the PAR and PLL estimates should take into consideration permanent and itinerant populations, any warning that may be possible, and the ability of people to evacuate the affected area. Also, the PLL appears to be based on the Document "*Guidelines for Estimating Life Loss for Dam Safety Risk Analysis*" published by Reclamation[19] and referenced by NZSOLD. This uses PAR as the basis to estimate PLL and defines PAR as "*Those people present in the inundation flood zone prior to dam failure. The PAR may include permanent residents and transient individuals such as recreationists, or travellers in autos, buses, etc.*". The March 2017 MWH/Stantec letter refers to a "*range*" of PLL estimates. We consider it appropriate for estimates of a range of scenarios to take account of itinerants.

14 If required to consider potential effects, the base data seems to be available for the applicant to refine PLL estimates as a result of each of the potential dam breach scenarios.

15 What are referred to in the MWH/Stantec discussion associated with the PLL estimate as high, medium and low "risk" are not risks as such. These are more like a probability of the impact/harm arising from the event; the risk would also take account of probability of individuals in the area and the probability of the event.

16 No large dam is risk free and there are recognised limits as to what may be considered an acceptable or tolerable risk, both to society and individuals. In order to understand potential effects from the proposal it may be appropriate to compare risk based PLL estimates to these criteria. It is open to debate if a quantitative risk assessment is necessary. We understand that this was undertaken as part of the initial Central Plains Water resource consent application.

17 MWH/Stantec have indicated that they do not see value in undertaking a quantitative risk assessment. We agree with MWH/Stantec that in this instance, refinement of the PLL estimate will not alter the High PIC that they have adopted. However, there does not appear to be agreement on the matter of refining the PLL estimates in order to better understand potential effects associated with the KSD i.e. the appropriate number of individuals to include in the PLL estimate insofar as assessing effects from the KSD is concerned. For example to take account of itinerants.

18 The NZSOLD guidelines require that the assessed damage level associated with a hypothetical dam break scenario is assessed. The assessed damage level takes account of damage to residential houses, damage to critical or major infrastructure, damage to the environment and community recovery time. MWH have assessed the damage level arising from a hypothetical dam break scenario to be Catastrophic to Major. Reproduced below in Table 2 is Table 2.2 from the NZSOLD guidelines outlining the basis of the Major and Catastrophic damage levels. Whilst we agree that the damage level associated with a dam break event could be Major or

[19] U.S. Department of the Interior Bureau of Reclamation; RCEM – Reclamation Consequence Estimating Methodology, Interim, Guidelines for Estimating Life Loss for Dam Safety Risk Analysis; February 2014.

Catastrophic, the level of detail exploring these potential effects is relatively light. For example, the potential impact on the Rangitata Water Limited ponds downstream of the KSD, as discussed in Section 13.3 following.

Table 2 Determination of assessed damage level

Damage level	Specified categories				
	Residential	Critical or major infrastructure		Natural environment	Community Recovery time
		Damage	Time to restore to operation		
Catastrophic	More than 50 houses destroyed	Extensive and widespread destruction of and damage to several major infrastructure components.	More than 1 year	Extensive and widespread damage	Many years
Major	4-49 houses destroyed and a number of houses damaged	Extensive destruction of and damage to more than 1 major infrastructure component.	Up to 12 months	Heavy damage and costly restoration	Years
Moderate	One to three houses destroyed and some damaged	Minor damage to major infrastructure components	Up to one week	Short-term damage	Days to weeks
Minimal	Minor damage	Minimal Minor damage to major infrastructure components	Up to one week	Short-term damage	Days to weeks

5.2 Canal upgrade

The dam breach assessment undertaken by the applicant pertaining to the proposed canal upgrade is described in the engineering report produced by Riley[20]. We have considered this document and we have found that:

1 The applicant has mostly undertaken what NZSOLD refer to as an "*initial assessment*" of the potential effects of a dam break scenario. An initial dam break hazard and consequences assessment is considered appropriate by the NZSOLD guidelines for a Low PIC dam (see Section 6.3)

2 Indications are that the assessment has taken account of itinerants. For example, the Riley assessment refers to "*farm workers tending to their normal farming duties and fishermen on the banks of the Rangitata River*".

3 Riley advice is that they have taken account of residential dwellings and they advise that it is unlikely that the inundation area would include residences.

4 Riley advise the following based on their initial level assessment:

- The PAR is in the range of 1 to 10.
- It is not highly likely that a life would be lost.

[20] Riley Consultants; Klondyke Water Storage Proposal - Canal Modification, Engineering report, Reference 11835/2-A, Revision 2.0; 14 July 2016.

– The assessed dam level is Moderate (refer Table 2 above).

5 The canal dam breach assessment does not consider potential scenarios that may eventuate in the RDR downstream of the KSD. Refer to Section 7 following for further discussion. The application acknowledges that in rare circumstances there is the potential for up to 40.7 m^3/s in the RDR beyond the KSD, 10 m^3/s greater than the advised 30.7 m^3/s capacity. Some freeboard above the 30.7 m^3/s flow is expected. The applicant has suggested that the flow could be contained within the freeboard of the existing canal, but acknowledged that further detailed checks are warranted to confirm this as described in Section 7. The checks suggested by MWH/Stantec should consider the potential for additional dam break scenarios associated with flows beyond the KSD greater than presently occur.

6 Dam potential impact classification

6.1 General

The NZSOLD guidelines define the PIC as the system of classifying dams according to the incremental consequences of dam failure, so that appropriate dam safety criteria can be applied. For example standards for investigation, design, construction, review, commissioning and operation.

The NZSOLD guidelines require the PIC to be assessed as a function of PAR, PLL and the assessed damage level. The PIC may be either Low, Medium or High. The NZSOLD guidelines also state that a dam's classification is purely a function of the consequences of a hypothetical failure breach or other uncontrolled release of the stored contents. It has no correlation with the probability of the dam failing or experiencing a dam safety incident. It is important to recognise that a High PIC does not mean a high likelihood of failure. Generally, because of the high consequences of an event, the probability of a High PIC dam break occurring should, so long as appropriate standards have been adopted and implemented, be very low because of the high performance standards appropriate to a High PIC structure.

6.2 Dam

The application states that the adopted PIC for the KSD is High. We consider this conclusion to be valid irrespective of the present uncertainty in the MWH/Stantec estimates of PAR and PLL. Some example design standards appropriate to a High PIC dam include (but are not limited to):

- Ongoing independent peer review input throughout the project (for example design and construction phases) by an appropriately skilled and experienced peer reviewer).
- The use of appropriate redundancy in arrangements, for example a back up to the proposed membrane liner, should the primary liner become compromised.
- Use of appropriate earth materials for embankment construction that are internally stable and filter compatible with adjacent materials.
- Selection of appropriate reservoir freeboard.
- Appropriate provisions for reservoir dewatering.
- Appropriate and thorough construction observation.
- Comprehensive dam surveillance procedures including regular ongoing Intermediate and Comprehensive Dam Safety Reviews.

We consider that it very important that all appropriate High PIC design and performance standards are adopted for the KSD if consent is granted.

6.3 Canal upgrade

Riley advise the following based on an "*initial*" level assessment of an uncontrolled flow release from the upgraded canal section:

- The assessed PIC for the RDR embankment subject to the upgrade is Low.
- The assessed PIC for each of the appurtenant structures is Low.

An initial dam break hazard and consequences assessment is considered by the NZSOLD guidelines appropriate for a Low PIC dam. It is important that all aspects of the canal upgrade works are undertaken in accordance with the appropriate PIC.

7 Design standards proposed by the applicant for the dam and canal upgrade works

The NZSOLD guidelines recommend different standards for the different PICs to account for the varying consequences of an uncontrolled release of the dams stored contents. The NZSOLD guidelines consider adoption of High PIC design and performance standards to be appropriate mitigation for the potential hazard posed by a large High PIC dam such as the KSD. The High PIC is, as far as the NZSOLD guidelines are concerned, the PIC with the greatest consequences of an uncontrolled release of a dams stored contents. Example requirements appropriate to a High PIC include (but are not limited to):

- Adoption of a an Inflow Design Flood in the range of a 1 in 10,000 year average recurrence interval flood to a probable maximum flood.
- Adoption of the 1 in 10,000 year average recurrence interval ground motion (earthquake) for the Safety Evaluation Earthquake (SEE) if developed by a probabilistic approach.
- Ongoing peer review input throughout the project (for example design and construction phases) by an appropriately skilled and experienced peer reviewer).

The application states that MWH/Stantec have "*identified the Klondyke storage pond as a High potential impact classification dam, therefore requiring the highest standards of design, construction and operation to be applied*"[21]. We agree that this approach is appropriate should consent for the KSD be granted.

Some thoughts on aspects of the present preliminary stage design are discussed below:

1 The applicant has proposed a rock lined channel to convey flow releases from the KSD to the Rangitata River e.g. spillway and flushing flows. Potential flow rates are large, for example 70 m^3/s based on the application (Drawing C202). The proposed channel is hydraulically steep, a 9 % gradient is mentioned by the applicant. High flows down a steep slope could result in high energy flows with large velocities and significant scour potential. Rock armour/rip rap to accommodate these conditions would most likely need to be large (in terms of overall quantity and size of individual boulders). Detailing would be critical for appropriate performance to be achieved. Steep rock lined channels can be problematic and are often considered risky, particularly if flows are sustained. Rock lined spillway channels are more commonly associated with lower PIC structures and it is relatively unusual for a rock lined spillway channel to be associated with a High PIC dam. Nonetheless, it is acknowledged that in principle a structure of this nature could be designed and built, so long as appropriate materials are to hand. However, at this stage the applicant has not yet demonstrated that the

[21] MWH; Klondyke Storage Proposal Engineering Report, Prepared for HOBEC on behalf of the Rangitata Diversion Race Management Ltd, Revision 4; August 2016.

channel can accommodate the required flows. If consent is granted it is important that this matter is appropriately addressed during the various project stages.

2 Indications are that the spillway gully has been formed by overland flow. It is important that design and construction activities associated with this area take account of overland flow concentrating at this location.

3 It is very important that the KSD includes sufficient freeboard or height above water level to the crest to accommodate wave action, both during normal and flood events. There was some uncertainty with the initial information provided to T+T about available freeboard. It is very important that the KSD design includes provision for adequate freeboard. It is also very important that the design adopts appropriate site specific wind velocity parameters to accommodate the KSD location close to the Rangitata Gorge.

4 The NZSOLD guidelines recommend that conduits within a High PIC dam embankment are not under pressure and have upstream control. Provisions for upstream control were not immediately obvious in the information provided to T+T. However, subsequent preliminary design stage drawings now illustrate upstream control gates. It is also important that the conduits through the KSD are designed and constructed so that open channel flow conditions exist within the conduits. Also, that arrangements can accommodate potential abrasion from flow with high sediment concentrations, including in the area of the liner interface.

5 There is a large terrace riser next to the Rangitata River adjacent to the KSD which is reported to be approximately 30 m high. The application states that from 1962 the top of the terrace appears to have been eroded by the river by between 20 m to 50 m towards the KSD. The application proposes locating the KSD at least 100 m away from the current terrace edge. The matter of the proximity of the KSD to the Rangitata River has also been raised by Mr Simpson who advises that a 40 m wide strip of land was lost to the river in 1994. The buffer is to facilitate stability works in the future, should these be necessary.

6 If consent is granted, we recommend that all Intermediate and Comprehensive Dam Safety Review assessment reports include a review of the terrace stability and actual and potential retreat associated with river erosion. It is important that this work clearly outlines potential requirements for river engineering/terrace stability works should they be necessary. It is important that the potential requirements (e.g. extent and timing) for any necessary river engineering/terrace stability works are identified in advance to enable the necessary works to be approved and the work undertaken within the required timeframe.

7 While in principle this approach to potential river movement is not unreasonable from an engineering perspective, it is important that planning matters are appropriately considered now. A significant dam safety issue may arise if engineering works were required but not able to be undertaken because of future consent issues. For example, we are unclear on the potential activity status of future work and what implications/limitations on river works may arise from the Water Conservation (Rangitata River) Order 2006. There may also be other factors that could impact on this work such as availability of materials and contractor resources, and possibly funding issues. It is recommended that ECan consider these matters now as appropriate.

8 Viewpoint simulations prepared by Beca appear to show the outside slopes grassed or otherwise vegetated as they are shown in a green colour. The MWH drawings nominate the outside slopes as 3H:1V (horizontal to vertical ratio). It is important that vegetation on the embankment is kept short to help identify potential dam safety issues. The Christchurch City Council Waterways, Wetlands and Drainage Guide (WWDG) recommend slopes 4H:1V and flatter if mowing is required. A 3H:1V slope is approximately 30 % steeper than a 4H:1V slope. The proposed 3H:1V slope may be too steep to safely maintain if planted/grassed. A possible consent condition proposed by the applicant appears to provide for a gravelled surface (e.g. similar to Opuha Dam). However, this appears inconsistent with the provided view point

simulations. Also, the provided draft Dam Safety Management System documentation states that grass coverage across the dam embankment shall be kept short, which may be difficult based on the CCC criterion.

9 The proposal includes a flexible membrane liner, the details of which are yet to be determined by the applicant. The present conceptual arrangement is incomplete. It is important that the liner design and construction are in accordance with appropriate standards such as the NZSOLD guidelines and referenced documents such as ICOLD Bulletin 135.

10 It is important that all aspects of the canal upgrade works, including relevant appurtenant structures, are undertaken in accordance with the appropriate PIC, advised as Low by the Applicant.

11 The application includes assessment of flow in the RDR canal from the intake to the KSD. Proposed flows are up to 40.7 m^3/s, 10 m^3/s greater than the advised 30.7 m^3/s canal capacity downstream of the sand trap. It is conceivable that there may be rare events whereby the flow in the canal downstream of the KSD may be 40.7 m^3/s. For example MWH/Stantec advise "*The case where 40.7 m^3/s is required to be conveyed down the RDR from the storage location (Klondyke corner) is extreme, and would be from an unexpected failure of the gate control into the storage*". MWH Stantec advise that flow could be contained within the freeboard of the existing canal, subject to detailed checks. It is important that these checks are completed and any other associated work identified and appropriately implemented. The checks should also take account of the RDR side spill structures as appropriate, for example the syphonic spillway discharging to the Hinds River South Branch.

12 The applicant has indicated that the maximum proposed flushing flow release to remove sediment from the KSD is 40.7 m^3/s. Issues related to sediment transport, accumulation and flushing are not dam safety matters and outside the scope of this assessment. It is understood that the maximum flushing flow rate from the existing sand trap was 70 m^3/s. On this basis the 40.7 m^3/s flow rate appears low relative to our understanding of flushing flows from a smaller area. It is suggested that these matters are considered as appropriate by the applicable party. From a dam safety perspective it is important that appurtenant structures are sized to accommodate appropriate flows.

Section 3.2 of the NZSOLD guidelines make reference to the RMA and states:

> *"In the RMA consent process the applicant needs to demonstrate that the design, construction and operation practices for the dam will address hazards that have the potential to impact on the environment. Hazards may be natural hazards such as earthquakes or floods, construction hazards such as poor materials, or operational hazards such as sudden changes in river flow. Typical design, construction and operation issues that need to be addressed in consent application documents include:*
>
> - *The site topography and how the dam will fit into or modify the topography.*
> - *The regional and local geology which greatly influences structural safety, water retention and reservoir slope integrity.*
> - *The proposed construction materials and dam arrangements to ensure safety during construction and operation.*
> - *The flood risks at the dam and how floods are managed and passed through the structure during construction and operation.*
> - *The seismic risks and earthquake loads which the dam, with its stored contents, and the reservoir shoreline may experience.*
> - *The surveillance, maintenance and operational procedures to ensure safe operation of the dam.*

- *Strategies for the management of other risks such as wind, slope stability upstream of the reservoir, and human error in design, construction, and operation of the project.*
- *The downstream effects of a potential dam failure and strategies for emergency management should the integrity of the dam be in doubt.*

For new dams, detailed design is usually not complete at the resource consent stage. Accordingly, the information presented for RMA consents must demonstrate that the hazards are manageable and appropriate."

The NZSOLD guidelines consider that adoption of High PIC standards to be appropriate mitigation for a High PIC dam. These standards are considered stringent and the likelihood of a dam safety incident occurring is low if High PIC standards are appropriately implemented. While the design documentation that we have sighted is still at a preliminary stage, the application has generally addressed the points listed above albeit at a very high and conceptual level. Notwithstanding, as discussed above the NZSOLD guidelines recommend that the consent application considers "*The downstream effects of a potential dam failure and strategies for emergency management should the integrity of the dam be in doubt*". While the High PIC is appropriate, there remains some uncertainty in the PAR, PLL and damage estimate which is required to assess the effect of the hazards posed by the KSD.

8 Site specific seismic hazard assessment

A site specific seismic hazard assessment is an important study used to understand and select the appropriate parameters for design, including the Safety Evaluation Earthquake (SEE). The SEE is an extreme event that the dam must be able to withstand without an uncontrolled release of the reservoirs stored contents. The NZSOLD guidelines state that the dam should be designed or analysed for the SEE and for a High PIC dam the SEE need not exceed the 1 in 10,000 AEP ground motion developed by a probabilistic approach.

We have read the updated and revised site specific seismic hazard assessment completed by GNS Science (GNS)[22] and we have found that in regard to this resource consent stage assessment provided to us:

1 Earlier reporting refers to potential fault locations close to the dam and further clarification of this matter was previously suggested. GNS now advise that located approximately 1 km south east of the proposed dam is an area that they have interpreted to be ground warping associated with ruptures on the Hutt Peel fault source over about the past 18,000 years. It is suggested that detailed design stage checks include consideration of outwash surface slopes/anomalies across the site area, based on detailed survey/LiDAR. Also, a sensitivity check is suggested to look at the amount of ground tilt required to get overtopping of the dam when the reservoir is full, or the amount of direct offset. This should be reconciled to relevant fault parameters.

2 We had previously observed that GNS had only considered a single ground motion prediction equation (GMPE) whereas good practice involves consideration of epistemic uncertainty (including recommendations as set out in the NZSOLD guidelines). Epistemic uncertainty previously associated with the use of a single dated ground motion GMPE has now been considered by using a weighted average of multiple GMPEs.

3 For the shallow active earthquake sources, five GMPE equations have been used, comprising three NGA-West2 GMPEs as well as the NZ Bradley (2013) and McVerry (2006) GMPEs. The

[22] GNS Science; Seismic Hazard Assessment for the Klondyke Storage Pond, GNS Science Consultancy Report 2017/160; August 2017.

GMPEs are considered appropriate. GNS have assigned weightings to the different GMPEs used.

4 A 'default' $V_{s,30}$ value of 250 m/s has been adopted by GNS. The report states that the actual $V_{s,30}$ may be higher and as a result the spectra may be conservative and therefore the peak ground acceleration (PGA) values slightly underestimated. It is not clear if a sensitivity analysis on the range of plausible $V_{s,30}$ values has been considered. If the appropriate sensitivity analysis is yet to be undertaken, it is appropriate that this matter is resolved at the project detailed design stage.

5 Spectra are presented for the "*Larger horizontal component*" of ground motion to be consistent with NZS1170.5. However NZS1170.5 was developed for more conventional commercial buildings and excludes dams and other civil engineering structures from its scope. There is some uncertainty as to whether this definition of spectral acceleration is appropriate for the KSD. That is, it is possible that the "*Maximum component*" or "*Median component*" could be more appropriate. For example, we have observed that there is about a twenty percent difference across the values. Either way, it is useful the report explicitly states which definition has been used. It is critical that whoever uses these spectra for design understands the definition used and how it relates to the various design analyses.

6 Near-fault factors do not appear to have been considered. Near-fault effects are small for PGA and short spectral periods and so are unlikely to affect the ground motion hazard for the embankment (assuming it has a period less than about 0.5 s). However, they have the potential to be important for structures with longer periods e.g. possibly some appurtenant structures. It is very important that near fault factors are considered at the detailed design stage.

7 Previously we had mentioned that it may be necessary for the site specific seismic hazard analysis for this High Potential Impact Category (PIC) dam to include recommendations regarding acceleration time history records relevant to the site and proposed design standards and arrangements (possibly for design of appurtenant structures and/or the embankment). The NZSOLD Guidelines also refer to a potential requirement for a site specific seismic hazard analysis for High PIC dams to include advice relating to appropriate acceleration time history records. The updated site specific seismic hazard analysis does not appear to address this matter (recognising that it is unclear at this stage to what extent this design stage analysis will be required).

8 Comparison of the latest PGA estimates for the site to those reported by GNS in June 2014 indicates an increase in PGA values across all return period events.

We consider that the August 2017 GNS site specific seismic hazard assessment is appropriate to provide a perspective on seismic hazards relevant to the project for the project resource consent stage. A number of matters may require further work as part of detailed design.

9 Identification of credible Potential Failure Modes

The NZSOLD guidelines recommend that a Failure Modes and Effects Analysis (FMEA) is undertaken during the design of any new Medium or High PIC dam. MWH have recommended a High PIC for the KSD.

The NZSOLD guidelines provide for the findings and understandings developed from the completion of the FMEA to be used to refine the dam design to address the identified potential failure modes. The purpose is to minimise the potential for failure mode development through the addition of risk reduction resilience. The FMEA outcomes can also be utilised to establish the surveillance and monitoring procedures for the dam.

The NZSOLD guidelines indicate that an FMEA is best completed in a facilitated workshop environment, attended by representatives of the Owner and Designer, and peer reviewers with relevant knowledge of the dam site characteristics and the proposed design.

The workshop should result in an enhanced understanding of the key vulnerabilities of the dam and surveillance requirements to provide early warnings of the development of the potential failure modes.

An FMEA workshop was held on 6 November 2017 based on preliminary stage design information, generally as reported by Stantec[23]. The workshop was facilitated by Mr Tony Pickford and attended by individuals from RDRML and Stantec. Also, a T+T representative attended in an observer capacity. The potential failure modes discussed at the workshop are appropriate given the project stage.

NZSOLD recommend that peer review input contributes to the workshop. We understand that Mr Tony Pickford attended as the facilitator and not necessarily as a peer reviewer. The design of the High PIC KSD will require peer review input and it is important that the peer reviewer contributes to and approves the FMEA process at the appropriate time.

It is important that workshop outcomes are used to inform the design as required and as intended by NZSOLD. It is also important that the FMEA is updated as may be required during the project investigation and design phases as necessary. This is acknowledged by the applicant and the draft Dam Safety Management System states that potential failure modes will be confirmed during detailed design. For example to take account of investigation data, to reflect refinements to the KSD that may arise from reservoir size changes and to take account of peer review input.

10 Construction methodology proposed by the applicant for the dam and canal upgrade as relates to dam safety matters

10.1 KSD construction

A report titled "*Klondyke Storage Proposal Construction Methodology Report*" has been provided outlining a plausible approach to construction[24]. This outlines at a high level how construction could proceed. It is important to appreciate that different constructors have access to different resources and will have different approaches to the project. Also, it is understood that the applicant may wish to pursue a storage smaller than 53 Mm^3. Therefore, it is important to appreciate that there is uncertainty in the described approach. For example, plant resources required, sequencing and programme.

The focus of this assessment is dam engineering and the construction methodology report is light on detail regarding these important matters. It is critical that construction and commissioning are undertaken with engineering input appropriate for a large High PIC dam. For example, as outlined in the NZSOLD guidelines a High PIC dam.

Among other considerations, project success will rely on appropriate arrangements and sequencing to deal with flow in the RDR and Mayfield Hinds Irrigation race during construction. Management of the works in the vicinity of the RDR is of particular significance. Conceptual arrangements to address these matters are described by the applicant at a very high level only. At this stage the specifics of how these interfaces will be safely addressed remain unclear albeit these details are not necessarily critical information at this early project stage. It is important that design and construction stage

[23] Stantec Pers. Comm. Woods/Morris; Klondyke Storage Potential Failure Modes Workshop; 8 November 2017.
[24] MWH; Klondyke Storage Proposal Construction Methodology Report, Prepared for HOBEC on behalf of the Rangitata Diversion Race Management Ltd, Revision 5; August 2016.

work takes appropriate account of these matters. In principle, these matters can be addressed so long as there is appropriate engineering input.

It is acknowledged that at this point it is likely difficult for the applicant to provide detailed information on construction stage matters to resolve present uncertainty. Nonetheless, it is considered that these matters of a dam engineering nature could be addressed by resource consent condition. For example, stipulating that construction and commissioning is in accordance with the NZSOLD guidelines for a High PIC dam. This would address matters such as:

- The appropriate level of construction observation and designer input.
- Construction and commissioning stage peer review input.
- Diversion, sequencing and staging.
- Appropriate level of constructor skill and expertise.
- The appropriate level of quality assurance testing.
- Appropriate plans and procedures for commissioning including an appropriate level of commissioning stage surveillance.

This assessment is limited to matters related to dam engineering. Many matters discussed in the construction methodology report, for example matters related to traffic, erosion and sediment control, waste, health and safety, environmental matters, as well as noise and dust are beyond the scope of this assessment.

10.2 Canal upgrade

The Preliminary Engineering Report completed by Riley has been provided outlining a possible approach to construction[25]. This outlines at a high level how construction could proceed. It is important to appreciate that different constructors have access to different resources and will have different approaches to the project.

Riley's advice is that the canal will be in full service whilst some of the works are undertaken, and no de-watering of the canal will be required for these components. In other areas (Riley cross section 5), the canal will need to be dewatered for approximately two to six weeks to allow access for construction machinery. It is very important that the work is well planned and appropriately executed because most of the work is being undertaken in close proximity to an operative canal.

10.3 Commissioning

A report titled "*Klondyke Water Storage Commissioning Plan*" completed by MWH/Stantec has been provided outlining a draft to approach to commissioning[26].

It is important that commissioning is in accordance with the appropriate procedures pertaining to PIC as outlined in the NZSOLD guidelines.

The draft commissioning plan for the KSD is generally in accordance with the NZSOLD guidelines for a High PIC dam. It is important that the completed commissioning plan is in accordance with the NZSOLD guidelines. Example requirements include:

- Prerequisites and signoffs required prior to the commencement of construction.
- A suitable dam surveillance regime.

[25] Riley Consultants; Klondyke Water Storage Proposal - Canal Modification, Engineering report, Reference 11835/2-A, Revision 2.0; 14 July 2016.
[26] Stantec/MWH; Klondyke Water Storage Commissioning Plan completed by MWH/Stantec, Revision 4 issued as "Consultation Draft"; March 2017.

- Appropriate level of designer input.
- Appropriate level of peer review input.
- Suitable hold points.
- Appropriate contingency measures and plans in the event of untoward performance.
- Measures for dry and wet commissioning of appurtenant structures.
- Commissioning procedures for canal upgrade works.

11 Dam Safety Management

It is very important that a High PIC dam has an appropriate Dam Safety Management System (DSMS), and that the plan is thoroughly understood and appropriately implement by RDRML.

Module 5 of the NZSOLD guidelines outlines a range of DSMS criteria that should be addressed by DSMS documentation. The level of documentation recommended is related to PIC. In the case of the KSD, it is important that the guidance for High PIC dams is followed.

The application acknowledges that a DSMS is required and that the DSMS should be in accordance with the NZSOLD guidelines. We have been provided with a document titled "*Klondyke Water Storage Facility, Dam Safety Management System*"[27]. The status of this document is stated to be "*Consultation Draft*". While the March 2017 draft is incomplete e.g. because the design is incomplete, it is generally in accordance with the NZSOLD guidance albeit that further work is required to complete the DSMS prior to it being suitable to issue as an operative document. This is not necessarily unusual as the design information we have seen is incomplete. Some comments follow regarding example areas where further work is required.

Section 7 of the DSMS report addresses requirements for an Intermediate Dam Safety Review (IDSW) process. We agree that IDSR assessments are required and recommend that these are undertaken at least annually. We suggest that IDSR reports are provided to ECan.

We also recommend that Comprehensive Dam Safety Reviews are completed in accordance with the NZSOLD guidelines and the draft DSMS. We suggest that CDSR reports are provided to ECan. This matter has also been raised by the Early Family Trust, refer also Section 13.2 following.

The building consent process does not provide an effective means to address matters related to DSMS documentation subsequent to issue of a code compliance certificate. It is important that if consent is granted that the present draft DSMS documentation is developed to accommodate the final design. We recommend that there are resource consent conditions stipulating that this is the case. We also recommend that from time to time DSMS documentation is reviewed and updated as proposed by the applicant and that these matters are also addressed by resource consent conditions.

DSMS documentation is also required for the upgraded canal albeit that the requirements should suit the Low PIC.

12 Emergency preparedness

The EAP forms part of the DSMS discussed above. It is very important that a High PIC dam has an appropriate Emergency Action Plan (EAP), and in the unlikely event that it is necessary to implement the plan, that the plan can be implemented as expected. For example, that the necessary relationships between the parties exist so that any response can be effective.

[27]Stantec/MWH; Klondyke Water Storage Facility Dam Safety Management System, Prepared for Rangitata Diversion Race Management Limited, Revision 4 issued as "Consultation Draft"; March 2017.

Module 6 of the NZSOLD guidelines outlines a range of EAP criteria that should be addressed by EAP documentation. The level of documentation recommended is related to PIC. In the case of the KSD, it is important that the guidance for High PIC dams is followed.

The application acknowledges that an EAP is required and that the EAP should be in accordance with the NZSOLD guidelines. We have been provided with a document titled "*Klondyke Water Storage Facility, Emergency Action Plan*"[28]. The status of this document is stated to be "*Consultation Draft*". While the March 2017 draft is incomplete e.g. Appendix G and inundation mapping as discussed below, it is generally in accordance with the NZSOLD guidance albeit that further work is required to complete the EAP prior to it being suitable to issue as an operative document. Inundation mapping aside, this is not necessarily unusual as the design information we have seen is incomplete. Some comments follow regarding example areas where further work is required.

Section 5 above comments on what we consider to be high level potential inundation mapping. The NZSOLD Guidelines state the following regarding inundation mapping suitable for inclusion in an EAP document:

> *"Dam break inundation maps should be included or referred to in all EAPs prepared for Medium and High PIC dams. They should show inundation areas at scales sufficient for the identification of areas at risk and should include inundation tables which show at key locations:*
>
> - *The arrival time of the first flood waters.*
> - *The arrival time of the peak flood level.*
> - *The peak flood elevation above mean sea level.*
>
> *It may also be useful to express flood levels as relative depths at key locations (eg bridges) and the time at which key structures may become unusable.*

Inundation mapping included in Appendix B of the draft EAP indicates that the depth of potential inundation may exceed 2 m near the dam. A potential effect that is clearly significant. However, we consider that based on present draft EAP mapping, it is difficult to determine what may happen at particular locations.

It is our view that the provided mapping does not contain all the data recommended by NZSOLD e.g. arrival times are not referenced to "*key locations*" such as significant roads, intersections or other key sites. It is our view that the present quality of mapping should be improved. It is appreciated that the document is in draft form, and it is recommended that inundation mapping included in further editions of the EAP is in accordance with the NZSOLD guidelines. Also, inundation mapping will alter if the applicant pursues a smaller storage volume. That is, it is acknowledged that there may be an opportunity for the appropriate level of mapping to be completed later, so long as there is an appropriate consent condition to ensure that this occurs as may be required, e.g. to inform emergency action planning.

Appendix D of the draft EAP contains a Property Owner Summary List, stated to be a "*list of unique owners affected by inundation of greater than 1 m from either the southeast breach or the west breach (east breach owners to be added)*". We comments follows regarding this list:

1 It is unclear why the 1 m parameter has been adopted. NZSOLD define the zone of potential inundation as the area where the depth of inundation may exceed 0.5m, half of that adopted by the applicant.

[28] Stantec/MWH; Klondyke Water Storage Facility, Emergency Action Plan, Revision 5 issued as "Consultation Draft"; March 2017.

2 It is suggested that the extent of properties included in the contact list relate to physical features that would promote quick and effective evacuation e.g. all properties west of a given road.

3 At this stage the list of properties is not related to inundation mapping. For example the Appendix D property number is not illustrated on inundation mapping.

4 We also recommend that properties are ranked based on the potential arrival time, velocity and depth of inundation.

5 It is important that there are contacts for occupiers as well as owners e.g. there is a reference to an address in Avonhead, Christchurch and potential Appendix C contacts too.

Table 5.1 includes primary contact details for key downstream locations such as large dam infrastructure downstream of the KSD. The details are incomplete.

The draft EAP includes what are referred to as consent conditions. Comments on potential conditions, including EAP related conditions are contained in Section 14 below.

The building consent process does not provide an effective means to address matters related to EAP documentation. It is important that if consent is granted that the present draft EAP documentation is developed to accommodate the final design. We recommend that there are resource consent conditions stipulating that this is the case. We also recommend that from time to time EAP documentation is appropriately tested.

13 Submissions

13.1 General concerns raised by submitters

We have read the submissions provided to us from Early Family Trust, Rangitata Water Limited and Mr. J M Simpson. The following is a brief summary of submissions provided to T+T in relation to the water storage proposal:

- Potential dam breach causing potential loss of life and potential property damage.
- The thoroughness of assessments undertaken by the applicant.
- The applicants' assessment of earthquake risk does not evaluate all fault lines. Concerns about earthquakes on nearby fault lines causing damage to the KSD.
- The storage lake poses a threat if it breaches.
- Ensure the complete nature of the dam monitoring conditions (including both regularity and thoroughness).

We understand that matters raised in the submissions such as costs, insurance, compensation and bond will be addressed separately by ECan.

Comments on matters raised by submitters within the scope of this memo are outlined in the following sections.

13.2 Submission of the Early Family Trust

Some key points raised in the Early Family Trust submission (the Early submission) within the scope of this memo are considered below:

1 The Early submission questions the assessment of seismic hazard (paragraph 2.7). The Early submission is dated 30 September 2016. We consider that the updated Site Specific Seismic Hazard Assessment undertaken by GNS dated August 2017 is in accordance with industry practice to investigate the site seismic hazard as described in Sections 8 above for a resource consent stage assessment.

2 The Early submission questions the Site Specific Seismic Hazard Assessment and dambreak assessment interface. The dam break study has been used to determine a High PIC. As outlined in Sections 8, the updated Site Specific Seismic Hazard Assessment is generally appropriate for a High PIC dam for a resource consent stage assessment. It is worth noting that the dam break assessment is based on a hypothetical failure scenario that is divorced from the likelihood of the failure. The dam break assessment being used to determine PIC and related design and performance standards. The Site Specific Seismic Hazard Assessment would outline the magnitude of parameters to suit the adopted PIC.

3 Paragraph 2.45 of the Early submission comments on a potential requirement for the consent holder (should consents be granted) to undertake a Comprehensive Dam Safety Review at a five yearly five frequency. The submission also refers to the potential availability of these data.

4 We consider that if consent is granted that it is important that this Comprehensive Dam Safety Review work is undertaken, as outlined by, and in accordance with, the NZSOLD guidelines. We consider it appropriate and in accordance with precedent that this information is submitted to the consent authority. We understand that information submitted to the consent authority is in the public domain.

5 The Early submission variously refers to the potential risk associated with dam leakage manifesting as seepage on the Early property. The application states that the KSD will feature an engineered membrane liner. In principle we consider that the risk of inappropriate seepage occurring on the Early property to be very low as far as dam safety is concerned. This is provided that the dam and dam liner are appropriately designed, constructed and operated. There is opportunity to deal with unintended nuisance seepage by way of appropriate resource consent conditions.

6 The Early submission variously refers to the potential risk a hypothetical dam break failure. Matters related to a hypothetical dam break failure are considered in Section 5 above.

13.3 Submission of Rangitata Water Limited

Rangitata Water Limited (RWL) has raised matters about the completeness of the dam break assessment.

We have mentioned matters related to the dam break assessment above. We consider that the application is sufficient to demonstrate that the KSD PIC is High. Nonetheless, we consider that the application considers some potential effects of a hypothetical dam break scenario at a very high level only, and that the level of information provided is not considered sufficient at this time to:

- Include in EAP documentation.
- Provide detailed information to understand in detail potential effects of a hypothetical dam break scenario at all locations downstream of the KSD.

That said, it is acknowledged that the applicant is yet to determine the final reservoir size and the dam arrangement. Therefore there is unavoidable uncertainty in estimating effects. It is important that finalised documentation, for example the EAPs, take account of the finalised reservoir size. Other matters being equal, it is likely that effects would be less adverse if the storage volume is reduced.

RWL own and operate a number of large dams downstream of the KSD on the true right (south) side of the Rangitata River. In particular, RWL have questioned the potential effects of a cascade failure. That is, a scenario whereby a possible KSD failure scenario instigates a failure of one or more of the RWL storage dams i.e. a domino effect. There may be other locations where this scenario may arise separate from the RWL infrastructure e.g. the Carew dams. The NZSOLD Guidelines recommend that when one or more dams are located downstream of the dam being analysed, the dam-break

flood hazard assessment should consider the potential for a cascade failure where the failure of the upstream dam could cause failure of the downstream dams. We have queried the applicant about this matter from 30 June 2016[29]. Subsequently, the applicant has now made a very high level qualitative assessment of this matter as outlined in sections 6.4 and 7 of their dam break assessment[30]. The applicant provides a very high level qualitative discussion about potential cascade failure scenarios and appears to acknowledge that there is a need to undertake further work. For example following the high level discussion MWH/Stantec state "*This assessment would need to be confirmed by further detailed modelling*". We agree that further work is required. It is possible that the estimated zone of potential inundation, PAR, PLL and assessed damage may increase from the present estimates if further work was to identify cascade failure scenarios as a likely outcome of a dam break scenario.

RWL have also commented on matters related to sediment transport in the Rangitata River including matters related to discharge of sediment from the KSD. Potential effects at their intake and reservoir from KSD discharges are outside the scope of this assessment that is related to dam safety matters.

13.4 Submission of Mr John McGregor Simpson

Mr Simpson has submitted on the adequacy of the GNS site specific seismic hazard assessment. Mr Simpson's submission is dated 29 September 2016. We consider that the updated Site Specific Seismic Hazard Assessment undertaken by GNS dated August 2017 is in accordance with industry practice to investigate the site seismic hazard as described in Sections 8 above for a resource consent stage assessment.

Mr Simpson has submitted on the adequacy of the dam break assessment. Mr Simpson's submission alludes to many potential consequences from a dam break event. For example, potential loss of life and damage to dwellings and infrastructure. We have discussed uncertainty in the applicant's estimate of the PLL parameter in Section 5.

We are not in a position to comment on Mr Simpson's concern regarding potential disturbance of the Cain Flat Clarke Flat battleground from a potential dam break scenario.

Mr Simpson has submitted on erosion of the Teradale Farm adjacent to the KSD by the Rangitata River. Mr Simpson advises that a 40 m wide strip of land was lost to the river in 1994. Erosion of land between the KSD and the Rangitata River is described above in Section 7.

14 Consent conditions

Proposed consent conditions were provided to T+T in March 2017. Initial comments on the proposed resource consent conditions were provided to ECan on 21 April 2017[31]. ECan advise that this matter is to be progressed later.

Conditions proposed by the applicant appear complicated relative to some existing resource consent conditions for other High PIC dams. For example, the conditions 6 and 8.2 initially suggested by the applicant, that requires certification of the design by an independent expert engaged by ECan. These conditions may also result in a double up of peer review input with the consequence of ongoing, but potentially avoidable cost to the consent holder. The conditions may also transfer risk from the consent holder to ECan and others.

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[29] T+T Pers. Comm. Morris/Ford; FW: KLONDYKE; 24 February 2017. T+T Pers. Comm. Morris/Ball; 51344.012 RDR Klondyke; 2 August 2016. T+T Pers. Comm. Morris/Curry; 51344.012 RDR Klondyke; 2 August 2016.

[30] MWH; Klondyke Storage Proposal Dam Break Assessment, Prepared for HOBEC on behalf of the Rangitata Diversion Race Management Ltd, Revision 4; August 2016.

[31] T+T Pers. Comm. Morris/Ford; proposed RDR Klondyke Dam; 21 April 2017.

15 Overall conclusion

The application states that MWH/Stantec have *"identified the Klondyke storage pond as a High potential impact classification dam, therefore requiring the highest standards of design, construction and operation to be applied"*[32]. We agree that this approach is appropriate should consent for the KSD be granted.

Given size and location, the NZSOLD guidelines are the recommended basis to inform delivery of the KSD project from initial studies through to operation. The NZSOLD guidelines state "*In the RMA consent process the applicant needs to demonstrate that the design, construction and operation practices for the dam will address hazards that have the potential to impact on the environment".* We consider it very important that all appropriate High PIC design and performance standards are adopted for the KSD if consent is granted. The NZSOLD guidelines consider adoption and implementation of High PIC design and performance standards to be appropriate mitigation for the potential hazard posed by a large High PIC dam such as the KSD. A indicated above, the application acknowledges that "*the highest standards of design, construction and operation" are applicable.* If consent is granted, we consider that it is important that this approach is formalised by consent condition as appropriate to complement the building consent process.

Apart from some comments of a general nature above, because of the high level nature of the provided information, a thorough review of the design cannot be undertaken at this stage. We recommend that if approved, all project stages are in accordance with the NZSOLD guidelines, for example: investigation, design, construction and commissioning. It is important that appropriate peer review input is provided at appropriate times in accordance with the High PIC adopted by the applicant.

We consider that there is uncertainty with the applicant's estimate of PAR, PLL and damage level associated with the hypothetical dam break scenarios adopted by the applicant. It is very unlikely, for the proposed 53 Mm^3 storage, that refinement of these parameters will alter the proposed High PIC. However, refinement of these parameters is considered necessary to inform emergency action planning and, potentially, to better understand effects associated with the proposal.

It is acknowledged that supply and review of detailed design information and finalised construction and operating documentations may not be a prerequisite for issue of a resource consent. However, where relatively little detail has been provided, and if consent is granted, it is important that thorough consent conditions are put in place to ensure appropriate plans are produced, maintained and enforced. In particular, it is important that resource consent conditions require the completion and maintenance of a Dam Safety Management System (DSMS) including an Emergency Action Plan (EAP). Ongoing matters such as dam surveillance and emergency action planning are not well addressed by current building consent processes following issue of a code compliance certificate.

It is acknowledged that the applicant may wish to pursue a storage volume less than the 53 Mm^3 that is the subject of this application. A dam storage smaller than 53 Mm^3 may have different requirements and effects may be slightly different. For example, size and extent of embankments as well as PAR and PLL.

The applicant has adopted a Low PIC for the canal upgrade. If consent is granted it is important that this aspect of the project proceed on the basis of the NZSOLD guidelines for a Low PIC structure, similar to that outlined for the KSD, albeit for a Low PIC standard.

[32] MWH; Klondyke Storage Proposal Engineering Report, Prepared for HOBEC on behalf of the Rangitata Diversion Race Management Ltd, Revision 4; August 2016.

16 Applicability

This report has been prepared for the exclusive use of our client Environment Canterbury, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

Report prepared by:

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Tim Morris

Senior Civil Engineer

Authorised for Tonkin & Taylor Ltd by:

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Peter Cochrane

Project Director

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