AUG 0 1 2019

Ms. Kate Mansfield
Senior Environmental Assessment Officer
Mackenzie Valley Environmental Impact Review Board
5102 – 50th Avenue
PO BOX 938
YELLOWKNIFE, NT X1A 2N7

VIA EMAIL

Dear Ms. Mansfield:

**Diavik Diamond Mines Inc.'s proposal to deposit processed kimberlite in pits and underground – Government of the Northwest Territories' Intervention (EA1819-01)**

I am pleased to provide the attached intervention from the Government of the Northwest Territories (GNWT) for the environmental assessment (EA) of Diavik Diamond Mines Inc.'s (DDMI) proposal to deposit processed kimberlite in pits and underground (the Project) [EA1819-01].

The GNWT is an intervener in the Mackenzie Valley Environmental Impact Review Board's (Review Board) EA of the Project. The GNWT has participated actively in all the stages of the EA process to date and has considered the evidence on the public registry for this file. The GNWT notes that the Review Board issued DDMI supplemental information requests on July 26 and that DDMI partly responded to the supplemental information requests on July 29, 2019. The GNWT did not consider the supplemental information requests from the Review Board or the additional information provided by DDMI in this intervention as there was not adequate time to meaningfully consider this new information. The GNWT will consider all new information provided by DDMI and will follow the Review Board's July 30, 2019 notice of proceeding regarding how to consider and respond to the supplemental information requests and DDMI's responses.

The departments of Lands; Environment and Natural Resources; Industry, Tourism and Investment; Health and Social Services; Justice; and Executive and Indigenous

.../2

Affairs have contributed to this intervention. These comments reflect the GNWT's various roles and responsibilities in EAs under the *Mackenzie Valley Resource Management Act* (MVRMA) and reflect GNWT and departmental mandates. Key GNWT interests and concerns are associated with water quality and social well-being.

Please note that in addition to the intervention, the curriculum vita for the GNWT's water quality expert has been attached. Dr. Barry Zajdlik will be in attendance at the public hearing to support the GNWT. As well, a separate reference package is also attached. This package provides hyperlinks to the references that the GNWT cited in its June 20, 2019 information requests (GNWT ID no. 17, PR#83). This reference package is being provided to the Review Board as evidence to support the GNWT's submissions.

I trust that this information is helpful. If you have any questions or concerns, please contact Katie Rozestraten, Project Assessment Analyst, at Katie_Rozestraten@gov.nt.ca or 867-767-9180 ext. 24022 or me at Melissa_Pink@gov.nt.ca or 867-767-9180 ext. 24021. The GNWT looks forward to participating in the public hearing.

Sincerely,

Melissa Pink
Acting Director, Securities and Project Assessment
Lands

Attachments

# Government of the Northwest Territories' Intervention

**for**

**EA1819-01 Depositing Processed Kimberlite in Pits and Underground at Diavik Diamond Mine**

Submitted to:

**Mackenzie Valley Environmental Impact Review Board**
200 Scotia Centre
PO BOX 938, 5102 – 50th Avenue
YELLOWKNIFE, NT X1A 2N7

**AUGUST 1, 2019**

## Plain Language Summary

The Government of the Northwest Territories (GNWT) is an intervener in the Mackenzie Valley Environmental Impact Review Board's (Review Board) environmental assessment (EA) of Diavik Diamond Mines Inc.'s (DDMI) proposal to deposit processed kimberlite in pits and underground mine workings (the Project). The GNWT has developed this intervention after active involvement in the EA process, including the review of DDMI's Summary Impact Statement (SIS) and Information Request Responses (IRR) and other materials on the public registry (PR). This intervention summarizes the GNWT's participation in the EA process to date as well as the GNWT's conclusions and recommendations with respect to the environmental assessment of the Project.

The lack of information provided by DDMI has resulted in the GNWT being unable to determine with confidence whether there will be any likely significant adverse impacts on the environment. Due to this inability to make significance determinations, the GNWT is not recommending any measures to the Review Board. The GNWT defers to the Review Board to determine whether the gaps in evidence and insufficient rationale from DDMI identified in this intervention warrant application of the precautionary principle and, if so, whether measure(s) should be recommended by the Review Board. The GNWT has made some recommendations to the Review Board for consideration regarding the Project.

**Water quality** – The GNWT has concern, and notes that there has been concern from other interveners in the EA, regarding the mitigation strategies proposed by DDMI for water quality. The GNWT's concern is the potential for unacceptable water quality conditions in pit lakes once processed kimberlite (PK) is deposited into pits and underground mine workings. The GNWT has made recommendations to the Review Board regarding water quality and will, if the Project proceeds to regulatory, participate in any Wek'èezhìı Land and Water Board (WLWB) proceedings. The GNWT has noted in some instances where additional information is still required to determine if there will be a significant adverse impact. The GNWT recommends that if the placement of PK into A21 is required to maintain operational flexibility, that a cover or barrier be placed over the PK to prevent the mixing with water that could result in poor water quality at closure.

**Wildlife** – The GNWT has not identified likely significant adverse impacts to reviewed wildlife species within the GNWT's jurisdiction. The GNWT recognizes DDMI's commitments in relation to wildlife and has no additional recommendations for the Review Board to consider.

**Social well-being** – The GNWT believes DDMI needs to work more closely with Indigenous governments and organizations (IGOs) to ensure potentially affected Indigenous communities are being provided opportunities to monitor the Project to ensure open communication and cultural continuity in relation to community well-being. The GNWT also believes that all potentially affected Indigenous communities need to be given the opportunity to identify potential mitigations to address their concerns regarding potential adverse effects to the safety, quality, and health of Lac de Gras and the surrounding area. The GNWT also encourages DDMI to continue fulfilling the commitments that exist in the Socio-economic Monitoring Agreement.

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## Tables

## Acronyms

| | |
|---|---|
| AEMP | Aquatic Effects Monitoring Program |
| CEAA | Canadian Environmental Assessment Agency |
| DDMI | Diavik Diamond Mines Inc. |
| EA | environmental assessment |
| EFPK | extra-fine processed kimberlite |
| GNWT | Government of the Northwest Territories |
| GOC | Government of Canada |
| IGOs | Indigenous governments and organizations |
| IR | Information Request |
| IRR | Information Request Response |
| LAA | local assessment area |
| MVRMA | *Mackenzie Valley Resource Management Act* |
| NIWTP | North Inlet Water Treatment Plant |
| ORS | Online Review System |
| PK | processed kimberlite |
| PKC Facility | Processed Kimberlite Containment Facility |
| PKMW | Processed Kimberlite to Mine Workings |
| PR | public registry |
| the Project | Depositing processed kimberlite in pits and underground mine workings |
| RAA | regional assessment area |
| Review Board | Mackenzie Valley Environmental Impact Review Board |
| SEMA | Socio-economic Monitoring Agreement |
| SIS | Summary Impact Statement |
| TDS | total dissolved solids |
| TK | traditional knowledge |
| WLWB | Wek’èezhìı Land and Water Board |

# 1 Introduction

As set out in the Land Use and Sustainability Framework, the Government of the Northwest Territories (GNWT) is committed to making balanced land management decisions in the context of sound environmental stewardship, with consideration of ecological, social, cultural, and economic values to ensure maximum benefits to current and future generations. This responsibility is shared with Indigenous, federal, territorial and municipal governments, boards and agencies and all residents of the NWT.

The GNWT supports environmental impact assessment and the Mackenzie Valley Environmental Impact Review Board's (Review Board) process as a planning tool to ensure that the impact to the environment from developments receive careful consideration before actions are taken in connection with them, and to ensure that the concerns of Indigenous people and the general public are taken into account.

This intervention summarizes the GNWT's conclusions with respect to the Review Board's environmental assessment (EA) of Diavik Diamond Mines Inc.'s (DDMI) proposal to deposit processed kimberlite (PK) in pits and underground mine workings [Review Board file number EA1819-01]. The GNWT has reviewed the Summary Impact Statement (SIS) and has participated actively in all phases of the EA to date, including participating in scoping sessions and submitting and responding to Information Requests (IRs). This submission takes into consideration all of the documents posted to the Review Board's public registry for this proceeding as of 5 pm Thursday, July 25, 2019. The partial response provided by DDMI on July 29, 2019 (PR#100), as a result of the Review Board's July 26, 2019 supplemental information request (PR#98), was not taken into consideration in this intervention as there was not enough time for the GNWT to meaningfully consider this new material. The GNWT will utilize the other opportunities listed in the Review Board's July 30, 2019 Notice of Proceeding (PR#103) in order to meaningfully respond to the new information from DDMI.

As described in its 2016-2019 mandate, the GNWT is committed to supporting social progress by improving education, training and youth development, the cost of living and community wellness and safety (GNWT 2017). The GNWT is also committed to environmental sustainability, economic development, and building strong governance. GNWT departments, including the departments of Lands; Environment and Natural Resources; Health and Social Services; Industry, Tourism and Investment; Justice; and Executive and Indigenous Affairs, have reviewed DDMI's proposal in terms of the GNWT's overall mandate and the mandates of the individual departments. This intervention is also reflective of the GNWT's responsibilities related to the Project.

The GNWT notes also that the following agreements between the GNWT and DDMI apply to this development: the Environmental Agreement, signed by Canada, the GNWT (Resources, Wildlife and Economic Development), DDMI and Indigenous signatories March 8, 2000; the Socio-economic Monitoring Agreement (SEMA), signed by DDMI, the GNWT (Industry, Tourism and Investment) and Aboriginal signatories and parties October 2, 1999; and the January 22, 2015 SEMA Amendment Agreement. The GNWT encourages DDMI to continue fulfilling the commitments from the SEMA related to training, hiring, and procurement for/from northerners for Operations[1] as defined in the SEMA.

The GNWT is working closely with Canada to enable governments to fulfill the duty to consult Indigenous peoples and, where applicable, accommodate potential adverse impacts of the development on asserted or established Aboriginal and/or Treaty rights.

The GNWT appreciates the opportunity to express its views and provide recommendations to the Review Board for this EA. Representatives from the GNWT will attend the public and community hearings in Behchokǫ̀, Dettah and Yellowknife, which are scheduled for September 3-6, 2019.

Because the proposed development is wholly on territorial land, Canada's March 27, 2014 delegation of certain *Mackenzie Valley Resource Management Act* (MVRMA) authorities to the GNWT Minister of Lands applies. The Minister of Lands and ministers of other relevant GNWT departments will participate in the MVRMA section 130 EA decision process as responsible ministers to fulfill their statutory decision-making responsibilities based on evidence provided during the EA.

This intervention is organized as follows:

Plain language summary

Section 1: Introduction

Section 2: Water Quality and Quantity

Section 3: Wildlife

Section 4: Social Well-Being

Section 5: Summary of recommendations

Section 6: References

Recommendations are presented in bold text throughout the document and are listed in Section 5.

## 1.1 Environmental assessment process

### 1.1.1 Overview of GNWT participation to date

The GNWT has participated actively in all phases of the Review Board's EA process (and prior to the EA, in the Wek'èezhìı Land and Water Board's (WLWB) process for DDMI's water licence amendment application); the GNWT will continue to participate in the remaining phases. To date, the GNWT's participation has included:

- Reviewing and commenting on DDMI's water licence amendment application (W2015L2-0001) to the WLWB (June 2018-February 2019);

[1] "Operations" as defined in the 1999 SEMA "means every kind of work done in respect of the operation of the Project from the time it goes into commercial production until permanent closure of the Project and includes mining, processing, environmental protection, and site reclamation."

- Participating in the scoping session (March 2019 - Review Board 2019a, PR#34);
- Reviewing and commenting on the scoping document and workplan (March 2019 - Review Board 2019b, PR#37);
- Reviewing and commenting on the scoping clarification request (May 2019 - Review Board 2019c, PR#65);
- Writing to Indigenous governments and organizations (IGOs) initiating consultation and encouraging their participation in the EA, particularly with respect to submitting evidence related to potential adverse impacts of the development on asserted or established Aboriginal and/or Treaty rights (March 2019 - GNWT and GOC 2019, PR#28 and GNWT 2019a, PR#35);
- Identifying the participation and status of GNWT departments in the EA (May 2019 – GNWT 2019b, PR#56 and GNWT 2019c, PR#61);
- Submitting and responding to IRs (June-July 2019, GNWT 2019d, PR#73 and Review Board 2019d, PR#83);
- Reviewing all submissions to the Review Board's public registry; and
- Providing relevant documents to the Review Board for filing on the public registry.

# 2 Water Quality

### 2.1.1 Alternatives to Deposition of PK into Open Pits

The GNWT has concern, and notes the concern raised by others, regarding the appropriateness of modeling conducted to date and the effectiveness of the mitigation strategies proposed by DDMI to ensure acceptable water quality conditions post deposition of PK into the pits and underground mine workings. After PK deposition into pits, and the filling of the pits with water, if water quality in the open pits is determined to be poorer than the existing modeling shows, and traditional users are unwilling or unable to use the pit lake area, this would represent a significant adverse effect. The GNWT is concerned that the mitigation options proposed by DDMI focus on the post-closure water quality after PK is deposited into the open pits.

### 2.1.2 Developer Conclusions

In DDMI's SIS (DDMI 2019a, PR#53), Section 2.6 discusses the following four alternatives/options to storing PK for the remainder of mine life:

1) Expand (raise) the existing PKC Facility to full proposed extent (Phase 7a and 7b Raise) to be able accommodate all PK over life of mine
2) Divert all PK to mine workings[2] (no expansion of PKC Facility)
3) Fill PKC Facility to approved capacity (Phase 7a raise) and construct additional onsite PK storage facility
4) Fill PKC Facility to approved capacity (Phase 7a raise) and divert remainder of PK to mine workings

Regarding option 1, DDMI states that:

> "Completing a traditional downstream rockfill dam raise is constrained by a lack of footprint on the east and west dam portions of the PKC Facility. Additionally, it is predicted that a dam raise greater than 5 m would be required to contain remaining PK. Given the technical, engineering, and costs associated with completion of a traditional downstream dam raise, DDMI has explored other options for extending the storage capacity of the PKC Facility.
>
> …DDMI's preferred option is to maximize the use of completed mine workings for PK storage over further PKC Facility raises and continued on-land storage. The earliest opportunity to use a completed mine working (A418) is currently November 2021. In this case, PK deposition will continue to fill the PKC Facility to its approved Phase 7a capacity and then to divert the remainder of PK over life of mine to the A418 mine workings. An expansion of the PKC facility to the Phase 7b level or higher would be required if use of mine workings is not permitted. Expansion is limited by available land area, thus focusing on upward expasion [sic]. Additional details related to consideration of alternatives are provided in Attachment 1 of DDMI's application to amend water licence W2015L2-001 (June 2018)" (Section 2.6 DDMI SIS, DDMI 2019a, PR#53).

In DDMI's information request responses (IRRs) posted on July 4, 2019 on the Online Review System (ORS) (Review Board 2019d, PR#83), DDMI states that if future water quality in the pit

[2] Mine workings are defined as "underground and open pits" as in DDMI's water licence W2015L2-0001 amendment request (DDMI 2018, PR#5).

lakes is deemed unacceptable (i.e., harmful to fish and fish habitat), mitigations prior to breaching the dike could include:

1) Block the passage way connecting the pit lakes with Lac de Gras and preventing fish from accessing the area (IRR to NSMA, comment ID no. 4, Review Board 2019d, PR#83).
2) In situ treatment options will be evaluated and if ineffective the breaches will be closed to isolate the pit lake from Lac de Gras (IRR to ECCC, comment ID no. 20, Review Board 2019d, PR#83).
3) Aerial application of lime, alum or a synthetic polymer to assist in clarifying mine area pool water to achieve acceptable water quality before dike breaching.
4) Surface water extraction from mine area with treatment in the North Inlet Water Treatment Plant (NIWTP) and simultaneous replacement with water from Lac de Gras.
5) Longer time frames for pool areas to clarify before breaching dikes (IRR to the Review Board, comment ID no. 30, Review Board 2019d, PR#83).

Mitigation strategies committed to by DDMI for options post-closure (after dike breaching) include:

1) Close the breaches or isolate the pit lake from Lac de Gras if water quality is later determined to pose a risk to water quality, fish and fish habitat, caribou, humans or cultural land uses (Attachment 5, DDMI July 4, 2019 IRRs, DDMI 2019b, PR#84).

The Review Board requested further information regarding the option of not connecting the pit lakes post deposition of PK, including issuing IRs to stakeholders on options of not reconnecting the pit lakes.

In DDMI's Response to the Review Board's IR on water quality modeling if the pits are not reconnected (Review Board comment ID no. 30, Review Board 2019d, PR#83), DDMI states that reconnection with Lac de Gras is their preferred option for closure.

> "DDMI recognizes that the MVEIRB [the Review Board] has issued IR to re-consider connection of pit lakes with Lac de Gras and that this re-consideration applies to scenarios with and without deposited PK. DDMI will fully consider all responses but currently our view is that the evidence supports a connection. It is unclear why the MVEIRB would request the analysis of a hypothetical condition that does not form part of DDMI's application.
>
> "…Given that hydrologic connectivity would be necessary, even in the hypothetical condition that reconnecting fish and boat passageways are not excavated, DDMI would expect water quality conditions to remain largely the same with or without the reconnecting passage ways. This is because the water exchange back and forth between the pit lakes and Lac de Gras will have to be similar with or without the passageway" (IRR to the Review Board, comment ID no. 30, Review Board 2019d, PR#83).

In the GNWT's June 20, 2019 IR (comment ID No. 7, recommendation no. 2, Review Board 2019d, PR#83), the GNWT states: "The GNWT requests that DDMI describe contingency options that exist if updated modeling results in different/poorer water quality within the open pits or Lac de Gras than have been assessed in this EA as a result of placing PK into open pits". DDMI's response (July 4, 2019 IRR to GNWT, comment ID no. 7, Review Board 2019d, PR#83) only considers options that include the deposition of PK to mine workings (i.e., A154, A148 and A21 pits).

### 2.1.3 GNWT's Conclusions and Rationale

In review of the July 4, 2019 IR responses from parties (Review Board 2019d, PR#83), the GNWT notes that there was concern regarding reconnecting the pit lakes to Lac de Gras following deposition of PK to the pits. If traditional users have concern with the placement of PK into the pits and then reconnecting the pits to Lac de Gras, which could result in a loss of use of the area for traditional purposes, this could constitute a significant adverse effect and the GNWT suggests the deposition of PK to the open pits should not be approved unless their water quality meet DDMI's existing benchmarks.

The GNWT supports the concept of deposition of PK and then reconnection of the pits upon demonstration of appropriate and acceptable water quality conditions. However, with the GNWT's previous requests for certainty around modeling results, (GNWT June 20, 2019 IR, comment ID no. 7, Review Board 2019d, PR#83) and parties concerns, it appears there should be more discussion from DDMI on the potential or feasibility of 'alternative options', that is, a traditional dam raise, or additional use of the PKC Facility instead of complete deposition of PK into the mine workings. In the event that updated modeling shows that deposition of PK to mine workings results in poor water quality which is unacceptable to traditional users such that the pit lakes or Lac de Gras in the vicinity of the mine will no longer be used for traditional purposes, DDMI should not deposit PK into the open pits and should expand the PKC Facility to store the PK in perpetuity.

### 2.1.4 Recommendation

**Recommendation #1:**

**The GNWT is of the opinion that if the deposit of PK into pits results in poor water quality which results in the avoidance of the area or results in traditional users no longer using the area for traditional purposes, the contingency mitigation option should include raising the PKC Facility such that it can store the remaining PK produced from the site. DDMI should commit to continue refining and updating modeling to confirm that the deposition of PK to mine workings would not result in unacceptable conditions in the pits or Lac de Gras prior to placing PK into the pits.**

## 2.2 Cumulative Effects Assessment and Risk Assessment

DDMI has not conducted a cumulative effects assessment or a risk assessment as previously requested by the GNWT. The response from DDMI with respect to conducting a cumulative effects assessment is that "DDMI expects that the YEAR 23 modeling results from the Jay Project represents a worst-case closure condition that would more than account for the additional pathways noted by GNWT" (DDMI July 4, 2019 IR Response to GNWT comment ID no. 15, Review Board 2019d, PR#83). This statement, without supporting rationale, does not satisfy the GNWT's request for cumulative effects assessment.

### 2.2.1 Developer Conclusions

Cumulative effects assessments by DDMI for the Project are limited to predicting worst case scenario water quality in each of the pit lakes over a 100-year period using project-specific effects and pertain to the pit lakes only.

However, the GNWT notes that instead of adding these concentrations to background concentrations it was assumed by DDMI that the Ekati Jay Pit was operating and that the worst-case YEAR 23 water quality predictions for those nodes closest to the respective pits was the worst case scenario (DDMI July 4, 2019 IR Response to GNWT comment ID no. 15, Review Board 2019d, PR#83). These predictions include "the operational discharge to Lac de Gras from the NIWTP at its maximum permitted limit”. The modeled predictions within the pit lakes were assumed to be the worst-case estimates at the dike breaches and consequently no modeling within Lac de Gras was conducted.

### 2.2.2 GNWT’s Conclusions and Rationale

It is not clear to the GNWT how the assessment of effects for this proposed Project could be determined without modeling of water quality within the pit lake but also the combined influence of the pit lakes, effluent discharges and other anthropogenic influences (i.e., Ekati Mine) on Lac de Gras. The GNWT is also not convinced that the modeling to date and the approach used to assess cumulative effects is complete or appropriate. Specific concerns about the modeling conducted by DDMI are further explained in the attached memo from Zajdlik and Associates (Appendix A). Key areas of concern include:

- the modeling conducted to date lacks calibration and key input data (e.g., nature and volume of porewater);
- the model used to predict pit lake stability has not been sufficiently rationalized and was not demonstrably selected via an objective process; and
- the lateral - averaging model used to predict pit lake stability is not representative for a pit lake that is essentially cylindrical.

Furthermore, the GNWT’s June 20, 2019 comment ID no. 12 (Review Board 2019d, PR#83) notes that the SIS environmental effects assessment “is based on methods used in the 1998 Comprehensive Study (DDMI 1998) to maintain consistency of the assessment of this modification of the mine operation with the original assessment of the Diavik Mine as a whole”. The GNWT notes that DDMI did not complete an assessment of the previous EA methods and newer EA methods as requested. The GNWT notes that the MVRMA applies to the current Project; the MVRMA (s.117(2)(b)) requires that cumulative impacts be considered in every environmental assessment. Therefore, the GNWT’s position is that more recent and revised methods for assessing cumulative effects, the inclusion of effects pathways and overall approach to assessing cumulative effects should be applied to this proposed Project.

### 2.2.3 Recommendation

**<u>Recommendation #2:</u>**

**The GNWT is unable to assess the significance of changes to the water quality as a result of cumulative effects from the Jay Project and the Diavik Mine at this time. Should updated modeling predict water quality conditions in the pit lakes or within Lac de Gras, in the vicinity of the mine, are of such poor quality that traditional users could either avoid the area or no longer use the area for traditional purposes, the placement of PK into the pits and underground mine workings should not be approved.**

## 2.3 North Inlet Water Treatment Plant

The GNWT recommends that the Review Board require DDMI to provide the total dissolved solids (TDS) loads to the NIWTP, as they have not been provided as requested. The GNWT is concerned that the TDS loads could impact water quality conditions as a result of the deposition of PK to the pit lakes.

### 2.3.1 Developer Conclusions

The GNWT’s June 20, 2019 IR comment ID no. 11 (Review Board 2019d, PR#83) posed the two following requests for information:

1. "The GNWT requests DDMI outline the expected volume of water treated by the NIWTP that will be comprised of the pit decant water (a mixture of PK and EFPK [extra-fine processed kimberlite] porewater and groundwater inflow) on a monthly basis. This information should be provided for the entire proposed deposition period (e.g., years 2021-2025).
2. The GNWT requests DDMI compare the anticipated total dissolved solids (TDS) loads from the pit decant water to the current TDS loads from the NIWTP on a monthly basis over the proposed deposition period (2021-2025)".

A section of the IR response provided by DDMI states: "If PK is deposited in mine workings the blend of water that is treated in the NIWTP will not change because the PKC Pond water will effectively be replaced by pit decant water". This statement assumes that the PKC Pond is not decanted, that the volume of decant water from the pit that consists of groundwater inflow to the pit plus leachate from the deposited PK (which will consist of a blend of groundwater moving through the PK and diffusive process acting at the PK – water interface) and that TDS loads from the PKC and pit lake decant water are identical. Statements from DDMI July 4, 2019 IR (Review Board 2019d, PR#83) responses leading to the final conclusion are summarized below:

- Recent TDS loads from the NIWTP to Lac de Gras between 3 to 4 x $10^6$ kg/year.
- 3 x $10^5$ kg of TDS is directed to the NIWTP via the PKC Facility in a "typical" year.
- Expected volume of excess slurry water and overall pit decant water (including groundwater contributions) throughout the operational phase is expected to range between 2 x $10^5$ and 3 x $10^6$ $m^3$ annually.
- Process circuit currently recycles about 3 x $10^6$ $m^3$ annually from the PKC Facility and North Inlet and this rate is expected to continue for the remaining life of mine.
- Additional comments are made regarding loads to Lac de Gras from the pit lakes which are not relevant to the question posed.

The conclusion from DDMI's response to the GNWT IR comment ID no. 11 (Review Board 2019d, PR#83) is: "For this reason, the PKMW [processed kimberlite to mine workings] TDS load to the NIWTP is expected to remain similar to current PKC rates during the Operational phase of the project".

### 2.3.2 GNWT's Conclusions and Rationale

It is not clear to the GNWT how the conclusion by DDMI, above, is reached. The GNWT still has concerns that the Project could change TDS loads that could potentially impact the receiving environment. Recent TDS loads from the NITWP to Lac de Gras are discussed by DDMI in their response. TDS loads in a typical year from the PKC Facility to the NIWTP are discussed. The volume of pit water (excess slurry water and overall pit decant water including groundwater contributions), but not TDS loads, reporting to the NIWTP is also discussed. A comment is made by DDMI regarding how much water is recycled from the PKC Facility and North Inlet. However, TDS loads to the NIWTP from the pit lakes, which would provide a direct comparison with current loads, are not provided although they were requested.

The arguments provided by DDMI do not support the conclusion that "In general, the PKMW project will not create a significant deviation from the current operational site water balance or North Inlet Water Treatment Plant (NIWTP) Operations" (Review Board 2019d, PR#83, p.30). DDMI should provide the information requested or any additional information that allows for comparison of loads to the NIWTP under the currently approved water licence and the proposed Project. This information will help reviewers determine if there are any significant adverse impacts from TDS loads to the receiving environment as a result of the Project. Without this information, the determination of significance is not possible.

### 2.3.3 Recommendation

<u>**Recommendation #3:**</u>

**Due to DDMI not providing information requested by the GNWT, the GNWT is unable to assess the significance of increased TDS loads on Lac de Gras as a result of placing PK into the open pits. The GNWT will request information on TDS loads in the water licencing process to ensure agreed to water quality thresholds or benchmarks are achieved in Lac de Gras.**

## 2.4 A21

The GNWT is concerned with using A21 pit for the deposition of PK and EFPK based on the water quality conclusions reached by DDMI.

### 2.4.1 Developer Conclusions

Based on previous concerns expressed by the GNWT (see June 20, 2019 GNWT IR comment ID no. 17, Review Board 2019d, PR#83), other parties (June 20, 2019 IR by ECCC comment ID no. 3, Review Board 2019d, PR#83), and the Review Board (comment ID no. 34, 37, 39 and 56, Review Board 2019d, PR#83) regarding the water quality predictions for A21 that show the potential for adverse conditions, DDMI has responded that:

> "DDMI has included an assessment of PK deposition to A21 to provide a complete evaluation of all foreseeable options. As evaluated in the Summary Impact Statement, A21 scenario 2a and 4a demonstrated no residual Project or cumulative effects on the aquatic environment within the pit lakes during closure and post-closure. For pit lake A21 scenario 3a modeling predicts an adverse high magnitude effect of moderate duration within the PDA during closure and post-closure. Based on the modeling and the significance definition developed by CEAA (1999), with application of mitigation and environmental protection measures, significant adverse effects on water quality are not anticipated for the A21 pit lake for all scenarios of PK deposition modelled" (July 4, 2019 IRR to GNWT IR comment ID no. 17, Review Board 2019d, PR#83).

DDMI also adds that "a need for storage in addition to these mine workings [A154 and A418] is not expected, however in the event the A21 mine becomes available before either the A418 or A154 mine, that option may be preferred."

DDMI continues in their IRR to the Review Board's (comment ID no. 34, Review Board 2019d, PR#83) question on why A21 should also be considered as a potential PK storage location based on the issues identified in the SIS that:

> "DDMI continues to advise that A418 is the preferred location at this time for PK deposition to mine workings if this proposal is approved. For a number of reasons, including those noted by the MVEIRB, A21 is the least preferred, at this time. We believe it is prudent to continue to consider all feasible options to provide the maximum practical flexibility. Limiting the deposition location option to only the preferred A418 could result in an inability to adapt to changes in mine plans because of the long lead times inherent in permitting processes. Continuing to model multiple pits also improves understanding of systems dynamics leading to increased confidence in final results. For these reasons DDMI believes it is premature to remove A21 as an option for PK deposition. If the PK to mine

workings proposal is approved by the MVEIRB and WLWB, DDMI will advance only a specific scope (including location) to detailed planning and design for final review and WLWB approval" (DDMI July 4, 2019 IRR to the Review Board's IR comment ID no. 34, Review Board 2019d, PR#83).

### 2.4.2 GNWT's Conclusions and Rationale

The GNWT notes that modeling using the CE-QUAL W2 model does not predict mixing for the A154 and A148 pits. During the review process, concerns expressed by reviewers led DDMI to evaluate the effects of unanticipated mixing within the pit lakes. The effects of unanticipated mixing are presented in Section 4.4.1.3 of the SIS and the summary is extracted below:

- "For scenario 2a, constituents are predicted to be below the AEMP [Aquatic Effects Monitoring Program] benchmarks at the surface and at 40 m depth;
- For scenario 3a, concentrations of three constituents are predicted to exceed the AEMP benchmarks at 40 m depth while none are predicted to exceed at the surface;
- For scenario 4a, concentrations of one constituent is predicted to marginally exceed the AEMP benchmark in both surface and at 40m depth." (DDMI 2019a, PR#53)

DDMI also (2019a, Section 4.4.3.2) summarizes the results of unanticipated mixing. These are extracted and presented below.

- "For pit lake A418 under modelled scenarios 2a, 3a, and 4a, water quality would be below the AEMP benchmarks for all parameters except nitrite for scenario 3a (0.076 mg/L, 26% higher than the benchmark);
- For pit lake A154 under modelled scenarios 2a, 3a, and 4a, water quality would be below the AEMP benchmarks for all parameters; and
- For pit lake A21 under modelled scenarios 2a, 3a, and 4a, water quality would be below the AEMP benchmarks for all parameters except nitrite for scenario 4a (0.062 mg/L, 3% higher than the benchmark)".

The GNWT is concerned that based on the information presented, it appears that A21 is the pit lake that is most likely to overturn (e.g., unanticipated mixing). The GNWT's position is that if placing PK into the A21 pit results in such poor water quality that leads to general avoidance of the area or traditional users no longer use the site for traditional purposes, this could constitute a significant adverse effect.

DDMI has stated in their IRRs (Review Board 2019d, PR#83, p.37) that both the A418 and A154 mine workings have sufficient storage capacity to contain all modeled fine PK and EFPK while maintaining a fresh water cover in excess of 100 m. The GNWT understands that DDMI's preferred pit to place PK is A418 and that A21 is the least preferable. Further, the GNWT understands that DDMI is researching a potential to commence underground or deep mining at A21, which in turn may eliminate the availability of A21 for PK storage.

Ultimately, if DDMI would like to maintain operational flexibility by using A21 for the PK storage, mitigation (such as a cover or barrier) should be used to prevent the water within this shallow pit lake from mixing or overturning.

### 2.4.3 Recommendation

**Recommendation #4:**

**The GNWT recommends that if the placement of PK into A21 is required to maintain operational flexibility, that a cover or barrier be placed over the PK to prevent the mixing with water that could result in poor water quality at closure.**

# 3 Wildlife

The Scope of EA (Review Board 2019e, PR#40) required DDMI to assess the potential effects of the proposed activities on wildlife, including species within the GNWT's jurisdiction such as barren-ground caribou from the Bathurst herd, grizzly bear, wolverine, raptors, and insects.

During the scoping of the Project, the GNWT's position, which remains unchanged, is that the pathway of potential effects on wildlife and wildlife habitat is through exposure of potentially contaminated surface water. Addressing potential effects on water quality (see section 2 of the GNWT's intervention) should address potential effects on wildlife and wildlife habitat.

## 3.1 Developer Conclusions

DDMI concluded in section 7 of the SIS that residual effects of the development on wildlife, including species within the GNWT's jurisdiction, are expected to be negligible and not significant after implementation of mitigation and environmental protection measures (DDMI 2019a, PR#53).

Because the proposed activities would occur within the existing Diavik Mine footprint, DDMI did not identify, in the SIS, any additional effects to wildlife and wildlife habitat from the ones identified in the 1998 Comprehensive Study (DDMI 1998); specifically no additional loss of habitat, or change in movement or mortality risk (DDMI 2019a, PR#53) was identified.

DDMI believes that the only potential effect that meets its significance definition of "an effect that has a high probability of a permanent or long-term effect of high magnitude, within the regional area, that cannot be technically or economically mitigated" from the 1998 Comprehensive Study (DDMI 1998) is a change in wildlife health due to exposure to surface water that could contain contaminants or consumption of potentially contaminated prey (DDMI 2019a, PR#53). DDMI's position is that potential effects to wildlife and wildlife habitat through the consumption of potentially contaminated surface water can be addressed by meeting water quality requirements (i.e., AEMP benchmarks) and with mitigations. DDMI listed follow-up monitoring and a summary of commitments in sections 7.8 and 7.9 of the SIS (DDMI 2019a, PR#53). Various mitigation measures are also listed in DDMI's IR responses (Review Board 2019d, PR#83) and commitments made by DDMI in the SIS pertaining to wildlife are reaffirmed in DDMI's table of commitments from the SIS (DDMI 2019b, PR#84, p.268). Examples of commitments from DDMI include monitoring of water quality, continuation of the existing wildlife monitoring program, removing wildlife from mine workings before pit lake infilling, using wildlife deterrents to reduce risks to wildlife, etc.

In its response to IR 31 from Łutselk'e Dene First Nation, DDMI indicated that although water quality exceedances were predicted at a 40 m depth, adverse effects to wildlife were not anticipated because wildlife would not have direct access to water at this depth (Review Board 2019d, PR#83).

DDMI also noted that no barren-ground caribou interaction had been recorded with the Diavik pits/mine workings area to date (Review Board 2019d, PR#83).

## 3.2 GNWT's Conclusions and Rationale

As noted in GNWT's comments on the scope of the assessment, the GNWT agrees with the DDMI's conclusion outlined in section 7 of the SIS, that significant adverse impacts to wildlife and wildlife habitat, including species within the GNWT's jurisdiction, are unlikely after implementation of mitigations (DDMI 2019a, PR#53), which include the recommendations made by the GNWT in this intervention.

The GNWT has reviewed information provided in the DDMI's SIS (DDMI 2019a, PR#53) and the additional IRs and responses with respect to wildlife (Yellowknife Dene First Nation 2019, EMAB 2019, Tłı̨chǫ Government 2019, Łutselk'e Dene First Nation 2019, GNWT 2019d, Northwest Territory Métis Nation 2019, Denínu Kų́ę́ First Nation 2019, North Salve Métis Alliance 2019, Fort Resolution Métis Council 2019, GOC 2019, NWT Treaty 8 Tribal Corporation 2019, Review Board 2019d, DDMI 2019b, c, and Thorpe Consulting Services 2019, PR# 69-78 and 82-86), and is satisfied with the information DDMI has filed on the EA registry to date and their existing commitments regarding wildlife (e.g., DDMI 2019b, PR#84 on p.268).

## 3.3 Recommendation

The GNWT has no recommendations at this time.

# 4 Social Well-being

The GNWT has reviewed information provided in DDMI's SIS (DDMI 2019a, PR#53) and in the IRRs provided by DDMI and other parties to the EA with respect to social well-being (Yellowknife Dene First Nation 2019, EMAB 2019, Tłı̨chǫ Government 2019, Łutselk'e Dene First Nation 2019, GNWT 2019d, Northwest Territory Métis Nation 2019, Denínu Kų́ę́ First Nation 2019, North Salve Métis Alliance 2019, Fort Resolution Métis Council 2019, GOC 2019, NWT Treaty 8 Tribal Corporation 2019, Review Board 2019d, DDMI 2019b, c, and Thorpe Consulting Services 2019, PR# 69-78 and 82-86).

## 4.1 Developer Conclusions

### 4.1.1 Assessment of Project Interactions with Cultural Use

In the SIS, DDMI notes that the Project "has the potential to affect traditional activities, sites, and resources identified by Indigenous groups," (DDMI 2019a, PR#53, p.145). DDMI did not discuss in their assessment; however, how the potential effect to Indigenous users' abilities to pursue traditional activities may or may not be connected to community well-being. DDMI also did not adequately discuss and develop mitigations to support Indigenous communities' perceptions of adverse effects to the safety, quality, and health of Lac de Gras and the surrounding area. In their analysis, DDMI found that "Residual effects on wildlife, fish, and water have the potential to affect the activities that are supported by these resources, including hunting, fishing, and cultural use for water. Overall, the residual effects of the Project on the availability of traditional resources for cultural use are predicted to be negligible in magnitude," (DDMI 2019a, PR#53, p.168). DDMI further noted that "…appropriate conditions for current use entail more than the availability of traditional resources and this assessment acknowledges that Indigenous groups may choose not to pursue cultural use activities near the mine site for a variety of personal, practical, aesthetic, and spiritual reasons. Participants of the TK [traditional knowledge] Panel Studies and the TLU [traditional land use] studies also indicated concerns with perceived effects of further development on wildlife, birds, fish, and water quality." Furthermore, DDMI considered "physical activities that might interact with cultural use and result in the identified environmental effect," and did not provide an analysis of, or information on, potential social effects as a result of the perception of risk or contamination (DDMI 2019a, PR#53, p.161).

Again, DDMI identified three potential environmental effects from the Project on cultural use: (1) "Change in availability of traditional resources for cultural use"; (2) "change in access to resources or areas for cultural use"; and, (3) "changes in sites or areas for cultural use," (DDMI 2019a, PR#53, table 8-1, pp.148-149). DDMI also identified "indirect effects on the experience of Indigenous peoples which adversely alter the perceived value of access to traditional resources for cultural use," as a potential effect pathway for each of the three potential effects. DDMI notes the "identification of change in resource from communities of traditional users" as a measurable parameter for effects (1) and (2), as well as "identification of change in use of sites or areas from participating Indigenous groups as a measurable parameter for effect (3).

DDMI defines a significant adverse effect on cultural use as "a long-term loss of availability of traditional use resources or access to lands relied on for cultural use practices or cultural use sites and areas, such that cultural use is critically reduced or eliminated within the RAA [regional assessment area]. This may include disruption to cultural use activities and practices where biological resources or physical sites are not significantly affected in the RAA," (DDMI 2019a, PR#53, p.154).

DDMI noted in their assessment of project residual environmental effects (1) and (2) that "appropriate conditions for current use entail more than the availability of traditional resources and this assessment acknowledges that Indigenous groups may choose not to pursue cultural use activities near the PKMW Project for a variety of personal, practical, aesthetic, and spiritual reasons," (DDMI 2019a, PR #53, pp. 168 and 170). Despite noting this, no further analysis or discussion was provided and DDMI concluded that:

1. "The residual effects of the PKMW Project on the availability of traditional resources for cultural use are predicted to be adverse, negligible in magnitude, limited to the LAA, short-term, and reversible," (DDMI 2019a, PR#53, p.168);

2. "The residual effects of the PKMW Project on the access to traditional resources or areas for cultural use are predicted to be adverse, negligible in magnitude, limited to the LAA [local assessment area], short-term to long-term in duration, and reversible." (DDMI 2019a, PR#53)

DDMI did not provide an analysis or evidence to support the conclusion that Indigenous groups choosing to not pursue cultural activities near the Project for "personal, practice, aesthetic, and spiritual reasons," is negligible. DDMI did not include the perception of risk to the biophysical environment and its effects on cultural use, cultural continuity, and well-being within this assessment. DDMI also did not include a discussion of potential mitigations or monitoring activities that may address the above concerns, as noted by the Fort Resolution Métis Council (Fort Resolution Métis Council IR5 and 6, Review Board 2019d, PR# 83, pp.23-24). DDMI's responses to these IRs were unclear on how they intend to address the concerns raised by parties regarding the perception of risk related to biophysical impacts and cultural use, or pathways and effects as a result of Indigenous groups choosing to not pursue cultural activities.

### 4.1.2 Assessment of Cumulative Environmental Effects

In section 8.5.2 Significance of Cumulative Effects of the SIS, DDMI concludes that the Project does not interact cumulatively with other projects or activities because it has negligible residual environmental effects on availability of traditional resources for cultural use or access to traditional resources or areas. DDMI states that "With mitigation and environmental protection measures, there are no residual environmental effects on cultural use that could contribute to cumulative effects" (DDMI 2019a, PR#53, p.175). Once again, DDMI reiterates that "appropriate conditions for current use entail more than the availability of traditional resources and this assessment acknowledges that Indigenous groups may choose not to pursue cultural use activities near the mine site for a variety of personal, practical, aesthetic, and spiritual reasons," and concludes that "Further assessment of cumulative effects on cultural use is not warranted because there are no residual effects on availability of traditional resources for current use or on access to traditional resources or areas for current use that are likely to interact cumulatively with other projects or activities" (DDMI 2019a, PR#53, p.174).

## 4.2 GNWT's Conclusions and Rationale

The GNWT is concerned that DDMI has not provided sufficient rationale and/or evidence to indicate that there are no potential residual or cumulative social and cultural effects of the Project on community well-being. The GNWT is specifically concerned about how the perception of potential risks and/or environmental effects to the biophysical environment from the Project may have cumulative adverse effects on the social and cultural well-being of Indigenous peoples and IGOs when considered in combination with other diamond mining projects.

Information provided to the Review Board through the scoping phase and IRs, as well as information provided by Indigenous peoples and IGOs in previous EAs, demonstrates that the Project area is socially, culturally and spiritually important to Indigenous peoples. It also demonstrates that Indigenous peoples and IGOs have significant concerns regarding the perception of risk and/or adverse environmental effects (e.g., Review Board 2019d, PR#83, pp.23-24). The initial effect pathway related to these concerns was not fully analyzed, nor did it provide potential mitigations in the SIS. In addition, the GNWT is concerned with the adequacy of the DDMI's responses to these concerns.

The GNWT notes that DDMI has engaged with potentially impacted IGOs that are signatories to the Environmental Agreement, the SEMA, and/or Impact Benefit Agreements on Project design through the TK Panels and that these Panel Reports are available through the WLWB. The GNWT also notes that DDMI has indicated in this EA that it will consider responses from Indigenous peoples and IGOs who are not signatories to the Environmental Agreement or SEMA. However, it is not clear how this will be considered nor is there a clear commitment stemming from these comments.

The GNWT first identified in its IR to DDMI the concern regarding how perception of adverse environmental effects may impact cultural use in the Project area and thereby affect social well-being (Review Board 2019d, PR#83, p.25). Other parties also noted that the perception of adverse environmental effects did not include social aspects or perspectives needed to understand impacts on Indigenous cultural use of the area in closure and post-closure (e.g., Review Board IR61 on pp.100-101, Tłı̨chǫ Government IRs on pp.114-115, and EMAB IR4 on pp.7-9 in Review Board 2019d, PR#83), and IGOs have indicated a preference for visual monitoring (Review Board 2019d, LKDFN ID no. 20, PR#83). The GNWT reiterated these concerns in its IR response (GNWT 2019d, PR# 73) to the Review Board and requested that the Review Board apply a holistic and integrated approach to the complex relationship between the biophysical environment, human and non-human health and well-being in their assessment of potential effects. The GNWT also included social well-being considerations in its IR response, which form the basis of the below recommendations.

## 4.3 Recommendation

DDMI indicated in multiple IRRs that they will continue to engage with IGOs that are signatories to the Environmental Agreement and SEMA, and that it would consider information provided to the Review Board from IGOs who are not signatories to these two agreements (e.g., DDMI responses to Fort Resolution Métis Council IRs 1, 3, 4 and 7 on pp.21-24, GNWT IRs 1, 3 and 4 on pp.25-27, Łutselk'e Dene First Nation IR 32 on p.49, Review Board IR 60 on p.100, Northwest Territory Métis

Nation IR 1 on p.111 and Yellowknives Dene First Nation IR 1 on pp.116-117 of Review Board 2019d, PR#83).

As previously raised (GNWT 2019d, PR#73 and GNWT IRs 1, 3 and 4 in Review Board 2019d, PR#83), the GNWT believes it is critical that DDMI work closely with all potentially affected IGOs to ensure that: all potentially affected Indigenous peoples and IGOS are receiving timely communications in plain language; are provided opportunities to monitor the Project (e.g., depositing of PK in pits and underground mine workings and the final approved closure plan) and identify questions or issues that need to be addressed; and are offered the opportunity to iteratively identify potential mitigations to support Indigenous communities' perception of adverse effects to the safety, quality, and health of Lac de Gras and the surrounding area. The GNWT has insufficient information to determine whether the proposed project is likely to have a significant adverse impact on social well-being related to the perception of risk related to biophysical impacts and cultural use of the area. Due to the insufficient information, the GNWT defers to the Review Board to determine whether the gaps in evidence and insufficient rationale from DDMI identified in this intervention warrant application of the precautionary principle and, if so, whether measure(s) should be recommended by the Review Board. The GNWT makes the following recommendations to ensure social well-being:

### 4.3.1 Recommendation

<u>**Recommendation #5:**</u>

**The GNWT recommends the Review Board require DDMI to publicly provide an updated framework for community engagement and participation in closure planning and the closure phase should PK be deposited in the pits. This framework and plans created from this framework should be developed collaboratively with all potentially affected IGOs and clearly identify how DDMI will actively work with communities to ensure that community concerns regarding potential adverse effects to the safety, qualities, and health of Lac de Gras are addressed. The updated framework could also be used by DDMI as engagement required during the regulatory phase.**

<u>**Recommendation #6:**</u>

**As IGOs have indicated a preference for visual monitoring of the Project, include potentially affected IGOs in the visual monitoring of all phases of the Project and publicly report on these monitoring activities to ensure that potentially affected Indigenous communities are well-informed and aware of Project design, activities, and potential effects for the life of mine.**

## 5 Summary of Recommendations

The GNWT's intervention outlines concerns over water quality and social well-being; the GNWT's belief that there is no pathway to impacts on wildlife is also addressed in this intervention. The lack of information provided by DDMI has resulted in the GNWT being unable to determine with confidence whether there will be any likely significant adverse impacts on the environment. Due to this inability to make significance determinations, the GNWT is not recommending any measures to the Review Board. The GNWT defers to the Review Board to determine whether the gaps in evidence and insufficient rationale from DDMI identified in this intervention warrant application of the precautionary principle and, if so, whether measure(s) should be recommended by the Review Board. The GNWT has made some recommendations to the Review Board for consideration regarding the Project, which are summarized in Table 1.

**Table 1 Summary table of GNWT recommendations**

| Recommendation number | Section | GNWT Recommendation |
|---|---|---|
| **Water quality** | | |
| 1 | 2.1.4 | The GNWT is of the opinion that if the deposit of PK into pits results in poor water quality which results in the avoidance of the area or results in traditional users no longer using the area for traditional purposes, the contingency mitigation option should include raising the PKC Facility such that it can store the remaining PK produced from the site. DDMI should commit to continue refining and updating modeling to confirm that the deposition of PK to mine workings would not result in unacceptable conditions in the pits or Lac de Gras, prior to placing PK into the pits. |
| 2 | 2.2.3 | The GNWT is unable to assess the significance of changes to the water quality as a result of cumulative effects from the Jay Project and the Diavik Mine at this time. Should updated modeling predict water quality conditions in the pit lakes or within Lac de Gras, in the vicinity of the mine, are of such poor quality that traditional users could either avoid the area or no longer use the area for traditional purposes, the placement of PK into the pits and underground mine workings should not be approved. |
| 3 | 2.3.3 | Due to DDMI not providing information requested by the GNWT, the GNWT is unable to assess the significance of increased TDS loads on Lac de Gras as a result of placing PK into the open pits. The GNWT will request information on TDS loads in the water licencing process to ensure agreed to water quality thresholds or benchmarks are achieved in Lac de Gras. |
| 4 | 2.4.3 | The GNWT recommends that if the placement of PK into A21 is required to maintain operational flexibility, that a cover or barrier be placed over the PK to prevent the mixing with water that could result in poor water quality at closure. |
| **Social well-being** | | |
| 5 | 4.3.1 | The GNWT recommends the Review Board require DDMI to publicly provide an updated framework for community engagement and participation in closure planning and the closure phase should PK be deposited in the pits. This framework and plans created from this framework should be developed collaboratively with all potentially affected IGOs and clearly identify how DDMI will actively work with communities to ensure that community concerns regarding adverse effects to the safety, qualities, and health of Lac de Gras are addressed. The updated framework could also be used by DDMI as engagement required during the regulatory phase. |
| 6 | 4.3.1 | As IGOs have indicated a preference for visual monitoring of the Project, include potentially affected IGOs in the visual monitoring of the all phases of the Project and publicly report on these monitoring activities to ensure that potentially |

| | | |
|---|---|---|
| | | affected Indigenous communities are well-informed and aware of Project design, activities, and potential effects for the life of mine. |

## 6 References

Denínu Kų́ę́ First Nation. 2019. DKFN response to Review Board IRs. (PR#75).

Diavik Diamond Mines Inc. (DDMI). 2019a. Summary Impact Statement, Processed Kimberlite Workings Project. (PR#53).

DDMI. 2019b. Index for Attachments to the Information Request- ORS Comments for DDMI's Depositing Processed Kimberlite in Pits and Underground (EA1 819-01) (Part 1 of 3). (PR#84).

DDMI. 2019c. Appendix G Response to Session #7 Recommendations Presentation. (PR#85).

DDMI. 2018. DDMI Water License W2015L-0001 Amendment Request for the Deposition of Processed Kimberlite to Mine Workings. (PR#5).

DDMI. 1998. Diavik Diamonds Project: Environmental Assessment Overview.

Environmental Monitoring Agency Board (EMAB). 2019. EMAB response to Review Board IR. (PR#70).

Fort Resolution Métis Council. 2019. FRMC response to Review Board IRs. (PR#77).

GNWT. 2019a. GNWT Notice of Initiation of Aboriginal Consultation - letter to Akaitcho Pre-screening Board. (PR#35).

GNWT. 2019b. GNWT letter to MVEIRB Re: participation and status of GNWT departments in EA. (PR#56).

GNWT. 2019c. GNWT response to MVEIRB letter Re: participation in EA. (PR#61).

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NWT Treaty 8 Tribal Corporation. 2019. Akaitcho IMA Office response to Review Board IRs. (PR#82).

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Thorpe Consulting Services. 2019. Our youth, our future: monitoring our land, water, fish and air. Report of the Diavik Diamond Mine Aquatic Effects Monitoring Program Traditional Knowledge Study. Prepared for DDMI. (PR#86).

Tłı̨chǫ Government . TG response to Review Board IRs. (PR#71).

Yellowknives Dene First Nation (YKDFN). 2019. YKDFN response to Review Board IRs. (PR#69).

## Appendix A

# Review of
# DDMI Processed Kimberlite to Mine Workings Water License and
# Environmental Assessment Hearing Submissions

Prepared for:

**B. Pain**

**Government of the Northwest Territories**

Prepared by:

**Zajdlik & Associates Inc.**

July, 2019

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## List of Tables

**Table 1: Acronym Definitions**

| Acronym | Definition |
|---|---|
| CCME | Canadian Council of Ministers of the Environment |
| COPCs | contaminant(s) of potential concern |
| DDMI | Diavik Diamond Mine Inc. |
| EA | Environmental Assessment |
| EFPK | extra fine processed kimberlite |
| GNWT | Government of the Northwest Territories |
| IRs | Information Request |
| MVEIRB | Mackenzie Valley Environmental Impact Review Board |
| NIWTP | North Inlet water treatment plant |
| PK | processed kimberlite |
| PKMW | Processed Kimberlite to Mine Workings |
| SIS | Summary Impact Statement |
| TDS | total dissolved solids |
| WL | Water License |
| WQG | water quality guideline |

# 1 General Introduction

In this document, recommendations are made to the GNWT regarding information requests to Rio Tinto in preparation for the Environmental Assessment (EA) Hearing in the fall of 2019. Section 2 represents a review of the Summary Impact Statement (Rio Tinto, 2019) that, in consideration of information provided during the water licence process, led to a series of recommendations to GNWT. Some of those recommendations were presented as Information Requests to the Proponent. In §3, the responses to the IRs are reviewed and additional recommendations are made to the GNWT.

# 2 Information Requests Submitted Prior to PKMW EA Hearing

## *2.1 Introduction*

Diavik Diamond Mines Inc (DDMI) requested a Water License (WL) amendment to place processed kimberlite (PK) in mine workings that would be subsequently flooded and reconnected to Lac de Gras. As this was a substantive change to the Project Scope that led the to the possibility of adverse ecological and sociological impact, the Mackenzie Valley Environmental Impact Review Board (MVEIRB) exercised its authority to require an Environmental Assessment for this Project Amendment. The MVEIRB presented a list of requirements regarding the Summary Impact Statement (SIS) to DDMI on April 18, 2019. Rio Tinto provided the response on May 17, 2019. The document:

Rio Tinto. 2019. Summary Impact Statement. Processed Kimberlite to Mine Workings Project, May 17, 2019. MVEIRB Project # EA1819-0.

is the subject of this review and comments provided in §1, herein.

## *2.2 Effects on Performance of the North Inlet Water Treatment Plant*

The Processed Kimberlite to Mine Workings (PKMW) Project proposal discusses decanting pit water to the North Inlet water treatment plant (NIWTP). It is not clear how this could affect the operations of the NIWTP. Review of the PKMW Project raises the following requests for additional information:

1. What proportion of water currently treated by the NIWTP will the pit decant water (a mixture of PK and EFPK porewater and groundwater inflow) comprise on a monthly basis, over the proposed deposition period (2021-2025)?

2. How do the total dissolved solids (TDS) loads from the pit decant water compare to the current TDS loads to the NIWTP on a monthly basis over the proposed deposition period (2021-2025)?

## *2.3 Congruence with Extant Technical Guidance*

Rio Tinto (2019 §3.2.4) states: "The characterization of residual effects is based on methods used in the 1998 Comprehensive Study (DDMI, 1998) to maintain consistency of the assessment of this modification of the mine operation with the original assessment of the Diavik Mine as a whole". The definition of significant environmental effects uses that of Canada (1999) to "provide consistency with the previous assessment and because of the consultation with regulators, indigenous groups, and communities that has taken place for the PKMW Project and for the AEMP" (Rio Tinto, 2019 §4.1.6). However, other aspects of the environmental assessment use more recent science (i.e. water quality benchmarks, Rio Tinto, 2019 §4.1.5 and ecological thresholds Rio Tinto, 2019 Table 4-3).

### 2.3.1 Recommendations

The Canadian Environmental Assessment Act promulgated in 2012 and associated technical guidance (CEAA, 2018a, b) supersedes earlier acts and definitions. Rio Tinto should tabulate how the methods used in the 1998 Comprehensive Study (DDMI, 1998) and Canada (1999) compare with current methods for environmental effects assessment (CEAA, 2018a) and cumulative effects assessment (CEAA, 2018b).

### *2.4 Significance Thresholds*

The significance thresholds presented in Rio Tinto (2019 Table 4-3) were not exhaustively reviewed at this time. However, it is noted that Rio Tinto proposes to use a deprecated Zn CCME water quality guideline (7 µg/L) to set the significance threshold. Golder (2019) recently proposed use of the draft CCME water quality guideline (WQG) for the protection of aquatic life (CCME 2018) because it incorporates both the effects of pH, dissolved organic carbon and hardness and uses more recent data than the previous CCME Zn WQG. Using available baseline data and the CCME (2018) water quality guideline the Zn benchmark would be 4.4 µg/L for dissolved Zn. Rio Tinto should review significance thresholds and adopt the most recent CCME and/or provincial WQGs when assessing water quality impacts. This should be accompanied by updated conclusions regarding water quality changes attributable to the PKMW Project.

### *2.5 Selected Model*

All predictions regarding pit lake stability and water quality in the mixolimnion and ultimately, statements regarding potential environmental effects rely on output from a single model (CE-QUAL W2). Concerns associated with this model include:

1. Rationalization for Model Selection: There are many models that could be used to asses pit lake stability. The very limited rationalization provided to date discusses use elsewhere but does not include discussions of similar model predictions that have been validated. There are various extant paradigms for choosing a water quality model that could be used to optimally choose a model (US EPA, 2009; Vandenberg et al., 2011; Mateus et al, 2018). General classes of models are more suitable for some applications. US EPA (2009) refers to this as “application niche uncertainty”. For example, for 2 dimensional physical and chemical modelling, Vandenberg et al. (2011) state that

"Laterally-averaged models (such as CE-QUAL W2) are applicable mostly to long and narrow lakes" (as opposed to deep and small pit lakes). As noted by US EPA (2009), "The project team should gain model acceptance before applying the model to decision making to avoid confusion and potential re-work".

2. Congruence between Model Strengths and Reviewer Requirements: Mateus et al. (2018) include the criterion that reviewer / end-user requirements should be considered when selecting models. One key element of model utility is the ability to address realistic variation in model parameters simultaneously. As noted by the Proponent, the one-at-time perturbations currently used, have limitations in assessing the full effect of related model parameters. Due to the reliance on model output, one important reviewer criterion is the ability of a model to use stochastic inputs with realistic run times.

3. Model Inputs: Model inputs drive model outputs and some key model input data were not available for the proof-of-concept modelling conducted to date. A set of PK consolidation model parameters are currently being estimated and would be helpful in understanding potential pore water volume and composition loads to the pit lake. To the best of my knowledge[1] those inputs have not been used in the PKMW Project EA.

### 2.5.1 Recommendations

As noted by MVEIRB (2019b) "Placement of processed kimberlite in the pits and underground mine workings would be permanent and irreversible". The PKMW Project proposal is based on preliminary results from a single model with a very limited rationalization for selection. Given

[1] "The consolidation of PK is conceptual and based on estimates of the material properties of PK and average porewater chemistry (there are high consolidation rates)" (Rio Tinto 2019 §4.4.1). It is not clear when results from the Diavik Fine Tailings Consolidation and Release Water Characterization Study being conducted by the University of Alberta will be available. The current worst-case scenario estimates may not necessarily be "worst case" estimates. For example, in the event that expressed pore water is lower in volume and/or analyte concentrations (i.e. "better") than expected, upsets in meromixis may occur more frequently (albeit with better water quality and less associated risk) due to the lower density gradient.

the importance of conclusions reached using this model, the irreversibility of PK and EPK placement, Rio Tinto should:

1. Corroborate model results using a model selected through an objective selection process. It would be helpful if model inputs included the results of the PK consolidation study.

## *2.6 Cumulative Effects Assessment*

MVEIRB (2019c) states that one consideration in the decision to proceed with an EA is that "the process has also not fully considered cumulative effects of the proposed activities in combination with other existing or planned projects in the area". This topic was raised during water licence hearings. The proponent responded that the requisite Lac de Gras water quality model had not yet been constructed and/or parameterized. This activity should be expedited, possibly by using the existing Lac de Gras water quality model built by Golder and used in the Jay Pit Licence EA and WL application.

The GNWT recommended that the EA scope include water quality modelling for assessing cumulative effects of the proposed activities on Lac de Gras to better inform the EA (MVEIRB, 2019a, GNWT Comment 8). Rio Tinto (2019, §4.5) discusses cumulative environmental effects on water quality. The statement is made that "No cumulative effects are anticipated to interact with water quality during the post-closure phase of the PKMW Project for A418 and A154, given that the dikes will not be breached until water quality meets AEMP benchmarks". This statement does not consider the possibility of unanticipated mixing causing interactions with missing exposure pathways from the Diavik mine. Some of these are:

- PKC "outlet water quality/quantity that is not adequate for release into Lac de Gras" (Rio Tinto, 2017 §5.2.6.6);
- "seepage water quality/quantity that is not adequate for release into Lac de Gras" (Rio Tinto, 2017 §5.2.6.6). Note that some North Country Rock Pile waste rock storage area

closure criteria (Ag, Cu, Ni and Zn) were not considered achievable (Rio Tinto, 2017 Appendix V).

- "total suspended particles and deposition/quality measurements of any dust generated from the closed PKC" (Rio Tinto, 2017 §5.2.6.7); and

- additional deposition of (contaminants of potential concern) COPCs via dust and erosion due to closure activities (i.e. removal of infrastructure) that may be occurring simultaneously with dike breaching.

The statement also omits the A21 pit lake where the chemocline is less stable than the other two pit lakes due to "shallower depth of water cover in A21 relative to A418 and A154" (Rio Tinto 2019 §4.4.1.3).

#### 2.6.1 Recommendations

Rio Tinto should revise the cumulative effects assessment to:

- be consistent with recent Federal guidance regarding assessment of potential cumulative effects under the Canadian Environmental Assessment Act (CEAA 2018b);

- include missing exposure pathways; and,

- consider the interaction between an upset of the chemocline and COPC loads from the missing exposure pathways.

### *2.7 Risk Assessment*

MVEIRB (2019b) notes that: "The 1999 CEAA Comprehensive Study did not assess the placing of processed kimberlite in the pits and underground mine workings, including: whether doing this is acceptable, what the related effects may be, what the acceptable level of risk to Lac de Gras and other valued components is, and how to mitigate potential impacts."

During the WL process reviewers discussed a risk assessment to quantify how an upset of meromixis would affect water quality in the vicinity of the pit lake if the Jay Pit were operating and, in consideration of Diavik waste rock storage area losses to Lac de Gras. DDMI discussed the effect of a breakdown in pit lake stratification on water quality within the pit lake under various scenarios but deferred a more complete risk assessment than includes effects within Lac de Gras and cumulative effects to the Closure and Reclamation Plan.

The GNWT recommended that the EA scope include a risk assessment to quantify how an upset of meromixis would affect water quality in the pit lake and in the vicinity of the pit lake to better inform the EA (MVEIRB, 2019a, GNWT Comment 9). Rio Tinto did not conduct such a risk assessment. After review of the additional evidence provided, the recommendation to conduct a risk assessment could be waived if:

1. those exposure pathways discussed in §2.6.1, herein are included in a cumulative effects assessment, that,

    a. combined with the results of a model selected through an objective selection process (as discussed in §2.5.1, herein) that corroborates current model predictions under the same scenarios,

    b. demonstrates that exceedances of chosen benchmarks (as discussed in §2.4, herein) are of limited duration, effect and geographic scale.

## *2.8 Requests for Clarification*

The following minor requests for clarification are provided in no particular order.

- It is not clear how "natural stabilization of water in pit lakes; monitoring of water quality in pit lakes prior to reconnection to Lac de Gras" (Rio Tinto 2019 Table 4-5) could lead to a change in the water quality of Lac de Gras. Rio Tinto should describe the pathway by which this could occur.

- Rio Tinto (2019 §4.4.1.3) states: "Openings of sufficient size will be made within the dike walls to allow adequate mixing and incorporate the pit lake back into Lac de Gras, to facilitate the recolonization of aquatic life". Rio Tinto should define "adequate mixing" and the criteria used to determine when adequate mixing is achieved.

- Rio Tinto (2019 §4.5.2.2) suggests that monitoring water quality within the pit lakes after breaching the dikes comprises mitigation for cumulative effects. Rio Tinto should remove this statement because it is not a statement of fact.

- Narrative statements regarding cumulative effects (Rio Tinto 2019 §4.5.2.3) appear to use the sum of a maximum predicted COPC over a 100-year period at a given pit lake depth and predictions from the Jay Pit Lac de Gras water quality model. It would be helpful if Rio Tinto could confirm that this is the case and also discuss:

    1. whether the maximum COPC concentration includes an overturn of meromixis scenario for the A154 and A418 pit lakes;

    2. what Jay Pit Lac de Gras model prediction nodes were used; and,

    3. the list of Jay Pit Lac de Gras model prediction COPCs.

## *2.9 Mitigating Potential Impacts*

Given an established pit lake morphometry, the wind sheltering coefficient (that has been found to be a key driver of stability in some cases (Noren, 2003; Huang and Liu; 2008; Rangel-Peraza et al. 2016) was shown by DDMI to not greatly affect the CE-QUAL W2 water quality predictions. This was also true of other one-at-time sensitivity analyses[2] conducted by DDMI. Thus, in the absence of large inputs of physical energy (tectonic or pit wall failure) and using the current modelling approach[3], the long-term persistence of meromixis in the proposed pit lakes is a function water quality input volumes, concentrations and input levels (i.e. depths). During the review process DDMI suggested that ground water inputs would be negligible once the pit was filled. Therefore, for fixed consolidation parameters (currently being assessed) and a given volume of PK to deposit, practical long-term mitigation of potential impacts is limited to controlling the volume of groundwater that fills the pit lake prior to breaching the dikes or, the choice of pits in which to deposit PK or extra fine processed kimberlite (EFPK).

A potential mitigation option is to avoid placement of PK and/or extra fine processed kimberlite (EFPK) into the A21 pit due to the elevated risk of adverse water quality (Rio Tinto 2019 §4.5.2.3) due to "the breakdown of meromixis and full mixing in A21 *which* is a result of the shallower depth of water cover in A21 relative to A418 and A154" (Rio Tinto 2019 §4.4.1.3). Rio Tinto should discuss:

1. why the A21 pit is being considered for the deposition of PK and EFPK; and,

2. reasonable and practical alternatives to depositing of PK and EFPK into the A21 pit.

[2] Limitations of one-at-a-time sensitivity analyses are discussed in Hamby, 1994 and US EPA 2009.

[3] Please refer to §8, herein for a discussion regarding the current modelling exercise.

# 3 Review of Information Request Responses

Rio Tinto (2019b) responded to reviewer Information Request (IRs). In this section, responses to those recommendations and /or requests submitted by the GNWT to DDMI with an emphasis on those presented in §1, herein are reviewed in this section. A synopsis of expected effects under the various scenarios is presented prior to reviewing information requests.

## *3.1 Synopsis of Expected Effects*

The main types of predictions are presented below. This is a work in progress due to a lack of clarity in describing the main types of predictions.

### 3.1.1 Project-Specific Effects

Project-specific effects are those attributed to the PKMW plan and pertain to the pit lakes only. Thus, pathways do not include losses from rock piles etc. Various scenarios that involve combinations of freshwater cap depth and deposition of PK and extra fine PK are presented in Rio Tinto (2019a, Table 3-2). Results are tabulated for average and maximum concentrations for a 100-year period in Tables B10-B12 (Rio Tinto, 2019). The results are summarized and extracted from Rio Tinto (2019a, §4.4.1.3) and are presented below.

- "For pit lake A418 under modelled scenarios 2a, 3a, and 4a, water quality constituents are generally predicted to decrease quickly following closure and to stabilize and maintain meromixis. Constituents are predicted to be below the AEMP benchmarks for all scenarios in waters in the surface and at 40 m depth (Table 4-7);

- For pit lake A154 under modelled scenarios 2a, 3a, and 4a, water quality constituents are generally predicted to decrease quickly following closure and to stabilize and maintain meromixis. Constituents are predicted to be below AEMP benchmarks for all scenarios in waters in the surface and at 40 m depth (Table 4-8); and

- For pit lake A21 under modelled scenarios 2a, 3a, and 4a, water quality constituents decrease very quickly at the surface but fluctuate at the 40 m depth. Nitrite, nitrate and molybdenum are predicted to exceed the AEMP benchmarks for scenario 3a and nitrite is predicted to exceed the AEMP benchmark in scenario 4a. All constituents are predicted to be below AEMP benchmarks for scenario 2a (Table 4-9)".

Note that Zn should also be added to the list of analytes that will be exceeded at pit lake A21 (see §2.4 and 3.5, herein for further details).

### 3.1.2 Unanticipated Mixing

Although modelling using the CE-QUAL W2 model does not predict mixing for the A154 and A148 pits (but does for A21), concerns expressed by reviewers led to evaluating the effects of unanticipated mixing within the pit lakes. These predictions do not address other loads that could simultaneously affect water quality within Lac de Gras. Because A21 is expected to be unstable, the effects of unanticipated mixing are also presented in (Rio Tinto 2019a, §4.4.1.3), a summary is extracted below:

- "For scenario 2a, constituents are predicted to be below the AEMP benchmarks at the surface and at 40 m depth;
- For scenario 3a, concentrations of three constituents[4] are predicted to exceed the AEMP benchmarks at 40 m depth while none are predicted to exceed at the surface;
- For scenario 4a, concentrations of one constituent is predicted to marginally exceed the AEMP benchmark in both surface and at 40m depth."

Rio Tinto (2019a, §4.4.3.2) summarizes the results of unanticipated mixing. These are extracted and presented below.

[4] This should may also include Zn (please see §1.4 and 2.6, herein) for additional details.

- "For pit lake A418 under modelled scenarios 2a, 3a, and 4a, water quality would be below the AEMP benchmarks for all parameters except nitrite for scenario 3a (0.076 mg/L, 26% higher than the benchmark);

- For pit lake A154 under modelled scenarios 2a, 3a, and 4a, water quality would be below the AEMP benchmarks for all parameters; and

- For pit lake A21 under modelled scenarios 2a, 3a, and 4a, water quality would be below the AEMP benchmarks for all parameters except nitrite for scenario 4a (0.062 mg/L, 3% higher than the benchmark)".

Detailed tables are presented in (Rio Tinto, 2019 Table B4-B6).

### 3.1.3 Cumulative Effects

Cumulative effects assessments are limited to predicting worst case scenario water quality in each of the pit lakes over a 100-year period as discussed in §3.1.1, herein. It was assumed that the Jay Pit was operating and that predicted worst-case[5] concentrations for those nodes closest to the respective pits[6] was the water quality at the dike breaches. These predictions include "the operational discharge to Lac de Gras from the North Inlet Water Treatment Plan (NIWTP) at its maximum permitted limit". The modelled predictions within the pit lakes were assumed to be the worst-case estimates at the dike breaches and consequently no modelling within Lac de Gras was conducted. Rio Tinto (2019a, §4.5.2.3) summarizes the results of unanticipated mixing. These are extracted and presented below.

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[5] "Updated Assessment Case YEAR 23 was used in support of the Water License Process as described in Golder Associates Ltd. 2015. Jay Project Compendium of Supplemental Water Quality Modelling. Prepared for Dominion Diamond Ekati Corporation. Yellowknife, NT, Canada. April 2015" (Rio Tinto, 2019 Response to GNWT Comment 15).

[6] The exact prediction nodes are presented in the response to GNWT Comment 21 (Rio Tinto, 2019b).

- "For pit lake A418 under modelled scenarios 2a, 3a, and 4a, water quality constituents are generally predicted to decrease quickly following closure and to stabilize. Constituents are predicted to be below the AEMP benchmarks for all scenarios in the surface water and at 40 m depth (Appendix B, Table B-7, Figures B20-22);

- For pit lake A154 under modelled scenarios 2a, 3a, and 4a, water quality constituents are generally predicted to decrease quickly following closure and to stabilize. Constituents are predicted to be below the AEMP benchmarks for all scenarios in the surface water and at 40 m depth (Appendix B, Table B-8, Figures B23-25);

- For pit lake A21 under modelled scenarios 2a, 3a, and 4a, water quality constituents are not predicted to decrease quickly following closure or to stabilize quickly. Constituents are predicted to be below the AEMP benchmarks for scenario 2a and 4a at both surface and 40 m depths and above the AEMP benchmarks for scenario 3a at 40 m depth (Appendix B, Table B-9, Figures B25-27)". These exceedances include nitrate, Cd, Mn, Mo and Zn (under the current draft Zn WQG).

It is not clear why under scenario 3A, nitrite AEMP exceedances are predicted at a depth of 40 m for the project-specific effect (Rio Tinto, 2019, Table B-12) but not in the cumulative effects assessment for the same depth and scenario which is explained as the sum of the project-effect and inputs from the Jay Project (Year 23) and maximum permitted discharges from the NIWTP. Nitrite exceeds the benchmark under scenario 4A at both depths (Rio Tinto, 2019, Table B-12) for the Project-specific assessment but nitrite predictions are not included for any of the cumulative effects assessments. Note that nitrate concentrations are provided in the cumulative effects assessments.  The nitrate AEMP benchmark is exceeded at a depth of > 40M in the A21 pit lake (Rio Tinto, 2019a, Appendix Table B-9).

## *3.2 GNWT Comment ID 7 - Modeling Updates for Final Water Licence Approval*

GNWT Comment ID 7, recommendation # 2 (Rio Tinto, 2019b) states: The GNWT requests that DDMI describe contingency options that exist if updated modelling results in different/poorer water quality within the open pits or Lac de Gras then have been assessed in this EA as a result of placing PK into open pits. The DDMI response (Rio Tinto, 2019b) considers only options that include the deposition of waste to Mine Workings (i.e. A154, A148 and A21 pits). In the event that updated modelling shows that deposition of waste to mine workings is unacceptable for whatever reason, DDMI should be prepared to discuss expansion of the PKC to store the mine waste in perpetuity.

### 3.2.1 Recommendation

It is recommended that the option to discuss expansion of the PKC to store the mine waste in perpetuity, as a contingency response, if updated modelling shows that deposition of waste to mine workings is unacceptable for whatever reason be included in the Rio Tinto submission.

### *3.3 GNWT Comment ID 11 - North Inlet Water Treatment Plant*

GNWT Comment ID 11, (Rio Tinto, 2019b) poses the two following requests for information:

1. “The GNWT requests DDMI outline the expected volume of water treated by the NIWTP that will be comprised of the pit decant water (a mixture of PK and EFPK porewater and groundwater inflow) on a monthly basis. This information should be provided for the entire proposed deposition period (e.g., years 2021-2025).

2. The GNWT requests DDMI compare the anticipated total dissolved solids (TDS) loads from the pit decant water to the current TDS loads from the NIWTP on a monthly basis over the proposed deposition period (2021-2025)”.

One section of the response provided by Rio Tinto (2019b) states: “If PK is deposited in mine workings the blend of water that is treated in the NIWTP will not change because the PKC Pond water will effectively be replaced by pit decant water”. This statement assumes that the PKC Pond is not decanted, that the volume of decant water from the pit that consists of groundwater inflow to the pit + leachate from the deposited PK (which will consist of a blend of groundwater moving through the PK and diffusive process acting at the PK – water interface) and, that TDS loads from the PKC and pit lake decant water, are identical. Statements from Rio Tinto (2019b) response leading to the final conclusion are summarized below:

- Recent TDS loads from the NIWTP to LDG between 3, 4 x $10^6$ kg/year.
- 3 x $10^5$ kg of TDS is directed to the NIWTP via the PKC in a “typical” year.
- Expected volume of excess slurry water and overall pit decant water (including groundwater contributions) throughout the operational phase is expected to range between 2 x $10^5$ and 3 x $10^6$ $m^3$ annually.
- Process circuit currently recycles about 3 x $10^6$ $m^3$ annually from the PKC and North Inlet and this rate is expected to continue for the remaining life of mine.
- Additional comments are made regarding loads to Lac de Gras from the Pit lakes which are not relevant to the question posed.

The conclusion from Rio Tinto (2019b) response is: “For this reason, the PKMW TDS load to the NIWTP is expected to remain similar to current PKC rates during the Operational phase of the project”. It is not clear how this conclusion is reached. The summary presented above shows that recent TDS loads from the NITWP to LDG are discussed. TDS loads in a typical year from the PKC to the NIWTP are also discussed as is the volume of pit water (excess slurry water and overall pit decant water including groundwater contributions) reporting to the NIWTP. Additionally, a comment is made regarding how much water is recycled from the PKC and North Inlet. The TDS loads to the NIWTP from the pit lakes which would provide a direct comparison with current loads are not provided although they were requested.

### 3.3.1 Recommendation

Changes in TDS loads to the NIWTP have not been provided as requested. The arguments provided do not support the conclusion that “In general, the PKMW project will not create a significant deviation from the current operational site water balance or North Inlet Water Treatment Plant (NIWTP) Operations”. It would be helpful if DDMI could provide the information requested or, any additional information that allows for comparison of loads to the NIWTP under the currently approved water licence and the proposed PKMW project.

## *3.4 GNWT Comment ID 12 - Congruence with Extant Technical Guidance - assessment methodology*

GNWT Comment ID 12, (Rio Tinto, 2019b) notes that the SIS environmental effects assessment “is based on methods used in the 1998 Comprehensive Study (DDMI, 1998) to maintain consistency of the assessment of this modification of the mine operation with the original assessment of the Diavik Mine as a whole. GNWT recommended that “DDMI tabulate how the methods used in the 1998-99 Comprehensive Study (DDMI, 1998 and Canada, 1999) compare with current methods for environmental effects assessment (CEAA, 2018a) and cumulative effects assessment (CEAA, 2018b) “ and, “that DDMI describe why these newer assessment methods, values and procedures would not apply to the project”. The Proponent response refers to “a framework developed by Stantec that has been used in environmental assessments under the Canadian Environmental Assessment Act, 2012 (CEAA 2012), Nunavut Planning and Project Assessment Act, MVRMA and Inuvialuit Final Agreement”. No citation is provided nor is concordance with extant guidance on Canadian EA practices (CEAA, 2018a), provided.

### 3.4.1 Recommendation

The response provided by DDMI does not address the question posed and mentions a framework but does not provide a citation. The response appears to be inconsistent with the SIS. Rio Tinto should provide the appropriate citation(s) and prepare a concordance table or lack thereof lack between methods presented in CEAA (2018a) and those in Canada (1998) as modified by Rio Tinto (2019a).

## *3.5 GNWT Comment ID 13 - Significance Thresholds*

GNWT Comment ID 13, (Rio Tinto, 2019b) requested that “DDMI review jurisdictional significance thresholds and comment if they will adopt the most recent CCME and/or provincial WQGs when assessing water quality impacts. This should be accompanied by updated conclusions regarding water quality changes attributable to the Project”. The DDMI response was that only the WQG noted by GNWT (Zn) that does not reflect the most recent guidelines is for Zn. The DDMI response also refers to IR3 as containing further implications regarding the use of a lower WQG for Zn. The response refers to the North Slave Metis Alliance comment 3 regarding the use of an outdated Zn WQG. The response from DDMI is that “A 30 microgram/L (µg/L) zinc benchmark threshold for the protection of aquatic life was used to maintain consistency with the 1998 assessment and the 2017 AEMP”. Further rationalization is that in one scenario (A21, scenario 3A) a high magnitude, long-term effect on water quality is already identified on the basis of other parameters. The rationalization is insufficient because 1) other WQGs have been updated since1998, and, 2) the full suite of analytes that lead to a high magnitude, long-term effect on water quality are of interest.

### 3.5.1 Recommendation

- DDMI should use WQGs that are current.

## *3.6 GNWT Comment ID 14 – Selected Water Quality Model*

GNWT Comment ID 14, (Rio Tinto, 2019b) requested that DDMI corroborate the model results using a different model due to the irreversibility of depositing PK into mine workings that are intended to be rejoined with Lac de Gras. There is evidence that the model chosen is not the best choice for a water body with bathymetry such as a pit lake (Please refer to §2.5, herein). Furthermore, other jurisdictions use paradigms to aid in model selection. DDMI has not provided rationalization for why the CE-QUAL W2 model should be used other than that it has been used before in similar applications. The response provided by DDMI is that the requested modelling was not conducted because there is no standard to do so. (Please note that in §3.4, herein, DDMI argues the converse and does not use the current standard for conducting environmental affects assessments). In the case of the GNWT IR 14 (Rio Tinto, 2019b), the recommendation suggests that best practices used elsewhere also be applied to the "Placement of processed kimberlite in the pits and underground mine workings *that* would be permanent and irreversible" (MVEIRB, 2019b). Given the consequences of unacceptable pit lake water quality following reconnection (possible local effects on biota, shunning the area by Landholders, etc.), the preliminary nature of the model used, the concern regarding applicability and the lack of rationalization for the currently selected model, the previous recommendation[7] remains.

[7] "Corroborate model results using a model selected through an objective selection process. It would be helpful if model inputs included the results of the PK consolidation study".

### *3.7 GNWT Comment ID 15 and 16 – Cumulative Effects Assessment and Risk Assessment*

DDMI did not conduct the risk assessment previously recommended by GNWT. GNWT reviewed the assessment that was conducted and expressed concerns regarding missing exposure pathways, use of appropriate significance thresholds and use of most recent Federal guidance on conducting cumulative effects assessments. The response from DDMI with respect to conducting a cumulative effects assessment is that "DDMI expects that the YEAR 23 modelling results from the Jay Project represents a worst-case closure condition that would more than account for the additional pathways noted by GNWT". This statement is an unsupported opinion that does not satisfy GNWT's request.

After reviewing the additional evidence provided by DDMI prior to the EA, GNWT recommended that a risk assessment could be waived if:

1. "Those exposure pathways discussed in the GNWT's requests discussed herein are included in a cumulative effects assessment, that,

2. combined with the results of a model selected through an objective selection process (as discussed in the GNWT *prior* comments on model selection, herein) that corroborates current model predictions under the same scenarios, and

3. demonstrates that exceedances of suitably chosen benchmarks (as discussed in the GNWT's comments on significance thresholds, herein) are of limited duration, effect and geographic scale" (GNWT Comment ID 16, Rio Tinto, 2019b).

The response from Rio Tinto points to Rio Tinto (2019a, §4.4.3.2) which states: "With the implementation of the mitigation and response measures, potential residual effects on water quality are anticipated to be localized and of short duration; therefore, the risk is remote (risk is acceptable; no additional risk mitigation required) and the effect is considered not significant". The risk is dismissed due to "implementation of the mitigation and response measures". This likely refers to Rio Tinto (2019a, Attachment 5, Commitment 3) which states: "Close the breaches or isolate the pit lake from Lac de Gras if water quality is later determined to pose a risk to water quality, fish and fish habitat, caribou, humans or cultural land uses". In a response to MVEIRB (Rio Tinto 2019, MVEIRB Comment 31) DDMI states: "If this occurred 50 years in the future when no equipment or operators were available at site, the equipment and operators would need to be mobilized. Backfill material would likely be excavated from the surface of adjacent remaining sections of dike or the east island". This has impacts with respect to securities that need to be held.

DDMI has not conducted a cumulative effects assessment or a risk assessment as requested. The rationalization provided is that the worst-case scenarios have already been assessed and that associated effects are of negligible risk. A synopsis of expected effects is presented in §3.1, herein. With the exception of A21, scenario 3A, the predicted concentrations suggest risks to the receiving environment are indeed low. However, concerns regarding the model selection (please see §2.5 and 3.6, herein[8]) and congruence with extant guidance, specifically definition of severity (magnitude, duration and spatial extent) (please see §2.3 and 3.4, herein) apply to the model and how adverse effects are designated. The evidence provided by DDMI has not allayed the concerns expressed to date regarding these subjects. By extension therefore, conclusions regarding cumulative effects and risks to the environment are also not allayed.

### *3.8 GNWT Comment ID 17 – Mitigating Potential Impacts*

GNWT Comment ID 17, (Rio Tinto, 2019b) requested that:

1. "The GNWT requests DDMI discuss why the A21 pit is being considered for the deposition of PK and EFPK; and reasonable and practical alternatives to depositing of PK and EFPK into the A21 pit.

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[8] A review of model calibration has yet to take place. A placeholder appears in §2.11, herein.

2. The GNWT requests that DDMI describe the capacity of A154 and A418 to store PK and EFPK and whether any additional storage is required”.

### *3.9 GNWT Comment ID 19 – Adequate Mixing*

GNWT Comment ID 19, (Rio Tinto, 2019b) requested that “DDMI define “adequate mixing” and the criteria used to determine the size and number of the openings and when adequate mixing is achieved”. The DDMI response is adequate and no further clarification is necessary.

### *3.10 GNWT Comment ID 21 – COPCs and Prediction Nodes*

GNWT Comment ID 12, (Rio Tinto, 2019b) pertained to details of the cumulative modelling. Specifically, the prediction nodes used to predict water quality in Lac de Gras subject to the worst-case inputs from the Jay Pit, and whether this modelling exercise included an upset condition. The response from DDMI was satisfactory and no further response is necessary.

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# DR. BARRY ZAJDLIK, PRINCIPAL

## PROFESSIONAL EXPERIENCE

1991–present Zajdlik & Associates Inc. Rockwood, Ont.

### *Principal*

- Project management, contract acquisition.
- Environmetrician, report writing.

1992–present Pollutech EnviroQuatics Pt. Edward, Ont.

### *Research Associate*

- Statistical consultation on experimental design, analysis and interpretation.
- Project manager.

1989–1990 Department of Population Medicine Guelph, Ont.

### *Statistician*

- Guidance in statistical design, analysis and interpretation to faculty and staff in biomedical statistics.
- Responsible for providing SAS seminars, computer support, (servicing, installation and purchasing), and custom Fortran and SAS programming.

1990-current Professional Activities

### *External Program/Project Manager*

- Managed international CIDA program, manage projects for other consulting firms.

### *Lecturer*

- An invited lecturer at various universities, governmental agencies, and professional societies with topics falling under the general umbrella of statistics and environmental science.

### *Panel Member*

- An invited panel member at the federal (since 1993), provincial (since 2000) and territorial (since 2012) governmental levels, on issues related to the application of statistics and environmental science.

### *Peer Reviewer*

- Review papers published in the primary literature, book chapters and governmental documents, in the areas of environmental toxicology and statistics.

### *Legal*

- Acted as expert witness, and provide reviews for legal proceedings.

## PROJECT EXPERIENCE: SELECTED RESEARCH

- **Comparison of Toxicity Test Endpoints.** A statistical methodology for hypothesis testing of toxicity test endpoints when raw data are unavailable is to be developed. Environment Canada, Methods Development and Application Unit. 2018- ongoing.
- **Statistical Assumptions for Defensible Estimation of Toxicity Test Endpoints.** Weighting (Poisson and inverse variance), transform both sides, and combinations thereof, were assessed for their ability to remedy heteroskedasticity and non-normality in the context of nonlinear regression. The effect of these remedies on bias and confidence interval coverage for ICp estimates was assessed. Environment Canada, Methods Development and Application Unit. 2015.
- **Assess Protectiveness of Safety Factors.** The level of protection afforded by safety factors was shown to vary by sample size, degree of variation and underlying statistical distribution. The level of protection varies wildly and has implications for environmental management. Mining Association of British Columbia. 2014-2015.
- **Investigate Standardization Methods to Derive Zn CCME Water Quality Guideline.** There is a desire to modify Zn water quality guidelines on the basis of known toxicity modifying factors. This project explored statistical adjustments of Zn toxicity in order to estimate site-specific Zn water quality guidelines. National Guidelines and Standards Office. 2013.
- **Develop a Tier II Site-Specific Remedial Objectives Paradigm.** Soil quality guidelines for PHCs in Canada are primarily driven by the soil contact pathway. Although there is a provision to modify Tier II SSROs there is no method to do so. This project investigates a new paradigm for doing so. PERD, CAPP, Stantec 2012 Research Fund. 2013.
- **Estimate Background Concentrations of Soil Analytes in Ontario.** Background concentrations underpin many of the regulations associated with soil use in Ontario. This project seeks to improve the current background estimation paradigm. 2007-2015. PhD.
- **Develop Soil Sampling Protocols for Cryosols.** Cryosols cover a vast area of Canada and to date no systematic soil sampling protocol has been developed. Such a protocol is necessary to assess potential development effects in the Canadian North. INAC: 2009.
- **Applying SSD Concepts to Bimodal Distributions.** This project involved extending the current CCME paradigm for generating water quality guidelines to substances that exhibit target-specific effects and non-target effects. Environment Canada: 2007.
- **Investigate Spatio-Temporal Variability in Arctic Lakes.** Oil and gas exploration and development along the Mackenzie Valley corridor may lead to requirements for monitoring of lake water quality. The drivers of tundra lake water quality are not currently understood and are under investigation. Indian and Northern Affairs Canada: 2006-2008.
- **Incorporate Toxicity Modifying Factors in the SSD Approach to Estimating Canadian Water Quality Guidelines**. The current water quality guidelines in Canada are generic and suffer from several shortcomings. New methods have been developed for use in Canada that obviate these shortcomings (work conducted by Zajdlik & Associates, Inc.). These new methods are still generic though. This project provides recommendations on how to make the new Canadian approach to generating water quality guidelines site-specific at least with respect to the principal toxicity modifying factors. CCME: February-April 2006.

## PROJECT EXPERIENCE: SELECTED RESEARCH

- **Toxicity Modifying Factors in Ammonia Toxicity to *D. magna*.** This project involves optimizing an experimental design to assess the simultaneous effects of pH and acclimation temperature on ammonia toxicity for Daphnia magna. The results will be used to improve the applicability of Canadian Water Quality Guidelines for ammonia. Ontario Ministry of Environment: 2006.
- **Identify Statistical Models to Describe Species Sensitivity Distributions.** This project involved assessing the statistical and ecotoxicological and regulatory literature to determine what statistical models have been used globally to describe species sensitivity distributions. Then, 7 species sensitivity distributions were examined to generate a suite of statistical models that could potentially describe all species sensitivity distributions for derivation of water quality guidelines within Canada. Ontario Ministry of Environment / CCME: March-October, 2005.

## PROJECT EXPERIENCE: NORTHERN

**NWT: Diavik Site**

1. 2005: B. Blais, AANDC. Review of DDMI Baseline Data Set.
2. 2007: D. Balint, DFO. Review of DDMI 2005 Lakebed Sediment, Water Quality and Benthic Invertebrate Study.
3. 2007: N. Richea, AANDC. Review of DDMI Limnology and "Lessons Learned" Reports.
4. 2007: B. Hanna, DFO. Review of A21 Dike & South Island Causeway Monitoring Study Design Plan.
5. 2008: N. Richea, AANDC. Review of DDMI Adaptive Management Plan.
6. 2008: N. Richea, AANDC. Review of DDMI Power Analyses.
7. 2009: B. Hanna, DFO. Review of DDMI Dike Monitoring Study Designs.
8. 2009: E. Erasmus, Tli Cho Government. Review of Selected Elements of the DDMI 2009 AEMP.
9. 2009: N. Richea, AANDC. Review of DDMI Eutrophication Indicators.
10. 2012: B. Hanna, DFO. Review of Diavik Diamond Mine A154 and A418 Dike Monitoring Program.
11. 2012: N. Richea, AANDC. Technical Advice; Diavik AEMP Design, Version 3.0.
12. 2014: K. Eggers, DFO. Power Analysis of Rio Tinto Dike Monitoring Benthic Diversity Indices.
13. 2016: P. Green, GNWT ENR. DDMI Reference Area Study.
14. 2016: B. Pain, GNWT ENR. DDMI 2011-2013 Aquatic Effects Re-Evaluation Report.
15. 2016: B. Pain, GNWT ENR. Review of 2014 AEMP.
16. 2016: B. Pain, GNWT ENR. Review of 2015 AEMP.
17. 2016: P. Green, GNWT ENR. Comment on Diavik AEMP Design, Version 4.0.
18. 2017: B. Pain, GNWT ENR. Review of 2016 AEMP.
19. 2017: B. Pain, GNWT ENR. Review of 2016 AEMP Response Plans.
20. 2018: B. Pain, GNWT ENR. Review of AEMP Design, Version 5.0
21. 2018: B. Pain, GNWT ENR. DDMI 2014-2016 Aquatic Effects Re-Evaluation Report.
22. 2018: B. Pain, GNWT ENR. Review of 2017 AEMP.

23. 2018: B. Pain, GNWT ENR. Review of Diavik Mine Water Quality Modelling of Mined Out Pits

**NWT: Ekati Diamond Mine Pipes**

24. 2004: C. Mills, IEMA. Review of the Ekati Diamond Mine 2002 AEMP
25. 2006: R. Chouinard, AANDC. Overview of the BHP Proposed AEMP.
26. 2007: N. Richea. AANDC. Review of the BHP Proposed Chloride Discharge Criterion.
27. 2008: R. Jenkins. Indian and Northern Affairs Canada. Comment on BHP Adaptive Management Plan.
28. 2009: N. Richea, AANDC. Review of 2008 BHP AEMP and SSWQOs
29. 2009: N. Richea, AANDC. Review of the BHP Proposed Environmental Quality Criteria for the Sable Site.
30. 2009: N. Richea, AANDC. Assess potential for nitrification and consequences on BHP AEMP.
31. 2012: N. Richea, AANDC. Defining Acceptable Effects Levels for the Ekati Diamond Mine.
32. 2013: P. Green, AANDC. Review of Chloride, Nitrate and Sulphate SSWQOs for the Ekati Diamond Mine.
33. 2015: P. Green, GNWT ENR. Technical Review of DDEC Jay Pipe Environmental Assessment.
34. 2015: P. Green, GNWT ENR. Review of Ekati 2015 AEMP.
35. 2016: P. Green, GNWT ENR. Review of Sable Pit AEMP version 1.0.
36. 2016: P. Green, GNWT ENR. Review of Sable Pit AEMP version 1.1.
37. 2016-17: P. Green, GNWT ENR. Technical Review of DDEC Jay Pipe Water Licence Application and Participation in Technical Meeting and Hearing.
38. 2017: B. Pain, GNWT ENR. Review of Ekati 2016 AEMP.
39. 2017: B. Pain, GNWT ENR. Review of 2016 Pigeon AEMP Re-Evaluation.
40. 2017: B. Pain, GNWT ENR. Review of Sable AEMP Design and Response Plan.
41. 2017: B. Pain, GNWT ENR. Review of Ekati 2016 Selenium, Potassium, Nitrogen and Fish Response Plans.
42. 2018: B. Pain, GNWT ENR. Review of Hydrodynamic and Pit Meromixis Modelling and implications on Effluent Quality Criteria.
43. 2018: 2016: B. Pain, GNWT ENR. Review of Misery Underground Water Licence Application.
44. 2019: B. Pain, GNWT ENR. Review of Jay Pipe 2018 AEMP.
45. 2019: B. Pain, GNWT ENR. Review of DDEC Fish, DO, TP and Chloride Response Plans.

**NWT: Lac de Gras**

46. 2015: L. Brekke, GNWT CIMP. Review of Lac de Gras Cumulative Effects Statistical Analysis.
47. 2016: J. Kanigan, GNWT CIMP. Detection of Cumulative Effects Associated with Diamond Mining in Lac de Gras.
48. 2016: J. Kanigan, GNWT CIMP. Guidance on AEMP Design for Assessing Cumulative Effects in Lac de Gras.

**NWT: Snap Lakes**

**49.** 2010: D. White, SLEMA. Review of Snap Lake AEMP.
**50.** 2013: D. White, SLEMA. Review of Snap Lake AEMP.
**51.** 2013: D. White, SLEMA. Recommendations for Snap Lake Management Response Action Levels.
**52.** 2015: P. Green and N. Richea, GNWT. Review of Power Analyses in the Snap Lake Mine Downstream Watercourses Special Study Plan.
**53.** 2017: R. Walbourne, GNWT ENR. Comment on 2016 AEMP.
**54.** 2017: R. Walbourne, GNWT ENR. Review of 2016 Downstream Watercourses Special Study.
**55.** 2019: R. Walbourne, GNWT ENR. Participation in Snap Lake Water Licence Renewal Workshop

**NWT: Marion River**

**56.** 2012: P. Green, AANDC. Review of the Fortune-Nico Developer's Assessment Report.
**57.** 2013: P. Green, AANDC. Review of Nico Project Water Licence Technical Information.
**58.** 2014: P. Green and N. Richea, AANDC. AEMP Development and Review of the SSWQO and Effluent Quality Criteria for the NICO Mine.
**59.** 2017: P. Green, GNWT. Review of Fortune Minerals Supplemental Baseline Monitoring Plan V 1.4.
**60.** 2018: B. Pain, GNWT. Review of Fortune Minerals Baseline Monitoring Data Report.

**NWT: Prairie Creek**

**61.** 2011: P. Green and N. Richea, INAC. Review of Prairie Creek Environmental Assessment Effluent Related Documentation.
**62.** 2011: P. Green and N. Richea, AANDC. Review of Canadian Zinc Water Licence Related Documentation.

**NWT: Gahcho Kué**

**63.** 2015: N. Richea, GNWT ENR. Gahcho Kué AEMP Review.
**64.** 2017: R. Walbourne, GNWT ENR. Gahcho Kué 2016 AEMP Review.

**NWT: Normal Wells**

**65.** 2018: R. Walbourne, GNWT ENR. Imperial Oil 2018 AEMP Review.

**NWT: General**

**66.** 2008: B. Koedy, DIAND CRD. Review of Colomac Benthic Invertebrate Monitoring Program
**67.** 2008: S. Kokelj, INAC. Sampling Protocols for Turbic Cryosols of the

## PROJECT EXPERIENCE: NORTHERN

Mackenzie Delta.

68. 2009: M. Culhane, INAC. Contribution to: INAC AEMP Guidance Document.
69. 2009: S. Kokelj, INAC. Analysis of Sump-Affected Lakes Data.
70. 2010: J. Kanigan, INAC. Analysis of Drilling Sump Soil Data.
71. 2010: Terriplan Consultants. Contribution to: NWT CIMP Monitoring Principles and VC Protocol Pilot Project.
72. 2010: P. Cott, DFO. Statistical support for assessing stressors on northern fishes.
73. 2011: A. Czarnecki and J. Sanderson, INAC. Modelling Slave River Water Quality Variables at Fitzgerald.
74. 2013: P. Green, AANDC. Preparation for sensitivity analysis of NWT Water Classification System.
75. 2014: P. Green and M. Culhane, AANDC. Estimating Ambient Concentrations of Water Quality Variables in the NWT.
76. 2015: M. McPherson, DFO. Giant Mine - Analysis of Metal concentrations in Fish Tissue in Yellowknife Bay.
77. 2016: L. Brekke and J. Kanigan, GNWT CIMP. General Guidance for Conducting Cumulative Impact Assessments in the NWT.
78. 2016: B. Pain, GNWT ENR. Guidance on Collecting Baseline Water Quality Data.
79. 2016: A. Czarnecki, GNWT ENR. Participation in trans-boundary water quality assessment workshop.
80. 2016: N. Richea, GNWT ENR. Participation in GNWT water classification workshop.

### Yukon and Nunavut

81. 2017: B. Slater, Slater Environmental. A Statistical Justification for Baseline Data Requirements in the Yukon.
82. 2019: H. Sonnenberg, Environmental and Regulatory Solutions. Derivation of site-specific water quality objectives for As, Cu, Cd and Fe for the Meadowbank Mine, Nunavut.

## PROJECT EXPERIENCE: SELECTED EXPERIMENTAL DESIGN

- Design of numerous benthic community surveys to delineate spatial and temporal changes in areas, potentially impacted by heavy metals, PAHs, chlorinated organic compounds, insecticides, thermal plumes and unexploded ordnance residues. Various clients: 1991-2018.
- Experimental Design Reviews: Approximately 30 distinct reviews of monitoring program designs pertaining to resource extraction in the Canadian Arctic. Aboriginal Affairs and Northern Development Canada, Government of Northwest Territories and Department of Fisheries and Oceans: 2004-2018.
- Water Quality Baseline Assessment Guidance Document. See PROJECT EXPERIENCE: SELECTED GUIDANCE DOCUMENTS: 2016.
- Probit analysis and study design approaches at field sites: context and analysis within a standardized toxicity testing framework. Environment Canada: 2014.
- Aquatic Effects Monitoring Program Guidance Document. See PROJECT

## PROJECT EXPERIENCE: NORTHERN

EXPERIENCE: SELECTED GUIDANCE DOCUMENTS. 2009.

- Soil Sampling Protocols for Toxicity Testing. Provide guidance and direct input to newly developed protocol. Environment Canada: 2009-2010.
- Design of environmental monitoring program to assess potential human and ecological effects of the Munitions Environmental Test Centre activities within the St. Laurence River and interpretation of results. Department of National Defense: 2004-2007
- Design of experiments to compare the hepatocyte toxicity test with the Environment Canada regulatory rainbow trout toxicity test. Ontario Ministry of Environment: 2003
- Redesign and interpretation of ongoing monitoring program to assess the potential cumulative ecological effects of uranium mines in northern Saskatchewan. Saskatchewan Environment: 2002 - 2004
- Design of fish consumption survey to determine age-specific consumption rates in a First-Nations community. GlobalTox Environmental Inc. 2004.
- Review of sampling plans to identify unexploded ordnance, Port Albert.
- Design of experiment to evaluate the relative sensitivity of trout hepatocyte and gill cell lines and the 96-hour acute lethality rainbow trout test, to spiked industrial effluents to evaluate utility as an Environment Canada test method.
- Design of experiments to assess the efficacy of Hg separators for dental amalgams and creation of a federal guidance document for technology verification. Ontario Centre for Environmental Technology Advancement: 2002
- Design of experiments to determine the efficacy of As mitigation technologies in Bangladesh. Over 1, 000, 000 wells are contaminated with As. The WHO and Government of Bangladesh are using Canadian expertise in verifying environmental technologies to design a series of field and laboratory verification experiments that will be implemented by the British Geological survey. Ontario Centre for Environmental Technology Advancement: 2001-2002
- Design of *in situ* bivalve bioaccumulation study to assess potential movement of PCB congeners from an industrial site. Confidential.
- Design of adaptive soil sampling plans designed to reduce sampling costs and quantify the risk of undetected hot spots. The contaminants of concern were PAHs that had been stockpiled in a mixture containing highly and slightly contaminated soils. Confidential.
- Design of experiments to estimate relative sensitivity of a sublethal, flagellate bioassay to mining effluents. This research contract was awarded through CANMET.

## PROJECT EXPERIENCE: SELECTED ANALYSIS AND INTERPRETATION

- Analyses of aquatic triad (benthic macroinvertebrate community structure, water quality and sediment quality) and tetrad (triad + bioaccumulation / toxicity) experiments conducted under Federal Pulp and Paper or Mining Effluent Regulations and other non-regulated monitoring programs. More than 35 distinct projects involving mixed effects modelling, multivariate analyses, power analyses, various parametric and nonparametric analyses. Various clients: 1991-2018.
- Model cumulative effects of diamond mining on Lac de Gras water quality. Government

of the Northwest Territories. 2016.

- Modelling fish tissue metal residues in association with the abandoned Giant mine. Department of Fisheries and Oceans. 2015.
- Historical Review of Sarnia Lambton Environmental Associations Sediment Quality Surveys. Pollutech EnviroQuatics. 2015.
- Mixed effects principal component regression of soil PHC fraction contaminants and toxicity modifying factors for Red Fescue emergence and growth metrics and Collembola survival and reproduction Stantec Consulting. 2014.
- Estimating zinc water quality guidelines using multiple toxicity modifying factors. Environment Canada. 2013.
- Modelling effects of contaminant releases from dikes in the Canadian Arctic. Department of Fisheries and Oceans. 2012.
- Modelling crop yields and predicting adverse effect concentrations. Stantec Consulting. 2012.
- Modelling temporal trends in Slave River water quality analytes. Aboriginal Affairs and Northern Development Canada: 2010-2011.
- Analysis and interpretation of soil toxicity data. Stantec Consulting. 2011.
- Historical Review of Sarnia Lambton Environmental Associations Sediment Quality Surveys. Pollutech EnviroQuatics. 2011.
- Geostatistical analyses of eutrophication indicators. Department of Indian and Northern Affairs Canada. 2009.
- Geostatistical analyses of sediment quality indices. Department of National Defense. 2007.
- Estimate thresholds for remediation using 26 types of soil toxicity tests conducted on 49 soil samples. Stantec Consulting Ltd. 2007.
- Assessed effects of mine tailings on plant growth in both field and laboratory experiments and assessed congruence between same. Ontario Ministry of Environment. 2004.
- Determined probabilistic intervention criteria for soil B(a)P in the Ivy Avenue area of Toronto, based upon a human health risk-based intervention criterion. Ontario Ministry of Environment. 2004.
- Predicted financial liabilities to the DFO due to ownership of contaminated sites across Canada. Department of Fisheries and Oceans 2002-2005.
- Nonlinear calibrations to determine probable time to failure for groundwater As mitigation devices. Ontario Centre for Environmental Technology Advancement: 2005.
- Interpreted multivariate data to independently confirm conclusions regarding potential human health effects of the Sydney tar ponds. Nova Scotia Department of Health: 2003.
- Managed a risk assessment of the capability of marshland to retard movement of radionuclides. Pollutech EnviroQuatics: 2002.
- Validation of toxicity test endpoint calculations conducted under GLP.
- Determined probabilistic intervention criteria for soil Ni in the Rodney St. Area of Port Colborne, based upon a human health risk-based intervention criterion. Ontario Ministry of Environment: 2002.
- Determined exposure of Walpole Island First Nation residents to contaminants in fish.

GlobalTox: 2003.

- Estimation of endpoints from problematic data generated by OECD method 201.
- An evaluation of methods used to interpret the *Vibrio fischeri* solid-phase luminescence test. Environment Canada, Waste at Sea is considering using the *Vibrio fischeri* test in determining the suitability of dredged materials for disposal at sea. Environment Canada: 2000.
- Developed the statistical component of the Canadian Environmental Technology Verification program. ETV Canada: 2000.
- Analysis and interpretation of TEQ emission rates used to determine the impact of wood stove combustion on dioxins and furan loadings. Environment Canada, Environmental Technology Centre: 2000.
- Analysis and interpretation of data generated by Cycle II EEM pulp and paper compliance monitoring programs (2 locations).
- Design and interpretation of a contaminated harbour assessment on the St. Lawrence River, using a sediment quality triad approach. Pollutech EnviroQuatics: 2000.
- Monte Carlo analysis of soil contaminant, volume estimates in an environment subject to tidal influences. Imperial Oil: 1999.
- Managed an ecological risk assessment to investigate the risks of remediation of contaminated sediments in the St. Clair River. Sarnia Lambton Environmental Association: 1999-2001.
- Determining the relationship between sediment, and porewater metal levels of lead in various forms to *Amphiporeia virginiana* following a spill of materials. Pollutech EnviroQuatics: 1999.
- A commentary on the statistical implications of compliance biological test design and interpretation.
- Estimation of limits of quantification used in setting criteria for the virtual elimination of PCBs and PCDDs in Canada. Environment Canada (Analysis and Methods Division).
- Interpretive guidance for bioassays using pollution gradient studies. The performance of sediment bioassays along a gradient of PAH and PCB contamination was examined. Concomitant sediment chemistry and benthic macroinvertebrate abundance data was used to link toxicity test responses with environmental measurements and effects using the sediment quality triad paradigm. Recommendations for the assessment of dredged materials in Canada prior to ocean disposal were given. Environment Canada, Ocean Disposal: 1999-2000.
- Analysis of round-robin data used to explore new methods for hydrocarbon analyses. BC MELP.
- Estimation of spatial extent of toxicant contamination in marine sediments following a spill event.
- Assessment of the correlation between metal contaminants in soil and crop yields and growth.
- Analysis of experiments to refine the standard operating procedure for an experimental biological test used to assess water quality of mining effluents. CANMET Research Grant.
- Analysis of air quality discontinuities resulting from process control changes in a chemical

manufacturing plant.

- Consultation on sampling design for routine monitoring of dredged material disposal sites. Environment Canada.
- Predicting process control parameters in pilot effluent remediation studies to ensure effluent compliance.
- Estimation of "Safe Levels" of food additives using structural class to conform to a defined risk. "Safe levels," were estimated using the 5th percentile of NOECs, and by an empirical bootstrapping method developed by Zajdlik & Associates. The effects of using various types on endpoints (mortality, blood, liver, gonadal, kidney, etc.), and stratifying factors such as sex, species tested, and structural class.
- Triad analysis of industrial, municipal and agricultural inputs to a fluvial system. This multi-year study compared sediment chemistry, sediment toxicity tests and benthic macroinvertebrate community structure using the sediment quality triad paradigm. Sarnia Lambton Environmental Association
- Consultation on survey design for estimating daily nutrient intakes in Canada.
- Incidence of mammary gland tumours in ACK treated rats. The dose-response between level of ACK and incidence of tumours in rat was estimated, stratifying by tumour type.
- Determining the probability of detecting occasionally non-compliant industrial effluent under various sampling regimes.
- Interpretative Guidance for Bioassays using Pollution Gradient Studies. The performance of sediment bioassays along a gradient of metal contamination was examined. Concomitant sediment chemistry and benthic macroinvertebrate abundance data was used to link toxicity test responses with environmental measurements and effects using the sediment quality triad paradigm. Environment Canada (Waste at Sea).
- Geostatistical analysis of background levels of sediment associated metals. This contract explored the utility of existing background metals data sets in estimating background levels of metals in potential disposal sites. Environment Canada (Waste at Sea).
- Conducted a statistical comparison of various micro and kit toxicity tests to the standard rainbow trout and *Daphnia magna* for the Canadian mining industry on behalf of Natural Resources Canada (CANMET). Tests were compared in part, on the basis of sensitivity to an effluent and the specificity of a response to toxicant levels within an effluent.
- Participated in the development and validation of a rapid aggregation toxicity test for mining effluents. This is a sublethal, micro-scale flagellate bioassay that may be used to explore a hitherto, unexamined trophic level. Conducted through a research grant from CANMET.
- Analysis of sediment quality triad data. Over 20 distinct projects.
- Analysis of toxicity test responses and water chemistry variables to identify potential sources of toxicity. This type of analysis is routinely done. In one instance, an analysis of egg toxicity in a flow through situation resulted in a reassessment of culpability.
- Analysis of multiple aquatic toxicity test types to determine most sensitive test.
- Analysis of pharmacokinetic data using compartment models.
- Analysis of non-quantal toxicity test data using threshold models.
- Statistical modelling of the distribution of the combustion by-products of transformer fires containing PCB's. This predictive atmospheric disturbance model is used to

determine evacuation areas downwind of PCB fires. Ontario Hydro.

## PROJECT EXPERIENCE: CUSTOM PROGRAMMING

- Custom software for international technology verification. Ontario Centre for Environmental Technology Advancement: 2003
- Custom Excel macros to address statistical requirements of Environment Canada toxicity test methods. Private Sector Laboratories: 2002 – ongoing.
- Creation of statistical worksheets for the Canadian Environmental Technology Verification program. Ontario Centre for Environmental Technology Advancement: 2001
- Writing software capable of predicting the dispersion of combustion by-products of PCB transformer fires. Ontario Hydro
- Writing custom software to analyze captured video images consisting of arising from gel electrophoresis studies. University of Guelph

## PROJECT EXPERIENCE: SOFTWARE VALIDATION

- Validation of selected CETIS toxicity test analyses. Environment Canada, Methods Development and Application Unit. 2015.
- Validation and translation of general effect size into a toxicologically-meaningful effect. Environment Canada, Methods Development and Application Unit. 2014.
- Validation of Canadian Council of Ministers of the Environment SSD Master Estimates. Environment Canada, National Guidelines and Standards Office. 2014
- Validation of algorithmic stability and implementation of statistical theory underlying the analysis of quantal response data using the "Stephan" program circulated by Environment Canada. ESG International.

## PROJECT EXPERIENCE: PROJECT MANAGEMENT

- Managed projects within Zajdlik & Associates Inc. since company inception.
- Managed CIDA funded program in Bangladesh, April 2003.
- Provide external project management on an as-needed basis to Pollutech EnviroQuatics.

## PROJECT EXPERIENCE: EXPERT WITNESS

- Diavik Diamond Mine Water Licence Amendment Hearing, Yellowknife, 2019.
- Misery Underground Water Licence Hearings, Behchoko, 2018
- Jay Pipe EA and Water Licence Hearings, Yellowknife, 2015, 2016.
- Fortune Minerals Water License Hearing, Behchoko, 2014.
- Prairie Creek EA Hearing, Fort Simpson, 2013.
- BHP Billiton AEMP Hearing, Yellowknife, 2009, Behchoko, 2013.
- Diavik Diamond Mine AEMP Hearing, Rae Edzo, 2007.
- Diavik Diamond Mine Technical Hearings, Yellowknife, 2005.
- Crown vs. Hay Bay Genetics, Napanee, 2001
- Crown vs. Provincial Papers, Thunder Bay, 2000.

## PROJECT EXPERIENCE: SELECTED PEER REVIEW

- Diavik Diamond Mine Pit Lake Modelling. Government of the Northwest Territories. 2018-2019.
- Ekati Diamond Mine Aquatic Effects Monitoring Program and Response Management Plans. Government of the Northwest Territories. 2018.
- Misery Underground Mine Expansion Water Licensing. Government of the Northwest Territories. 2017-2018.
- Jay Pipe Environmental Assessment and Water Licensing. Government of the Northwest Territories. 2015-2017.
- Consumer Release Aquatic Model. Environment Canada, Ecological Assessment Division. 2015-2016.
- Fortune-NICO Environmental Assessment and Water License Submissions- Aboriginal Affairs and Northern Development. 2012; 2014, respectively.
- Canadian Zinc Environmental Assessment and Water License Submissions- Aboriginal Affairs and Northern Development. 2011; 2013, respectively.
- Aquatic Effects Monitoring Program Baseline – Diavik Diamond Mine. Department of Indian Affairs and Northern Development. 2006.
- Aquatic Effects Monitoring Program – Ekati Diamond Mine. Department of Indian Affairs and Northern Development, Independent Environmental Monitoring Agency, Environment Canada. 2004.
- Cumulative Effects Monitoring Program - Review of ongoing monitoring program to assess the potential cumulative ecological effects of uranium mines in northern Saskatchewan. Saskatchewan Environment. 2002 – 2004.
- Urinary As Study for the Greater Sudbury Area. Ontario Ministry of Environment. 2004.
- Test for Measuring Emergence and Growth of Terrestrial Plants Exposed to Contaminants in Soil. Environment Canada. 2004.
- Human Health Risk Assessment. Designated expert reviewer for Ontario Ministry of Environment. 2003.
- Ecological Risk Assessment Designated expert reviewer for Ontario Ministry of Environment. 2003.
- CCME. 1996. A Protocol for the Derivation of Environmental and Human Health Soil

## PROJECT EXPERIENCE: SELECTED PEER REVIEW

Quality Guidelines. 2003.

- Statistical Guidance for Environment Canada Test Methods, Environment Canada, 2001-2003.
- Part A: MOE Report Soil Investigation and Human Health Assessment for the Rodney Street Community: Port Colborne, Ontario Ministry of Environment, 2001.
- Background Environmental Concentrations for the Sydney Tar Ponds, Nova Scotia Department of Health, 2001.
- EPA. 1999. Emission test evaluation of a crematory at Woodlawn Cemetery in the Bronx, N.Y. Volume I of III. Office of Air Quality, Planning and Standards. EPA-454/R-99-049. For, Ontario Ministry of Environment, 2001.

## PROJECT EXPERIENCE: SELECTED GUIDANCE DOCUMENTS

- Author: Zajdlik, B.A. 2016. Baseline Water Quality Data Collection Guidance. Prepared for the Government of the Northwest Territories.
- Author: Zajdlik, B.A. 2016. Guidance for Aquatic Cumulative Effects Assessments in the Northwest Territories. Prepared for the Government of the Northwest Territories.
- Contributor to: Environment Canada, 2012. Guidance Document on the Sampling and Preparation of Contaminated Soil for Use in Biological Testing. Science and Technology Branch, Ottawa, February 2012.
- Contributor to: Biological Test Method: Fertilization Assay Using Echinoids. EPS1/RM/27, Environment Canada. 2011.
- Terriplan Consultants, C. Burn and B. Zajdlik. 2010. A Shared Path to Understanding the Land, NWT CIMP Guidelines and Principles for Monitoring Discussion Paper, March 31. Submitted to: M. Lange, Environment & Conservation, INAC, Yellowknife.
- Contributor to: Guidelines for designing and implementing aquatic effects monitoring programs for development projects in the Northwest Territories. Indian and Northern Affairs, Canada: 2008-2009.
- Contributor to: CCME. 2007. A Protocol for the Derivation of Water Quality Guidelines for the Protection of Aquatic Life – Draft. July, 2007.
- Contributor to: Statistical Methods for Environmental Toxicity Tests. EPS 1/RM/46. Environment Canada. 2005.
- Contributor to: OCETA (Ontario Centre for Environmental Technology Advancement). 2005. Environmental Technology Testing and Verification Protocol for Mercury Amalgam Removal Technologies. Version 1.0.
- Author of: Guidance on Evaluating Environmental Monitoring Programs for Diamond Mines in the Canadian Arctic. Environment Canada. 2004.

## OPINION PAPERS

- Potential Statistical Models for Describing Species Sensitivity Distributions. Canadian Council of Ministers of the Environment. 2006.
- New Statistical Paradigms for Two-sample Toxicity Tests. U.S. EPA. 2005.
- Guidance on Evaluating Environmental Monitoring Programs for Diamond Mines in the Canadian Arctic. Environment Canada, 2005.
- Statistical Inference and the Species Sensitivity Distribution Approach to Deriving Water Quality Guidelines, Ontario Ministry of Environment, Canadian Council of Ministers of the Environment. 2004-2005.

## SHORT COURSES

- I'm Gonna Make You Love Me: Discover That You Love Stats and Stats Loves You Back.
- Topics:
    1. Analysis of Field Toxicity Test Data when a Reference Site is Unavailable
    2. Power Analysis – Theoretical Underpinnings
    3. Why Statistical Assumptions Matter
  - Aquatic Toxicity Workshop, Ottawa, 2015. 30 participants.
- Statistics for Environmental Scientists
- SETAC Laurentian, - 30 participants, 1 day. July 2014, Guelph.
- Environment Canada, Edmonton – 25 participants, 1.5 days, March 2012/13, Yellowknife – 20 participants, 3 days, January 2006.
- Department of Indian Affairs and Northern Development - approximately 10 participants, 3 days, March 2005.
- Bruce Nuclear – approximately 15 participants, 2 days, February 2005.
- Ontario Ministry of Environment, - over 70 participants, 5 days, February 2004.
- Graphical Presentation of Statistical Data, Ontario Ministry of Agriculture and Foods, approximately 30 participants, 1 hour, September 2013.
- Principal Components Analysis, Agriculture and Agrifoods Canada - approximately 15 participants, 3 days, March 2013.
- Working with Large Datasets, Department of Fisheries and Oceans, Yellowknife - approximately 10 participants, 3 days, January 2008.
- Introduction to the ANOVA Table, Annual Aquatic Toxicity Workshop, Waterloo, 7 participants, October 2005.
- Applied Environmental Statistics, Nonlinear Regression as Applied to Environment Canada Test Methods for Measuring Survival and Growth in Soil Using Terrestrial Plants. Environment Canada, Method Development and Technology Section, Charlottetown approximately 10 participants, October 2004
- What to Look for and How to Interpret a Benthic Invertebrate Report: From Bugs to Statistics. Zaranko and Zajdlik, Annual Aquatic Toxicity Workshop, Ottawa, approximately 10 participants, October 2003.
- An Introduction to Statistical Methods for Chronic Biological Testing, Annual Aquatic Toxicity Workshop, Québec, approximately 7 participants, October 1998.

## SHORT COURSES

- Statistical Issues in Toxicology, Annual Aquatic Toxicity Workshop, Calgary, Alberta, approximately 20 participants, October 1996.
- Statistical Methods and Software for Toxicological Data Analysis", Society of Environmental Toxicologists and Chemists, Annual Meeting, Denver, Colorado, 50 participants, November 1994.

## PROFESSIONAL AFFILIATIONS AND COMMITTEES

- Invitee: NWT Water Quality Workshop – Towards the Development of a Decision Support Tool for the Protection of Northern Waters. Sponsored by the Government of the Northwest Territories. 2016.
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- Invitee: A Workshop on Ecological Soil Levels—Next Steps in the Development of Metal Clean-up Values, Sponsored by US EPA. Utah. 2014.
- Member of SSWQO Derivation Committee: Aboriginal Affairs and Northern Development, 2012.
- Member of Scientific Advisory Committee: "Development of an Environment Canada Test Method for Measuring Survival and Growth in Soil Using Terrestrial Plants. Environment Canada, Method Development and Technology Section, 2001-2003.
- Member of the Cumulative Effects Monitoring, working group for northern Saskatchewan. Saskatchewan Environment. (2001-2004)
- Member of the "Advisory Committee on Statistics and Programs for Biological Tests" sponsored by the Technology Development Branch of Environment Canada. 1993-present.
- Panel Member, "The Statistics Workshop for Toxicological Testing", 1999 and 2001. Invitational Meeting under auspices of Environment Canada, Method Development and Application Section. Vancouver, British Columbia.
- Statistical Workshop Chairperson, 1995 Annual Aquatic Toxicity Workshop, St. Andrews, New Brunswick. This workshop addressed the topic of "Statistical Issues in Toxicity Testing."
- Member of the 1995, SETAC U.K. discussion group entitled "Ecotoxicological Statistics: Asking the right questions," Egham, Surrey, U.K.
- Chairperson, 1994 Aquatic Toxicity Workshops session entitled "Toxicological Statistics," Sarnia, Ontario.

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1991–1995 University of Waterloo Waterloo, Ont.

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- 2014 Risk Management Paper of the Year. Awarded by Journal of Human and Ecological Risk Assessment, 2013. See Renoux et al in Papers Published.
- 2006 Ontario Ministry of Environment Strategic Partnership Grant
- 1994 University of Waterloo Graduate Scholarship
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# ScoRE—A Simple Approach to Select a Water Quality Model

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**Abstract:** Over the past decades, water quality models have become unique tools in the management of aquatic resources. A consequence of their widespread application is the significant number of models now available. Available methodologies to compare models provide limited support for their choice in the first place, especially to end-users or modelers with limited experience. Here we propose a method to assist in the selection of a particular model from a set of apparently similar models. The method is termed ScoRE, as it grades models according to three main aspects: Scope (aim, simulated processes, constituents, etc.), Record (reference to the model in publications, its range of applications, etc.), and the Experience of using the model from the user perspective (support material, graphical user interface, etc.). End-users define the criteria to be evaluated and their relative importance, as well as the conditions for model exclusion. The evaluation of models is still performed by the modelers, in open discussion with end-users. ScoRE is a complete approach, as it provides guidance not only to exclude models but also to select the most appropriate model for a particular situation. An application of this method is provided to illustrate its use in the choice of a model. The application resulted in the definition of 18 criteria, where 6 of these were defined exclusively by the end-users. Based on these and the relative importance of each criterion, ScoRE produced a ranking of models, facilitating model selection. The results illustrate how the contributions from modelers and end-users are integrated to select a model for a particular task.

**Keywords:** water-quality modeling; model choice; CE-QUAL-W2; MIKE HYDRO River; MOHID Water; SIMCAT; SisBaHIA; TOMCAT; QUAL2Kw; WASP7

## 1. Introduction

The widespread use of water quality models over the past decades has increased the capacity to manage water quality in both marine and freshwater systems. Water quality models have become important, if not irreplaceable, tools in management, planning and pollution control for government agencies, local authorities and many other entities supervising water resources [1–3]. This is evident in the significant number of water quality models produced over the years [4–6]. Now, the question is no longer whether to use models in water management but, instead, which models to use. In the current paradigm, the selection of a model is a determinant step in the study for understanding and managing a particular aquatic system or water body [7]. However, the selection process can be a challenge, especially to end-users lacking the modelling, computational or mathematical skills to undertake a thorough evaluation of the models.

Given the implications that model results can have in the selection of management practices, both the model and its selection process must be robust and valid. Transparency and accountability are critical for robustness and essential for validating the method. This is particularly relevant, as most likely stakeholders will be involved at later stages of the water management process, whether in the modelling stages, in the development or evaluation of courses of action, or the implementation processes, and therefore, stakeholders will need to understand which management options are being proposed and why. While the literature is prolific in testing and evaluating models [8–14], it is quite omissive regarding approaches to assist end-users in the choice of models.

In the present paper, we address the model selection stage. Model selection is usually a small part of the whole decision-making process. Consequently, the same effort put into the entire process of modelling and water management, concerning time, resources and stakeholder involvement, cannot be expected to be reflected in model selection. A simple procedure is required, with a compromise between the degree of participation of stakeholders (and modelers) vs. practicality of this step. The use of participatory approaches in the context of environmental resources decision making and modelling shows an increasing trend [15–17]. However, the degree of involvement of end-users and modelers (technical team) at the model selection stage, i.e., whether end-users should be involved in the evaluation of the models and to which degree, is still subject of a debate within the literature (e.g., Solaranta et al. [18] vs. Boorman et al. [19]).

This paper contains a review of the main approaches found in the literature for water quality model selection. This review is discussed from a multicriteria decision analysis perspective. Building on the results from this literature review, we propose an approach for model selection providing more detailed guidance on how to select a model, producing a more flexible process and promoting the dialog between end-users and technical teams. The proposed approach applies only to model selection, and it excludes the socioeconomic and institutional spheres of water management.

Throughout this paper, we refer to the terms model end-user and modelers. By model end-user, we refer to those that will use the model results, such as water managers and other stakeholders. By modeler, technical team or expert, we mean the person who has the knowledge to understand the processes behind the model and knows the modelling approaches.

## 2. Procedures for Selecting Water Quality Models

One of the earliest guidelines to select water quality models for lakes, rivers or estuaries dates back to a 1976 guidebook developed for governmental use by the US Environmental Protection Agency (EPA) [20]. The volume described a selection process with four levels of criteria. The first two phases allow the elimination of models and the latter two stages rank the remaining models. In brief, the phases are:

- Phase I: eliminatory phase, based on: appropriateness of the model to the problem at hand (type of water body, time variability, discretization, constituents modelled, model input data, driving forces and boundary factors);
- Phase II: eliminatory phase, based on: cost (model acquisition requirements, equipment requirements, data acquisition costs, machine costs, manpower costs);
- Phase III: ranking models, based on: weights attributed to the criteria from phases I and II;
- Phase IV: further ranking of models based on: relevant processes included, accuracy (model representation, numerical stability, dispersion), sufficiency of available documentation, output form and content, data deck design, ease of modification.

Only in the last 15 years have new complete frameworks for water quality model selection started to appear, guiding the whole process of model selection, including the definition of which characteristics of the models are being compared (i.e., defining the criteria of comparison) and how to compare these [18,19,21,22]. Some approaches [18] identify a set of questions to guide the definition of criteria to be used as a means of comparison between models. Some examples are "How well does the model's output relate to the management task", "How well is the model suited for sensitivity and uncertainty analyses and how well have these analyses been performed and documented?" or "How are the model's user manual and tutorial?" In another study [19], authors defined the evaluation criteria itself for model selection, along with some guiding questions for the water manager to help to determine further criteria to be used for model comparison. In this particular study, modelers then evaluated the different models under those criteria. In a more recent protocol for model selection [21], the main aim was to provide a framework to assist inexperienced model users, as well as to provide an auditable process. Although not explicitly identified, this protocol is based on a Multi-Criteria Decision Analysis (MCDA) process. The main distinction of this protocol with the previous work referred to Boorman et al. [19] is that this latter work does not require the involvement of modelers in evaluating the models, just end-users. While modelers make the questions that guide the protocol, it is up to end-users to evaluate criteria through a literature review.

In our review of the literature, we considered the following concepts: (i) criteria: the attributes used to compare the different models; (ii) valuation or scoring: stage in which all models are compared under each criterion, resulting in a model rank for each criterion; (iii) aggregation procedure: process of aggregating the results from the different criteria (i.e., converting all ranks to the same scale in order to be compared), usually by attributing weights to the criteria, which represent the "conversion factors" between them.

### 2.1. Valuation of Models

There is intense debate in the literature about which stages model users should be involved in. A particular point of disagreement relates to the valuation of models or scoring, a term used in MCDA to refer to the evaluation of the models in each criterion. Some authors [18,20–22] claim that the scoring (and the whole model selection process, including choice of criteria and which models to evaluate) should be carried out exclusively by end-users, for transparency reasons and to reduce time and costs of the model selection stage. Chinyama et al. [21], for instance, suggested that model users can score the models on the criteria based on a literature review on the models. Interestingly, in the case study proposed here, authors (modelers), not the end-users, score the criteria. However, no test has been made to evaluate if end-users can access the literature and understand it to be able to score all criteria regarding the models or have the time for such a process. Grimsrud et al. [20], on the other hand, considered that external consultants might be used and, in this case, give planners (end-users) the tools to know what to ask for and what to expect.

Other authors (e.g., Boorman et al. [19]) claimed that end-users might not process all the knowledge necessary to adequately evaluate the models under the criteria defined and, therefore, argued that modelers should conduct the process of assessing models within each criterion. In this particular case ([16]), although the valuation of models is left to the modelers, criteria are still defined by end-users.

It is the opinion of the authors of the present work that knowledge of end-users is essential to score the criteria, but some criteria might require knowledge that some end-users may lack.

### 2.2. Aggregation Procedures

The aggregation procedure corresponds to the phase where the scores of each model in all criteria are aggregated together to obtain a final value per model. The final result is a ranking of the models. The way the scores from models in each criterion are "converted" into a standard unit to be aggregated can vary. Within the literature on water quality model selection, there is a fair degree of similarity between the process of aggregating values from different criteria. Most methods consider eliminatory criteria, setting a minimum base level so that, if not satisfied, the model is excluded from the process [18–22]. No additional guidance is provided to select one model out of the remaining adequate models (Figure 1). With no further guidance, end-users end up with a reduced list of models to choose from. An additional process is required to assist end users to identify which of the remaining models should be selected. Very few studies provide guidance on this [20,22].

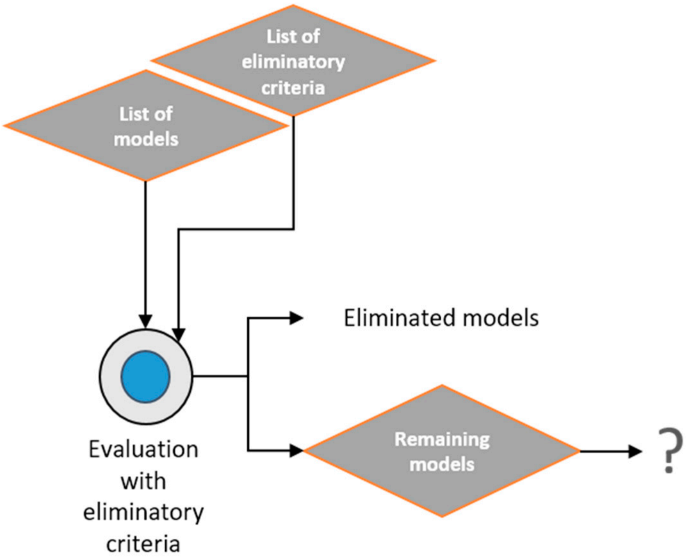


**Figure 1.** The use of eliminatory criteria on model selection for water quality.

The EPA Model Selection Process [20] considers eliminatory criteria (corresponding to Phases I and II from the process). However, they also present weighted criteria (corresponding to Phases III and IV from the process) where (ranges of) weights for the criteria are suggested by the authors for the remaining (not eliminated) models. The aggregation procedure used in this guidance manual is a linear additive process. In Tuo et al. [22], on the other hand, there are some eliminatory criteria, linked with the modelling objective but also to other features such as model complexity. For non-eliminatory criteria, the criteria are assumed to have equal weights, although authors recognize that different weights could be provided to the criteria if the method is compatible with that situation.

The use of eliminatory criteria, as mentioned before, makes the methods non-compensatory or partially compensatory. Compensatory methods are methods where weights are seen as trade-offs, i.e., where a model is selected by being good when judged against one criterion, even if it performs low against another criterion. Non-compensatory methods attribute weights or importance coefficients to criteria, expressing the relative importance of each criterion [23,24].

## 3. The ScoRE Method

ScoRE is a multicriteria-based method for water quality model selection, applying only to model selection, and excluding the socioeconomic and institutional spheres of water management. The main features of the method are that it provides detailed guidance on how to select a model, it is a more flexible process and promotes the dialog between end-users and technical teams. The method is grounded on a set of three broad clusters (as in Parsons et al. [25]), through which end-users and a technical team define a set of criteria for model evaluation and selection. Water quality models are then evaluated on each criterion by the technical team, which will then discuss the weights for the clusters with end-users. Weights are applied to the clusters to provide a final ranking of the water quality models. ScoRE engages model end-users by involving them in the definition of the criteria, in the selection of models to be evaluated, and in the weighing of the clusters. End-users have the opportunity to go through the whole process and debate the final results with the technical team. Figure 2 provides an overview of ScoRE, and the next sections provide a more detailed description of the process.

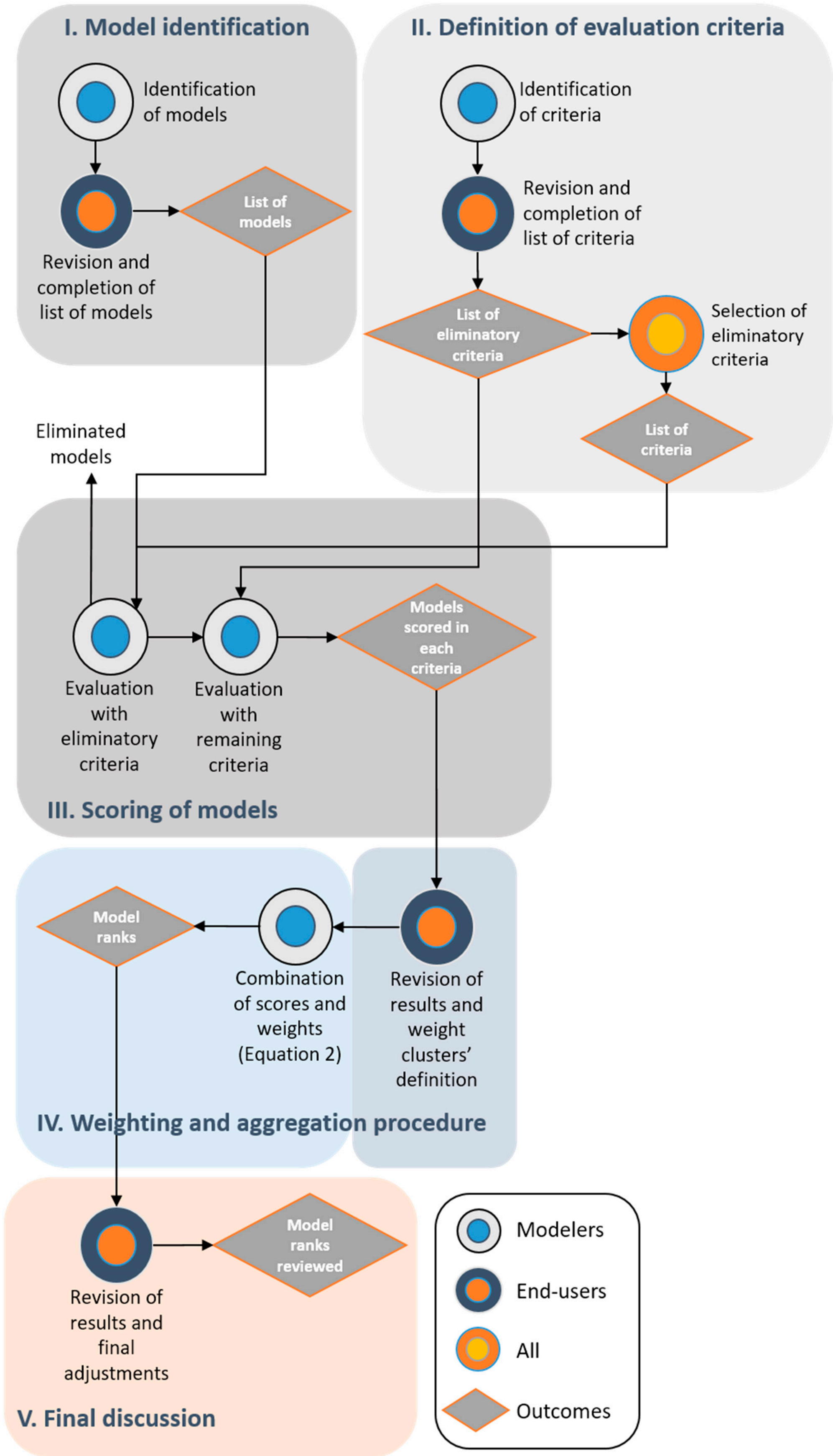


**Figure 2.** A schematic representation of the ScoRE process.

### *3.1. Definition of the Evaluation Criteria*

In ScoRE, criteria are defined by the technical team in dialog with end users. The scientific consistency of the criteria choice, a criterion identified as relevant by Loucks and Beek [26], is ensured by the technical team. Model end-users ensure that additional aspects are not left out of the analysis, either related to the particularities of the context being modelled, data availability or any sort of constraints from the user side (e.g., available funds or level of familiarity with modelling techniques). This procedure warrants results to better satisfy the needs of end-users.

The criteria are grouped in three clusters, defined a priori. These are "model Scope", its "publication/dissemination Record" and the "overall Experience to users", hence its designation: ScoRE (Scope—Record—Experience). Together, the three clusters aim at assessing the models for a variety of parameters, thus providing an overall evaluation. The cluster Scope addresses the nature of the model (stochastic, deterministic, process-oriented, etc.), its complexity and the range of constituents and processes the model simulates. The cluster Record provides a proxy for the dissemination and acceptance of the model amongst modelers, by quantifying the number of technical publications where a particular model features. The cluster Experience defines the experience of using the model, and how it can be defined as straightforward or difficult, based on the interface and material available to help the model user. A more detailed description of each cluster is offered in the next sections.

#### 3.1.1. Model Scope

Considering that a model is a (simplified) representation of reality, the scope of a model is the purpose for which it was built in the first place. Water quality models, for instance, may be developed to simulate fresh-water systems, brackish environments or marine and coastal waters, focusing on pollutants, ecological processes, water chemistry, etc. Thus, the scope of a model defines its nature, methods, parameterization, processes simulated, and all other components that expresses its validity to simulate any particular system. These include the type of approach (conceptual, empirical, physically based), the nature of the model (deterministic or stochastic), the state (steady-state or dynamic simulations), and its spatial analysis (distributed, lumped), data requirements, dimensions (1D, 2D or 3D), and robustness, among other aspects [3,7].

#### 3.1.2. Publication Record

Publication record is defined in ScoRE as the number of publications in science and engineering journals featuring a particular model. This can be seen as an alternative for the impact of a model, based on the assumption that a widely cited model implies wide acceptance by the scientific community and, consequently, a proxy to its consistency, validity and robustness.

Some examples of criteria within this cluster can be the number of papers featuring the name of the model in the title or in relevant fields such as the summary and keywords, or simply the number of times a given model is mentioned in the text body. The information for this indicator can be retrieved from web services such as *ScienceDirect* or *Web of Knowledge*. Also, the type of systems for which the model has been applied to, or its worldwide dissemination, can also be used to assess the model Record.

#### 3.1.3. User Experience

Interface

The experience of using a particular model is strongly conditioned by the graphical user interface (GUI). The GUI aims to facilitate the input of data, running of the model and output visualization, and should provide a user-friendly environment, with graphical elements that allow the user to interact with the software. Most models come with a native GUI but some occasionally have alternative options created by third parties, frequently with additional features such as advanced pre- and post-processing tools, extra visualization options, etc. These alternative GUIs usually require payment for the software or a licensing fee of some kind.

Support Material

Support material is a basic requirement for any model and must be available either online or on paper. Numerical models, like any other software, should have a set of supporting documents containing information on the model structure, description of simulated processes, a list of the parameters, and additional relevant information on its functioning. Commercial models frequently have comprehensive guides while academic software and freeware usually rely on more concise manuals. Thus, user guides vary significantly in detail and quality among models and this difference can weigh on the choice of a model. The model can also have a published detailed model calibration, validation, and parameter assessment.

Technical Support

Technical support is a common service provided by commercial software developing companies, to help users overcome any difficulties or problems they may face when using a product. Since it requires having the staff to interact with the client (by phone, Skype, email, etc.), technical support is frequently a paid service or a service that is offered as part of a paid software package. Alternative ways to provide technical support to users may be less expensive or even cost-free, such as online forums, in which users and developers post technical questions and answers.

Cost

Numerical models, like any other software, are available to the user in many different ways, some of which may require payment of a licensing fee, implying that some models have a cost associated with their use and exploration. The implication of a payment can pose problems to some users, frequently depending on the price, so this criterion can have a significant influence on the selection.

### *3.2. Defining "Eliminatory Criteria"*

"Eliminatory criteria" set the conditions that models need to satisfy in order to proceed to the next stage in the evaluation process. For example, type of water body could be an eliminatory criterion, defining that if a model does not apply to lakes, for example, the model would be excluded. Another example could be whether the model presents a vertical thermal structure of reservoirs, if essential for a particular case, and where models could be excluded from the analysis if they were not able to present such vertical thermal structure.

### *3.3. Valuation of Criteria*

The first step in the valuation of criteria stage is to evaluate all models in the "eliminatory criteria" in order to weed out some of the models. The valuation of criteria is conducted by the technical team (and later discussed with the end-users). After the valuation according to the eliminatory criteria, the remaining models are evaluated in the criteria. All remaining models are compared in each criterion and ranked in a scale from 1 to $n$ ($n$ being the number of models), where 1 is the worst-performing model and $n$ the best-performing model. If models are assumed to be equal for a particular criterion, then the same value can be assigned to both. This process is repeated for each criterion. The result is a rank of models in each criterion (i.e., if the number of criteria defined is $nt$, then there will be $nt$ ranks).

### 3.4. The Aggregation Procedure of ScoRE

The aggregation procedure of ScoRE makes use of weights. First, criteria scores within each cluster are averaged:

$$\begin{aligned} S &= \left(\sum_{i=1}^{nt} S_i\right) \times nt_S{}^{-1}, \\ R &= \left(\sum_{i=1}^{nt} R_i\right) \times nt_R{}^{-1}, \\ E &= \left(\sum_{i=1}^{nt} E_i\right) \times nt_E{}^{-1}, \end{aligned} \tag{1}$$

where $S$, $R$ and $E$ are the average scores for each cluster, $S_i$, $R_i$ and $E_i$ are the scores of the criteria within each cluster, and $nt_x$ is the total number of criteria per cluster. This means that the scores of criteria within the same cluster are seen as equally relevant. ScoRE values can range from 1 to $n$ and so the result from Equation (1) will allow models to be ranked from the less suitable (lower ScoRE) to the more adequate (higher ScoRE), in each of the criteria.

Weights defined by end-users are attributed to each cluster. The aggregation procedure follows a linear additive model to provide a final ranking of models. This is expressed by (2):

$$\text{ScoRE} = (W_S \times S) + (W_R \times R) + (W_E \times E), \tag{2}$$

where $W_S$, $W_R$ and $W_E$ are the relative weights of each cluster, provided that $W_S + W_R + W_E = 1$.

A summary of the main characteristics of ScoRE and its comparison with other studies is presented in Table 1.

**Table 1.** ScoRE compared to other approaches.

| Approaches | Criteria Definition | Who Conducts the Valuation of Models in Each Criterion | Aggregation Procedures |
|---|---|---|---|
| Saloranta et al. [18] | Predefined questions to guide criteria definition | End-users | Eliminatory criteria |
| Boorman et al. [19] | Predefined questions to guide criteria definition | Modelers | Eliminatory criteria |
| Grimsrud et al. [20] | Predefined | End-users with possibility of hiring modelers | Eliminatory criteria and detailed guidance for how to proceed for the non-eliminated models (weighting process) |
| Chinyama et al. [21] | Predefined questions to guide criteria definition | End-users | Eliminatory criteria |
| Tuo et al. [22] | Predefined | End-users | Eliminatory criteria. Some insights into how to proceed for non-excluded models |
| ScoRE | No pre-definitions. Criteria defined between modelers and end-users | Modelers. Results discussed with end-users | Eliminatory criteria. Detailed guidance for how to proceed for the non-eliminated models (weighting process) |

## 4. Using ScoRE in a Real Case

### 4.1. Study Sites

The Ceará State in the northeast region of Brazil is characterized by semi-arid meteorological conditions, frequently leading to water scarcity. As such, a sound management of water resources is critical, requiring decisions from managers and regulators that balance water availability and quality for human and animal consumption. Most available water is stored in reservoirs scattered across the state, the majority of which are under significant pressures originating in the watershed, ranging from intense cultivation to human and industrial effluent discharge. Fundação Cearense de Meteorologia e Recursos Hídricos—FUNCEME (Ceará's Meteorological and Hydric Resources Foundation)—is the federal organization responsible for managing the water resources in the state, along with Companhia de Gestão dos Recursos Hídricos—COGERH (Water Resources Management Company). Over the past few years, FUNCEME and COGERH have explored new water management strategies, some of which require the use of numerical models. Both organizations were engaged in the choice of a water quality model to study three reservoirs located in the Ceará State, in the northeast region of Brazil: Acarape do Meio, Araras and Olho d'Água. The location of the reservoirs is depicted in Figure 3.

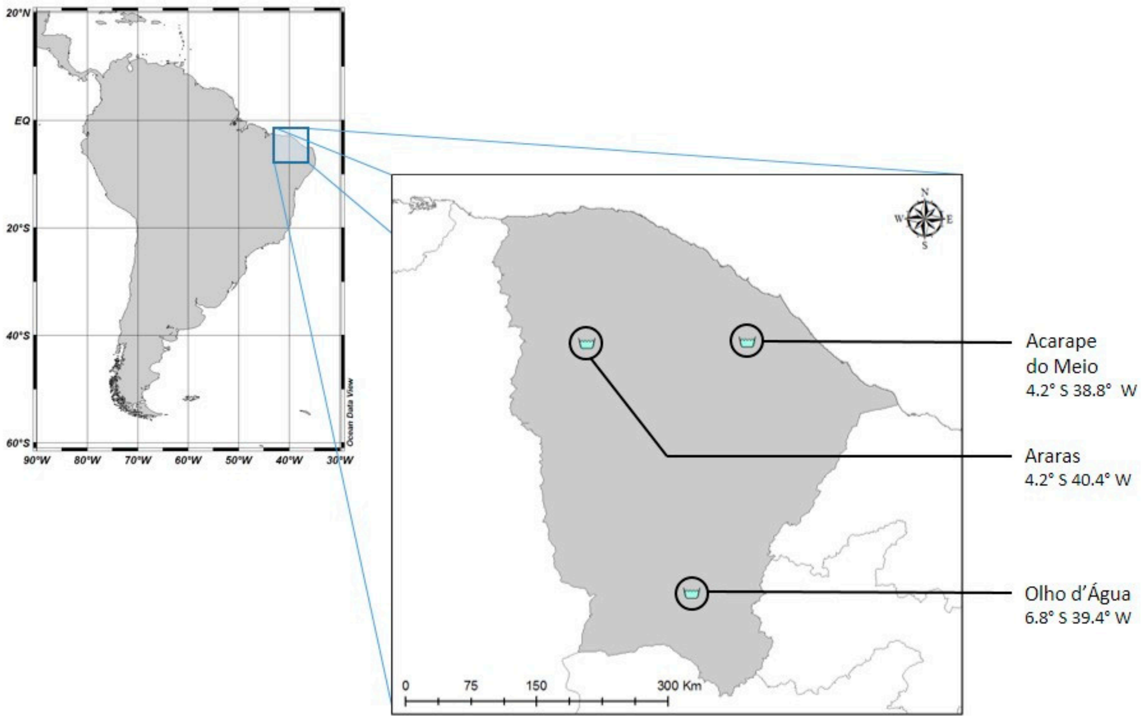


**Figure 3.** Location of the study sites in the Ceará State, Brazil.

These reservoirs differ in their characteristics, physical setting and pressures originated in the basin. They share, however, some basic features, such as a relatively low mean depth, high water temperatures all year around, the presence of a mild thermocline frequently disrupted by episodes of intense wind-induced mixing, strong vertical chemical stratification, and persistent oxygen-depleted bottom layers.

### *4.2. Application of ScoRE*

The technical staff from FUNCEME and COGERH were the end-users and the modelers consisted of the authors of this paper. Modelers had a background in environmental modeling, ecology of aquatic environments and water quality. The application of ScoRE followed the process described in Section 3, schematized in Figure 2. The process is summarized below:

1. End-users were provided with a list of models identified by modelers. This list was defined by modelers taking into account existing validated models. The list was discussed with the end-users, who were given the possibility of including additional models if they had any they wanted to see included.
2. The criteria were defined by modelers, based on the conditions of the case study at hand. These criteria were defined taking into account three clusters of ScoRE. The list was discussed with the end-users, who added additional criteria to the list. End-users, together with the modelers, reviewed the criteria to select which of these should be eliminatory criteria.
3. Each model was evaluated within the eliminatory criteria first. This allowed the exclusion of some of the models. The remaining models were then evaluated in each of the criteria. The

valuation process was conducted by modelers. The result was a rank of the models for each criterion. The resulting scores were discussed with the end-users.

4. End-users attributed weights to the clusters of criteria. With the weights, it was then possible for modelers to average scores in each cluster (using Equation (1)) and apply the linear additive model (Equation (2)) to obtain the final rank of the models.
5. Final rankings were then discussed with end-users and, when necessary, final adjustments were made to the criteria, scores or weights in accordance.

The process was conducted over two meetings between end users and modelers. The first meeting included steps 1 and 2 and the second meeting included steps 4 and 5. Step three was conducted by the modelers alone and results were taken for discussion in the second meeting.

## 5. Results

### 5.1. Models Included in the Evaluation

Eight water quality models were selected by the technical team and reviewed by the end-users. These models were: CE-QUAL-W2, MIKE HYDRO River, MOHID Water, SIMCAT, SisBaHIA, TOMCAT, QUAL2Kw e WASP7 (Table 2). The models are process-based (or process-oriented), have been used worldwide to some extent, and encompass a wide range of complexity, both in parameterization and number of simulated processes. They are briefly described in their basic principles, simulation elements, limitations and intended use. While some have been used extensively in the past, others are less disseminated. A summary of their main features is presented in Table 3 and detailed descriptions can be found in the references provided.

**Table 2.** Models evaluated.

| Model | Origin and model website |
|---|---|
| CE-QUAL-W2 | US Army Corps of Engineers/Portland State University, Portland, USA http://www.ce.pdx.edu/w2/ |
| MIKE HYDRO River | Danish Hydraulic Institute, Hørsholm, Denmark http://www.mikepoweredbydhi.com/products/mike-hydro-river |
| MOHID Water | Instituto Superior Técnico, Lisbon, Portugal http://www.mohid.com |
| QUAL2KW | Washington State Department of Ecology, Olympia, WA, USA http://www.ecy.wa.gov/programs/eap/models.html |
| SIMCAT | Environment Agency, Rotherham, UK |
| SisBaHIA | Fundação COPPETEC - COPPE/UFRJ, Rio de Janeiro, Brazil http://www.sisbahia.coppe.ufrj.br/ |
| TOMCAT | Environment Agency, Rotherham , UK |
| WASP7 | The United States Environmental Protection Agency, Washington, DC, USA http://www.epa.gov/athens/wwqtsc/html/wasp.html |

#### 5.1.1. CE-QUAL-W2

CE-QUAL-W2 (Table 2) is a public domain model that has been widely used in the study of stratified water systems, including lakes, reservoirs and estuarine environments [27–32]. CE-QUAL-W2 is a two-dimensional (longitudinal-vertical) hydrodynamic and water quality model. The model was originally developed by the U.S. Army Corps of Engineers [33,34], and a comprehensive description of CE-QUAL-W2 can be found in Cole and Wells [35]. The model is based on a finite-difference approximation to the laterally averaged equations of fluid motion and quantifies free surface elevation, pressure, density, vertical and horizontal velocities, and constituent concentration and transport. Explicit numerical schemes are employed to compute velocities, controlling the transport of energy and biochemical constituents. CE-QUAL-W2 simulations are rather fast and require low computational power, but need a significant amount of data. Also, the high number of parameters makes the calibration tasks difficult. Nonetheless, this model has been optimized for water quality in reservoirs and is one of the most used models in the study and management of these aquatic systems [36–41].

#### 5.1.2. MIKE HYDRO River

The MIKE HYDRO River model (Table 2) is a one-dimensional modeling tool developed by the Danish Hydraulic Institute (DHI), for the detailed design, management and operation of river and channel systems with different levels of complexity [42]. This model has been widely used in the modeling of rivers and lakes [43,44]. The model is composed of several modules that can be either used together or as stand-alone simulators, including rain fall, hydrodynamic, advection-dispersion, sediment and water quality. The hydrodynamic module is one-dimensional and computes unsteady flow, discharge and water level based on Saint–Venant equations. This model has been optimized for operational modeling in flood forecasting, ecological assessment of water quality in rivers and wetlands, sediment transport and river morphodynamics. However, the MIKE HYDRO River model requires a large amount of data and a proper simulation of some constituents can be difficult to achieve if data are lacking [4]. The model is also highly dependent on bathymetric accuracy.

#### 5.1.3. MOHID Water

MOHID Water (MOHIDw henceforth) is an open-source water modeling system (Table 2) designed for the effective simulation of 3D baroclinic circulation across river-to-ocean scales, using a finite volume approach that solves the primitive continuity and momentum equations for the surface elevation and 3D velocity field for incompressible flows. Temporal discretization is performed by a semi-implicit (ADI) algorithm with two time levels per iteration. MOHID Water couples the hydrodynamic model with two water quality/biogeochemical models with different levels of complexity: a simpler NPZ (nutrient-phytoplankton-zooplankton) model using the EPA formulation [45] and a complex multi-elements model for marine ecological processes [46]. The model was originally developed for marine systems but its modular code configuration allows its use in a variety of spatial and temporal scales to study processes occurring in reservoirs [47], estuaries and coastal lagoons [48–53], up to regional scales [54]. More recently the MOHID Land model has been developed for watershed and groundwater processes [55,56], aiming at a future full modeling of the land-to-ocean water continuum [57].

#### 5.1.4. QUAL2KW

QUAL2Kw (Table 2) is the recent development of models in the QUAL 2 series [58–60], released by the EPA. QUAL2Kw is a 1D steady-state model for rivers, tributaries and well-mixed lakes. Unlike the previous versions, QUAL2Kw allows for unequal river reaches, and multiple water inputs and abstractions in each segment. The model solves both the advective and dispersion modes of transport in the mass balance of constituents. The model allows the simulation of several parameters: dissolved oxygen (DO), biochemical oxygen demand (BOD), temperature, pH, conductivity, suspended solids, alkalinity, total inorganic carbon, organic nitrogen, ammonia, nitrite, nitrate, organic phosphorus, inorganic phosphorus, algae (chlorophyll a), coliform bacteria, one arbitrary non-conservative constituent solute, and three conservative constituent solutes. QUAL2Kw is a well-documented freeware model and is specially designed for a system where macrophytes play an important role. It has been used to simulate lotic systems [61–63].

**Table 3.** Summary of the main characteristics of the selected water quality models (adapted from [7,61]).

| Features | CE-QUAL-W2 | MIKE HYDRO River | MOHID Water | QUAL2KW | SIMCAT | SisBaHIA | TOMCAT | WASP7 |
|---|---|---|---|---|---|---|---|---|
| Dimensions/Types | 2D, dynamic | 1D, dynamic | 3D, dynamic | 1D, steady-flow | 1D, steady-state (time-invariant), stochastic | 3D, dynamic | 1D, steady-state (time-invariant) | 3D, dynamic |
| Modeling approach | ADE, unequal river reaches, river branches | ADE, unequal river reaches, | Regular grid, finite elements | ADE, unequal river reaches, | CSTR | Non-structured grid, finite differences | CSTR | ADE, dynamic compartmental |
| Element cycles | O, C, N, P, Si, Fe | O, N, P | O, N, P | O, C, N, P | O, N | O, N, P | O, N | O, N, P, Si |
| Constituents/processes | Temperature, pH, N (ON, $NO_2$, $NO_3$, $NH_3$), P (OP, $PO_4$), DO, CBOD, TIC, alkalinity, phytoplankton (4 groups), bottom-algae, SOD, detritus | User defined (ECO Lab module) | Temperature, N (ON, $NO_2$, $NO_3$, $NH_3$), P (OP, $PO_4$), DO, phytoplankton, detritus | Temperature, pH, N (ON, $NO_2$, $NO_3$, $NH_3$), P (OP, $PO_4$), DO, CBOD, TIC, alkalinity, phytoplankton, bottom-algae, SOD, detritus | DO, CBOD, ammonia, user defined conservative parameter | Temperature, pH, N (ON, $NO_2$, $NO_3$, $NH_3$), P (OP, $PO_4$), DO, phytoplankton, detritus | DO, CBOD, ammonia, chloride, user defined parameter | Temperature, pH, N (ON, $NO_2$, $NO_3$, $NH_3$), P (OP, $PO_4$), DO, CBOD, TIC, alkalinity, salinity, phytoplankton, bottom-algae, SOD, detritus, OCHEM |
| Open | Yes | No | Yes | Yes | - | No | - | Yes |
| Strength | Optimized for reservoir modeling; detailed parameterization of sediment diagenesis | Extensive support material | Full hydrodynamic simulation | Auto-calibration | Simulations requiring low computational time with limited data, auto-calibration | Grid adaptation to complex domain geometries | Simulations requiring low computational time with limited data, auto-calibration | Organic and heavy metal pollution |
| Weakness | Requires extensive data | Requires extensive data | Computational demand | Does not simulates branches | Over-simplistic | Limited number of users | Over-simplistic | Requires extensive data |

Note: ADE: advection dispersion equation, CSTR: continually stirred tank reactor in series, DO: dissolved oxygen, CBOD: carbonaceous biochemical oxygen demand, OCHEM: organic chemicals, ON: organic nitrogen, OP: organic phosphorus, SOD: sediment oxygen demand, TIC: total inorganic carbon.

#### 5.1.5. SIMCAT

SIMCAT (Simulation of Catchments, Table 2), originally developed by the Anglian Water Group, UK, is a one-dimensional, time-invariant (steady-state) model to simulate the fate and transport of solutes in a river [6,64]. SIMCAT is a stochastic model relying on Monte Carlo analysis techniques. The model includes the inputs from point-source effluent discharges including DO, non-conservative substances such as BOD with a decay rate, and conservative substances which are assumed not to decay. The model splits the river into user defined reaches, and in each run, the model randomly selects values for quality and flow from the given distributions for all the inputs. This model excludes processes such as photosynthesis and oxygen consumption in the sediments, thus becoming limited to model the reservoir dynamics. However, it is suited for modeling constituents in freshwater that do not rely on sediment interactions. SIMCAT is easy to use, allows fast runs and requires a relatively small amount of data to operate. The model can easily be applied at the basin scale and used as an evaluation and management tool by trained technicians [65].

#### 5.1.6. SisBaHIA

SisBaHIA® (Sistema Base de Hidrodinâmica Ambiental) (Table 2) was originally developed to simulate coastal and in-land water bodies [66,67], and is composed of a 3D hydrodynamic model coupled to a water quality model. The advection–diffusion equation is solved individually for each constituent, taking into consideration the advective and diffusion terms, together with the transformation terms [68]. The model relies on finite elements and the finite difference approach in the spatial and time discretization, respectively. Turbulent stress is parameterized according to filtering techniques derived from the approaches known as large eddy simulation. The water quality model uses the same basic transformation equations presented in the WASP (Water Quality Analysis Simulation Program) model, and also uses the same spatial grid as the hydrodynamics model. SisBaHIA can have non-restricted used for non-profit applications such as research purposes. However, its use in a commercial activity (e.g., for consultancy purposes) can only be done under the payment of a fee defined by direct agreement with COPPE/UFRJ.

#### 5.1.7. TOMCAT

The TOMCAT (Temporal Overall Model for Catchments) (Table 2) model was advanced in the 1980s by Thames Water, a UK water utility company, to assist in studying and improving effluent quality at all Thames water sites [69,70]. While TOMCAT follows a similar approach to SIMCAT, by assuming a continuous stirred-tank reactor (CSTR) method and Monte Carlo stochastics, it differs by allowing more complex temporal correlations. The model allows for setting the number of parameters by river segment, as well as the length, mean area, cross-section, and depth for each river reach. Equations relating the processes that control the concentration of solutes are identical to SIMCAT, except for temperature and DO. The simpler approach of TOMCAT requires a rather limited amount of data when compared to other models. However, its simpler approach also comes with some limitations, like the number of simulated processes, some of which are relevant for aquatic systems, such as photosynthesis, respiration, and sediment dynamics.

#### 5.1.8. WASP7

The WASP model (Water Quality Analysis Simulation Program) (Table 2) is a freeware model developed by the EPA for surface water quality processes [71]. WASP7 can be coupled to hydrodynamic and sediment transport models that provide flow, depths, current velocities, temperature, salinity and sediment fluxes. As such, the WASP7 model can become a full 3D dynamic model, but linking the model to multi-dimensional hydrodynamic models is not a straightforward task. The model relies on the finite difference method to calculate the temporal and spatial evolution of these constituents in each segment of the computational geometry. WASP models have been applied to address several water quality problems in a variety of aquatic systems, such as ponds, lakes, rivers, reservoirs, estuaries and coastal waters [72–74]. WASP7 addresses processes that take place both in the water columns and sediment and is particularly useful to simulate organic chemicals. However, the model does not simulate mixing zones and near-field effects and does not handle the sinking and flotation behavior of some constituents.

### *5.2. Evaluation Criteria for the Case Study*

A list of 16 criteria was defined (Table 4), with two identified as eliminatory criteria: criterion S9 (modelling approach) and criterion E6 (cost). If the modelling approach was CSTR (see Table 3) on criterion S9, then the model was excluded from the evaluation process, since this approach fails to reproduce the vertical thermal structure of the reservoirs, a relevant process for the present case study. The criterion for exclusion, E6, was based on the model not being freeware or open source. This exclusion factor was applied as long as there were enough open source or freeware models suitable for the case study in the evaluation process.

**Table 4.** Set of criteria defined for each cluster used in the evaluation of the models. Criteria defined by the technical team ($^{T}$) and/or the end-users ($^{E}$).

| Clusters | Criteria |
|---|---|
| Scope | $S_1$: model outputs for chlorophyll (besides biomass) for a direct validation with field data $^{T,E}$<br>$S_2$: explicit simulation of different functional groups of primary producers, including cyanobacteria $^{T,E}$<br>$S_3$: inclusion of iron, given its role in the quality of water for human consumption $^{E}$<br>$S_4$: simulation of pH, for its relevance on fresh water chemical reactions $^{T,E}$<br>$S_5$: O, N and P cycles $^{T}$<br>$S_6$: carbon dynamics $^{T}$<br>$S_7$: sediment-water fluxes, with detailed parameterization of processes occurring in the sediment $^{T,E}$<br>$S_8$: adequate spatial description and hydrodynamics processes to simulate thermal stratification and related water movement $^{T}$<br>$S_9$: modelling approach $^{T}$ |
| Record | $R_1$: number of publications $^{T}$<br>$R_2$: model dissemination (local vs. global applications) $^{T,E}$<br>$R_3$: type of water systems (higher to lower score: reservoirs, rivers, estuaries/coastal lagoons) $^{T}$ |
| Experience | $E_1$: quality of the Graphical User Interface $^{E}$<br>$E_2$: availability and quality of support manuals $^{E}$<br>$E_3$: examples of running applications $^{T,E}$<br>$E_4$: user forums $^{E}$<br>$E_5$: technical support by the developing team $^{E}$<br>$E_6$: costs $^{E}$ |

### *5.3. Valuation of Criteria for the Case Study*

Three models were excluded from the evaluation process based on the eliminatory criteria. These were MYKE HYDRO River (criterion E6), SIMCAT (criterion S9) and TOMCAT (criterion S9).

For the remaining models (CE-QUAL-W2, MOHIDw, SisBaHIA, QUAL2KW and WASP7) the results for each cluster are shown in Figure 4 and the values for the ranking of models for each criterion are presented in Table 5. The results show that CE-QUAL-W2 had higher values for all clusters, with a clear gap to the remaining models. The WASP model showed the second-highest mark for all clusters, followed by MOHIDw and SisBaHIA in Scope, MOHIDw in Record and QUAL2Kw in Experience. A brief analysis is presented in the next sections for each cluster.

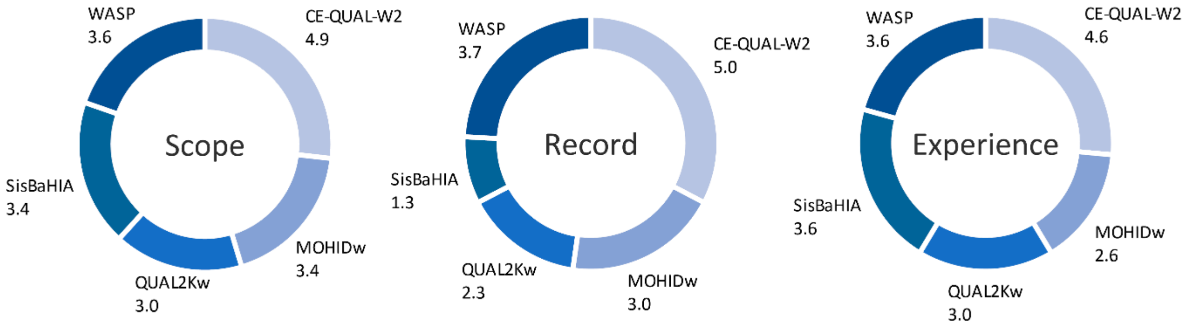


**Figure 4.** Scoring of models within each cluster, according to Equation (1) applied to their defining criteria (see text for details).

**Table 5.** ScoRE impact matrix. The scale represents the number of models under evaluation and, consequently, ranges from 1 (inferior) to 5 (better). Overall results for Scope, Record, and Experience are calculated according to Equation (1).

| Criteria/Item | CE-QUAL-W2 | MOHIDw | QUAL2Kw | SisBaHIA | WASP |
|---|---|---|---|---|---|
| $S_1$: chlorophyll | 5 | 3 | 3 | 3 | 4 |
| $S_2$: cyanobacteria | 5 | 3 | 3 | 3 | 4 |
| $S_3$: iron | 5 | 4 | 4 | 4 | 4 |
| $S_4$: pH | 5 | 3 | 3 | 4 | 3 |
| $S_5$: O, N and P cycles | 5 | 3 | 4 | 3 | 4 |
| $S_6$: carbon dynamics | 5 | 3 | 4 | 3 | 3 |
| $S_7$: sediment-water fluxes | 5 | 3 | 1 | 2 | 4 |
| $S_8$: hydrodynamic processes | 4 | 5 | 2 | 5 | 3 |
| **Scope** | **4.9** | **3.4** | **3.0** | **3.4** | **3.6** |
| $R_1$: publications | 5 | 4 | 2 | 1 | 3 |
| $R_2$: model dissemination | 5 | 3 | 2 | 1 | 4 |
| $R_3$: type of water systems | 5 | 2 | 3 | 2 | 4 |
| **Record** | **5.0** | **3.0** | **2.3** | **1.3** | **3.7** |
| $E_1$: GUI | 4 | 1 | 2 | 5 | 3 |
| $E_2$: support manuals | 5 | 2 | 4 | 3 | 5 |
| $E_3$: examples | 5 | 4 | 5 | 4 | 5 |
| $E_4$: user forums | 5 | 4 | 3 | 1 | 2 |
| $E_5$: technical support | 4 | 2 | 1 | 5 | 3 |
| **Experience** | **4.6** | **2.6** | **3.0** | **3.6** | **3.6** |

#### 5.3.1. Evaluation of Model Scope

Considering the criteria in model Scope, CE-QUAL-W2 had the highest score, denoting a better capacity to address all the characteristics of the studied systems under consideration. The WASP model followed in the ranking for Scope, since it also addresses most of the items. Like CE-QUAL-W2, the WASP model was developed for fresh water systems, having a detailed parameterization of chemical reaction characteristics of such water bodies, including sediment processes and water-sediment mass fluxes. MOHIDw and SisBaHIA both have an advantage with their 3D setup, allowing a more realistic simulation of hydrodynamic processes in larger reservoirs. WASP7 also enables the user to work on 3D systems, when coupled with a 3D hydrodynamic model. CE-QUAL-W2, on the other hand, only allows for a 2D setting, relying on the assumption that this approach is suited for most reservoirs. However, MOHIDw and SisBaHIA miss some relevant processes/constituents in fresh water systems.

#### 5.3.2. Evaluation of Model Record

Models were searched for hits in *ScienceDirect* (SD), in both the combination of 'Title, abstract and keywords', and 'all fields', and *Web of Knowledge* (Wok), for both 'Title' and 'Topic'. The results are depicted in Figure 5. According to both portals, CE-QUAL-W2 stands as the model with the highest number of hits, except for 'Title' in SD where MOHIDw had the highest score. SisBaHIA was the model with fewer hits on both SD and WoK. Browsing available studies of each model reveals that CE-QUAL-W2 is the most disseminated model, having numerous applications worldwide, followed by WASP and MOHIDw models also with a global reach, but with lesser applications, and finally by SisBaHIA, almost confined to Brazil. CE-QUAL-W2 also ranks higher in the type of water systems, since it has been purposely developed for rivers and reservoirs, unlike other models that were mostly developed for coastal and transitional waters (e.g., MOHIDw and SisBaHIA).

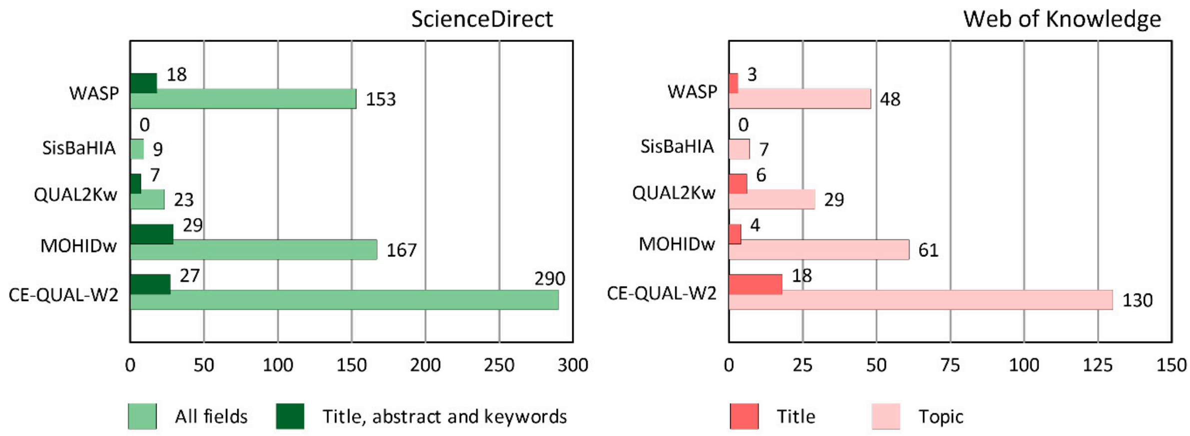


**Figure 5.** Number of hits obtained for each model in *ScienceDirect* and *Web of Knowledge* by 20 December 2016. Conditions for search: all journals and books available in *ScienceDirect* (SD) and available papers in *Web of Knowledge* (WoK); WASP model versions from 4 to 7 were considered.

5.3.3. Evaluation of Model Experience

All models provide a GUI interface, support material and running examples, and have user forums where users and developers can post comments and exchange information. These, however, vary in sophistication and completeness between models. CE-QUAL-W2 is the model that offers the more comprehensive user manual, detailed examples of running applications and a dedicated user forum. MOHIDw, for example, is a community model in continuous development by a number of users worldwide and, although a highly complex and comprehensive modeling platform, the support documents are dispersed over several sources and not centralized and updated in the form of a user manual. SisBaHIA has the most intuitive native GUI, followed by CE-QUAL-W2 with a software developed by the community of users. All other models have a suitable GUI, and MOHIDw even provides the use of an advanced GUI, in the form of the commercially licensed software MOHID Studio (Action Modulers: Mafra, Portugal). This software integrates model simulations with the management of field data, among many other modeling support tools. Likewise, CE-QUAL-W2 also has the option of using a GUI with additional options when compared to the native version. SisBaHIA is the only model that offers technical support in the form of a service, the terms of which are decided on a case-by-case basis. Other models offer interspersed support in the form of help to users provided by authors (e.g., CE-QUAL-W2), the institution responsible for the model (e.g., WASP7) or the team of developers (e.g., MOHIDw).

*5.4. Model Ranks*

Model ranks were obtained using Equation (2), and by assigning the relative weight of 50% to Scope ($W_S$), 25% to Record ($W_R$) and 25% to Experience ($W_E$), according to the end-users.

The ScoRE ranking, determined according to Equation (2) with the calculated values for each cluster (Table 5), showed that CE-QUAL-W2 was the most suited model (ScoRE = 4.8), followed by WASP (ScoRE = 3.6), MOHIDw (ScoRE = 3.1), SisBaHIA (ScoRE = 2.9) and QUAL2Kw (ScoRE = 2.8). In fact, not only did CE-QUAL-W2 perform better overall, it performed better in terms of the three clusters, being the best model in terms of Scope, Record and Experience for this particular case study. The results are graphically illustrated in Figure 6.

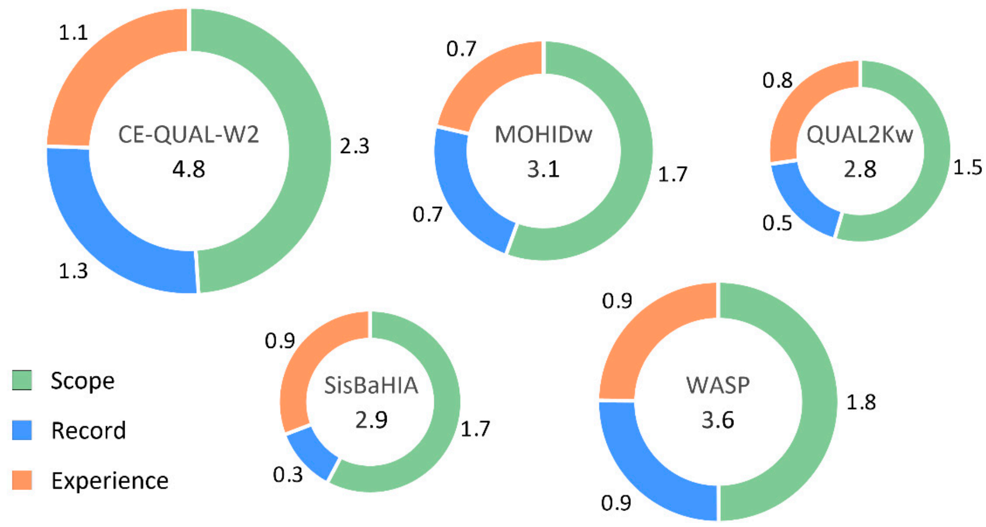


**Figure 6.** The ScoRE results for the evaluated models. Scope, Record and Experience values are calculated in Table 5. ScoRE was determined using Equation (2), with the following relative weights: $W_S$ = 50%, $W_R$ = 25% and $W_E$ = 25%.

## 6. Discussion

### *6.1. Criteria Defined in ScoRE*

The ScoRE approach starts with only three broad clusters of criteria and a blank list of criteria. Consequently, it imposes less framing regarding criteria definition than other methods found in the literature [18–20]. Reducing framing means the list is more flexible and allows new criteria to emerge, but it can also mean relevant criteria might not be identified and used in the analysis. This is the reason why authors propose the involvement of both the technical team and end-users in the criteria definition process; while the technical team has a better understanding of the processes being modelled, end-users have a better grasp of the relevant social, political, institutional and economic context and constraints. However, in the present case, end-users have only defined financial criteria.

A total of 18 criteria were defined. This is a higher number than other studies, which presented on average of 10 criteria [18,19,21,22], with the exception of Grimsrud et al. [20] which offered a total of 24 criteria (Table 6). From Table 4, we can see that half of the criteria were generated from the technical team and half generated from the end-users. Both defined six of the criteria. The criteria outlined by end-users were mostly related with the Experience cluster. This shows that both model users and modelers can contribute meaningfully to the definition of criteria.

**Table 6.** Number of criteria identified in ScoRE and in other approaches (approximate numbers).

| Number of Criteria Related with | Saloranta et al. [18] | Boorman et al. [19] | Grimsrud et al. [20] | Chinyama et al. [21] | Tuo et al. [22] | ScoRE |
|---|---|---|---|---|---|---|
| Scope | 5 | 8 | 13 | 5+(a) | 3 | 9 |
| Record | 1 | 1 | 0 | 0 | 0 | 3 |
| Experience | 8 | 3 | 11 | 4 | 1 | 6 |
| Total | 14 | 12 | 24 | 9+ | 4 | 18 |

(a) the guiding questions proposed can give origin to more than five criteria.

The criteria defined in the case study are within the range of criteria found in the literature. Despite the freedom in criteria definition for ScoRE, novel criteria did not emerge from this particular case study. In this sense, ScoRE lead to similar results to those expected if other methods were used for criteria definition. From the literature analyzed, ScoRE was the only approach where the list of criteria is empty at the beginning of the process and where both modelers and end-user define the criteria for the evaluation process. The results obtained show that model users can define criteria for the evaluation, complemented with additional criteria suggested by the modelers. This means that criteria definition can be opened up for discussion between modelers and end users, in addition to the valuation stage.

The range of criteria defined for this particular case did not include, for example, criteria linked with the accuracy of the data and model, if the models include uncertainty or sensitivity analyses to the results, or even on the availability of data [18,20,25]. Such criteria, however, should be part of the criteria list in further studies, given their implications on the use of the model and validity of its results.

### *6.2. Valuation of Criteria in ScoRE*

In ScoRE, the technical team performs the valuation of criteria, not the end-users. The particularity of ScoRE is that values for models in the criteria are discussed with the end-users, in particular, those referring to criteria within the cluster "Experience". The advantages of having the technical team performing the scoring are that the end-users might not process all the knowledge necessary to adequately evaluate the models under the criteria [19], in particular, the criteria falling under the cluster "Scope".

The disadvantages of such an approach are that the process can become less transparent (and less accountable), costlier (due to the costs of hiring a technical team) and lengthier [18,20–22]. The fact that ScoRE allows the discussion of the scorings with the end-users helps to restore transparency in the model selection process. Furthermore, for this particular project, the decision to use a technical team to model water quality has been made before the decision of whether to involve the technical team on model selection. Therefore, in this particular case, asking the technical team to select the appropriate model for the case study was just an additional small cost to the overall budget.

Another particularity of ScoRE was the use of eliminatory criteria that had two values linked with acceptable and not acceptable scores. Being scored unacceptable in any of these eliminatory criteria meant the elimination of the model from the process. In this case study, two eliminatory criteria were defined which resulted in the elimination of three models from the evaluation. In this regard, the main difference between ScoRE and Tuo et al. [22] is that, for the remaining models, ScoRE presents clear guidance for weight definition.

### *6.3. The ScoRE Aggregation Procedure*

The results show that CE-QUAL-W2 performed better than the remaining four models analyzed (Figure 6). It is important to stress that results are specific for this particular case study, as the choice of criteria and the weights attributed to the clusters can vary from application to application, resulting in different rankings. The outcome of this method reflects the importance that the technical team and the end-users assign to different criteria. Even for a reservoir, for example, SisBaHIA or MOHIDw could have a higher ScoRE than other models, if the focus of the study relied heavily on hydrodynamics, since both achieved better spatial simulation of transport processes [38,75]. Likewise, if an integrated watershed–river–reservoir modelling approach was favored, MOHIDw would be a better option, reaching a higher ScoRE, as it can be coupled with MOHID Land, which describes the transport of water in the watershed [57,76].

In this case study, end-users attributed higher weight to the cluster "Scope," and equal weights to the clusters "Record" and "Experience" (Section 5.4). These results are not surprising and in line with other works on model selection, in which most of the criteria are related with the cluster "Scope" [19–21,25,77], as shown in Table 6. The only literature case analyzed that provided a higher number of criteria to another category rather than "Scope" was Saloranta et al. [18], which defined five criteria for scope, but eight for Experience (and one for record).

Although the clusters Record and Experience had equal weights (25% each, Section 5.4), the cluster Experience scores were higher or similar to the scores from the cluster Record (Figure 6), with a small exception for the model CE-QUAL-W2, where Record value was 0.1 points higher than the value for Experience. Interestingly, the literature shows more criteria related to the cluster Experience, than with the cluster Record [18–20,25,77]. Therefore, results obtained here seem to agree with the observed patterns in the literature concerning criteria relevance (Table 6).

The aggregation procedure used in ScoRE to obtain ranking is a procedure which includes a mixture of approaches: from eliminatory criteria [18–21], averaging scores of criteria (within the same cluster), and consulting with end-users to define weights to the clusters which are then added using a linear additive model (a compensatory aggregation procedure).

The proposed approach requires communication between modelers and end-users, thus promoting the pivotal exchange of information [78]. This, in turn, leads to rational reflection, and potentially, some learning from both sides. Additionally, by making use of a linear additive model for aggregating results, the outcome is more straightforward to understand by end-users, improving the transparency of the method. However, the linear additive procedure is a compensatory method in which weights are recognized as trade-offs. This is an essential issue for sustainability, as certain voices and some ecosystem services should not be traded off [23,79,80]. For models, it can mean that a combination of a high score in the interface with a low score regarding a specific relevant modeled parameter, can exceed a higher score in the referred parameter combined with a lower score on the interface. By using the eliminatory criteria, ScoRE allows reducing some of this compensatory nature, being a partially compensatory approach. However, criteria within each cluster are still averaged. By doing so, one is assuming that all criteria not classified as an eliminatory criterion within the same cluster are equally relevant, which might not always be the case.

In this case study, as in all the approaches reviewed in this paper, end-users are clearly defined and limited in the number of individuals, and it's not infrequent to have only one decision-maker. Under more complex decisions, with more decision-makers, a discussion on whether weights should or not be used needs to take place to avoid social traps, ensure all relevant voices are included, and ensure that value disparities and conflicts are recognized and managed correctly [16].

### *6.4. A Word on Robustness, Sensitivy and Transparency of the Process and Results Obtained*

Finally, results from ScoRE are discussed with the end-user who can go through the whole process and change it. This way, results are exposed to validation by the end user. Furthermore, ScoRE starts with a clean sheet regarding the criteria to be used for the evaluation (and the relative importance of each criterion—the weights), which allows different end-users (and modelers) to participate in the identification of which criteria to include in the evaluation, potentially accommodating different perspectives in the process. The two factors mentioned help ScoRE to reduce ambiguity in its results and to be seen as potentially more robust than other approaches. This step also entails a sensitivity analysis in which some of the assumptions or parameters included in the model are given a different value, to test whether the final ranking of alternatives changes. This methodology is more in line with the post-normal approach to science (with the use of a peer-review community [81]). It is also in line with other approaches dealing with uncertainty (e.g., Stirling [82]), where the focus is not on accepting scientific inputs uncritically, i.e., without articulating the degree of risk associated with the results or the values that inevitably enter in the presence of uncertainty.

## 7. Conclusions

For many years, decision-makers have managed water quality in rivers and reservoirs empirically, relying to some extent on scientific tools and input, but frequently based on political motivations. The need for sound decisions, however, has pushed the development of numerical models to address specific environmental and socioeconomic setting. Eventually, this effort resulted in the myriad models that are now available, raising the problem of their choice by users. A model will hardly possess all the required functionalities for a specific application and, consequently, the choice of a model depends upon many conditions and requirements.

Given the significant number of available modeling tools for such tasks, water managers wanting to use numerical tools must, at some point, choose among the myriad options, frequently without any specific criteria or methodology. The debate on how to select water quality models is relatively recent, and only a few approaches to model choice have been proposed. While not being a method to compare models in their essence, ScoRE may be useful for that purpose.

The main advantages of ScoRE are:

- Criteria to compare models are defined in a dialog between the modelers and end-users. Introducing both perspectives into criteria definition can lead to a more comprehensive list.
- ScoRE is a transparent method, as end-users are invited to go through the whole process and to discuss final results with the technical team.
- The guidance on how to select a model when models are not excluded by eliminatory criteria (in contrast with most of the literature found, with some exceptions [22]).
- The final discussion of results with end users, allowing for the refinement of results, and producing a more robust outcome.

ScoRE is not free from limitations, nonetheless. In ScoRE, end-users have little say in the scoring stage, making the process more resource-consuming (concerning time and costs), as a technical team is required for the scoring stage. ScoRE's weighting procedure is still a complex procedure involving averaging scores within clusters and attributing weights to clusters. This could be further simplified. Finally, more emphasis can be put into eliminatory criteria (higher number of criteria classified as eliminatory). These will be the target of improvement in further stages of this research.

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