FORT HILLS

FORT HILLS ENERGY CORPORATION
FORT HILLS OIL SANDS PROJECT

MCCLELLAND LAKE WETLAND COMPLEX OPERATIONAL PLAN OBJECTIVE 3

December 2021

Operated by SUNCOR ENERGY

FORTHILLS

Operated by Suncor Energy

McClelland Lake Wetland Complex Operational Plan

Executive Summary / Introduction / Supporting Attachments

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4. OBJECTIVE 3: ASSESS POTENTIAL IMPACTS OF MINE DEVELOPMENT

4.1. Introduction

Understanding the potential impacts on the non-mined portion of the McClelland Lake Wetland Complex (MLWC; Figure 1.1-1) due to continued development of the Fort Hills Oil Sands Project (Fort Hills Project) is critical to determining the water management design features that will be required to maintain the functionality and diversity of the MLWC. While the Fort Hills Project has been the subject of several impact assessments since 2001, potential impacts to the non-mined portion of the MLWC were only assessed in the original Fort Hills Project Environmental Impact Assessment (EIA). However, the specific assessment of the non-mined portion of the MLWC was withdrawn, with any further assessment deferred until the development of the Operational Plan (OP). Objective 3 utilizes the observed pre-mining baseline conditions for the MLWC (defined under Objective 1 [Section 2]) as the input to an integrated groundwater/surface water model for the evaluation of several scenarios:

- a no development in the MLWC watershed scenario (R0)
- a development scenario with no implementation of water management design features (R1)
- a development scenario with implementation of the selected water management design features (S1)

The water quality model also incorporated observed pre-mining baseline conditions for the MLWC as input; however, there were only two scenarios evaluated:

- a no development in the MLWC watershed scenario (R0)
- a development scenario with implementation of the selected water management design features that resulted in water quality equivalent to the no development scenario (S1)

Indicators selected in Objective 2 are the focus of the modelling exercise and assessment.

Results from the R0 and R1 scenarios are used in Objective 4 as an input to the identification of the design features considered for implementation.

During development of the OP, Fort Hills Energy Corporation (FHEC) developed a numerical integrated surface water and groundwater flow model to assess potential design features to minimize water flows into the mining area and to maintain water levels in the non-mined portion of the MLWC. The numerical integrated surface water and groundwater flow water model was developed in HydroGeoSphere (2020 MLWC HGS model; Aquanty 2021). In addition, an Environmental Fluid Dynamics Code (EFDC+) model is being developed to simulate changes to surface water quality, using the results from the integrated surface water and groundwater flow model as inputs at the boundaries of the EFDC+ model (DSI 2021). A description of both models is provided in Section 4.3.1.

4.2. Sustainability Committee Input

Over the course of various MLWC Sustainability Committee (SC) meetings and workshops, Indigenous Traditional Knowledge (ITK) holders and Indigenous land users have shared some of their perspectives, concerns, and knowledge about the MLWC. Development of the conceptual model was an iterative effort and the Technical Advisory Group (TAG) critiqued the MLWC Conceptual Model work through a series of workshops and made recommendations as it evolved. Input from indigenous land users has been braided together with the scientific knowledge in the development of the MLWC conceptual model. The current conceptual model is provided in Appendix F. The MLWC TAG and the MLWC SC also helped guide the development of the integrated flow model through feedback during updates on modelling progress.

As detailed in the Conceptual Model Appendix (Appendix F), ITK helped inform the conceptual model, how water flows through the system, the terrain, the connectivity of the ground and surface water, how climate has influenced the wetland and lake and how water flows out of the MLWC. Review and input from the SC as well as the TAG and Aboriginal Advisory Group (AAG) has vastly improved the understanding and communication of how MLWC watershed resides atop hummocky, glaciated terrain located within the Western Boreal Forest. Iterative reviews of the water models with the TAG improved the construction, calibration, validation, and presentation of the modelling work.

4.3. Assessment Methodology

The assessment completed for Objective 3 focuses on determining the risk to the non-mined portion of the MLWC following implementation of the design features. The risk assessment completed for this objective is focused on the integrated primary effects indicator metrics selected by FHEC within Objective 2. A quantitative risk assessment was completed for the metrics that could be predicted using the numerical integrated surface water and groundwater flow model (i.e., hydrogeology, surface water hydrology), while a qualitative risk assessment was completed for the metrics for the primary effects indicators that could not be predicted within that model (i.e., water quality, aquatic resources, and vegetation). Qualitative assessments described potential effects to the primary effects indicators based on assessment results of relevant key stressors (e.g., no substantial change in water levels or water quality). Groundwater quality was not modelled at this time but is part of future work planned.

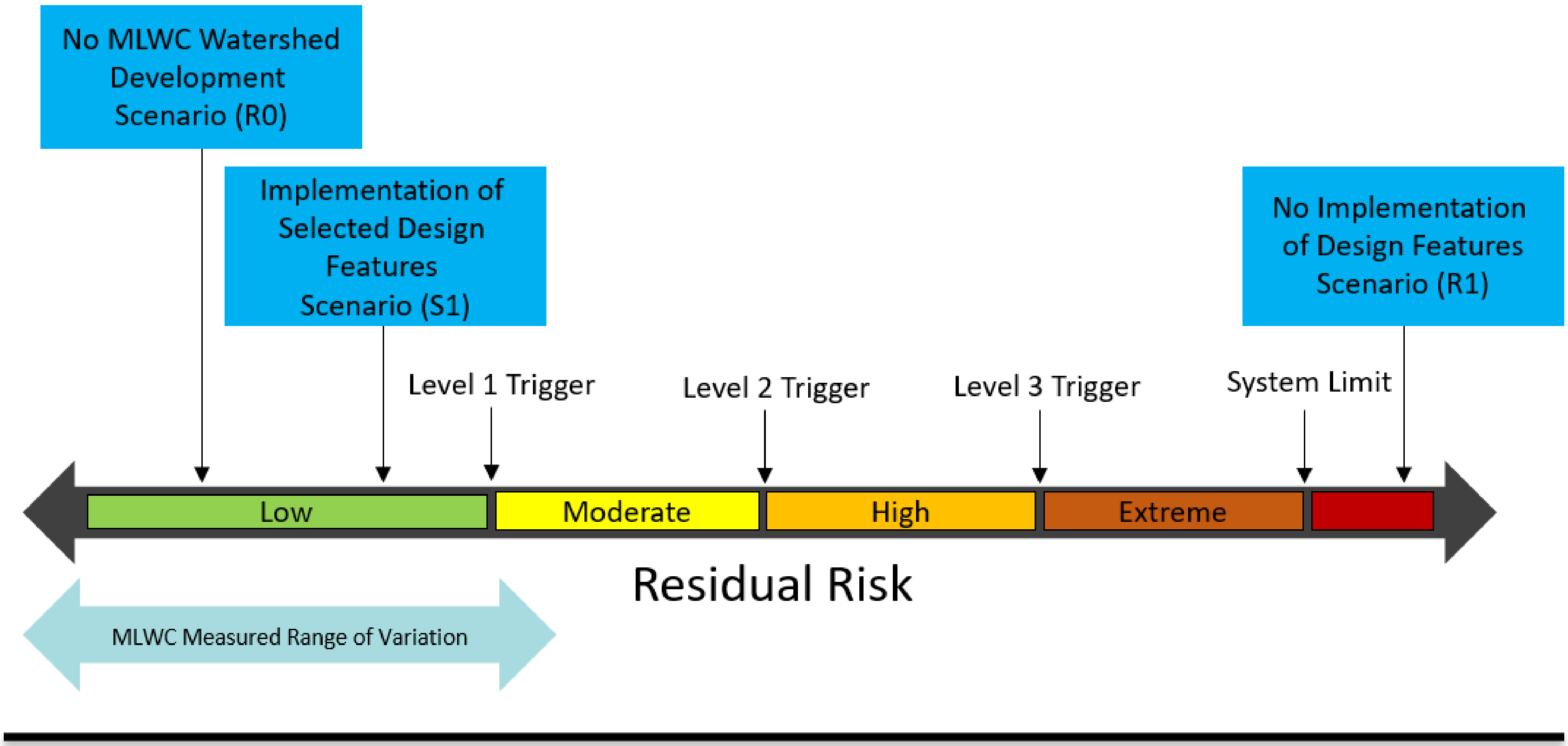
The quantitative risk assessment uses the results of the R0 and R1 model runs as “endpoints” to evaluate whether the design features are effective in minimizing or eliminating effects to the hydrogeology and hydrology of the non-mined portion of the MLWC. For the identified design features, a model run was completed that included the proposed design feature, and the results from the run were compared to the R0 and R1 results. The closer the results are to the R0 results, the lower the risk of impacts to the non-mined portion of the MLWC. A diagram of this risk assessment approach is provided in Figure 4.3-1.

Using this risk assessment approach, the closer the modelled effects of a design feature are to the predicted effects from the R0 scenario indicates there is a lower risk to non-mined portion of the MLWC. As such, in addition to comparing the results of the design feature modelling to the R0 and R1 scenarios, the risk assessment also evaluates the results using the response framework developed for Objective 6 (Section 7). This approach helps to confirm that implementation of the design features not only results in conditions closest to what is predicted in the R0 scenario, but those results are below Level 1 trigger values, as defined in the response framework, which is considered the lowest risk to the functionality and diversity of the MLWC. The template of the risk assessment summary that is presented in Section 4.3.2 for each primary effects indicator metric assessed is provided in Table 4.3-1.

Table 4.3-1: Risk Assessment Summary Template

Primary Effects Indicator	No MLWC Watershed Development Scenario		No Design Features Scenario		Implementation of Selected Design Features Scenario	
	Result	Below Level 1 Trigger Value?	Result	Below Level 1 Trigger Value?	Result	Below Level 1 Trigger Value?
Metric 1	aaa	Yes/No	bbb	Yes/No	ccc	Yes/No

Note: aaa, bbb, ccc represent hypothetical values.
MLWC = McClelland Lake Wetland Complex.



MLWC = McClelland Lake Wetland Complex.

Figure 4.3-1: Risk Assessment Approach

4.3.1. Description of Models Used

4.3.1.1. 2021 MLWC Conceptual Model

This section provides a high-level overview of the conceptual understanding developed for the MLWC region to support the construction and application of a numerical water model of the system. Further details of the numerical model are provided in Appendix D and the conceptual model in Appendix F. Hydrologic Response Areas (HRAs) are used in the MLWC Conceptual Model and are arrived at while considering the five criteria in Devito et al. (2005) and perform the dual hydrologic functions of:

- water storage and redistribution to the surrounding landscape during dry or drought periods
- the transmission of significant volumes of water through the landscape during wet periods or cycles (drainage)

The practical application of the Devito et al. (2005) characterization framework to develop HRAs for the 2021 MLWC Conceptual Model required identifying and considering all the contributing landscape storage, redistribution and transmission components and then determining how these hydrological components interact with one another. Figure 4.3-2 presents the configuration of the HRAs developed within the MLWC watershed and shows the conceptual water flow directions.

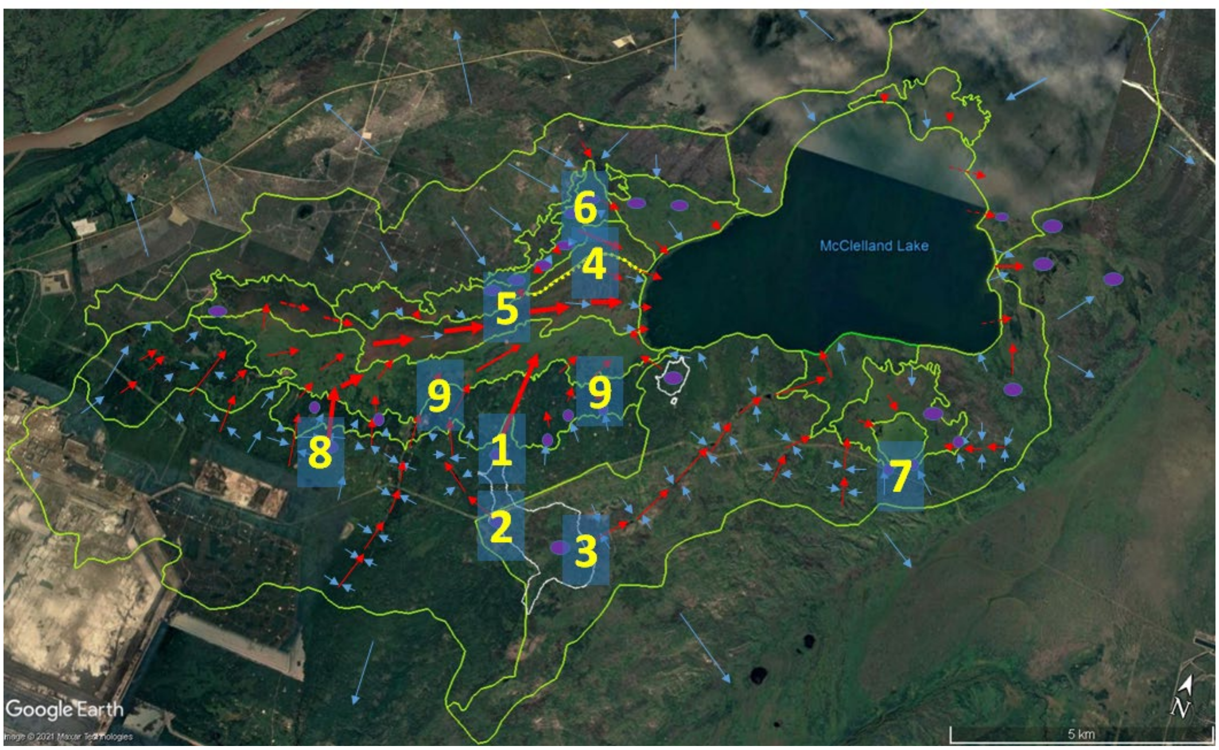


Image source: Google Earth/Maxar Technologies.

Note: The red arrows in the figure represent surface water flows, the blue arrows represent groundwater flows and the purple ovals areas of groundwater discharge to surface (springs). Dashed arrows are where flow sometimes occurs. The areas outlined in green are the MLWC HRAs and the areas outlined in white are mapped hydraulic windows. The yellow stippled line by Location 4 is a surface water divide.

Figure 4.3-2: Conceptualized Dominant Flow Paths within the MLWC

As can be inferred from Figure 4.3-2, the surface and subsurface flow systems are highly interactive with several locations where groundwater is exfiltrating to surface and flowing as surface water towards the MLWC fen and lakes. The dominant flow paths in the watershed (and the key hydrological processes connected to the flow paths) are annotated at 9 locations on Figure 4.3-2. Summary descriptions of these key flow paths are as follows:

- Location 1: Locations 1-3 are places where groundwater is discharging to surface (or just below surface) via a large hydraulic window present in the Clay Till 1 unit (outlined in white). When groundwater comes to surface away from a surface water feature such as a stream or lake, it typically does so via a groundwater spring. Locations 1-3 on Figure 4.3-2 are interpreted to be three groundwater springs that emanating from this large hydraulic window. The groundwater spring occurring at Location 1 is presumed to produce more water than the other two locations given that it sits at a lower elevation, thereby presumably making it more sensitive to changes in groundwater levels in the aquifers feeding it. A portion of the precipitation falling on the uplands of HRA 17 (location shown on Figure 29 in Appendix F) recharges the groundwater in the underlying silt sand aquifers and, in turn, causing groundwater levels in these units to rise. In turn, a portion of this recharged groundwater advectively comes back up to surface via the groundwater spring located at Location 1 in Figure 183 in Appendix F. Once at surface, it would be convert to surface water overland flow that will migrate downgradient across HRA 08 (Coniferous Swamp – South) and through the melted permafrost zones of HRA 04 (Non-patterned Fen – South) before ultimately discharging into HRA 01 (Patterned Fen – South).
- Location 2: Location 2 is another location of a groundwater spring originating from the large hydraulic window shown in Figure 4.3-2 (outlined in white). At this location, groundwater advectively discharging to surface is converted to surface water channel flow (possibly ephemeral channel flow). This channel also receives groundwater baseflow inputs along its reach. Like at Location 1, this channelized flow moves downgradient across HRA 17 (Fort Hills – West), HRA 08 (Coniferous Swamp – South) and HRA 04 (Non-patterned Fen – South) before ultimately discharging into HRA 01 (Patterned Fen – South).
- Location 3: Location 3 is the third and final groundwater spring interpreted to emanate from the large hydraulic window shown in Figure 4.3-2 (outlined in white). Groundwater advectively discharging to surface at this location is converted to channelized flow in Unnamed Creek (the stream exiting the hydraulic window to the east). Unnamed Creek flows along HRA 18 (Fort Hill – East) in a shallow valley supported by a zone of shallowly subcropped Clay Till 1 (refer to Figure 4.3-2) and with deep sand deposits on either side of this valley (which also contribute baseflows to Unnamed Creek). Unnamed Creek discharges to HRA 11 (South Wetland – To McClelland Lake) and then into McClelland Lake itself.
- Location 4: Location 4 is a surface water divide that impedes surface water in HRA 02 (Patterned Fen North) from mixing with from mixing with surface waters entering HRA 01 (Patterned Fen South). The evidence for the existence of this surface water divide is apparent both in the orientation of the strings in this region and also in the hydrogeochemical signatures of the surface waters of HRAs 01 and 02.
- Location 5: Location 5 is the easternmost point in the MLWC system where nutrient poor groundwater flows originating from the relatively deep surface sand deposits along the North Outwash Plains (NOP) edge of the watershed boundary can enter HRA 01 (Patterned Fen – South). East of Location 5, all groundwater flowing towards the MLWC fen would enter HRA 02 (Patterned

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Fen – North) or discharge towards McClelland Lake. So while HRA 02 (Patterned Fen – North) only receives these nutrient poor groundwater inputs from the surrounding landscape, HRA 01 receives a combination of this NOP-derived nutrient poor groundwater as well as more alkaline water originating from the Fort Hills (refer to Section 1.4.3 in Appendix F). The groundwater processes governing how driving groundwater flow originating from HRA 05 (Non-patterned Fen – West) becomes surface water flow entering HRA 01 at Location 1 are a function of the water table position. When the water table is deep (drier conditions), groundwater from HRA 05 just advectively flows into HRA 01. When the water table is less than a few metres below ground surface, its capillary fringe will extend to and intercept the land surface. Under these conditions, incoming precipitation will result in groundwater ridging which will, in effect, pump groundwater out of the ground via capillary action and convert it to IEOLF (infiltration excess overland flow) which will flow into HRA 01 in the form of surface water. Under very wet conditions, where the water table is at or above land surface at this location, groundwater from HRA 05 will flow advectively towards HRA 01 and 'daylight' as surface water before entering HRA 01. This latter set of hydrologic processes are conceptualized to govern water flows from HRA 05 to HRA 01 most times in regions west of Location 5 in Figure 4.3-2.

- Location 6: Location 6 is where nutrient poor groundwater flows originating from the relatively deep surface sand deposits along the NOP edge of the watershed boundary can enter HRA 02 (Patterned Fen – North) from HRA 05 (Non-patterned Fen – West) directly or alternatively enter HRA 06 (Non-patterned Fen – North) before discharging to McClelland Lake. Similar to Location 5, the water table position will govern the specific groundwater processes driving the flow from HRA 05 to either HRA 02 or HRA 06.
- Location 7: Location 7 is a region is significant groundwater drainage towards Unnamed Lake. The surrounding surface sand deposits can be in excess of 50 m deep (primarily to the south of Location 7 but also the southeast and southwest) and drain towards Unnamed Lake (HRA 11 [South Wetland – Towards McClelland Lake], HRA 12 [South Wetland – Towards Unnamed Lake] and HRA 13 {Unnamed Lake]). The surface sand deposits in this region and within the confines of the MLWC watershed will drain towards HRAs 11-13 while those outside of the watershed will drain eastward towards the Muskeg River valley at the base of the Firebag Moraine. Because the depths associated with the surface sand deposits (it will take time for recharge to reach the water table in these deposits), it is expected that drainage towards HRAs 11-13 will experience a degree of hydraulic lag and drainage experienced today would be driven by groundwater recharge that occurred several months ago or earlier. Because this drainage is originating from surface sand deposits, it is presumed that the hydrogeochemical signature of this groundwater would be similar in character to the nutrient poor groundwater being produced along the western boundary of the watershed in the NOP surface sand deposits (from the same hydrostratigraphic unit). One exception to this would be incoming flows into HRA 12 from the east. As can be seen in Figure 187 in Appendix F, there is a groundwater spring located east of HRA 12 (groundwater spring location 4 in Figure 187 in Appendix F). It is very likely that groundwater flowing through this spring has an alkaline hydrogeochemical signature.
- Location 8: Location 8 in Figure 183 in Appendix F coincides with the location of groundwater spring 1 in the same figure. Unlike the groundwater springs at Locations 1-3 in Figure 183 in Appendix F, the groundwater spring at Location 8 does not manifest through a hydraulic window. Instead, the Clay Till 1 unit terminates right below Location 8 and groundwater in Silty Sand AQ 1-2 advectively flows over the terminal edge of Clay Till 1, converting to surface water overland flow,

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and downgradient over HRA 08 (Coniferous Swamp – South) and HRA 04 (Non-patterned Fen – South) before discharging into HRA 01 (Patterned Fen – South). The hydrogeochemical nature of groundwater discharging to surface at Location 8 is presumed to be alkaline and less dilute.

- Location 9: The groundwater charges emanating from Locations 1, 2, 3 and 8 could be broadly classified as focused flows because they all originate from very definable point sources. Location 7 is a mix of focused and diffuse flows; some water is entering HRAs 11-13 via groundwater drainage discharging into ephemeral channels that drain to these HRAs while the remainder is groundwater advectively discharging to surface just south of Unnamed Lake. Location 9 in Figure 183 in Appendix F is also an example of a diffuse flow generating region in the MLWC watershed. Location 9 corresponds to HRA 08 (Coniferous Swamp – South) and is located at the base of the Fort Hills slopes. A very large portion of HRA 08 is covered with low permeability tills or silt clays (refer to Figure 16 in Appendix F to see the surface hydrostratigraphy) which will facilitate runoff of any incoming surface water draining off the Fort Hills Upland Complex (FHUC) slopes or entering the HRA as exfiltrated groundwater. Although the vegetation above HRA 08, coupled with thin permeable substrates, would not be expected to generate significant runoff most years, any groundwater drainage to rills above HRA 08 will pass over HRA 08 on its way downgradient. This HRA (08) also contains some smaller hydraulic windows that would also potentially generate runoff.

4.3.1.2. Water Quality Conceptual Model Framework

The conceptual model for water quality was built upon the conceptual model for water movement through MLWC provided in Section 4.3.1.1. Further detail is provided in the EFDC+ Appendix (Appendix E).

Surface water flows within the MLWC watershed are entirely derived from precipitation (rainfall and snowmelt) and groundwater exfiltration (discharge). Groundwater exfiltration originates from two distinct areas, the NOP and FHUC. Both the NOP and FHUC contain HRAs with similar characteristics regarding relative dominance of surface and groundwater flow paths, and atmospheric exchange of water (evapotranspiration). Descriptions of the NOP and FHUC and characterization of their respective water quality are provided in subsequent sections.

Water quality exfiltrated from the NOP is relatively dilute and more acidic due to higher hydraulic conductivity of the permeable substrates resulting in a short contact time for dissolution processes to occur.

Compared to the NOP, water exfiltrated from the FHUC generally has higher concentrations of base cations and is more alkaline due to lengthened contact times of groundwater with the clays forming the glacial till deposits.

4.3.1.3. 2020 MLWC HGS Model

Fort Hills has continued development of a numerical integrated surface water and groundwater flow model using 2020 MLWC HGS model to assess potential design features to minimize water flows into the mining area and to maintain water levels in the non-mined portion of the MLWC.

The calibrated 2020 MLWC HGS model was then used to simulate potential impacts of mine development on the groundwater and surface water levels in the non-mined portion of the fen, the surface water levels in the lake, the groundwater discharge rates into the lake and fen, and the water balances of the lake and fen of the MLWC. The following assessment cases were simulated:

- simulated pre-mining baseline
- operations
- active closure
- far-future (post-closure) for historic climate and climate change scenario

A detailed discussion of the 2020 MLWC HGS model setup, calibration results and simulated flows for pre-mining baseline, operations, closure, and far-future cases is provided in Appendix D.

4.3.1.4. EFDC+ Surface Water Quality Model

The EFDC+ model for MLWC was developed to model surface water quality dynamics both during mining activities (i.e., operations and active closure) and following mine closure. The numerical model is intended to provide water quality results of the MLWC using a primarily surface water and conservative constituent (non-reactive) transport approach. The model builds on existing hydrologic understanding of the MLWC and incorporates non-reactive (conservative) constituents to characterize the hydrologic flow paths. Further details on the EFDC+ model and early results are provided in the EFDC+ Appendix (Appendix E).

Development of the numerical model is still in progress at the time of submission of the OP. Additionally, the EFDC+ model is a surface water model that only simulates the surface water portion of the fen. Based on the field data, EFDC is able to represent this portion of the water quality well (Appendix E). However, as other portions of the fen flow regime are critical to understand from a water quality perspective, more modelling work is required. Figure 4.3-3 provides a roadmap for the future work required for water quality modelling. As the modelling work is still being refined, a qualitative risk assessment for surface water quality has been completed using the conceptual model and results from the 2020 MLWC HGS model.

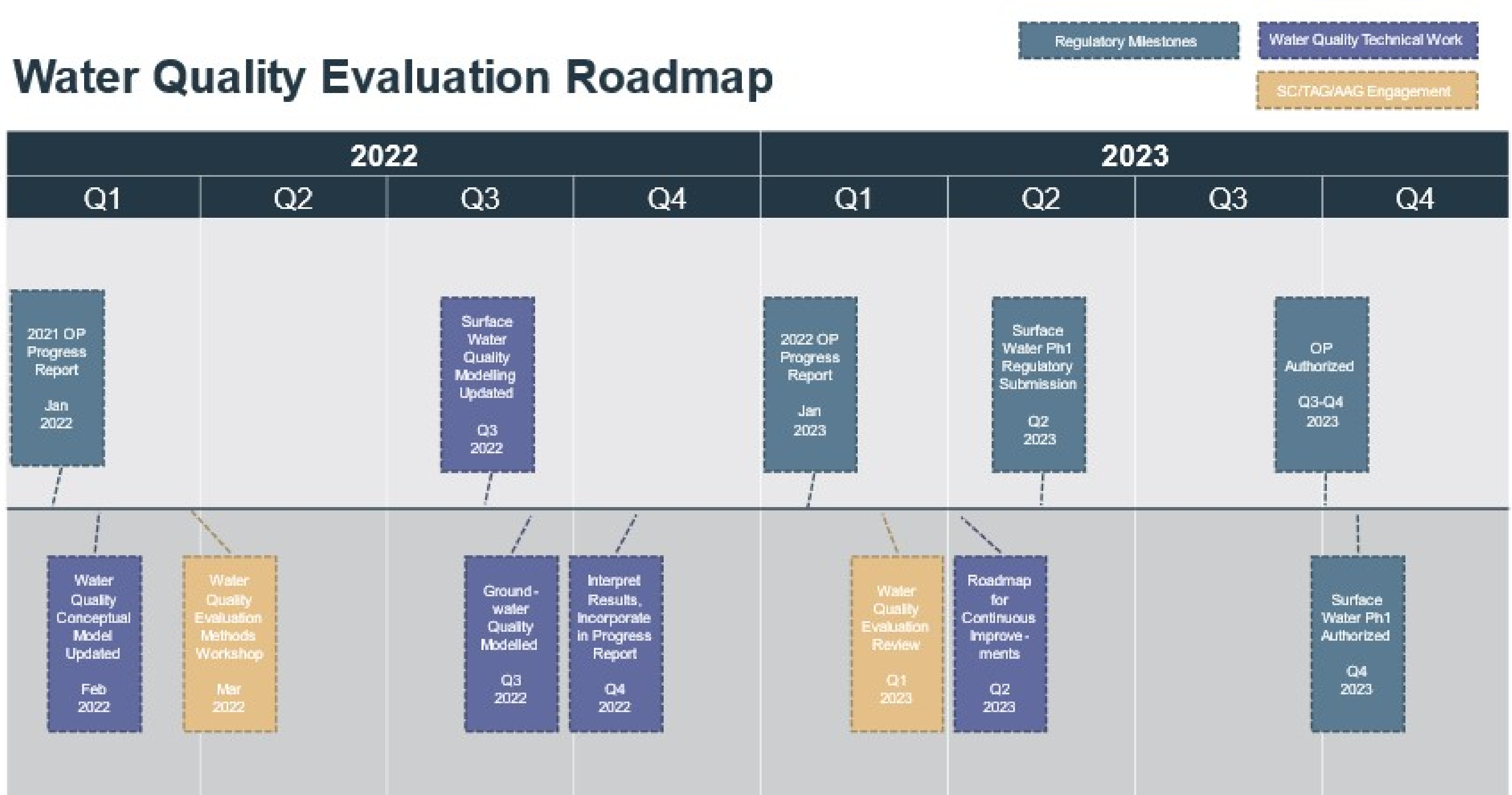

Figure 4.3-3: Water Quality Evaluation Roadmap

4.3.1.5. Prediction Confidence

Assessment of the Fort Hills Project effects has inherent uncertainty associated with data, selected methods, and the predictive nature of the assessment. Also, changes in future environmental conditions could result in added uncertainty. Assessment confidence was determined by considering:

- Quality and quantity of observed pre-mining geological, hydrogeological, and hydrological baseline data used in the assessment; the overall confidence in the data quality is high and spatial coverage over the MLWC system and regionally is good. Potential future refinements could be made to characterization of the definition and extent of the rafted McMurray deposits at the base of the Fort Hills and better incorporation of local (as opposed to regional) climate data to drive the numerical water models. Groundwater data coverage of the system is extensive. Some additional quality control on select MLWC wells screened in the peat may be needed for reasons discussed in the next bullet point. The McClelland Lake level data is considered high quality but there is some uncertainty in the corresponding lake discharge data (also discussed in next bullet point). Stream discharge data (along South Creek) is of reasonable quality but of limited duration (two seasons). The water quality data at the MLWC is of sufficient duration in time but not continuous; the data tend to be clumped to time periods corresponding historical sampling campaign schedules, primarily during the ice-free period.
- Confidence in measurements; There is medium to high overall confidence in the measured data (chemistry, flows, levels). Groundwater level data within the peatlands (muskeg) would have a relatively small degree of uncertainty on the order of centimetres given that the muskeg swells and decompresses cyclically and a subset of the peat-screened wells may not be fully-anchored into the substrate (underlying sand). There is also uncertainty in measured discharges from McClelland Lake given the nature of the outlet (water can flow around the instrumentation and discharge). Data at other locations is considered very high quality. The microtopography present in the fen is a confounding factor in obtaining sub-centimeter accuracy throughout the data in the fen region.
- Confidence in assessment methods and the model itself; the employed assessment methods are judged appropriate. The numerical platforms used in this work have established track records and are suitable for this type of hydrological analysis on the MLWC system. Subsurface-specific water quality simulations are an ongoing task. These subsurface results will be used to complement and refine the existing surficial water quality simulations. The current state of the subsurface flow modelling results with HGS in this groundwater dominated system are deemed reasonable; the model calibrates well to the surficial sand aquifers present in the watershed and exhibits a slight over pressurization bias in the siltier aquifers within the FHUC. Planned enhancements discussed in Appendix D (i.e., adjustments to soil freezing and thawing as well as adjustments to applied AET targets for aspen stands) are expected to improve model performance. McClelland Lake level data was used to calibrate the 2020 MLWC HGS model but stream discharge data from South Creek was not (and is of limited duration). Predicted flows along South Creek currently exhibit a large degree of flashiness during the freshet period not seen in the observed data. This model behavior can primarily attributed to currently assigned freeze and thaw properties assigned to the shallow subsurface of the FHUC and, as noted above, is also an area of identified future model enhancement (the surface sand overlying the South Creek portion of the FHUC drains into South Creek and adjustments to the freeze thaw properties is anticipated to improve this simulated fit). The net effect of these planned model adjustments is anticipated to be a net reduction in simulated runoff from the FHUC, particularly during the freshet. With these caveats in mind, the 2020 MLWC HGS is

able to simulate the hydrological functioning of the complex MLWC hydrological system effectively: 1) simulated peak flows through the patterned fens happen during the freshet although peak rainfall occurs in June or July (system seasonality is properly represented); 2) flow is simulated to occur at the groundwater springs identified in the 2021 MLWC Conceptual Model (Appendix F) even though they were never specifically parameterized to do so (a function of the hydrostratigraphic characterization built into the model); 3) the model is able to represent observed key wintertime hydrological processes (such as groundwater head build up during winter; albeit the freeze-thaw properties need additional refinement in the FHUC); and 4) the overall HGS model results align well with the conceptual understanding of the system. Future enhancements to numerical water modelling efforts are expected to continue concomitantly with ongoing refinements to the conceptual understanding of the MLWC flow system and its hydrogeochemical cycling.

- Confidence in the success of the effectiveness of the water management design features; the water management design features are currently at a conceptual stage and engineering work to advance the features is ongoing. The conceptual engineering work to date has not identified any fatal flaws in the design features. The features will continue to be rigorously evaluated (additional field data acquisition, monitoring and numerical modelling) as the engineering work advances.
- Potential changes in future environmental conditions, such as possible climate change influences on hydrogeology and surface water hydrology; most currently available climate change studies indicate that the climate around the MLWC (central Alberta) will be generally wetter and warmer in the future (including the work upon which the climate change analysis presented in Appendix D is based). There is a medium level of confidence that these trends will occur over time. There is much lower confidence on when this trend may start to occur (the MLWC climate is trending drier currently) as well as with respect to how much warmer and how much wetter the region may get.

The effects of climate change are included under prediction confidence discussions because of the uncertainty that climate change may have on predictions as well as the uncertainty associated with future climate conditions due to climate change. In addition, the Fort Hills Project plan and the water management design features have been developed with the recognition of climate change.

4.3.2. Assessment Results

Results of the risk assessment for the selected metrics for each primary effects indicator are provided in this section.

The maximum potential effects to the non-mined portion of the MLWC are listed in the sections entitled Mining without Water Management Design Features (which is the simulated R1 scenario). If mitigation is unsuccessful, it is assumed that results would move towards this R1 scenario and that R1 would be the maximum effects. The R1 scenario is only presented for the hydrogeology and surface water hydrology assessments, since water quantity modelling established that functionality of the fen would not be maintained for the R1 scenario, and therefore, further assessment of potential water quality was not completed. Given the importance of other water quality modelling scenarios to the OP, this was not considered for further work.

4.3.2.1. Hydrogeology and Surface Water Hydrology

The hydrogeology and surface water hydrology assessments evaluate the simulated effects of Fort Hills mine development on the groundwater and surface water levels, groundwater/surface water exchange, and the water balance in the non-mined portion of the MLWC.

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The general methodology for quantifying the changes in the hydrogeological and hydrological conditions due to the Fort Hills mine development was to:

- identify the main aquifers, groundwater features, and receiving waterbodies to be affected by the Project
- select the locations within the affected flow system for measuring changes
- examine the schedule of mining and water management activities and select representative assessment periods for detailed analysis of the change
- select key hydrologic and hydrogeologic parameters for characterizing the variable conditions
- compare the predicted changes of mine development using results from the integrated surface and groundwater model compared to simulated pre-mining baseline conditions to quantify the incremental and cumulative effects of development

4.3.2.1.1. Linkage Assessment

The Fort Hills mine development in the MLWC watershed could potentially impact the groundwater and surface water hydrologic systems of the non-mined portion of the MLWC (i.e., the groundwater and surface water systems for the fen and the McClelland Lake). Various activities during site preparation and operation phases of the Project will result in removal of part of the MLWC and will have a direct effect on the aquifers underlying the fen, the non-mined portion of the fen and McClelland Lake. As discussed in Objective 4 (Section 5), the two main design features that will be used as mitigation are a cutoff wall and a surface water resupply system. These two features will serve to prevent groundwater from moving into or out of the MLWC and the mine pit, and supplying surface water to the MLWC that would have instead come from the mined portion of the MLWC. Groundwater injection is another design feature that will be used to mitigate any potential impacts to the groundwater system underlying the fen.

During the closure phase of the Project, new drainage systems consisting of main drainage channels, secondary drainage ditches, and shallow wetlands will be constructed west and southwest of the remaining MLWC. The addition of constructed wetlands will result in an increase in evaporative losses and provide storage to attenuate runoff and may impact the surface water and local groundwater flow patterns within the watershed. Options for the cutoff wall at closure include complete removal, removal of the above-ground portion, perforation of the wall, or a combination of these options. It is expected that the northwest portion of the cutoff wall will remain in place. Final plans for the cutoff during the closure phase are expected to alter groundwater flow conditions, allowing flow between the non-mined portion of the fen and the reclaimed mined area during the far-future case.

The primary effects indicator metrics are considered to evaluate the impacts on groundwater and surface water systems. For the hydrogeology assessment, the primary effects indicator metrics considered are groundwater levels in the fen and groundwater discharge to the fen and to McClelland Lake. For the surface water hydrology assessment, the integrated indictor metrics considered are water levels in the fen and McClelland Lake.

4.3.2.1.2. Assessment Cases and Simulated Scenarios – Hydrogeology

A total of ten groundwater monitoring locations were selected to illustrate the change in the groundwater flow system for the operational, active closure, and far-future periods in relation to the simulated pre-mining baseline conditions. The selected locations and the range of simulated hydraulic heads are shown in Figure 4.3-4. These ten locations are existing monitoring wells with measured pre-mining baseline data and cover the spatial extent of the fen.

Simulated Pre-Mining Baseline

Simulated pre-mining baseline results were obtained using the calibrated 2020 MLWC HGS model (Appendix D). The measured groundwater levels for the pre-mining baseline case are documented in Section 2.5.4, Objective 1.

The measured and simulated baseline groundwater levels at a total of ten selected monitoring locations (within the Quaternary) are compared for the change assessment (Table 4.3-2 and Figure 4.3-4). The model was calibrated and compared to measured groundwater levels, surface water flows, McClelland Lake stage data, and evapotranspiration. The simulated groundwater levels were compared to the measured groundwater levels, which results in an R^2 value of 0.97 (Appendix D); average groundwater levels are generally higher for the simulated results for the wells shown on Figure 4.3-2. The 2020 MLWC HGS model calibration and a detailed comparison between the measured and simulated groundwater levels are documented in Appendix D.

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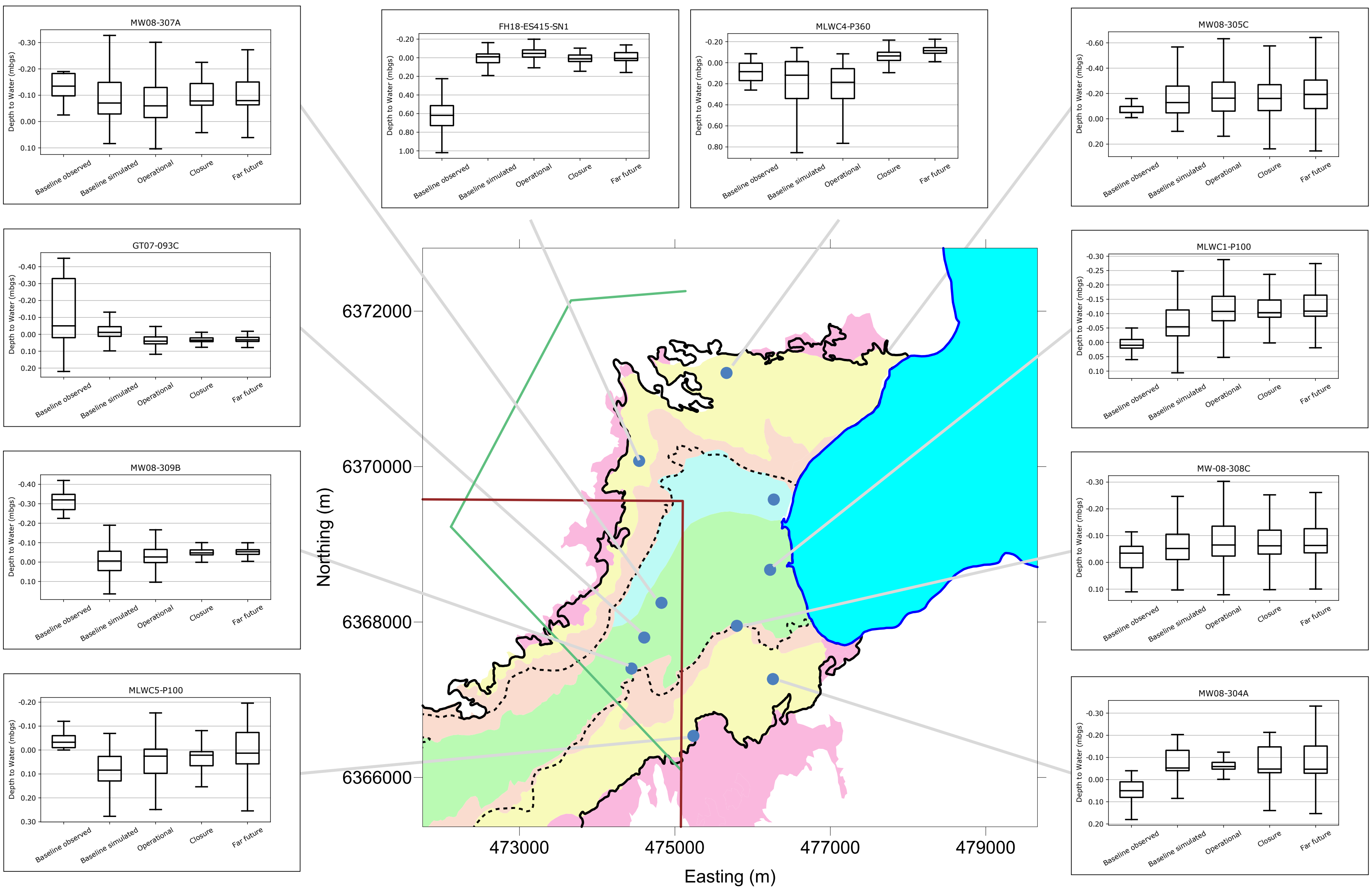

LEGEND

- Observation well location
- McClelland Lake
- Patterned Fen
- Non-patterned Fen
- Cutoff wall
- Approved project area

Ecohydrology Zones:
1
2
3
4
5
6

Note: Closure and Far future hydraulic head distributions are for the mining with mitigation case.

CLIENT
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YYYY-MM-DD	2021-10-19
PREPARED	PL
DESIGN	RS
REVIEW	LW
APPROVED	RM

PROJECT
McCLELLAND LAKE WETLAND COMPLEX – OPERATIONAL PLAN

TITLE
SELECTED HYDROGEOLOGY ASSESSMENT LOCATIONS SIMULATED AND OBSERVED WATER LEVELS

PROJECT No.	CONTROL	Rev.	FIGURE
20140450	100	0	4.3-4

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A

Table 4.3-2: Measured and Simulated Groundwater Levels at Assessment Locations

Well Name	EHZ	Top of Screen [m bgs]	Bottom of Screen [m bgs]	VWP or Well	Completion Formation	Observed Baseline Groundwater Levels				Simulated Baseline Groundwater Levels				Difference (Observed minus Simulated)			
						Average [m bgs]	Max [m bgs]	Min [m bgs]	Range [m]	Average [m bgs]	Max [m bgs]	Min [m bgs]	Range [m]	Average [m bgs]	Max [m bgs]	Min [m bgs]	Range [m]
MW08-305C	1	0.0	1.5	Well	Peat	0.07	0.16	0.01	0.15	0.16	0.7	-0.1	0.80	-0.09	-0.54	0.11	-0.65
GT-07-093C	2	1.2	2.7	Well	Peat	0.13	0.45	-0.22	0.67	0.01	0.21	-0.13	0.34	0.12	0.24	-0.09	0.33
MLWC1-P100	2	0.8	1.0	Well	Peat	-0.01	0.16	-0.1	0.26	0.07	0.55	-0.11	0.66	-0.08	-0.39	0.01	-0.40
MW08-307A	2	1.6	4.6	Well	Peat	0.13	0.19	0.03	0.16	0.09	0.38	-0.08	0.46	0.04	-0.19	0.11	-0.30
MW08-309B	4	0.0	0.8	Well	Peat	0.32	0.42	0.22	0.20	0.00	0.19	-0.16	0.35	0.32	0.23	0.38	-0.15
MW-08-308C	4	0.0	0.7	Well	Peat	0.02	0.11	-0.11	0.22	0.07	0.39	-0.1	0.49	-0.05	-0.28	-0.01	-0.27
MW08-304A	5	0.0	1.0	Well	Peat	-0.05	0.11	-0.18	0.29	0.07	0.2	-0.08	0.29	-0.12	-0.09	-0.1	0.00
MLWC4-P360	5	3.4	3.6	Well	Peat	-0.09	0.09	-0.26	0.35	-0.18	0.14	-1.12	1.27	0.09	-0.05	0.86	-0.92
MLWC5-P100	5	0.8	1.0	Well	Peat	0.02	0.12	-0.15	0.27	-0.09	0.07	-0.34	0.41	0.11	0.05	0.19	-0.14
FH18-ES415-SN1	5	2.1	N/A	VWP	Peat	-0.62	-0.23	-1.02	0.79	0.00	0.20	-0.30	0.50	-0.62	-0.43	-0.72	0.29

m = metre; m bgs = metres below ground surface; EHZ = Ecohydrology Zone; N/A= no depth available; VWP = vibrating wire piezometer.

Forecast Scenarios

A series of forward simulation were run representing the following scenarios:

- a no development in the MLWC watershed scenario (R0)
- a development scenario with no implementation of water management design features (R1)
- a development scenario with implementation of the selected water management design features (S1)

A description of the model setup and results are documented in Appendix D, Section 5.2. This section presents predicted changes in groundwater levels in the non-mined portion of the MLWC for the operational (2014 to 2063), active closure (2063 to 2075), and far-future (after 2076) periods in relation to the simulated pre-mining baseline conditions. The assessment also includes impact of climate change during active closure and far-future conditions. As part of the assessment, predicted changes in the groundwater recharge and discharge are also presented for the operational and far-future conditions, and the results are compared with the simulated pre-mining baseline conditions.

The objective of the design features is to sustain the non-mined portion of MLWC and to keep the mine pit dry during operations. To achieve this, the plan is to continue to provide an appropriate amount of water with suitable quality to sustain the non-mined portion of the MLWC during construction/mining operations, active closure, and far-future. The effects of mining on the non-mined portion of MLWC were evaluated for the following time periods:

- **Throughout the operational period (2014 to 2063):** to estimate the effect of the cutoff wall and water resupply systems installed to maintain the groundwater levels, groundwater recharge and discharge within the MLWC.
- **Active closure period (2063 to 2075):** to estimate effects that would occur during the decommissioning of the water resupply system and the implementation of the closure structures.
- **Far-Future Period (beyond 2076):** to determine groundwater flow conditions within the MLWC for the far-future conditions when runoff from the reclaimed area in the west is releasing water into the non-mined portion of the MLWC.

Mining without Water Management Design Features

The effect of mining on the non-mined portion of MLWC without any water management design features was simulated. The simulation results indicate the groundwater table declines approximately 1.5 m on the western side of the non-mined portion of the fen around 2048, with impacts to the groundwater table first noticeable in 2046. During the operational period, the seasonal groundwater table fluctuations within the fen and the net groundwater discharge to the non-mined portion of MLWC were simulated to decrease.

This level of impact during operations was considered substantial because it exceeds the predicted and measured ranges of natural variation of 0.4 and 0.6 m, respectively (the simulated range in water levels are provided for the R0 scenario in Appendix D and the measured range of water levels is shown in the pre-mining baseline in Figure B2-39 of Appendix B2). Therefore, the closure and far-future conditions without water management design features were not evaluated.

Mining with Water Management Design Features

The effect of mining, with the water management design features (i.e., cutoff wall and water resupply system) installed and operational, was simulated in the 2020 MLWC HGS model and the simulated results indicate less impact to the MLWC groundwater levels and the groundwater discharge to MLWC. The water levels at the selected monitoring locations for the simulated pre-mining baseline, operational, active closure, and far-future conditions including the climate change scenarios are presented in Table 4.3-3 through Table 4.3-5 and Figure 4.3-4. Note that the water level distributions shown Figure 4.3-4 for the operational, active closure, and far-future periods are only for mining with water management design features and that the active closure and far-future distributions were generated using all climate scenarios. The Project with water management design features installed and operational was predicted to result in minimal change (i.e., less than 0.1 m on average) to mean annual groundwater level within the non-mined portion of the fen during the operational period compared to the simulated pre-mining baseline conditions (Table 4.3-3). During the active closure period, the water levels were simulated to increase by up to 0.3 m (at the monitoring well MLWC4-360, located in the northern portion of the fen near the east of North External Dump [NED]).

The effects of projected climate change scenarios on the hydrogeology of reclaimed areas were assessed. Five climate change scenarios were considered for the far-future conditions (i.e., cool-dry, cool-wet, median, warm-dry, and warm-wet). The average far-future groundwater levels at the selected monitoring wells for the historic climate conditions were simulated to be within 0.3 m of the average simulated pre-mining baseline groundwater levels (Table 4.3-3). The simulated groundwater levels for the individual climate change scenarios are close to 1 m different than those of the pre-mining baseline conditions (Table 4.3-4). Only the historical climate scenario is directly comparable to the simulated pre-mining baseline results. The pre-mining baseline case was simulated with the historical climate data (1944 to 2019).

Table 4.3-3: Assessment of Average Groundwater Levels

Well Name	EHZ	Top of Screen [m bgs]	Bottom of Screen [m bgs]	VWP or Well	Completion Formation	Average Groundwater Levels				
						Baseline[(a)]	Operational		Active Closure	
						Average [masl]	Average [masl]	Change from Baseline[(a)] [m]	Average [masl]	Change from Baseline[(a)] [m]
MW08-305C	1	0.0	1.5	Well	Peat	294.69	294.71	+0.02	294.7	+0.01
GT-07-093C	2	1.2	2.7	Well	Peat	295.82	295.77	-0.05	295.77	-0.05
MLWC1-P100	2	0.8	1.0	Well	Peat	294.79	294.85	+0.06	294.84	+0.05
MW08-307A	2	1.6	4.6	Well	Peat	295.40	295.38	-0.02	295.41	+0.01
MW08-309B	4	0.0	0.8	Well	Peat	296.21	296.24	+0.03	296.25	+0.04
MW-08-308C	4	0.0	0.7	Well	Peat	295.06	295.07	+0.01	295.06	0.00
MW08-304A	5	0.0	1.0	Well	Peat	295.50	295.48	-0.02	295.51	+0.01
MLWC4-P360	5	3.4	3.6	Well	Peat	295.60	295.56	-0.04	295.84	+0.24
MLWC5-P100	5	0.8	1.0	Well	Peat	296.80	296.85	+0.05	296.85	+0.05
FH18-ES415-SN1	5	2.1	N/A	VWP	Peat	295.58	295.63	+0.05	295.57	-0.01

[(a)] Reference to Baseline is to the simulated pre-mining baseline, and all changes were calculated in relation to the simulated pre-mining baseline conditions.

m = metre; masl = metres above sea level; m bgs = metres below ground surface; EHZ = Ecohydrology Zone; N/A= no depth available; VWP = vibrating wire piezometer.

Table 4.3-4: Assessment of Average Water Level – Active Closure Climate Change Scenarios

Well Name	EHZ	Top of Screen [m bgs]	Bottom of Screen [m bgs]	VWP or Well	Completion Formation	Average Water Level [masl]												
						Baseline[a]	Average Year Climate		Cool and Dry		Cool and Wet		Median		Warm and Dry		Warm and Wet	
						Average	Average	Change[a]	Average	Change[a]	Average	Change[a]	Average	Change[a]	Average	Change[a]	Average	Change[a]
MW08-305C	1	0.0	1.5	Well	Peat	294.69	294.70	+0.01	294.71	+0.02	294.76	+0.07	294.66	-0.03	294.67	-0.02	294.70	+0.01
GT-07-093C	2	1.2	2.7	Well	Peat	295.82	295.78	-0.04	295.77	-0.05	295.78	-0.04	295.76	-0.06	295.76	-0.06	295.77	-0.05
MLWC1-P100	2	0.8	1.0	Well	Peat	294.79	294.84	+0.05	294.84	+0.05	294.86	+0.07	294.82	+0.03	294.82	+0.03	294.83	+0.04
MW08-307A	2	1.6	4.6	Well	Peat	295.40	295.41	+0.01	295.41	+0.01	295.41	+0.01	295.40	+0.00	295.40	+0.00	295.40	+0.00
MW08-309B	4	0.0	0.8	Well	Peat	296.21	296.26	+0.05	296.25	+0.04	296.26	+0.05	296.24	+0.03	296.24	+0.03	296.24	+0.03
MW-08-308C	5	0.0	1.0	Well	Peat	295.06	295.07	+0.01	295.06	+0.00	295.07	+0.01	295.05	-0.01	295.05	-0.01	295.06	+0.00
MW08-304A	5	0.0	1.0	Well	Peat	295.50	295.52	+0.02	295.51	+0.01	295.51	+0.01	295.50	+0.00	295.50	+0.00	295.50	+0.00
MLWC4-P360	5	3.4	3.6	Well	Peat	295.60	295.81	+0.21	295.86	+0.26	295.90	+0.30	295.80	+0.20	295.81	+0.21	295.87	+0.27
MLWC5-P100	5	0.8	1.0	Well	Peat	296.80	296.87	+0.07	296.85	+0.05	296.90	+0.10	296.83	+0.03	296.83	+0.03	296.86	+0.06
FH18-ES415-SN1	5	2.1	N/A	VWP	Peat	295.58	295.57	-0.01	295.57	-0.01	295.59	+0.01	295.56	-0.02	295.56	-0.02	295.57	-0.01

[a] Reference to Baseline is to the simulated pre-mining baseline, and all changes were calculated in relation to the simulated pre-mining baseline conditions.
masl = metres above sea level; m bgs = metres below ground surface; EHZ = Ecohydrology Zone; N/A= no depth available; VWP = vibrating wire piezometer.

Table 4.3-5: Assessment of Average Water Level – Far-Future and Climate Change Scenarios

Well Name	EHZ	Top of Screen [m bgs]	Bottom of Screen [m bgs]	VWP or Well	Completion Formation	Average Water Level [masl]												
						Baseline[a]	Historical Climate		Cool and Dry		Cool and Wet		Median		Warm and Dry		Warm and Wet	
						Average	Average	Change[a]	Average	Change[a]	Average	Change[a]	Average	Change[a]	Average	Change[a]	Average	Change[a]
MW08-305C	1	0.0	1.5	Well	Peat	294.69	294.76	+0.07	294.69	+0.00	294.7	+0.01	294.73	+0.04	294.69	+0.00	294.71	+0.02
GT-07-093C	2	1.2	2.7	Well	Peat	295.82	295.78	-0.04	295.77	-0.05	295.77	-0.05	295.77	-0.05	295.77	-0.05	295.77	-0.05
MLWC1-P100	2	0.8	1.0	Well	Peat	294.79	294.86	+0.07	294.83	+0.04	294.83	+0.04	294.85	+0.06	294.83	+0.04	294.83	+0.04
MW08-307A	2	1.6	4.6	Well	Peat	295.40	295.42	+0.02	295.4	+0.00	295.4	+0.00	295.41	+0.01	295.4	+0.00	295.4	+0.00
MW08-309B	4	0.0	0.8	Well	Peat	296.21	296.26	+0.05	296.24	+0.03	296.25	+0.04	296.25	+0.04	296.24	+0.03	296.25	+0.04
MW-08-308C	4	0.0	0.7	Well	Peat	295.06	295.08	+0.02	295.05	-0.01	295.06	+0.00	295.07	+0.01	295.06	+0.00	295.06	+0.00
MW08-304A	5	0.0	1.0	Well	Peat	295.50	295.51	+0.01	295.5	+0.00	295.5	+0.00	295.5	+0.00	295.5	+0.00	295.5	+0.00
MLWC4-P360	5	3.4	3.6	Well	Peat	295.60	295.91	+0.31	295.87	+0.27	295.88	+0.28	295.9	+0.30	295.87	+0.27	295.89	+0.29
MLWC5-P100	5	0.8	1.0	Well	Peat	296.80	296.88	+0.08	296.86	+0.06	296.87	+0.07	296.87	+0.07	296.86	+0.06	296.87	+0.07
FH18-ES415-SN1	5	2.1	N/A	VWP	5	295.58	295.6	+0.02	295.57	-0.01	295.57	-0.01	295.58	+0.00	295.57	-0.01	295.57	-0.01

[a] Reference to Baseline is to the simulated pre-mining baseline, and all changes were calculated in relation to the simulated pre-mining baseline conditions.
masl = metres above sea level; m bgs = metres below ground surface; EHZ = Ecohydrology Zone; N/A= no depth available; VWP = vibrating wire piezometer.

The predicted effect of mining, with water management design features, on the net groundwater discharge to the MLWC for the operational, closure, and far-future scenarios is shown in Table 4.3-6 to Table 4.3-8. Groundwater discharge to the fen is simulated to remain relatively unchanged (i.e., less than 5 millimetres per year [mm/year] of difference) for the operational, closure, and far-future cases. The simulation results indicate an increase of groundwater discharge to the lake for the operational, active closure and far-future cases by 42 mm/year, 1 mm/year and 27 mm/year, respectively, compared to the pre-mining baseline case (Table 4.3-6 to Table 4.3-8). The pre-mining baseline case discussed herein is the model-simulated baseline case (HGS simulation). The baseline conditions measured in Objective 1 were used as the basis of calibration for the simulated baseline.

The effect of climate change on the far-future groundwater discharge is shown in Table 4.3-8. The far-future case was simulated for the historic climate and five climate change scenarios. Note that the pre-mining baseline case was simulated using the historical climate data, while no climate change scenario was completed for the pre-mining baseline case (i.e., without mining operations). For the far-future case with historical climate scenario, the model simulated an increase in groundwater discharge to the lake and fen by 54 mm/year and 2 mm/year, respectively. On average, the Project is simulated to result in a 27 mm/year increase in groundwater discharge to the lake relative to the pre-mining baseline discharge and a 1 mm/year increase in discharge to the fen, also relative to the pre-mining baseline discharge (Table 4.3-9). All these increases in discharge are moderate and are predicted to have negligible impact on the overall groundwater flow system in the MLWC.

For the far-future case with the five climate change scenarios, the model simulated a change in groundwater discharge to the lake that ranged from -17 (decrease) to +69 mm/year (increase) based on the results of the cool-wet and the median climate scenarios, respectively. The model simulated a moderate increase in groundwater discharge to the fen of approximately 1 mm/year in all climate change scenarios.

The water balance in the fen and McClelland Lake is discussed in more detail in the hydrology section of the assessment (Section 4.3.2.1.3).

Without the water management design features, the groundwater table near the mined portion of the fen was simulated to drop by 1.5 m during operations. This level of impact was considered to be substantial, and the effect of mining without water management design features during the active closure and far-future periods was not investigated.

With the water management design features, the simulated operational groundwater levels within the non-mined portion of MLWC are similar to the pre-mining baseline case. The greatest impact is predicted to occur in the northern portion of the fen, nearest to NED. In this area, the average water level elevation is predicted to increase by 0.24 m during active closure and the water level variation is predicted to decrease. Water levels at the other monitoring locations, further away from the NED, changed at most by 0.05 m relative to the pre-mining baseline. During the operations period, the water level is predicted to decrease from pre-mining baseline by 0.04 m on average near the NED and the maximum simulated change in water level was an increase of 0.06 m relative to the pre-mining baseline.

Table 4.3-6: Assessment of Average Water Level – Far-Future and Climate Change Scenarios

Well Name	EHZ	Top of Screen [m bgs]	Bottom of Screen [m bgs]	VWP or Well	Completion Formation	Average Water Level [masl]												
						Baseline[a]	Historical Climate		Cool and Dry		Cool and Wet		Median		Warm and Dry		Warm and Wet	
						Average	Average	Change[a]	Average	Change[a]	Average	Change[a]	Average	Change[a]	Average	Change[a]	Average	Change[a]
MW08-305C	1	0.0	1.5	Well	Peat	294.69	294.76	+0.07	294.69	+0.00	294.7	+0.01	294.73	+0.04	294.69	+0.00	294.71	+0.02
GT-07-093C	2	1.2	2.7	Well	Peat	295.82	295.78	-0.04	295.77	-0.05	295.77	-0.05	295.77	-0.05	295.77	-0.05	295.77	-0.05
MLWC1-P100	2	0.8	1.0	Well	Peat	294.79	294.86	+0.07	294.83	+0.04	294.83	+0.04	294.85	+0.06	294.83	+0.04	294.83	+0.04
MW08-307A	2	1.6	4.6	Well	Peat	295.40	295.42	+0.02	295.4	+0.00	295.4	+0.00	295.41	+0.01	295.4	+0.00	295.4	+0.00
MW08-309B	4	0.0	0.8	Well	Peat	296.21	296.26	+0.05	296.24	+0.03	296.25	+0.04	296.25	+0.04	296.24	+0.03	296.25	+0.04
MW-08-308C	4	0.0	0.7	Well	Peat	295.06	295.08	+0.02	295.05	-0.01	295.06	+0.00	295.07	+0.01	295.06	+0.00	295.06	+0.00
MW08-304A	5	0.0	1.0	Well	Peat	295.50	295.51	+0.01	295.5	+0.00	295.5	+0.00	295.5	+0.00	295.5	+0.00	295.5	+0.00
MLWC4-P360	5	3.4	3.6	Well	Peat	295.60	295.91	+0.31	295.87	+0.27	295.88	+0.28	295.9	+0.30	295.87	+0.27	295.89	+0.29
MLWC5-P100	5	0.8	1.0	Well	Peat	296.80	296.88	+0.08	296.86	+0.06	296.87	+0.07	296.87	+0.07	296.86	+0.06	296.87	+0.07
FH18-ES415-SN1	5	2.1	N/A	VWP	5	295.58	295.6	+0.02	295.57	-0.01	295.57	-0.01	295.58	+0.00	295.57	-0.01	295.57	-0.01

[a] Reference to Baseline is to the simulated pre-mining baseline, and all changes were calculated in relation to the simulated pre-mining baseline conditions.

masl = metres above sea level; m bgs = metres below ground surface; EHZ = Ecohydrology Zone; N/A= no depth available; VWP = vibrating wire piezometer.

Table 4.3-7: Changes of Net Groundwater Discharge to the McClelland Lake Wetland Complex – Operational Case

	Annual Average Net Groundwater Discharge to the MLWC [mm/year]				
	Pre-Mining Baseline[(a)]	Operational		Closure	
	Average	Average (groundwater out)	Change from Pre-Mining Baseline[(a)]	Average (groundwater out)	Change from Pre-Mining Baseline[(a)]
Fen	2.53	0.03	-2.50	3.34	+0.81
Lake	0.42	42.35	+41.93	1.23	+0.81

(a) Reference to Baseline is to the simulated pre-mining baseline, and all changes were calculated in relation to the simulated pre-mining baseline conditions.

Note: The groundwater discharging to surface water is reported as a positive number (on average, there is only groundwater discharge). A positive change indicates an increase in groundwater discharge to surface water and a negative change indicates a decrease in groundwater discharging to surface water.

MLWC = McClelland Lake Wetland Complex; mm/year = millimetres per year.

Table 4.3-8: Changes of Net Groundwater Discharge to the McClelland Lake Wetland Complex - Closure Case (Average Climate and Climate Change Scenarios)

	Annual Average Groundwater Net [mm/year over footprint]												
	Pre-Mining Baseline[(a)]	Average Year Climate		Cool and Dry		Cool and Wet		Median		Warm and Dry		Warm and Wet	
	Average	Average	Change from Pre-Mining Baseline[(a)]	Average	Change from Pre-Mining Baseline[(a)]	Average	Change from Pre-Mining Baseline[(a)]	Average	Change from Pre-Mining Baseline[(a)]	Average	Change from Pre-Mining Baseline[(a)]	Average	Change from Pre-Mining Baseline[(a)]
Fen	2.53	3.10	+0.57	3.42	+0.89	4.00	+1.47	3.02	+0.49	3.02	+0.49	3.52	+0.99
Lake	0.42	-41.06	-41.48	15.97	+15.55	23.38	+22.96	-5.79	-6.21	19.03	+18.61	-4.17	-4.59

(a) Reference to Baseline is to the simulated pre-mining baseline, and all changes were calculated in relation to the simulated pre-mining baseline conditions.

mm/year = millimetres per year.

Table 4.3-9: Changes of Net Groundwater Discharge to the McClelland Lake Wetland Complex - Far-Future Case (Historic Climate and Climate Change Scenarios)

	Annual Average Groundwater Net [mm/year over footprint]												
	Pre-Mining Baseline[(a)]	Historical Climate		Cool and Dry		Cool and Wet		Median		Warm and Dry		Warm and Wet	
	Average	Average	Change from Pre-Mining Baseline[(a)]	Average	Change from Pre-Mining Baseline[(a)]	Average	Change from Pre-Mining Baseline[(a)]	Average	Change from Pre-Mining Baseline[(a)]	Average	Change from Pre-Mining Baseline[(a)]	Average	Change from Pre-Mining Baseline[(a)]
Fen	2.53	4.14	+1.61	3.63	+1.10	3.70	+1.17	4.06	+1.53	3.55	+1.02	3.85	+1.32
Lake	0.42	54.75	+54.33	16.05	+15.63	-17.36	-17.78	69.75	+69.33	37.03	+36.61	3.91	+3.49

(a) Reference to Baseline is to the simulated pre-mining baseline, and all changes were calculated in relation to the simulated pre-mining baseline conditions.
mm/year = millimetres per year.

The change in groundwater discharge to the fen and McClelland Lake was assessed with the water management design features installed and operational. Groundwater discharge to the fen decreases relative to pre-mining baseline by 2.5 mm/year on average during the operations period and increases by about 1 mm/year for the active closure and far-future climate change scenarios. Groundwater discharge to the lake increases relative to pre-mining baseline by 40 to 60 mm/year for the operations period and the far-future climate change scenarios. Groundwater discharge to the lake was simulated to decrease by 41 mm/year during active closure for the average year climate scenario. The impact of changing groundwater discharge to the overall water balance of the MLWC is discussed in detailed in the hydrology section (Section 4.3.2.1.3)

Summary

The potential impact to the groundwater levels and groundwater discharge within the MLWC was assessed for the operational, closure, and far-future scenarios.

Without water management design features, the groundwater table near the mined portion of the fen was simulated to drop by 1.5 m during operations. This level of impact was considered to be substantial, and the effect of mining without water management design features during the active closure and far-future periods was not investigated.

With water management design features, the simulated operational groundwater levels within the non-mined portion of MLWC are similar to the pre-mining baseline case. The greatest impact is predicted to occur in the northern portion of the fen, nearest to NED. In this area, the average water level elevation is predicted to increase by 0.24 m during active closure and the water level variation is predicted to decrease. Water levels at the other monitoring locations, further away from the NED, changed at most by 0.05 m relative to the pre-mining baseline. During the operations period, the water level is predicted to decrease from pre-mining baseline by 0.04 m on average near the NED and the maximum simulated change in water level was an increase of 0.06 m relative to the pre-mining baseline.

The average far-future groundwater levels at the selected monitoring wells for the historic climate conditions are simulated to be within 0.31 m of the average pre-mining baseline groundwater levels. Again, the greatest simulated change in water level occurs nearest to the NED (well MLWC4-P360). The next largest change in water level was simulated to be less than 0.10 m.

The change in groundwater discharge to the fen and McClelland Lake was assessed with water management design features installed and operational. Groundwater discharge to the fen decreases relative to pre-mining baseline by 2.5 mm/year on average during the operations period and increases by about 1 mm/year for the active closure and far-future climate change scenarios. Groundwater discharge to the lake increases relative to pre-mining baseline by 40 to 60 mm/year for the operations period and the far-future climate change scenarios. Groundwater discharge to the lake was simulated to decrease by 41 mm/year during active closure for the average year climate scenario. The impact of changing groundwater discharge to the overall water balance of the MLWC is discussed in detailed in the hydrology section (Section 4.3.2.1.3).

4.3.2.1.3. Assessment Cases and Simulation Scenarios – Surface Water Hydrology

Changes in the fen and McClelland Lake water levels are presented for operational (2014 to 2063), active closure (2063 to 2075) and far-future (beyond 2076) period in reference to the pre-mining baseline conditions.

The effect of mining, without water management design features, would be to reduce surface, near-surface (through the upper peat) and groundwater flows through the non-mined portion of MLWC including McClelland Lake. Ultimately, the objective of the flow-related aspects of the OP is to provide sufficient flow volumes and quality to sustain ecological functions of the remaining MLWC through the various project time periods. The effects of mining were evaluated for the following time periods:

- **Throughout the operational period (2014 to 2063) and active closure period (2063 to 2075):** to estimate the time when (i.e., what year of mining) a lower permeability cutoff wall and pumping system is required to be in place, to design the configuration of the wall and water supply system, and to simulate water levels in the remaining fen and McClelland Lake.
- **Far-future period (beyond 2076):** to determine hydraulic conditions in the MLWC including McClelland Lake in far-future conditions when runoff from reclaimed area in the west is releasing water to the non-mined portion of the MLWC.

Mining without Water Management Design Features

The effect of mining on the non-mined portion of MLWC including McClelland Lake, without water management design features was simulated using the 2020 MLWC HGS model. The model was simulated using 50 years of climate data that was constructed by repeating twice a data series of 25 years (i.e., 1989 to 2013), which is a relatively drier period in the climate history. Comparison of these scenario to pre-mining baseline demonstrates the relative effect of mining on the MLWC.

This level of impact during operations was considered substantial and the closure and far-future conditions without water management design features were not evaluated.

Mining with Water Management Design Features

The water management design features developed for the project are discussed in Objective 4, while the implementation of those components in the model is discussed in Section 4.3.1.

Non-mined Portion of the Fen

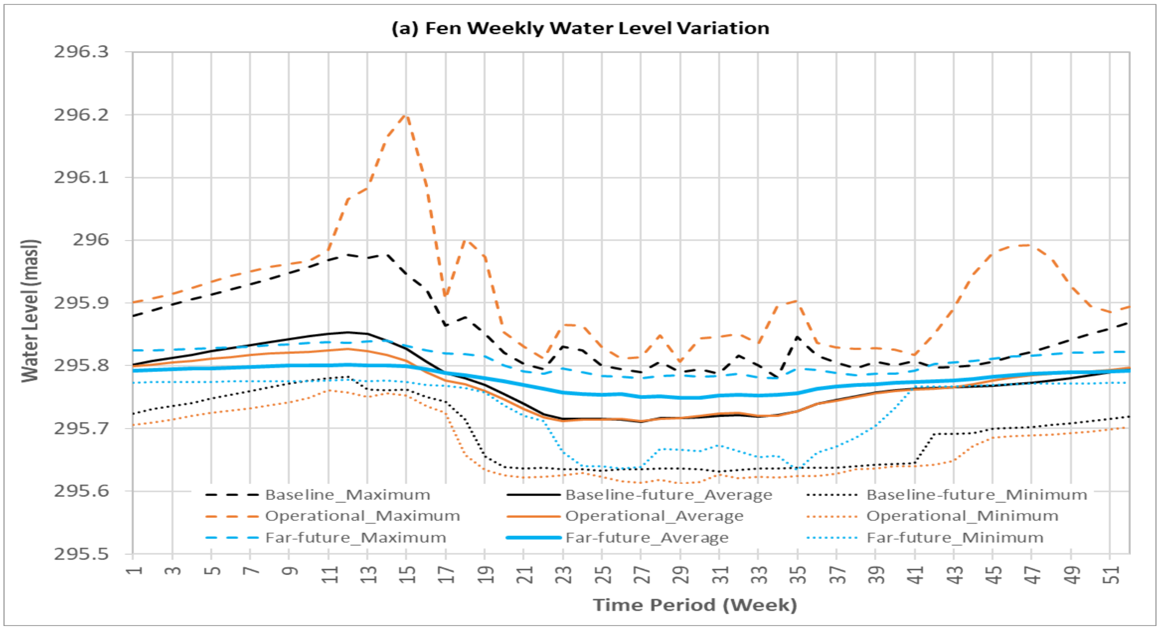
With installation and operation of the water management design features, the Project is predicted to result in negligible (i.e., 0.005 to 0.009 m) decrease of the mean annual, open-water and ice-covered water level in the non-mined portion of the fen during operational period compared to the pre-mining baseline condition as shown in Table 4.3-10 and Figure 4.3-5.

Table 4.3-10: Water Level Statistic

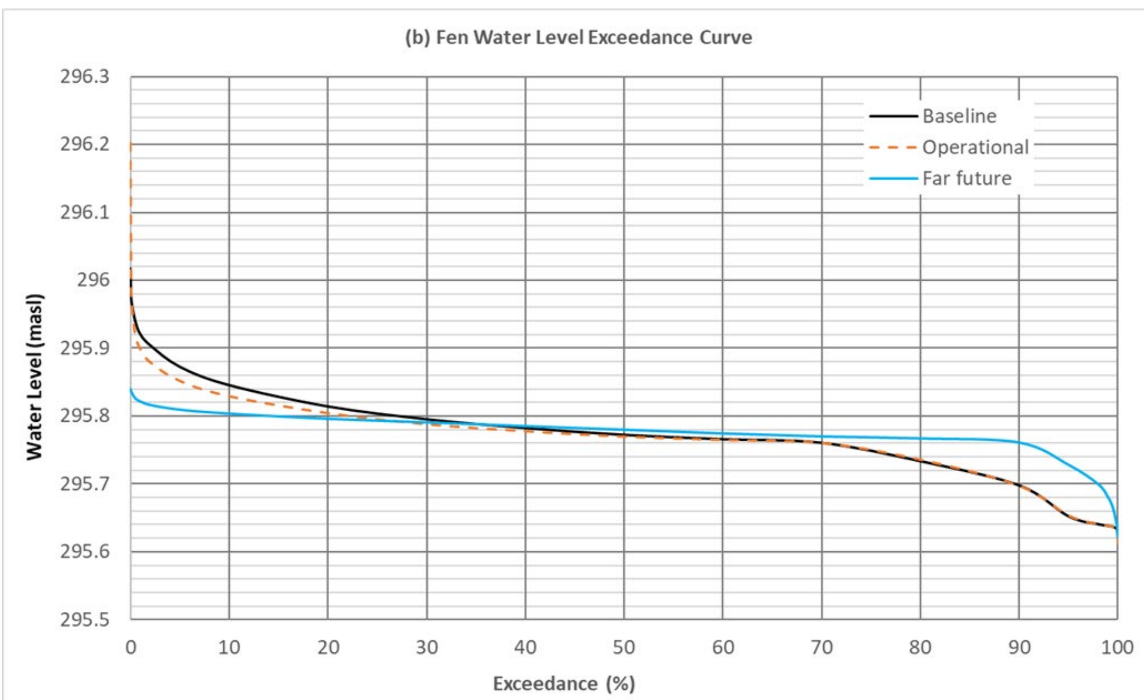
MLWC area	Parameters [masl]	Simulated Pre-Mining Baseline	Operation Period	Far-Future
Non-mined portion of Fen	Mean annual	295.773	295.768	295.778
	Mean open-water	295.743	295.741	295.766
	Mean ice-covered	295.816	295.807	295.795
McClelland Lake	Mean annual	294.563	294.577	294.607
	Mean open-water	294.560	294.570	294.597
	Mean ice-covered	294.567	294.588	294.621

masl = metres above sea level; MLWC = McClelland Lake Wetland Complex.

(a)



(b)



% = percent; masl = metres above sea level.

Figure 4.3-5: Simulated McClelland Fen Water Levels

However, the simulated range of seasonal water level variations are slightly wider during operational period as shown in Figure 4.3-5(a) compared to the pre-mining baseline conditions, particularly for high water levels in the fen. After the mine closure in 2075, runoff from reclaimed areas and outflow from the reclaimed wetland in the mining area will be directed to the non-mined portion of the fen. There is predicted to be a small (i.e.,0.005 to 0.023 m) increase in mean annual and open-water water levels and small (i.e., 0.021 m) decrease in mean ice-covered in the non-mined portion of the fen compared to the pre-mining baseline conditions as shown in Table 4.3-10. However, the simulated range of seasonal water level variations are very narrow for far-future conditions as shown in Figure 4.3-5(b) compared to the pre-mining baseline conditions, mainly for winter water levels in the fen.

With application of the water management design features, the Project is expected to result in a small increase (i.e., 0.01 to 0.021 m) in mean annual, open-water and ice-covered water level in McClelland Lake during mine operation compared to the pre-mining baseline condition, as shown in Table 4.3-10 and Figure 4.3-6. The simulated range of seasonal water level variations during the operational period are also similar to the pre-mining baseline conditions as shown in Figure 4.3-6(a).

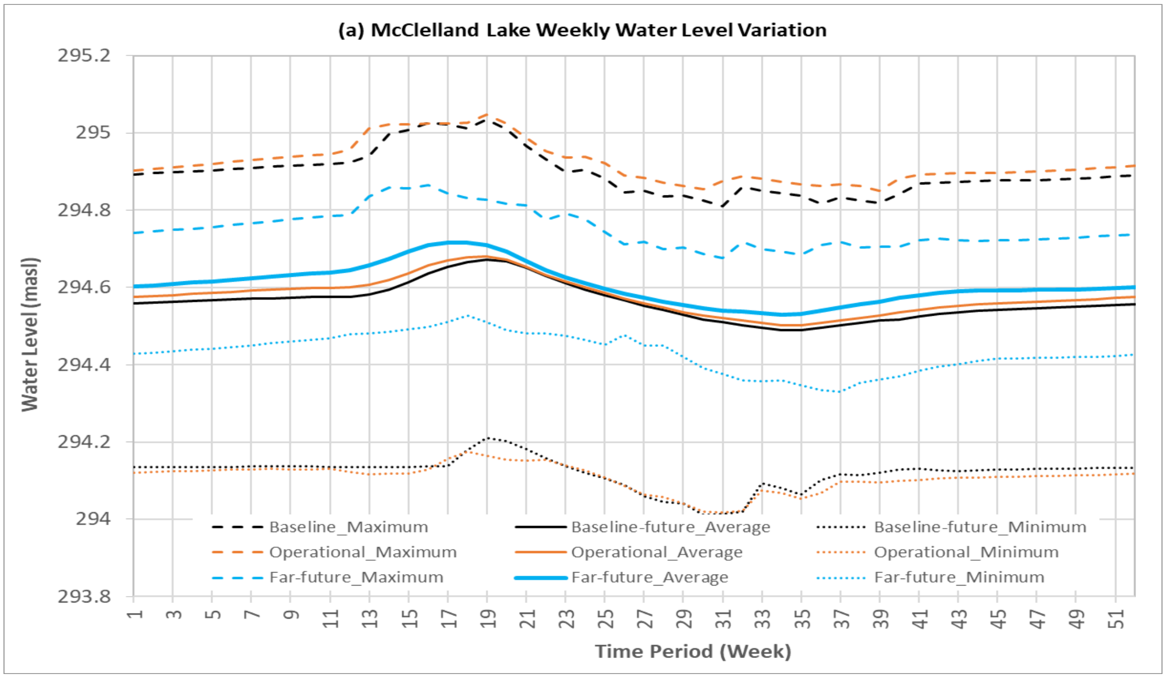
McClelland Lake

With the installation and operation of water management design features, the Project is expected to result in a small increase (i.e., 0.01 to 0.021 m) in mean annual, open-water and ice-covered water level in McClelland Lake during mine operation compared to the pre-mining baseline condition, as shown in Table 4.3-10 and Figure 4.3-6. The simulated range of seasonal water level variations during the operational period are also similar to the pre-mining baseline conditions as shown in Figure 4.3-6(a).

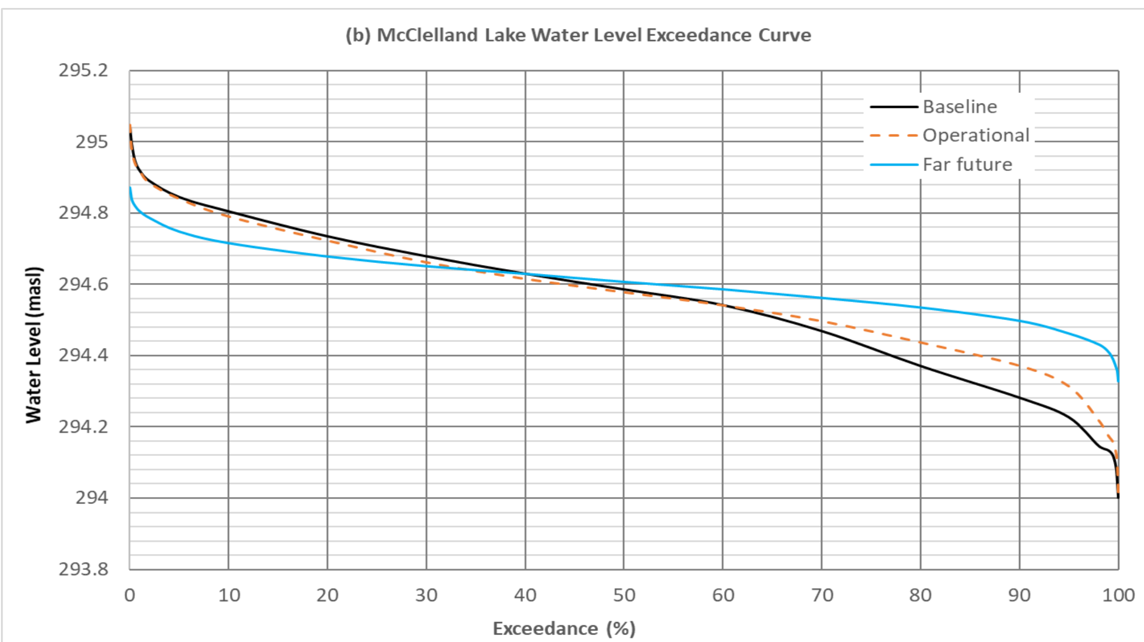
After the mine closure in 2075, runoff from reclaimed areas and outflow from wetland will be directed to the non-mined portion of the fen and then to McClelland Lake. There is expected to be some increase (i.e., 0.037 to 0.054 m) in McClelland Lake water level compared to the pre-mining baseline condition. However, the simulated range of seasonal water level variations are very narrow for far-future conditions as shown in Figure 4.3-6(b) compared to the pre-mining baseline conditions.

The results of water level simulation show that the proposed water management design features implemented during mine operation and at closure are expected to maintain the water balances in the non-mined portion of the fen and in the McClelland Lake within the simulated range of variation for pre-mining baseline condition.

(a)



(b)



% = percent; masl = metres above sea level.

Figure 4.3-6: Simulated McClelland Lake Water Levels

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Water Balance

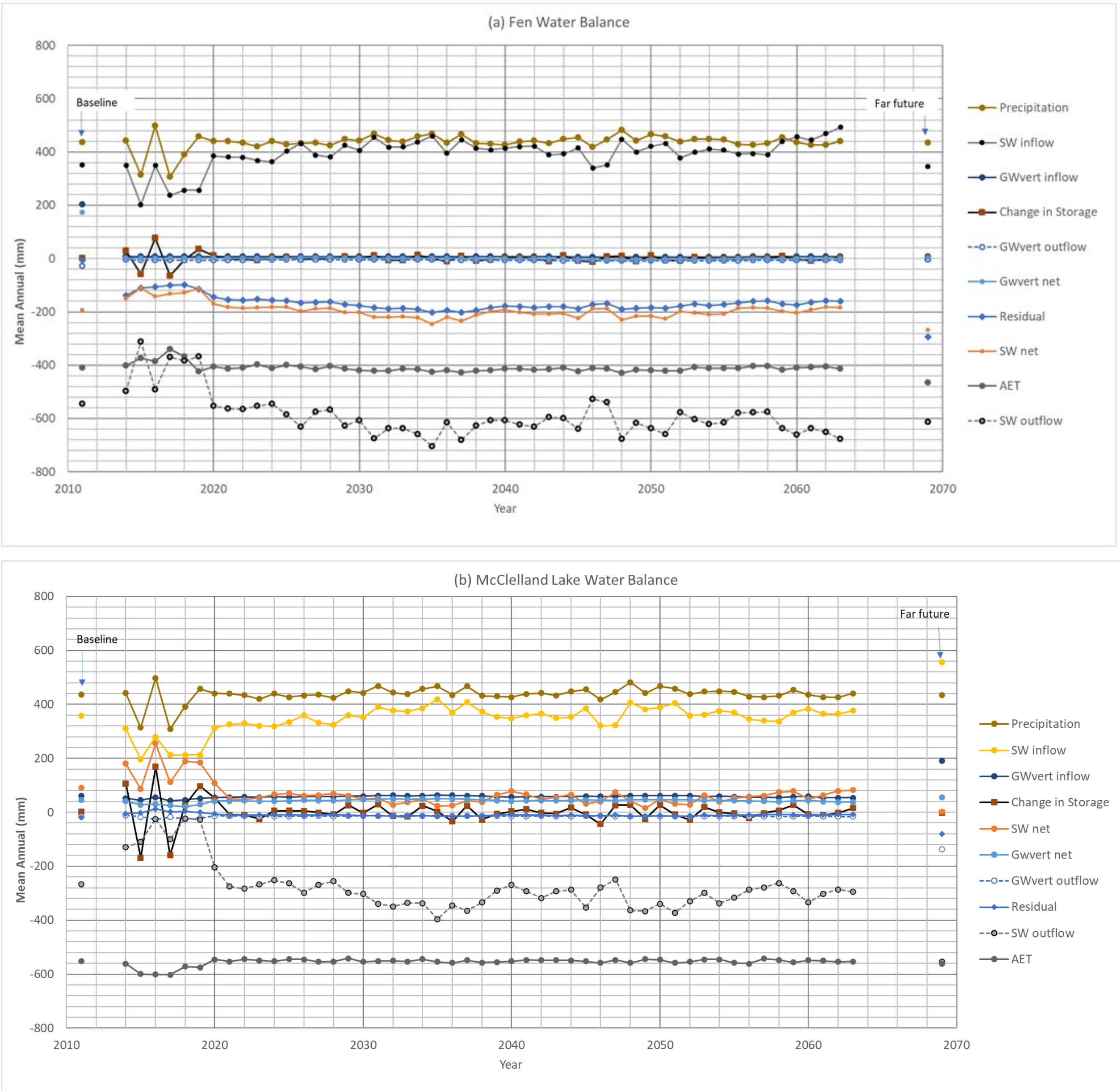
The conceptual water balance of the MLWC is driven by a number of component water fluxes into, within, and out of the MLWC. Predominant water fluxes which directly impact the water balance area:

- precipitation
- evaporation/evapotranspiration
- surface water inflow and outflow
- local groundwater inflow and outflow
- storage changes

As shown in Figure 4.3-7, precipitation and surface water are the primary input to the non-mined portion of the fen and the McClelland Lake. Evaporation and evapotranspiration also play important roles in the water balance of the MLWC. Contribution from local groundwater (i.e., inflow and outflow) are not significant.

During mine operation period (i.e., 2014 to 2063), after application of water management design features described in Section 4.3.2.1.1 and Objective 4 (Section 5), the water balance for the non-mined portion the fen and the McClelland Lake are similar to the pre-mining baseline condition as shown in Figure 4.3-7.

The far-future snapshot represents conditions after reclamation activities are complete and simulates hydrologic conditions far into future. The expected water balance for the far-future is also similar to pre-mining baseline condition as shown in Figure 4.3-7.



mm = millimetre.

Figure 4.3-7: Simulated Water Balance

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Climate Change

The effects of forecasted climate scenarios on the hydrology of reclaimed areas were assessed to determine the level of sensitivity associated with potential climate change. Water levels in the non-mined portion of the MLWC were simulated using the 2020 MLWC HGS model with five climate change scenarios (i.e., cool and dry, cool and wet, median, warm and dry, and warm and wet scenarios). Table 4.3-11 and Figure 4.3-8 provide a comparison of results of forecasted climate conditions relative to predicted far-future flows (without consideration of potential climate change) and relative to the pre-mining baseline conditions.

The results of the sensitivity analysis show that the predicted mean annual water level for the non-mined portion of the fen decreases by about 0.011 m for the cold-dry scenario and by about 0.005 m for the median scenario, relative to the far-future condition. The decrease is negligible compared to the pre-mining baseline condition (i.e., zero for median scenario and 0.006 for cold-dry scenario).

The results of the sensitivity analysis show that the predicted mean annual water level for McClelland Lake decreases by about 0.071 m for the cold-dry scenario and by about 0.02 m for the median scenario, relative to far-future condition. The decrease is small compared to the pre-mining baseline condition (i.e., 0.01 for warm-wet scenario and 0.027 for cold-dry scenario).

Potential climate change is expected to have more of an effect on the McClelland Lake water levels than the water level in the non-mined portion of the fen. Appendix D provides a description of the five climate change scenarios.

Table 4.3-11: Water Level Statistic For Future Climate Conditions

MLWC Area	Parameters [masl]	Simulated Pre-Mining Baseline	Far-Future	Climate Change Scenario				
				Cold-Dry	Cold-Wet	Median	Warm-Dry	Warm-Wet
Non-mined Portion of Fen	mean annual	295.773	295.778	295.767	295.771	295.773	295.768	295.770
McClelland Lake	mean annual	294.563	294.607	294.536	294.584	294.587	294.552	294.553

masl = metres above sea level; MLWC = McClelland Lake Wetland Complex.

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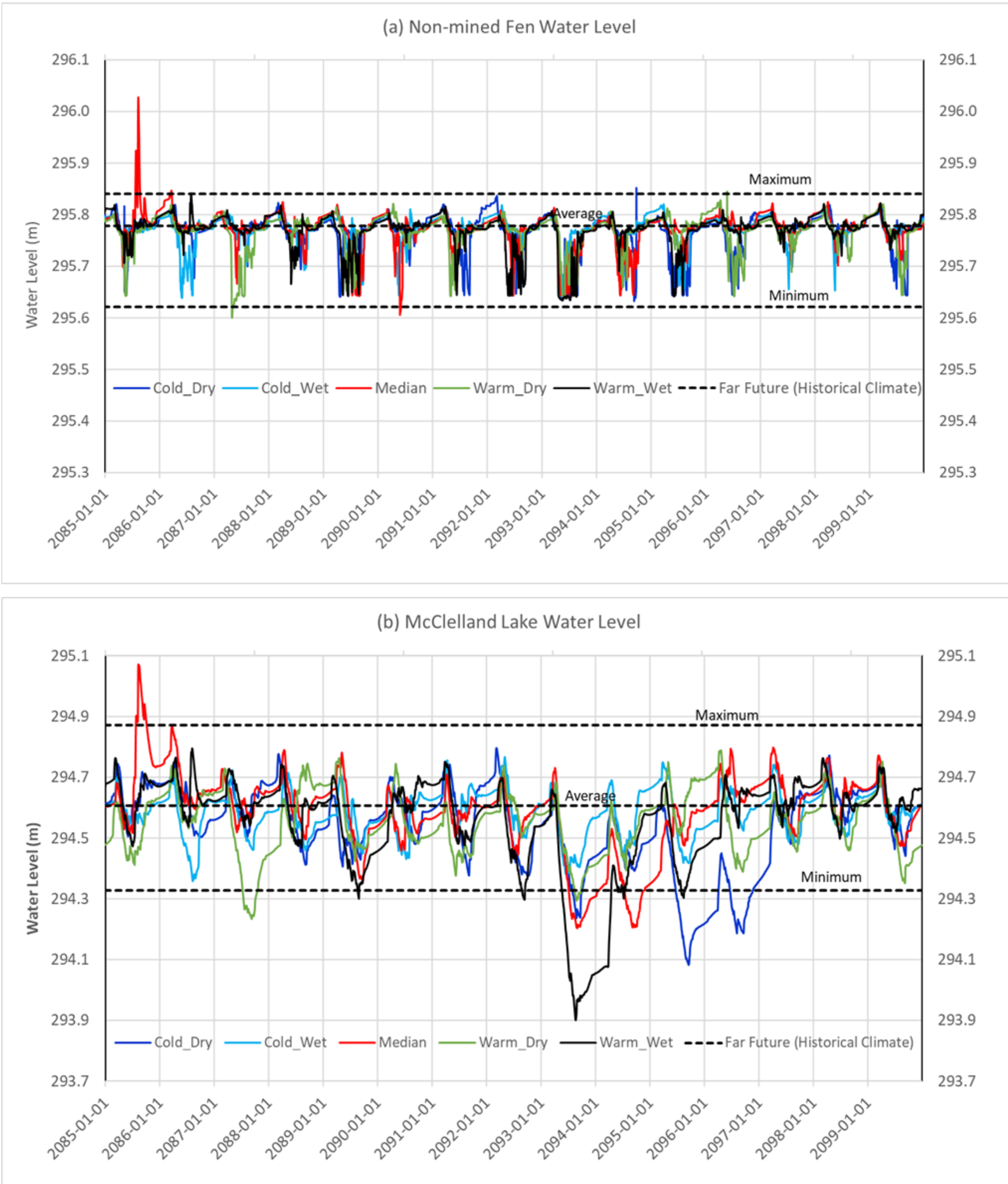

m = metre

Figure 4.3-8: Simulated Water Level

Summary of Assessment Cases and Simulation Scenarios – Surface Water Hydrology

The potential impact to the surface water hydrology in the non-mined portion of the MLWC was assessed for the operational, active closure, and far-future scenarios. The largest impact is predicted to occur for the Mining without Water Management Design Features scenario (R1), with water level close to the mine pit decreasing by more than 1 m with progression of the mine pit into MLWC around year 2047.

In scenario S1, with water management design features installed and operational, the water levels in the non-mined portion of the MLWC (i.e., the fen and McClelland Lake) show similar season variations as the pre-mining baseline scenario (i.e., without any development).

For the far-future period in scenario S1, the mean water levels in the non-mined portion of the MLWC (i.e., the fen and McClelland Lake) are expected to be slightly higher but show similar season variations as the pre-mining baseline scenario.

4.3.2.1.4. Risk Assessment for Hydrogeology and Surface Water Hydrology

For the Hydrogeology – Lake and Wetland indicator, the change in vertical gradient across the peat/sand interface within the fen metric is considered for the risk assessment. This metric is evaluated on a location by location basis. For the purposes of this assessment, one location with existing historical data was selected for comparison purposes. The comparison to modelling results for vertical gradients in the non-mined portion of the fen for the Pre-Mining Baseline scenario (R0), No Design Features scenario (R1) and Operation and Closure periods of the Implementation of Selected Design Features scenario (S1) are presented in Table 4.3-12.

Table 4.3-12: Hydrogeology – Vertical Gradient in the Fen Indicator Preliminary Risk Assessment Results

Metric		No MLWC Watershed Development Scenario (R0)		No Design Features Scenario (R1)		Implementation of Selected Design Features Scenario (S1) – Operation Period	
		Result [m/m]	Below Level 1 Trigger Value?	Result [m/m]	Below Level 1 Trigger Value?	Result [m/m]	Below Level 1 Trigger Value?
Vertical Gradient Across the Sand/Peat Interface at MLWC1	Maximum Minimum Mean	0.029 -0.023 0.0020	Yes Yes	0.030 -0.10 0.0049	Yes No	0.034 -0.025 0.0033	Yes Yes

m/m = metres per metre; MLWC = McClelland Lake Wetland Complex.

For the selected location (MLWC1), a preliminary vertical gradient trigger was generated for comparison purposes. It should be noted that these triggers are to be considered preliminary, as additional background data collection will be conducted at this location, and others, and triggers will be refined. The triggers as generated for the selected location, MLWC1, are presented in Table 4.3-13.

Table 4.3-13: Preliminary Trigger Calculations for Vertical Gradient at MLWC1

Location/Wells	Upper Trigger Vertical Gradient [m/m]	Lower Trigger Vertical Gradient [m/m]	Minimum Observed Vertical Gradient [m/m]	Maximum Observed Vertical Gradient [m/m]
MLWC1-P460 and MLWC1-P530	0.294 (downward)	-0.025 (upward)	-0.050	0.269

m/m = metres per metre.

As shown in Table 4.3-12, the R1 scenario results in groundwater levels in the non-mined portion of the fen that would exceed the Level 3 trigger; however, when design features are implemented (S1), during both the operation and closure periods, predictions of groundwater levels in the non-mined portion of the fen are below the Level 1 trigger, and as such, are considered low risk to the functionality and diversity within the fen.

For the Surface Water Hydrology – Lake indicator, the metric that is considered for the risk assessment is elevation. The modelling results for water levels in McClelland Lake for the Pre-Mining Baseline scenario (R0) and Operation and Closure periods of the Implementation of Selected Design Features scenario (S1) are presented in Table 4.3-14. The result of applying the risk assessment framework, as outlined in Section 4.3, to the McClelland Lake water levels is presented in Table 4.3-14.

Table 4.3-14: Surface Water Hydrology – Lake Primary Effects Indicator Risk Assessment Results

Metric	No MLWC Watershed Development Scenario (R0)		No Design Features Scenario (R1)		Implementation of Selected Design Features Scenario (S1) – Operation Period		Implementation of Selected Design Features Scenario (S1) – Closure Period	
	Result [masl]	Below Level 1 Trigger Value?	Result [masl]	Below Level 1 Trigger Value?	Result [masl]	Below Level 1 Trigger Value?	Result [masl]	Below Level 1 Trigger Value?
Elevation	294.563	Yes	293.56	No – Exceeds Level 3 Trigger	294.577	Yes	294.607	Yes

Note: Range of seasonal Trigger vales established based on available recorded data area presented in Section 7.3.2.2 of the OP (i.e., Figure 7.3-4). For example, weekly Level 1 Trigger value varies from 294.279 to 294.673 masl.
masl = metres above sea level; MLWC = McClelland Lake Wetland Complex.

As shown in Table 4.3-14, the R1 scenario results in McClelland Lake levels that would exceed the Level 3 trigger; however, when design features are implemented, during both the operation and closure periods, predictions of water levels in McClelland Lake are below the Level 1 trigger, and as such, are considered low risk to the functionality and diversity within the lake.

For the Surface Water Hydrology – Wetland indicator, the metric that is considered for the risk assessment is elevation. The modelling results for water levels in non-mined portion of the fen for the Pre-Mining Baseline scenario (R0) and Operation and Closure periods of the Implementation of Selected Design Features scenario (S1) are presented in Table 4.3-15. The result of applying the risk assessment

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framework, as outlined in Section 4.3, to the water levels in the non-mined portion of the fen is presented in Table 4.3-14.

Table 4.3-15: Surface Water Hydrology – Wetland Primary Effects Indicator Risk Assessment Results

Metric	No MLWC Watershed Development Scenario (R0)		No Design Features Scenario (R1)		Implementation of Selected Design Features Scenario (S1) – Operation Period		Implementation of Selected Design Features Scenario (S1) – Closure Period	
	Result [masl]	Below Level 1 Trigger Value?	Result [masl]	Below Level 1 Trigger Value?	Result [masl]	Below Level 1 Trigger Value?	Result [masl]	Below Level 1 Trigger Value?
Elevation	295.773	Yes	N/M	No[(a)]	295.768	Yes	295.778	Yes

(a) although not modelled, it's expected that based on results for Hydrogeology levels in the No Design Features Scenario, there would be similar changes for Surface Water Hydrology levels, which would result in a value that exceeds the Level 1 trigger.

Note: Range of seasonal Trigger vales established based on available recorded data are presented in Section 7.3.2.2 of the OP (i.e., Figure 7.3-4). For example, weekly Level 1 Trigger value varies from 295.585 masl to 295.845 masl.

masl = metres above sea level; MLWC = McClelland Lake Wetland Complex; N/M = not modelled.

As shown in Table 4.3-14, when design features are implemented, during both the operation and closure periods, predictions of water levels in the non-mined portion of the fen are below the Level 1 trigger, and as such, are considered low risk to the functionality and diversity within the non-mined portion of the fen.

4.3.2.2. Water Quality

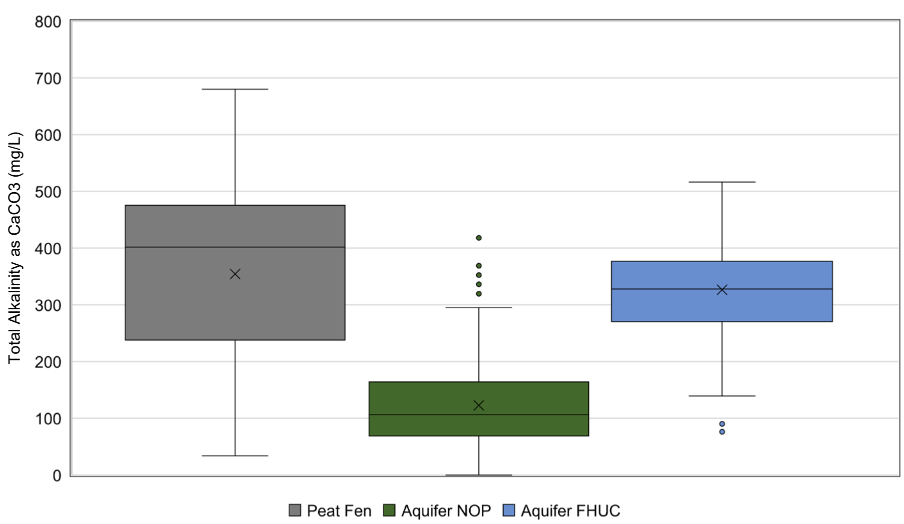
Development of the Fort Hills Project in the MLWC watershed could potentially impact water quality in the non-mined portion of the MLWC. As described in Section 4.3.2.1.2 and Section 4.3.2.1.3, the predicted changes to hydrogeology and hydrology during operations and active closure with implementation of the water management design features compared to baseline are expected to be minor. Therefore, the total flows within the fen and to the lake are not likely to affect water quality, but rather the proportions of the flows. In the context of water quality there are four baseline water sources to the fen and lake that have somewhat distinct chemistry, either in terms of their nutrient or major ion content (Figure 4.3-9 to Figure 4.3-15). These water sources include:

- Precipitation: very low in nutrients and major ions, precipitation dilutes water in the fen and lake.
- Water that originated from the NOP area: typically relatively low in alkalinity, calcium, magnesium, potassium, dissolved organic carbon (DOC), dissolved phosphorus, and total nitrogen.
- Water that originated from the FHUC: typically relatively high in alkalinity, calcium, magnesium, and potassium
- Water that fell as precipitation on the fen and infiltrated (shallow peat/fen groundwater): the data shown in Figure 4.3-9 to Figure 4.3-15 likely represent a mix of waters that interacted only with fen substrate and groundwater from the NOP and FHUC that flowed into the fen, but in general the peat shows higher concentrations of alkalinity, calcium, magnesium, DOC, total dissolved phosphorus, and total nitrogen. The upper range of these parameters tends to be higher than either the NOP or FHUC waters, suggesting the fen itself is a source of these constituents (Figure 4.3-9 to

Figure 4.3-11, and Figure 4.3-13 to Figure 4.3-15). As described in Innotech (2021), there are multiple geochemical processes occurring in the fen, including carbon dioxide generation via the decomposition of organic matter. The additional carbon dioxide dissolves to 1) increase the alkalinity in fen waters, and 2) can shift the pH to lower values. The latter process (lowered pH) may result in the dissolution of carbonates present in the fen substrate, thereby releasing calcium and magnesium to the fen waters. The DOC, phosphorus and nitrogen are supplied in part via mineralization of the peat (Vitt and House 2020). Furthermore, as the fen waters flow from west to east (toward the lake) they undergo evaporative enrichment (InnoTech 2021), which may in part explain the higher upper range.

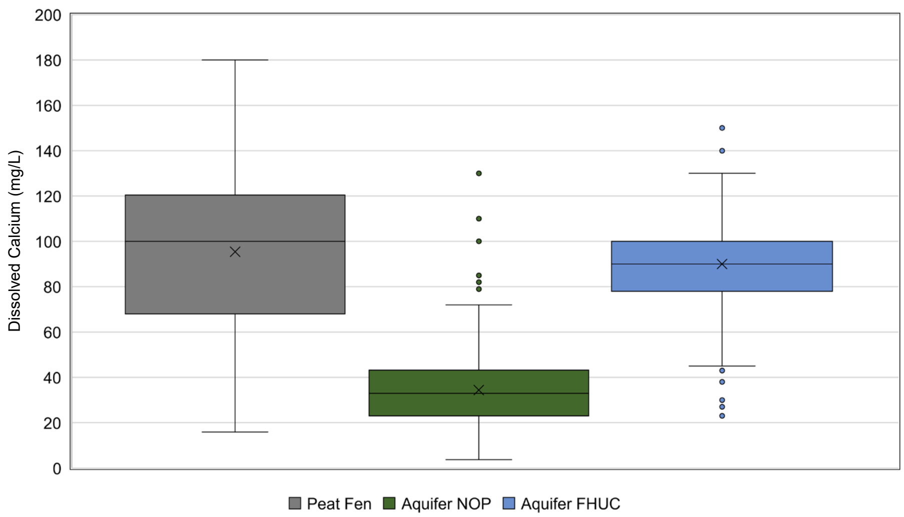
Note that the FHUC and NOP data shown in Figure 4.3-9 to Figure 4.3-15 are groundwater data. However, the surface water concentrations in the areas of the NOP and FHUC, and on the edges of the fen, are very similar to the groundwater concentration ranges for the parameters shown. It is conceptualized that the surface waters in these areas are composed largely of groundwater that exfiltrated from the NOP and FHUC aquifers. For a comparison of ranges between surface water and groundwater see Section 2.5.6.2, Objective 1.

For Figure 4.3-9 to Figure 4.3-15, the length of the boxplot represent the inter-quartile range (25th and 75th interquartiles) with the median denoted by the horizontal line and mean by the x symbol. The whiskers represent the minimum and maximum values of the dataset unless outliers are present, in which case the whiskers extend to a maximum of the 1.5 times the inter-quartiles range. Outliers (circles) are values greater than 1.5 times the inter-quartiles range.



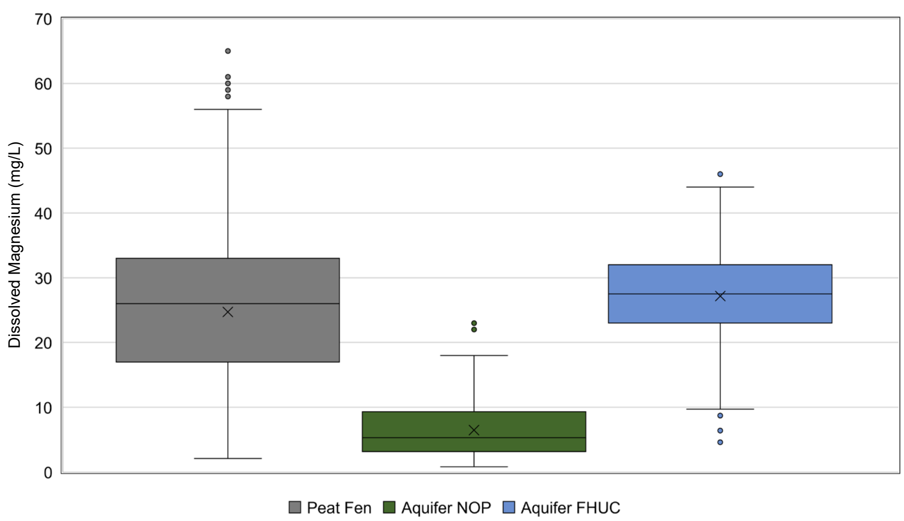
$CaCO_3$ = calcium carbonate; NOP = North Outwash Plain, FHUC = Fort Hills Upland Complex.

Figure 4.3-9: Range of Total Alkalinity Concentrations in the Peat/Fen, NOP, and FHUC Groundwater



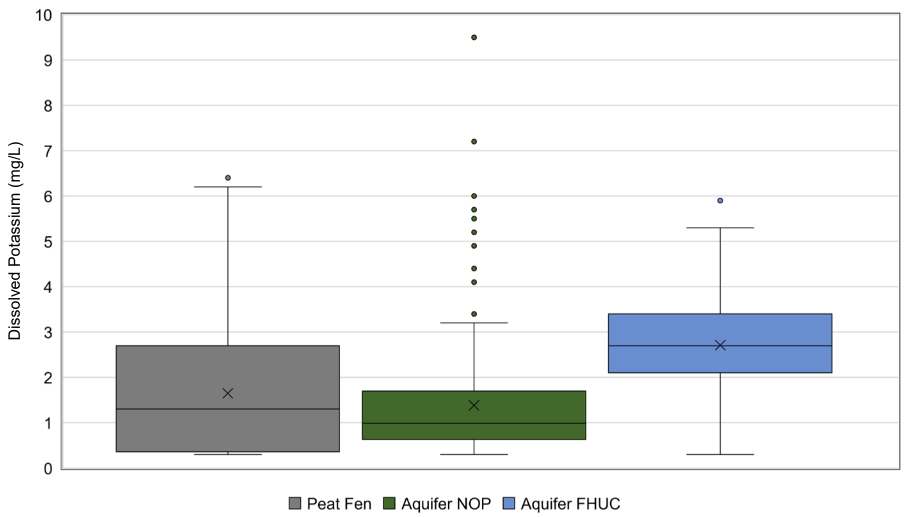
NOP = North Outwash Plain, FHUC = Fort Hills Upland Complex.

Figure 4.3-10: Range of Calcium Concentrations in the Peat/Fen, NOP, and FHUC Groundwater



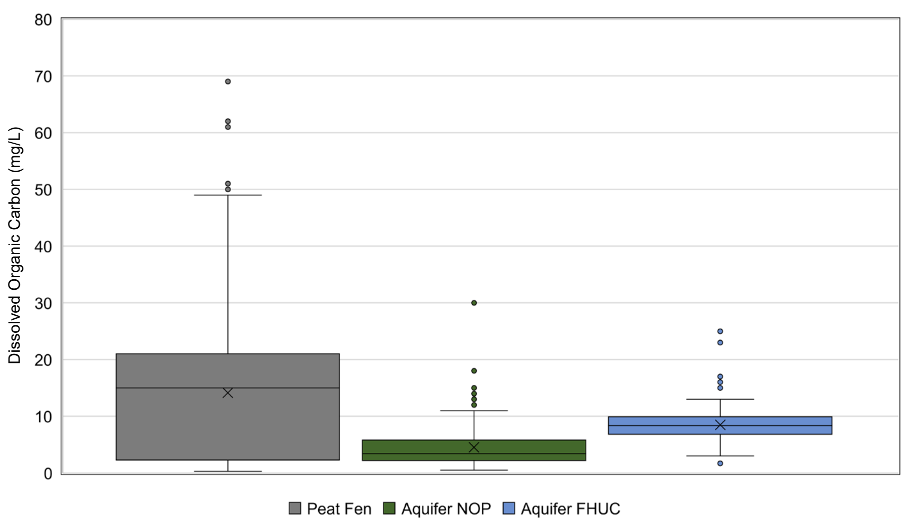
NOP = North Outwash Plain, FHUC = Fort Hills Upland Complex.

Figure 4.3-11: Range of Magnesium Concentrations in the Peat/Fen, NOP, and FHUC Groundwater



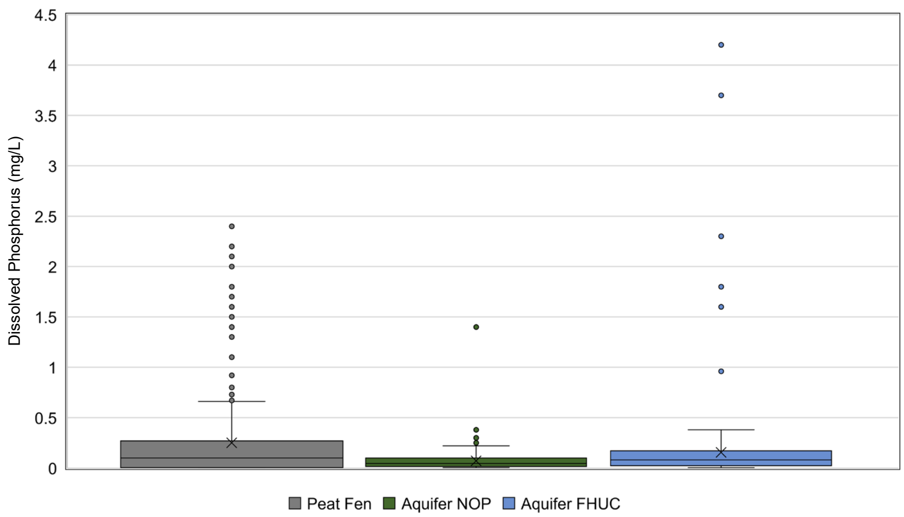
NOP = North Outwash Plain, FHUC = Fort Hills Upland Complex.

Figure 4.3-12: Range of Potassium Concentrations in the Peat/Fen, NOP, and FHUC Groundwater



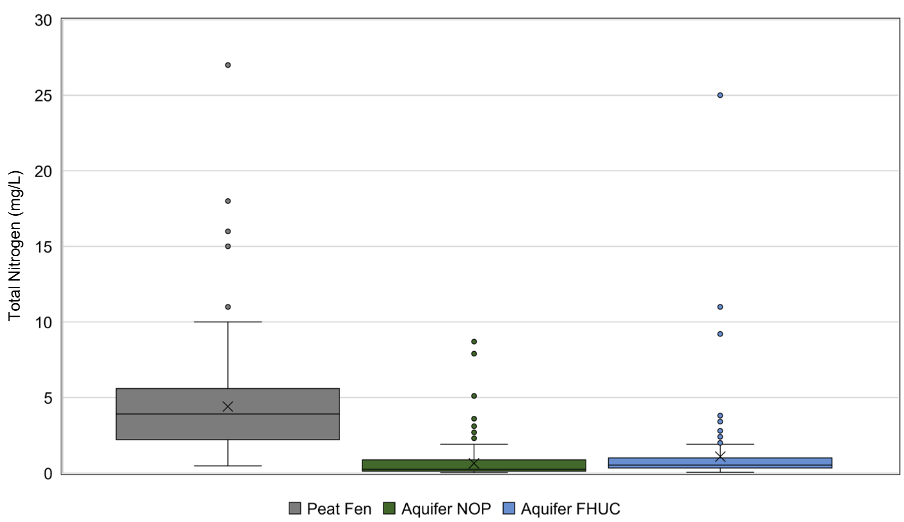
NOP = North Outwash Plain, FHUC = Fort Hills Upland Complex.

Figure 4.3-13: Range of Dissolved Organic Carbon Concentrations in the Peat/Fen, NOP, and FHUC Groundwater



NOP = North Outwash Plain, FHUC = Fort Hills Upland Complex.

Figure 4.3-14: Range of Total Dissolved Phosphorus Concentrations in the Peat/Fen, NOP, and FHUC Groundwater



NOP = North Outwash Plain, FHUC = Fort Hills Upland Complex.

Figure 4.3-15: Range of Total Nitrogen Concentrations in the Peat/Fen, NOP, and FHUC Groundwater

The water quality assessment described in this section is qualitative and focuses on the changing proportions of these sources and how the changes may impact water quality. Specifically, for the non-mined portion of the fen and McClelland Lake, the proportion of flows across the model boundaries shown in Figure 4.3-16 were calculated for each of the mining time periods (baseline, operations, active closure, and far-future, described in Section 4.3.2.1.2) and closure and far-future climate scenarios (median, cold-dry, cold-wet, warm-dry, warm-wet, described in Appendix D). The flows across the model boundaries (Figure 4.3-16) were assigned one of the four water sources described previously in this section. In some cases, the flows likely represent a mix of waters, in these cases the dominant water type, assumed based on the conceptual understanding of the system (Section 4.3.1.1), was assigned. Operational re-supply flows (water re-injection or supply across the wall) are tracked separately (called "wall operations" for re-supply across the wall, and "groundwater injection" for water injected to the north of the fen). Natural fen water that crosses the "Wall_D_E" boundary (Figure 4.3-16) is called "upstream fen" water, and water that crosses the "Lake_Inlet" boundary from the non-mined fen is called "downstream fen". Table 4.3-16 shows a description of the flows and the water type assigned.

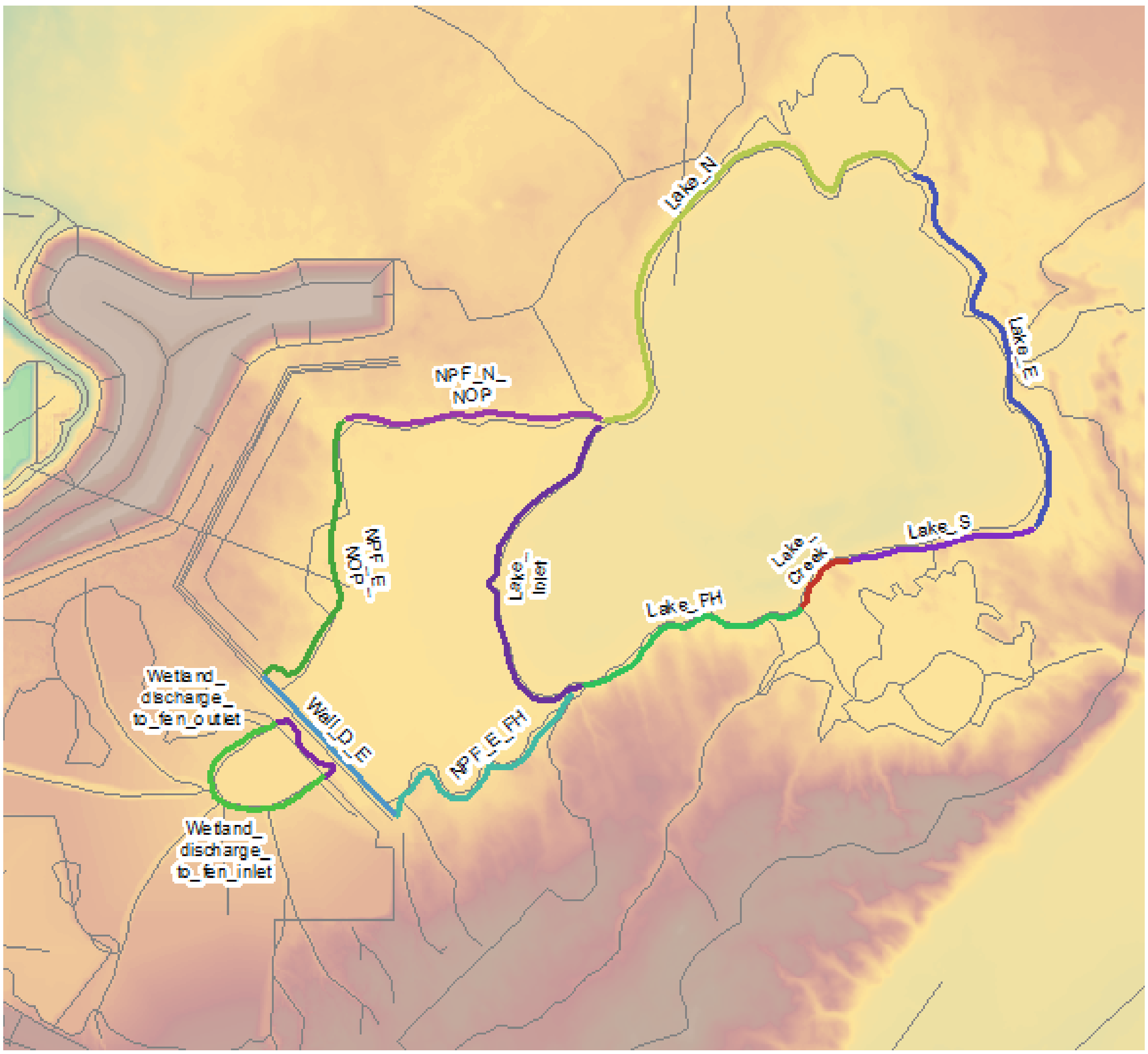


Figure 4.3-16:Model Boundaries (Appendix D) Across Which Flows Were Tracked for the Water Quality Assessment

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Table 4.3-16: Assigned Water Type to Each Flow

Description of Flow	Water Type
Direct precipitation to fen area	Precipitation
GW inflow to fen across NPF_E_FH	FHUC
GW inflow to fen across NPF_E_NOP	NOP
GW inflow to fen across Lake_Inlet	Downstream fen
GW inflow to fen across NPF_N_NOP	NOP
GW inflow to fen across Wall_D_E	Upstream fen
SW inflow to fen across NPF_E_FH	FHUC
SW inflow to fen across NPF_E_NOP	NOP
SW inflow to fen across Lake_Inlet	Downstream fen
SW inflow to fen across NPF_N_NOP	NOP
SW inflow to fen across Wall_D_E	Upstream fen
Resupply water to fen	Wall_Operations
Resupply water to fen	GWInj
Resupply water to fen	Wall_Operations
Direct precipitation to lake area	Precipitation
GW inflow to lake across Lake_Creek	FHUC
GW inflow to lake across Lake_E	NOP
GW inflow to lake across Lake_FH	FHUC
GW inflow to lake across Lake_Inlet	Downstream fen
GW inflow to lake across Lake_N	NOP
GW inflow to lake across Lake_S	NOP
SW inflow to lake across Lake_Creek	FHUC
SW inflow to lake across Lake_E	NOP
SW inflow to lake across Lake_FH	FHUC
SW inflow to lake across Lake_Inlet	Downstream fen
SW inflow to lake across Lake_N	NOP
SW inflow to lake across Lake_S	NOP

NOP = North Outwash Plain, FHUC = Fort Hills Upland Complex, SW = surface water, GW = groundwater

Note that evaporation is not included in the compilation of results as the data is not available to support the analysis of this process but is discussed in the context of water quality impacts in Sections 4.3.2.2.1 and 4.3.2.2.2.

Conceptually, the mining activities that may impact flow proportions, and hence water quality, are described as:

- Operations:
  - Installation of the cutoff wall and hydraulic isolation of the non-mined portion of the fen

  - Addition of re-supply water to the fen, as re-injection water or water supplied at the location of the wall
- Active closure:
  - Perforation and partial removal of the cutoff wall
  - New drainage systems consisting of main drainage channels, secondary drainage ditches, and shallow wetlands constructed west and southwest of the non-mined portion of the fen
  - Soil placement on the disturbed Fort Hills Project landscape
  - Hydraulic reconnection of the fen on the Fort Hills Project side of the cutoff wall with the non-mined portion of the fen
- Far-future:
  - Similar to baseline except that a portion of the cutoff wall will remain (between NED and the non-mined portion of the fen), and a portion of the western part of the fen will have been mined and subsequently backfilled and reclaimed
  - Flows are assumed to be typical of a boreal ecosystem

For a more detailed description of the operational water management systems and closure landscape plan see Section 5.3, Objective 4. The flows over these timeframes were averaged prior to determining their relative proportions. Similar to the hydrogeological and hydrological assessments, it was assumed that the closer the results are to the baseline results, the lower the risk of impacts to the non-mined portion of the MLWC. The water quality assessment for the fen is described in Section 4.3.2.2.1, and the lake in Section 4.3.2.2.2.

4.3.2.2.1. Water Quality - Fen

The proportions of water types for the baseline, operations, active closure, and far-future timeframes are shown in Figure 4.3-16. The operations period is further divided into two parts:

- 2020 – 2037: ramp up to installation of the cutoff wall, during this period there is some bypass water from the upstream fen to the downstream fen. More details on the water management system plans are provided in Section 5.3, Objective 4, specifically the groundwater management and control system components are described in Table 5.3-2.
- 2037 – 2063: the cutoff wall is fully operational and water across the wall and to the fen is managed through re-supply and re-injection.

As shown in Figure 4.3-17, the early operations period is similar to baseline and if the “wall operations” flows can be managed to resemble the water coming from the upstream fen, no substantial change in water quality is expected. The later operations period results in a substantial decrease in upstream fen and direct precipitation inputs, and an increase in the proportion of FHUC and “wall operations” (re-supply) relative to baseline conditions. However, the large proportion of resupply water allows for flexible and active management of the water quality in the fen such that the resupply water chemical make-up will be selected or treated to achieve a chemical balance similar to baseline.

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At active closure and in the far-future the proportional make-up of fen water is similar to baseline, with some exceptions. In the active closure period, the proportion of precipitation (62.9%) is greater relative to baseline (50.4%). However, the predicted evaporation rates (not represented in the pie charts) are also greater in active closure (6.5 M m^3/day) compared to baseline (5.5 M m^3/day), such that the net precipitation amounts in the two timeframes are similar. Also, in both the active closure and far-future periods the upstream fen flows are lower than in baseline. One thing to note in this context is that the proportion called "precipitation" is direct precipitation to the upstream fen. Once the precipitation falls on the fen it interacts with the peat substrate to generate a chemistry that is likely similar, but slightly diluted, relative to the upstream fen water chemistry. The primary change to fen water quality as water flows from upstream to downstream in the fen is evapoconcentration effects, and this is part of the reason more concentrated waters are expected as water moves along the flowpath from the upstream to the downstream fen. In the active closure and far-future time periods more water is being generated in the downstream area of the fen (represented as precipitation; Figure 4.3-17) compared to upstream, which initially may result in lower concentrations of constituents. However, the evaporation rates (not represented in the pie charts) are higher in the active closure (6.5 M m^3/day) and far-future (6.2 M m^3/day) compared to baseline (5.5 M m^3/day). It is likely the same magnitude of evapoconcentration achieved in the baseline period through long residence times/flowpath lengths will be achieved via the increase in evaporation. One area of uncertainty is whether the increased evaporation will be sufficient to replicate baseline levels of DOC and nutrients, which are sourced via peat decomposition and nutrient cycling, and may be more directly impacted by the reduction in flowpath length. Future work will focus on potential impacts of mining on carbon cycling and the nutrient cycle. With respect to the FHUC proportion, in baseline the proportion is 3.6 %, compared to 6.0 and 7.8% in the active closure and far-future periods, respectively. This change in FHUC proportions across the time periods is relatively minor. As such, no substantial changes to fen water quality are expected.

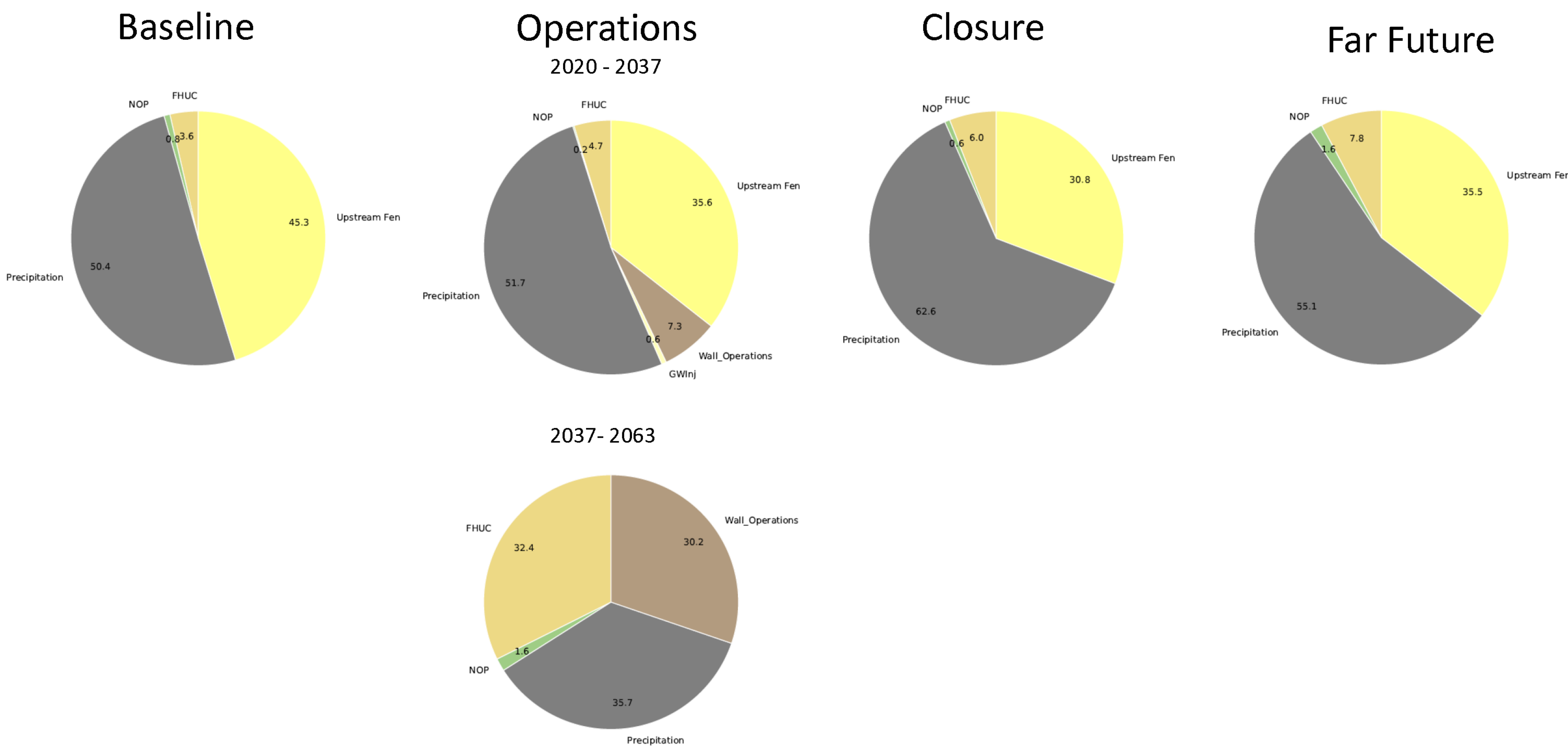

Figure 4.3-17: Predicted Proportions of Water Types in the Non-mined Fen for Historical Climate Scenario: Baseline, Operations, Active Closure, and Far-Future Timeframes

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Climate Change

Two time periods were assessed for potential impacts of climate change on fen water quality: active closure and far-future. The proportions of the different water types for active closure and far-future are shown in Figure 4.3-18 and Figure 4.3-19, respectively.

In the active closure period, the following ranges in proportions across the different climate change scenarios are observed:

- NOP: 0.7 – 1.1%
- FHUC: 6.5 – 7.1%
- Upstream Fen: 29.4 – 36.6%
- Precipitation: 54.8 – 63.4%

The overall distribution of the different water types is similar across the climate change scenarios and the ranges within each water type are relatively narrow. Compared to baseline (Figure 4.3-17), the active closure climate change cases are similar, with some subtle differences: a somewhat higher proportion of FHUC (6.5 – 7.1%, compared to 3.6%) and higher precipitation proportions (54.8 – 63.4% compared to 50.4%).

In the far-future period, the following ranges in proportions across the different climate change scenarios are observed:

- NOP: 0.8 – 1.5%
- FHUC: 6.7 – 7.7%
- Upstream Fen: 31.4 – 36.5%
- Precipitation: 54.3 – 60.9%

The overall distribution of the different water types is similar across the climate change scenarios and the ranges within each water type narrow. Compared to baseline (Figure 4.3-17), the far-future climate change cases are similar, with some subtle differences: a higher proportion of FHUC (6.7 – 7.7%, compared to 3.6%) and lower Upstream Fen proportions (31.4 – 36.5% compared to 45.3%).

In both time periods, the changes in water quality relative to baseline due to climate change are likely small, and the increase in the higher ion content water source (FHUC) is offset by a lower ion content water (e.g., precipitation).

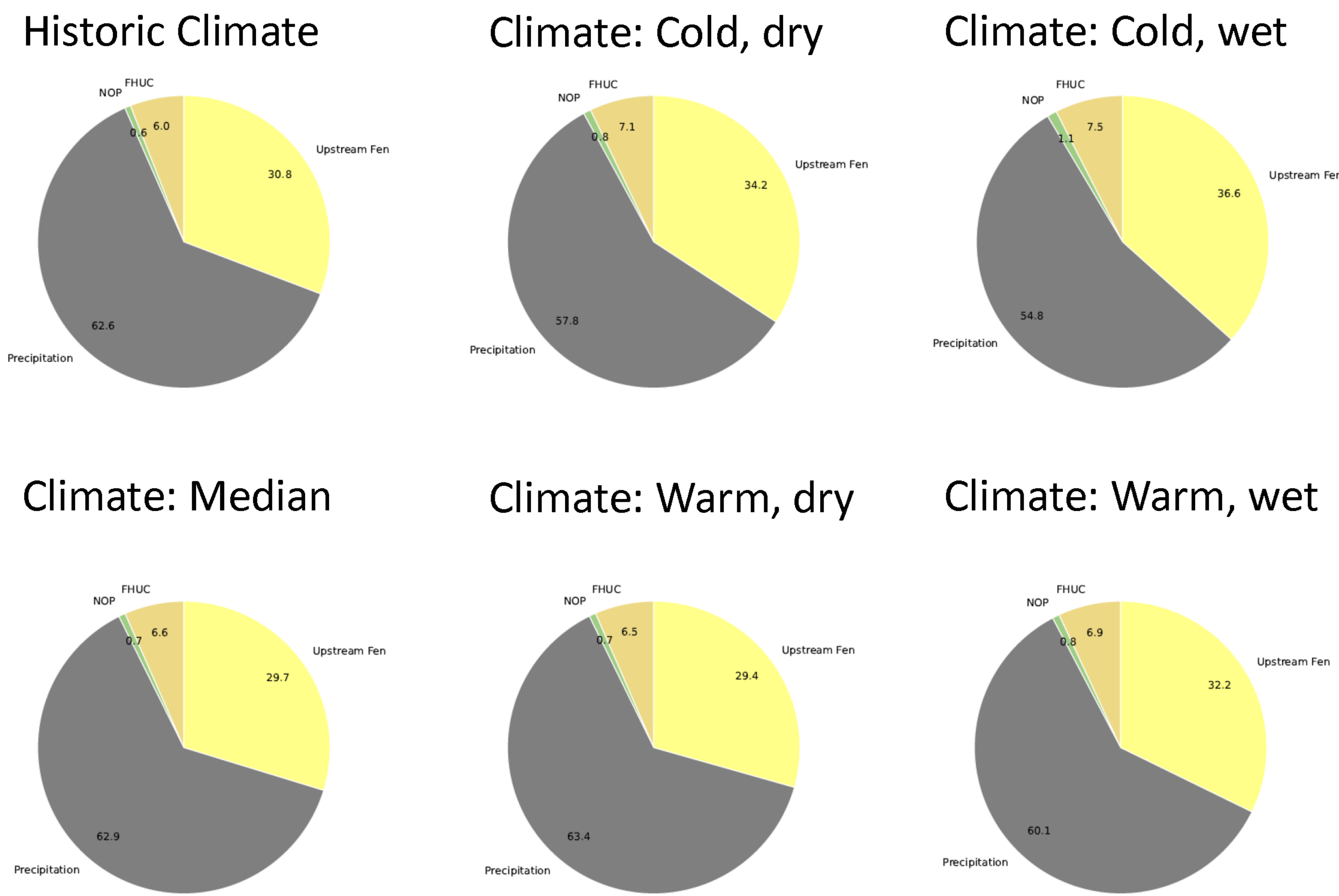

***Figure 4.3-18:** Predicted Proportions of Water Types in the Non-mined Fen for the Climate Scenarios: Active Closure*

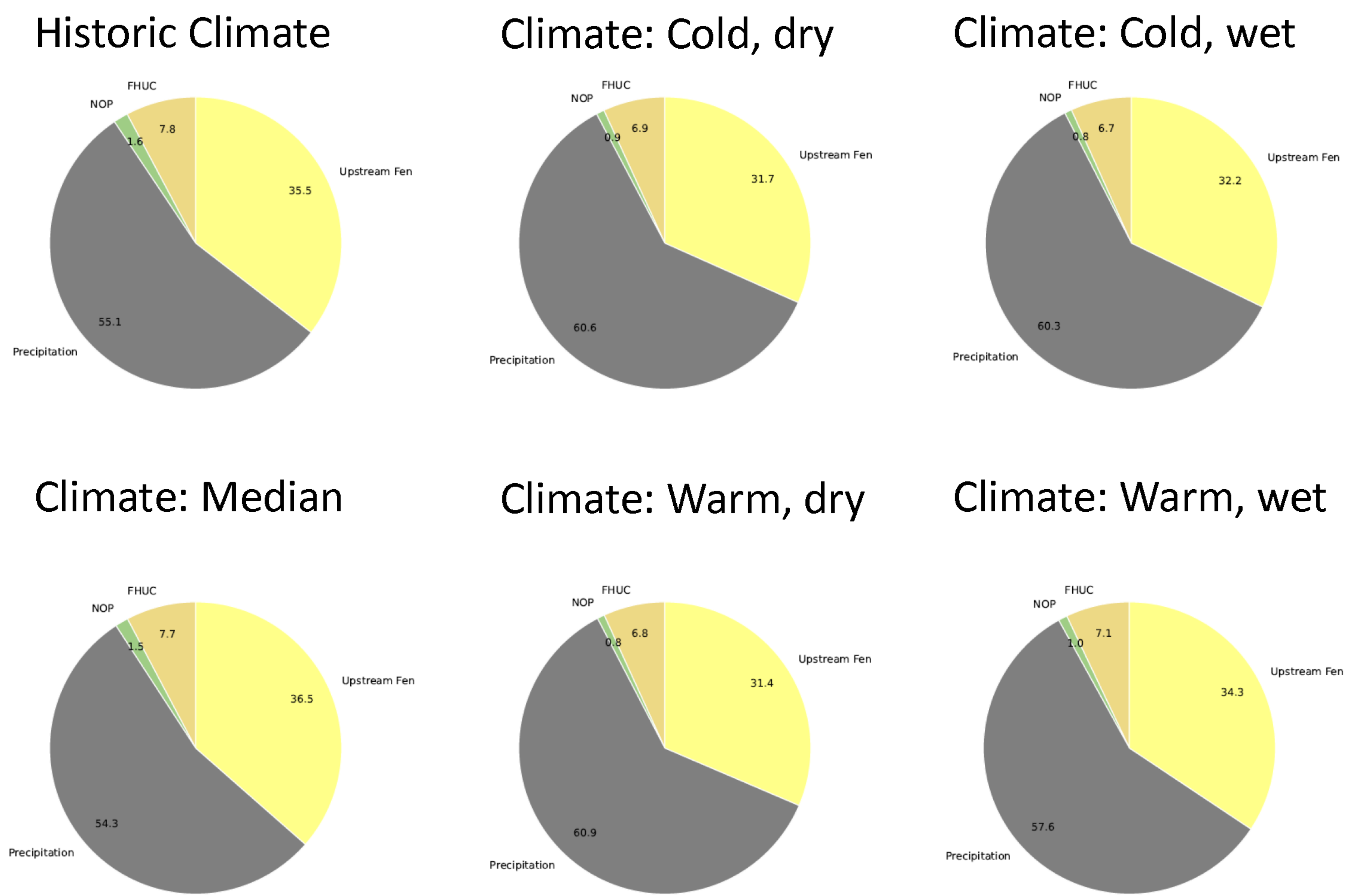

Figure 4.3-19: Predicted Proportions of Water Types in the Non-mined Fen for the Climate Scenarios: Far-Future

4.3.2.2.2. Water Quality – McClelland Lake

The proportions of water type for the baseline, operations, active closure, and far-future periods in McClelland Lake are shown in Figure 4.3-20. As described in Section 4.3.2.2.1, the operations period is further divided into two parts:

- 2020 – 2037: ramp up to installation of the cutoff wall, during this period there is still bypass water from the upstream fen to the downstream fen.
- 2037 – 2063: the cutoff wall is fully operational and water across the wall is managed through re-supply and re-injection.

As shown in Figure 4.3-20, the early operations period is similar to baseline and if the “wall operations” flows can be managed to resemble the water coming from the upstream fen, as discussed in the previous section, no substantial change in water quality is likely. The later operations period shows a substantial decrease in upstream fen proportion (13.4% in baseline compared to no flows in late operations) and a change in the FHUC proportions from 10.4% in baseline to 19.7% in the late operations period. As discussed in the previous section, the relatively large proportion of resupply water in late operations (9.6%) allows for flexible and active management of the water quality in McClelland Lake such that the resupply water chemical make-up will be selected or treated to achieve a chemical balance similar to baseline.

At closure the proportional make-up of McClelland Lake water is similar to baseline, with some exceptions. In the closure scenario the proportion of water from the upstream fen (6.7%) is lower compared to baseline (13.4%), and the proportion of NOP water (14.3%) is higher than in the baseline (10.3%). Overall, the impact of these proportional changes to water types is unlikely to result in substantial changes to water quality in McClelland Lake as both the upstream fen and NOP are conceptualized to both be relatively dilute with respect to major ions and nutrients, such that an increase in one and decrease in the other likely balances out the overall proportion of dilute water types in the pie chart. A more substantial change in precipitation proportions in the far-future (39.6%) compared to baseline (51.1%), and NOP proportions (21.5% in far-future compared to 10.3% in the baseline) are predicted. However, similar to the active closure case, the overall balance of the more dilute water types (precipitation, NOP, and upstream fen) is similar between the two time periods (70.0% in the far-future timeframe and 74.8% in the baseline). No substantial changes to water quality in McClelland Lake are expected.

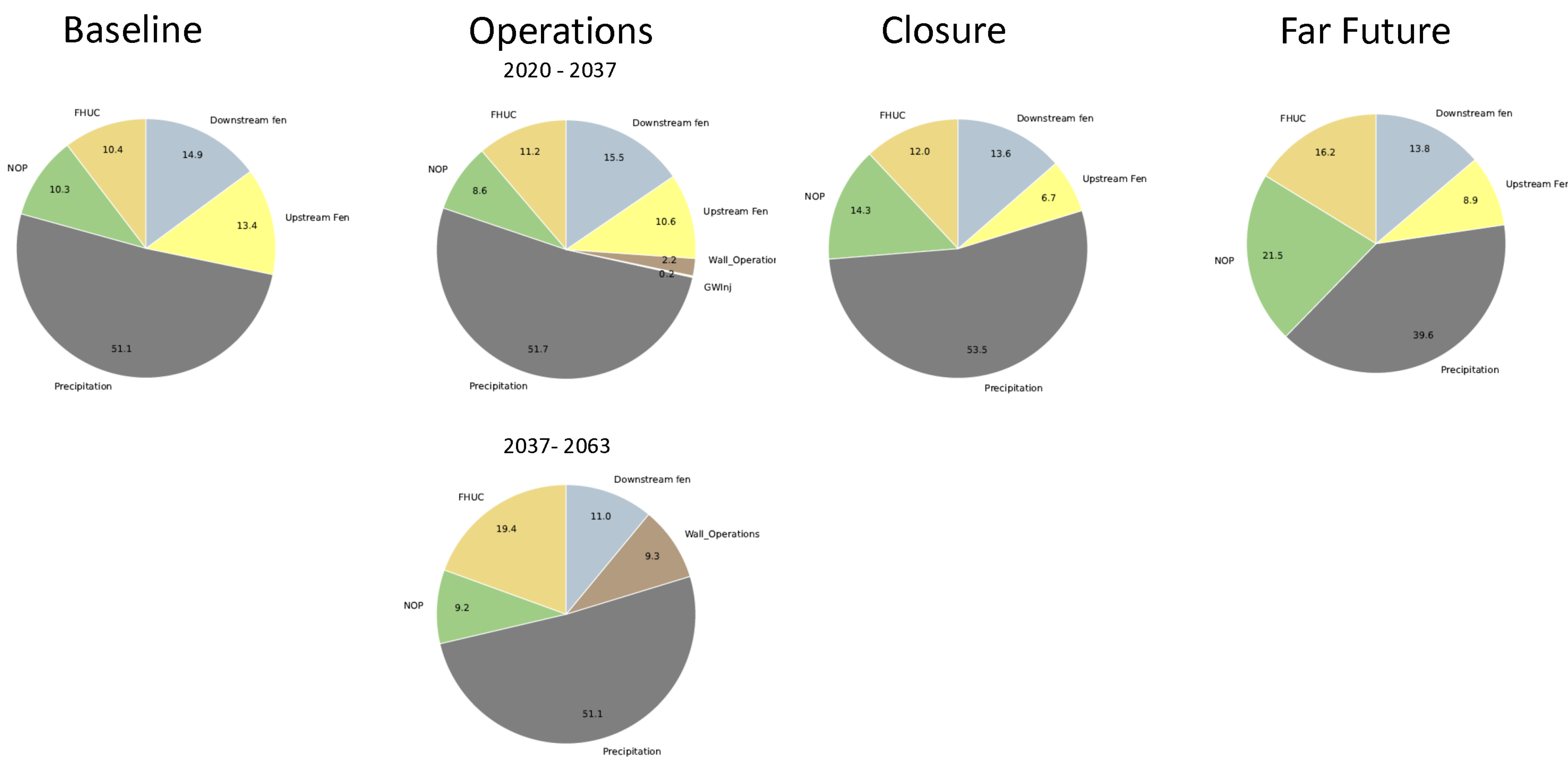

Figure 4.3-20: Predicted Proportions of Water Types in McClelland Lake for Historical Climate Scenario: Baseline, Operations, Active Closure, and Far-Future Timeframes

4.3.2.2.3. Climate Change

Two time periods were assessed for potential impacts of climate change on McClelland Lake water quality: active closure and far-future. The proportions of the different water types for active closure and far-future are shown in Figure 4.3-21 and Figure 4.3-22, respectively.

In the active closure timeframe the following ranges in proportions across the different climate change scenarios are observed:

- NOP: 14.2 – 18.1%
- FHUC: 12.0 – 14.9%
- Downstream fen: 14.6 – 14.8%
- Upstream Fen: 6.8 – 9.8%
- Precipitation: 42.6 – 52.3%

The overall distribution of the different water types is similar across the climate change scenarios and the ranges within each water type are narrow. Compared to baseline (Figure 4.3-20), the active closure climate change cases are similar, with some subtle differences: a slightly higher proportion of NOP (14.2 – 18.1%, compared to 10.3%), and FHUC (12.0 – 14.9%, compared to 10.4%), and lower upstream fen proportion (6.8 – 9.8% compared to 13.4%). In all cases, the difference in climate change proportions relative to baseline is less than 4%.

In the far-future timeframe, the following ranges in proportions across the different climate change scenarios are observed:

- NOP: 17.0 – 18.3%
- FHUC: 13.1 – 15%
- Downstream Fen: 14.3 – 14.6%
- Upstream Fen: 7.4 – 9.8%
- Precipitation: 42.3 – 48.2%

The overall distribution of the different water types is similar across the climate change scenarios and the ranges within each water type are narrow. Compared to baseline (Figure 4.3-20), the far-future climate change cases are similar, with some subtle differences: a higher proportion of NOP (17.0 – 18.3%, compared to 10.3%), FHUC (13.1 – 15%, compared to 10.4%), and lower precipitation proportions (42.3 – 48.2% compared to 51.1%).

In both timeframes, the changes in water quality relative to baseline due to climate change are likely small, and the increase in the higher ion content water source (FHUC) is offset by an increase in lower ion content water (e.g. NOP).

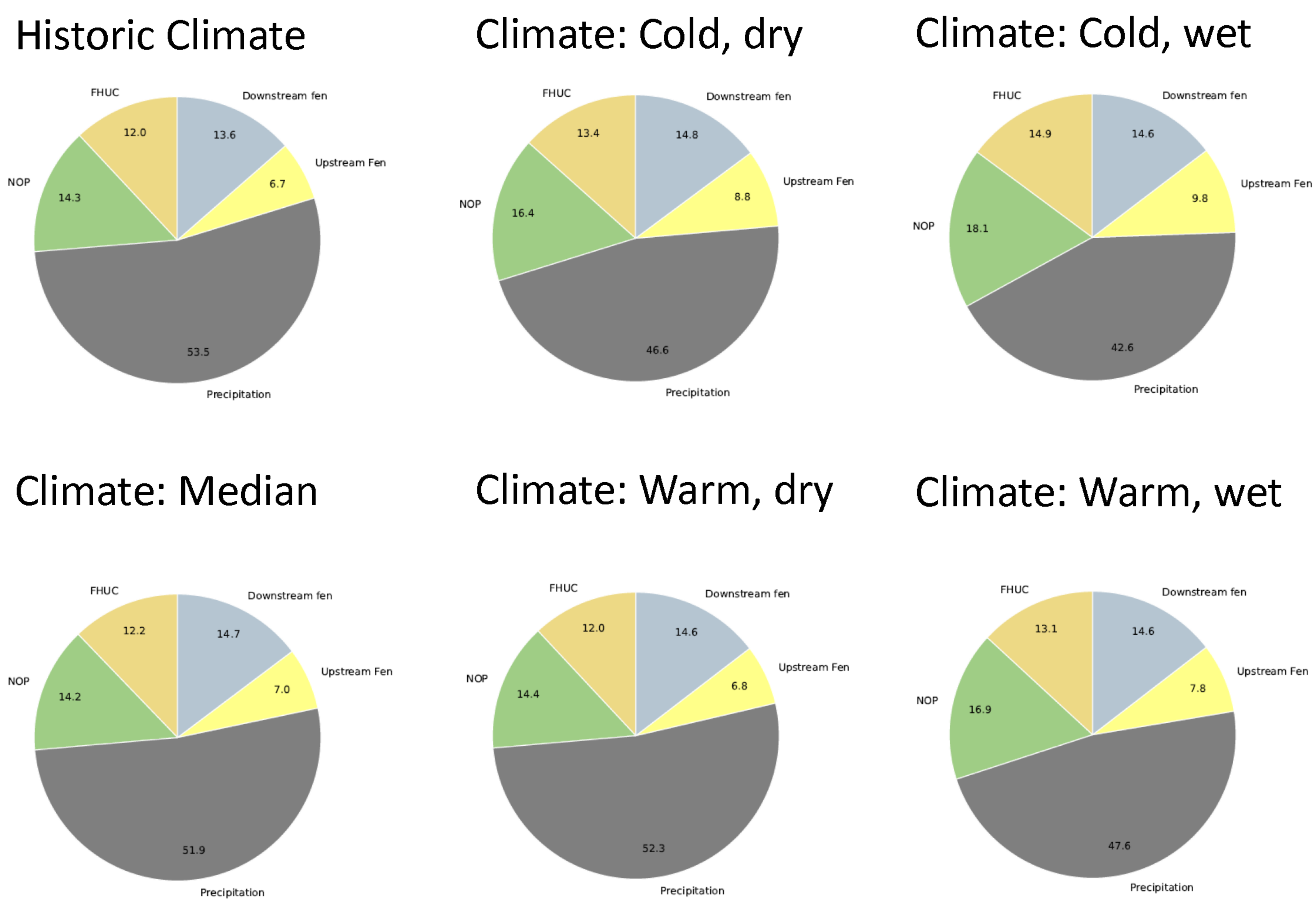

Figure 4.3-21: Predicted Proportions of Water Types in McClelland Lake for the Climate Scenarios: Active Closure

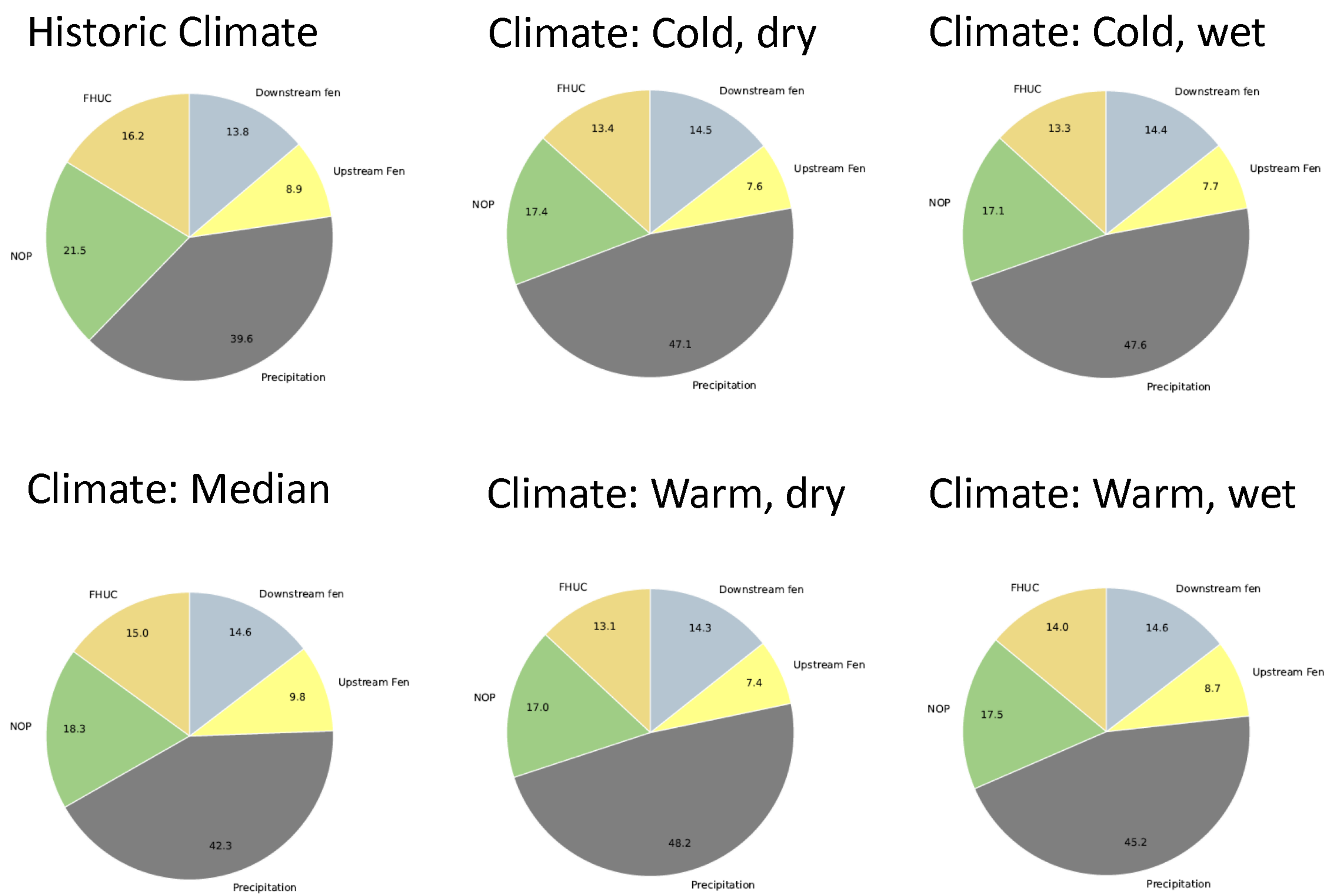

Figure 4.3-22: Predicted Proportions of Water Types in McClelland Lake for the Climate Scenarios: Far-Future

4.3.2.3. Aquatic Resources - Lake

Chlorophyll *a* is the aquatic resources indicator and is used as an estimate of primary productivity. Primary productivity in the non-mined portion of the MLWC may be affected by mine development and operations with potential impacts to lake aquatic life. In a lake environment, at the base of the food-web, macrophytes, phytoplankton in the water column, and periphyton on shoreline rocks use nutrients and light to produce carbon for growth, and provide food to benthic invertebrates and zooplankton. Zooplankton feed on phytoplankton, while benthic invertebrates feed on periphyton and decaying organic material (dead plankton and macrophytes, or sloughed-off periphyton) that settle onto sediments. Fish feed on zooplankton and benthic invertebrates, and larger predatory fish feed on smaller fish. The key drivers predicted to affect aquatic resources in McClelland Lake are changes in surface water levels (Section 4.3.2.1) and water quality (Section 4.3.2.2). These key drivers may be linked, where a change in water level could result in changes in water quality.

Changes in lake surface water levels have the potential to affect primary productivity in McClelland Lake. Reduced water levels may directly remove (i.e., dewater or expose) and alter habitat that was previously available to biota, and increased water level fluctuation may reduce macrophyte cover. Elevated water levels may increase the overall habitat area, however, the quality of waters may be affected through the introduction of terrestrial materials. A substantial change in lake water level was predicted without water management design features and, as such, was not evaluated. With the water management design features developed for the project, water levels in McClelland Lake are predicted to increase during operations and for far-future conditions (0.010 to 0.021 m and 0.037 to 0.054 m, respectively) compared to pre-mining baseline (Section 4.3.2.1.3 and Table 4.3-9), but water balance is expected to be maintained within the measured range of variation for pre-mining baseline conditions. These changes are small, and are within the background water level fluctuation regime of the lake. Therefore, with the installation and operation of the water management design features, changes in lake water levels are not expected to result in substantial changes in productivity, as measured by chlorophyll *a* concentration, in McClelland Lake.

Changes in lake water quality also have the potential to affect primary productivity. Elevated concentrations of water quality parameters (including the toxicity modifying effect from ions such as magnesium and calcium) have the potential to reduce primary productivity through toxicological impairment, reducing food availability to higher level organisms, while elevated nutrient concentrations may stimulate aquatic ecosystem productivity, potentially resulting in lower dissolved oxygen concentrations in deep waters. If nutrient enrichment occurs, sediments may become rich with organic matter through settling of decaying excess plant detritus, phytoplankton and zooplankton, and sloughing of periphyton from shoreline areas, and may therefore experience an increase in sediment oxygen demand. Such elevation of oxygen consumption at depth, especially in late winter (under-ice), may reduce dissolved oxygen concentrations to levels that may alter invertebrate community composition and biomass, and compromise the health and survival of fish. With the installation and operation of the water management design features, substantial changes to water quality are unlikely (Section 4.3.2.2.2). Increased frequency of water table fluctuations associated with mining in the MLWC watershed and implementation of the surface water resupply system could result in increased peat decomposition rates, which could influence nutrient concentrations. However, as noted above, predicted changes in water level fluctuation in the lake are small (on the order of a few cm) and within the background water level fluctuation regime of the lake. Therefore, based on the current predictions for hydrology and water quality, no substantial changes in productivity, as measured by chlorophyll *a* concentration, are expected of McClelland Lake.

4.3.2.4. Vegetation

The key drivers predicted to affect wetland plant community composition and function in the MLWC are changes in surface water levels (Section 4.3.2.1.3) and surface water quality (Section 4.3.2.3). These key drivers may themselves be linked, where a change in water level could result in changes in water quality. Modelling results for mining without water management design features predicted substantial and unacceptable effects to water levels in the non-mined portion of the MLWC; therefore, a scenario for mining without water management design features is not considered in this section. Modelling results for mining with water management design features predicted water levels within 0.5 to 0.9 centimetres (cm) of simulated pre-mining baseline water levels during the operational period, and within 0.5 to 2.3 cm of pre-mining baseline after mine closure. Similarly, mining with water management design features is expected to result in wetland water chemistry similar to baseline throughout the operational and active closure periods.

Impacts to plant communities could occur if water management design features are not fully effective. Some of these potential changes are explored in the following sections to characterize possible outcomes if water levels or water quality within the non-mined portion of the MLWC change beyond predictions for mining with water management design features. Changes to plant communities and wetland functions are not anticipated if mitigation due to the water management design features is fully effective.

Water level is an important factor in determining bryophyte distribution within the patterned portion of the MLWC. For example, Vitt and House (2020) found that wetter flarks were dominated by *Scorpidium scorpioides* and had higher proportions of alkaline sentinel bryophyte species (i.e., *Aneura pinguis*, *Meesia triquetra*, *Pseudocalliergon trifarium*, *Scorpidium cossonii*, *S. revolvens*, and *S. scorpioides*). Drier flarks in the patterned fen at the MLWC were dominated by *Hamatocaulis vernicosus* (Vitt and House 2020). At the other end of the moisture gradient, *Tomentypnum nitens* occurs with high prominence values on strings and is apparently excluded from flarks because of excessive amounts of water in flark habitats within the patterned fen at the MLWC (Vitt and House 2020) and within similar rich fen habitats (Slack et al. 1980). *Sphagnum* species, when present, also occur only in drier locations such as on strings (Vitt and House 2020). Bryophytes from poorer wooded fen plant communities are similarly organized by moisture regime. Within the non-patterned portion of the MLWC where *Sphagnum* prominence is higher (>10% cover), one can find a similar ecological series along a moisture gradient as previously reported by Vitt et al. (1975): *Sphagnum angustifolium* -> *S. magellanicum* -> *S. fuscum* -> *Aulacomnium palustre* -> *Tomentypnum falcifolium* as conditions go from relatively wet to relatively dry (Vitt et al. 1975); these species all occur within the non-patterned portion of the MLWC with >10% cover.

Bryophyte distribution is similarly influenced by water chemistry. For example, areas of the patterned fen at the MLWC with lower levels for surface water parameters (e.g., pH of 7.2 to 7.3, electrical conductivity from 153 to 448 microsiemens per centimetre (µS/cm), and lower base cation concentrations) are dominated by *Hamatocaulis vernicosus* (Vitt and House 2020). In contrast, areas of the patterned fen at the MLWC with higher levels for surface water parameters (e.g., pH of 7.7 to 7.9, electrical conductivity from 392 to 448 µS/cm, and higher base cation concentrations) are dominated by *Scorpidium scorpioides* and alkaline sentinel species (Vitt and House 2020). Similarly, Gignac et al. (1991) found that some of the same alkaline sentinel species (e.g., *Meesia triquetra*, *Sorpidium revolvens*, and *S. scorpioides*) are typically limited to habitats with pH values above 5.2-5.5.

Net accumulation of organic matter is an important function of peatlands that is related to climate and water levels. Changes to fen surface water levels associated with mining in the MLWC watershed could

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affect plant productivity and peat decomposition rates if mitigation due to the water management design features is not fully effective. Specifically, water table depth influences the proportion of oxic and anoxic conditions within the peat profile (Frolking et al. 2001; St-Hilaire et al. 2010). Lower water levels could increase peat decomposition rates (Gignac and Vitt 1994; Strack et al. 2006; Munir et al. 2015) by increasing the thickness of the upper, aerobic portion of the peat profile. For example, lower water levels can result in insufficient moisture uptake in bryophytes, resulting in bryophyte desiccation (St-Hilaire et al. 2010), and thus, increased surface organic matter relative to live vegetation; lower water tables and resulting decreases in bryophyte cover may be accompanied by changes in plant community composition (Strack et al. 2006). Conversely, increased water levels could lead to increased peat accumulation (Frolking et al. 2001) due to reduced thickness of the upper portion of the peat profile and decreased decomposition rates. Furthermore, increased frequency of water table fluctuations associated with mining in the MLWC watershed and implementation of the surface water resupply system could result in increased peat decomposition rates (Kim et al 2021). Cooler conditions can result in a decrease in total vegetation productivity, and thus, lower peat accumulation (Frolking et al. 2001). In contrast, warmer, drier conditions can result in a replacement of bryophyte biomass with vascular plant and lichen biomass (Munir et al. 2015).

Potential structural and functional responses to changes in surface water hydrology and surface water quality are discussed in more detail in the following sub-sections. Surface water hydrology models predicted a 0.5 to 0.9 cm decrease of mean annual, open-water and ice-covered water levels in the non-mined portion of the MLWC during the operational period relative to the simulated pre-mining baseline period; most of the studies reviewed in the surface water hydrology sub-section describe changes beyond the changes predicted for the MLWC. Thus, they represent possible outcomes if mitigation due to the water management design features is not fully effective and water level changes exceed model predictions. Similarly, the studies reviewed for surface water quality are meant to characterize how changes to surface water quality outside the values normally experienced in a particular wetland may bring about changes in plant community composition. Many of these potential changes to plant community composition are related to wetland function.

4.3.2.4.1. Potential Vegetation Response to Changes in Surface Water Hydrology

Changes in fen surface water levels have the potential to affect wetland plant communities. Inferred historical surface water levels in the patterned fen at the MLWC range from 11 to 32 cm below the surface (Vitt and House 2020). Moss-graminoid dominated areas of the patterned fen at the MLWC range from 5 to 12 cm below the ground surface layer, while historical levels ranged from 11 to 28 cm below the ground surface (Vitt and House 2020). String habitats in the patterned fen at the MLWC range from 4 to 19 cm below the ground layer, while historical marginal treed sites adjacent to the patterned fen ranged from 6 to 32 cm below the surface (Vitt and House 2020). A water level reduction of 15 cm in peatlands can result in desiccation, acidification, and eutrophication, which can negatively impact bryophyte species (Cusell et al. 2013). Prolonged water inundation can also negatively impact bryophyte species (i.e., cause mortality), resulting in changes in plant community species composition, which can eventually lead to a shift in wetland type. Additionally, changes in water levels may cause changes in the presence or abundance of foundation species, which may in turn affect carbon sequestration and peat accumulation rates (Vitt and House 2020). Flooding that occurs after a decrease in water table can lead to soil subsidence; fluctuating water levels may have different impacts on vegetation depending on the peat chemistry (Mettrop et al. 2015). Different plant groups and species have different water level tolerances, and thus, respond in different ways to changes in water quantity. An overview of the moisture preferences and responses to water table fluctuations for some of the bryophyte species presented in the following paragraphs is provided in Table 4.3-17.

Table 4.3-17: Bryophyte Moisture Preferences and Response to Water Table Fluctuations

Species	Preferred Microhabitat/ Moisture Conditions	Response to Water Table Fluctuations	
		Change in Water Table	Species Response
Aulacomnium palustre	Hummocks (Vitt and Lüth 2017)	Submergence for 4 or more weeks	Decrease in cover; recovery was limited (Borkenhagen and Cooper 2018)
Calliergon giganteum	Emergent in pools (Vitt and Lüth 2017)	Water level 15 cm below surface for 7 weeks	Decline in vitality (Mettrop et al. 2015)
Hamatocaulis vernicosus	Lawns or wet depressions (Vitt and Lüth 2017)	Submergence for 1, 2, 4, 6 or 8 weeks	No change in cover (Borkenhagen and Cooper 2018); tolerant of submergence
Scorpidium scorpioides	Most abundant when water table is 8 cm below to 5 cm above the ground layer (Vitt and House 2020)	Water level 15 cm above or below surface	No change with increase in water level; decrease in photosynthesis and biomass with decrease in water level (Cusell et al. 2013)
Sphagnum palustre	Most abundant when water table is 4-19 cm below ground layer (Vitt and House 2020)	Water level 15 cm above or below surface for 7 weeks	No change in vitality (Mettrop et al. 2015)
Sphagnum warnstorfii	Most abundant when water table is 4-19 cm below ground layer (Vitt and House 2020)	Submergence for 1, 2, 4, 6 or 8 weeks	Decrease in cover to <2% for all submergence durations (Borkenhagen and Cooper 2018); not tolerant of submergence
Tomentypnum nitens	Most abundant when water table is 4-19 cm below ground layer (Vitt and House 2020)	Submergence for 8 weeks	Short-term decrease in cover after 8 weeks of submergence; some long-term recovery (Borkenhagen and Cooper 2018); tolerant of submergence

Reduced water levels do not generally negatively impact vascular plant species and may even result in increased vascular plant growth, resulting in reduced water, space, and light available for bryophytes below (Mettrop et al. 2015). Vascular plants can generally reach lower water levels with their deep roots and control water loss through their stomata; thus, they are not as susceptible to decreased water levels as *Sphagnum* species (Breeuwer et al. 2009). However, at the MLWC, tamarack (*Larix laricina*) is abundant on strings when water levels are below the ground layer and buckbean (*Menyanthes trifoliata*) occurs where water levels range from 8 cm below the ground layer to 5 cm above the ground layer (Vitt and House 2020); changes to water levels may eliminate or reduce habitat available for these species. Furthermore, species such as *Carex diandra* and *C. chordorrhiza* prefer wetter habitats (Vitt and House 2020) and may therefore be negatively impacted by reduced water levels. Tahvanainen (2011) found that disturbance within a drainage catchment inadvertently reduced minerogenous water inputs, which resulted in a shift of dominant vegetation in a fen away from *Carex* towards *Sphagnum*, both of which are present in the wooded fen around the periphery of the patterned portion of the MLWC.

Responses of mosses to changing water levels can vary substantially, and changing water levels can negatively influence moss vitality, especially for fen species (Cusell et al. 2013; Mettrop et al. 2015). *Sphagnum warnstorfii* cover declined sharply following increased water table levels (Borkenhagen and Cooper 2018) but *Sphagnum palustre* was not negatively impacted by 15 cm changes in water levels in either direction, even when the water was base-rich, which was unexpected for a species generally associated with acidic conditions (Mettrop et al. 2015). *Sphagnum warnstorfii* is present with relatively high cover at wooded fen vegetation monitoring sites around the periphery of the patterned portion of the MLWC, and is present with lower cover at some vegetation monitoring sites in strings within the patterned portion of the MLWC. *Sphagnum palustre* has been documented with relatively low cover values (i.e., <10%) within two wooded fen vegetation monitoring sites.

Hummock moss species have less strong responses to changes in water levels (Tahvanainen and Tolonen 2004) compared to species that inhabit lower micro-topographical positions. For example, *Hamatocaulis vernicosus* cover did not decrease in response to flooding (Borkenhagen and Cooper 2018; Cusell et al. 2013); however, photosynthesis and biomass decreased when water levels were lower in a laboratory experiment (Cusell et al. 2013). In the MLWC, *Scorpidium scorpioides* and alkaline bryophytes occur where water levels are between 8 cm below the ground layer and 5 cm above the ground layer; exceeding these values may result in unsuitable habitat for these species (Vitt and House 2020). However, others have found that *Scorpidium scorpioides* was not affected by flooding (Cusell et al. 2013), but photosynthesis and biomass decreased when water levels were lower (Cusell et al. 2013; Mettrop et al. 2015), likely due to a preference of this species for wetter habitats, such as flarks (Slack et al. 1980; Vitt and House 2020). Reduction in water levels by 15 cm can also result in a decline in *Calliergon giganteum* or an increase in *Sphagnum* cover (Mettrop et al. 2015). In contrast, *Aulacomnium palustre* has been shown to tolerate short periods of flooding, but Borkenhagen and Cooper (2018) found that cover decreased after four or more weeks of increased water levels, and long-term recovery was limited. In the MLWC, *Tomentypnum nitens* and *Sphagnum* species are abundant in strings where water levels are below the ground layer, and it is expected that increased water levels would reduce suitable habitat (Vitt and House 2020). *Tomentypnum nitens* cover has been shown to decrease after approximately eight weeks of increased water levels, however, it can recover in the long-term (Borkenhagen and Cooper 2018); this species typically prefers drier habitats, such as strings (Slack et al. 1980; Vitt and House 2020). *Bryum pseudotriquetrum* and *Calliergon giganteum* have been shown to establish after short- and long-term flooding (Borkenhagen and Cooper 2018). While increased water levels can decrease the amount of CO_2 and light availability for bryophytes (Mettrop et al. 2015), *Hamatocaulis vernicosus* and *Tomentypnum nitens*, both of which are pleurocarpous mosses, seem to be more tolerant of increased water levels compared to some other fen bryophytes (Borkenhagen and Cooper 2018).

4.3.2.4.2. Potential Vegetation Response to Changes in Surface Water Quality

Changes in fen surface water quality have the potential to affect wetland plant communities in different ways. Different plant species have differing tolerances, and thus, have different responses to changes in water quality. Bryophytes are more sensitive than vascular plants to environmental changes due to the way in which they absorb water and dissolved minerals directly through a single cell thick leaf, rather than through roots. Therefore, unlike vascular plants, changes to water quality affect bryophytes directly (Kapfer et al. 2012; Pouliot et al. 2012). An overview of the surface water quality preferences for plant species with high fidelity to Ecohydrology Zones (EHZ) 1 and 2 (Vitt and House 2020) and responses to altered water quality regimes (where available) is provided in Table 4.3-18. In addition, key water quality exceedance thresholds based on the work of Vitt and House (2020) for EHZ 1 and 2 are provided in

Table 4.3-18. Additional information about the differences in water quality between EHZ 1 and 2 is provided under Objective 1 (Section 2).

Typically, vascular plants respond to nutrient changes while bryophytes respond to acidity, calcium, and magnesium changes (Vitt and Chee 1990). While changes in water quantity and quality may result in specific changes to plant communities, these are closely linked and interactions between them exist. While Kolari et al. (2021) found water quantity impacted fen plant communities more than water quality parameters such as pH, other studies have found that there is an interacting effect of changing water quantity and quality, and that changing water levels can result in changes to water quality, and thus, plant communities. As vascular plants are less sensitive to changes in water quantity, these interacting effects seem to be more noticeable for bryophyte species.

Magnesium, calcium, and potassium concentrations influence water alkalinity and thus, represent a proxy of an alkalinity-acidity gradient, and bryophyte species growing in an area typically reflect this gradient, unlike vascular plants, which reflect a eutrophic-oligotrophic gradient (Vitt and Chee 1990). *Carex diandra*, *Potentilla palustris*, *Epilobium palustre*, *Hamatocaulis vernicosis*, and some species of *Sphagnum* occur most abundantly in areas with relatively low base cation concentrations, whereas *Scorpidium scorpioides* and bryophyte species that prefer alkaline conditions (i.e., *Aneura pinguis, Meesia triquetra, Pseudocalliergon trifarium, Scorpidium cossonii,* and *S. revolvens*) occur most abundantly in areas that have higher concentrations of base cations, particularly where calcium and magnesium are above 75 mg/L (Vitt and House 2020). A decrease in magnesium and calcium concentrations would likely result in decreased cover of alkaline sentinel species, which are rare and require alkaline base rich waters (Vitt and House 2020). These communities would likely be replaced by *Hamatocaulis vernicosus*, which can occur along the entire base cation gradient (Vitt and House 2020). As conductivity is correlated to magnesium, calcium, potassium, and sodium, a decrease in conductivity would likely yield similar community changes as a decrease in base cation concentrations.

High water levels have been shown to result in increased chloride and calcium concentrations in soil pore water and bryophyte tissue (Cusell et al. 2013), and reduced water levels have been shown to result in decreased calcium concentration (Mettrop et al. 2015). Additionally, reduced water tables in iron and sulphur-rich fens may result in more pronounced oxidation and acidification compared to in fens with high concentration of calcium; responses of phosphorus availability during periods of low water tables may also differ as phosphorus binding capacity may vary depending on the calcium and iron soil content (Mettrop et al. 2015). High calcium concentrations can inhibit growth of *Sphagnum* species, especially when combined with high pH, as cell wall exchange sites become saturated, while true mosses such as *Tomentypnum nitens, Hamatocaulis vernicosus,* and *Aulacomnium palustre* have shown to have enhanced growth in these same conditions (Vicherová et al. 2015). Similar responses to changes in chlorine concentrations are expected, with a shift in community composition to species more tolerant of the new conditions. Additionally, soils with high calcium content may not experience a decrease in pH in response to a decreased water table (Mettrop et al. 2015). This is important as a decrease in pH can result in increases in *Sphagnum* cover, which can result in losses of fen species and brown mosses, especially during the summer (Cusell et al. 2013). In addition to decreases in pH, decreased water levels can result in increased enzyme activity, which can affect the carbon dynamics of a wetland, possibly due to decreased pH and shifts in nutrient acquisition (Straková et al. 2011).

While sodium is found naturally in wetlands, sodium concentrations are typically lower in poor fens, and higher in moderate-rich and extreme-rich fens (Vitt and Chee 1990). Pouliot et al. (2012) found that common beaked sedge (*Carex utriculata*), cattail (*Typha latifolia*), and seaside arrowgrass (*Triglochin maritima*), all of which have been identified in the MLWC, are able to grow without any signs of stress, and sometimes with even higher productivity, when exposed to increased salinity and naphthenic acid concentrations (i.e., as high as 569 milligrams per litre [mg/L] and 54 mg/L, respectively), likely due to increased ammonia levels. Persistence or increased productivity of these species, particularly if accompanied by decreases in abundance of more sensitive species, may indicate changes to surface water quality associated with FHO.

Nutrient enrichment has been attributed to a loss of specialist species, which are replaced with generalist species, which may be of concern in the patterned fen at the MLWC. Nutrient addition has been shown to increase plant production in some fens (Sarneel et al. 2010), but not in others (Mettrop et al. 2015). This is likely related to water chemistry in a fen; nitrification occurs at high pH, so if base-rich conditions remain high, then ammonium can be oxidized to nitrate, but if the pH drops, ammonium toxicity can occur (Kooijman 2012). Also, when water inputs are associated with increased nutrient loads, eutrophication can occur, as well as sulphide and ammonium toxicity (Cusell et al. 2013). However, increased growth associated with eutrophication may dilute and mask the toxic effects from ammonium toxicity (Geurts et al. 2009) due to different responses by plant species to nutrient enrichment. For example, Geurts et al. (2009) found that biomass of *Menyanthes trifoliata* increased after nitrogen and phosphorus fertilization, while Mettrop et al. (2015) found that increased nitrogen availability resulted in a decline in *Scorpidium scorpioides,* and that when water levels were at 0 cm, phosphorus addition resulted in declines in *Cyperaceae* species. The variation in plant species responses to nutrients is likely because vegetation increases due to additions of phosphorus are primarily by eutrophic species. Increases in eutrophic species can increase species richness and Simpson's diversity index, but decrease species evenness and change the plant community composition as the community changes from being driven by nutrient competition to light competition (Sarneel et al. 2010). Thus, if surface water quality at the MLWC is impacted by nutrient addition, particularly if accompanied by a decrease in surface water pH or changes to surface water levels, it may result in a loss of foundation species in the patterned fen.

Table 4.3-18: Surface Water Quality Preferences for Plant Species with High Fidelity to Ecohydrology Zones 1 and 2 and Response to Altered Water Quality Regimes

<table>
<tr><th colspan="2" rowspan="2">Species</th><th colspan="6">Water Quality Characteristics</th><th rowspan="2">Response to Water Quality Changes</th></tr>
<tr><th>pH</th><th>EC [µS/cm]</th><th>Ca^{2+} [mg/L]</th><th>Mg^{2+} [mg/L]</th><th>Na^{+} [mg/L]</th><th>K^{+} [mg/L]</th></tr>
<tr><td rowspan="5">Species with high affinity for EHZ 1 (Vitt and House 2020)</td><td>Carex diandra</td><td rowspan="5">7.2-7.3</td><td rowspan="5">153-189</td><td rowspan="5">31-34</td><td rowspan="5">9-13</td><td rowspan="5">3-4</td><td rowspan="5">2-3</td><td>-</td></tr>
<tr><td>Epilobium palustre</td><td>-</td></tr>
<tr><td>Hamatocaulis vernicosus</td><td>-</td></tr>
<tr><td>Comarum palustris</td><td>-</td></tr>
<tr><td>Sphagnum spp.</td><td>Growth inhibition of some Sphagnum species when Ca^{2+} exceeded 32 mg/L, 60 mg/L, and 96 mg/L (Vicherova et al. 2015)</td></tr>
<tr><td colspan="2">Key exceedance thresholds for EHZ 1[a]</td><td><7.0 or >7.5</td><td><130 or >220</td><td><10 or >60-80</td><td><5 or >25</td><td>>5</td><td>>5</td><td>n/a</td></tr>
<tr><td rowspan="8">Species with high affinity for EHZ 2 (Vitt and House 2020)</td><td>Aneura pinguis</td><td rowspan="8">7.7-7.9</td><td rowspan="8">392-448</td><td rowspan="8">63-74</td><td rowspan="8">29-37</td><td rowspan="8">7-9</td><td rowspan="8">4-7</td><td>-</td></tr>
<tr><td>Meesia triquetra</td><td>-</td></tr>
<tr><td>Pseudocalliergon trifarium</td><td>-</td></tr>
<tr><td>Scorpidium cossonii</td><td>-</td></tr>
<tr><td>Scorpidium revolvens</td><td>-</td></tr>
<tr><td rowspan="2">Scorpidium scorpioides</td><td>Mortality when pH = 6.2, EC = 49 uS/cm, Ca^{2+} = 5 mg/L, Mg^{2+} = 2 mg/L, Na^{+} = 3 mg/L (Vitt et al. 1993)</td></tr>
<tr><td>Reduced growth and survival when pH = 6.7, EC = 2,000 uS/cm, Ca^{2+} = 31 mg/L, Mg^{2+} = 86 mg/L, Na^{+} = 2,080 mg/L (Vitt et al. 1993)</td></tr>
<tr><td>Triglochin maritima</td><td>No signs of stress; increase in length of longest shoot when exposed to Na^{+} concentrations as high as 569 mg/L and naphthenic acid concentrations as high as 54 mg/L (Pouliot et al. 2012)</td></tr>
<tr><td colspan="2">Key exceedance thresholds for EHZ 2[a]</td><td><7.5 or >8.0</td><td><250 or >500</td><td><45 or >120</td><td><20 or >50</td><td><3 or >15</td><td><5 or >10</td><td>n/a</td></tr>
</table>

[a] Bold values are the most important (Vitt and House 2020).

> = greater than; < = less than; - = information not available; Ca = calcium; EC = electrical conductivity; EHZ = Ecohydrology Zone; K = potassium; Mg = magnesium; mg/L = milligrams per litre; Na = sodium; n/a = not applicable.

4.3.2.4.3. Potential Wetland Function Response

A key function of the peatland portion of the MLWC is to accumulate peat. Peat accumulation occurs when plant production rates exceed losses due to decomposition and dissolution as dissolved organic carbon (Vitt et al. 2009). Aerobic processes (i.e., processes requiring oxygen) such as plant growth and decomposition occur within the upper portion of the peat column. In the lower, water-saturated, mainly anaerobic portion of the peat column, decomposition rates may be extremely low (Belyea and Warner 1996). Net peat accumulation in bogs and poor fens is driven by relatively slow decomposition rates due to acidic conditions and rot-resistant *Sphagnum* plant material (Vitt et al. 2009). In contrast, both plant production rates and decomposition rates are relatively rapid in rich fens similar to the patterned portion of the MLWC. Inputs of dense plant material outweigh decomposition, and an overall balance of peat accumulation is maintained (Vitt et al. 2009). Specifically, at the MLWC, the rate of peat accumulation is approximately 5.57 cm/100 years (0.557 millimetres per year [mm/yr]) and over a 50-year period, 158,056 metric tons of organic matter has been estimated to have accumulated (Vitt and House 2020). These levels are similar to the mean accumulation rate of 0.529 mm/yr that was recorded near Calling Lake, Alberta (Bauer et al. 2003).

The relationship between plant productivity, decomposition, and overall peat accumulation rates in peatlands is influenced by climate variables including temperature and moisture regime (e.g., Gignac and Vitt 1994; Yu et al. 2003). Warmer temperatures may bring about lower water tables because of increased evapotranspiration rates; lower water tables may increase peat decomposition rates and bring about an overall decrease in peat volumes (Gignac and Vitt 1994). If lower water tables result from mining within the MLWC watershed, a similar effect could be observed. Peat accumulation rates may be more sensitive to climate fluctuations (e.g., water level changes) than is plant community composition (Yu et al. 2003). Therefore, if changes in MLWC plant community composition are documented, this may indicate that changes to the peat accumulation function have already occurred.

4.3.2.4.4. Summary of Risk Assessment for Vegetation – Wetland Primary Effects Indicator

Declines in surface water quantity have the potential to benefit vascular plant species, whereas changes in surface water quantity may impact different bryophyte species in different ways. Declines in cover of certain bryophyte species may be accompanied by increases in overall bryophyte cover as more tolerant species establish, changing bryophyte community composition. If water levels increase where flood tolerant bryophyte species are absent, or water levels decrease where drought tolerant bryophyte species are absent, bryophyte cover may be negatively impacted and vascular plant species, which alter ecosystem functions, may establish and further change the species composition of the plant community. However, with the installation and operation of water management design features developed for the Project, predicted changes to surface water levels compared to pre-mining baseline conditions are not expected to result in changes to plant community composition.

Similar to vegetation responses for water quantity, changes in fen surface water quality have the potential to impact different plant species in different ways; vascular plants are less likely to be negatively impacted by water quality changes compared to bryophyte species. Not only is there a potential for water quality to change, but initial changes to water quantity have the potential to further alter the water quality, and some plant species may respond differently to those interacting changes. If base cation concentrations change in the non-mined portion of the fen, there is the potential for a change in plant community to reflect species that are better suited to those water quality conditions, accompanied by a change in relative abundance of plant functional groups. However, resupply water going to the fen will be selected or treated to achieve a chemical balance similar to baseline, and predicted changes to water sources are not expected to result in changes to plant community composition.

Overall, a key function of the MLWC (and peatlands in general) is to accumulate organic matter. While plant species composition could shift in response to changing water levels or water quality, peat accumulation rates may be more sensitive than species composition to minor climate fluctuations such as a change in moisture regime (Yu et al. 2003). Maintenance of water levels and surface water quality within the ranges recorded for the pre-mining baseline period is necessary to maintain structure and function of the non-mined portion of the MLWC.

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ABBREVIATIONS, ACRONYMS, AND UNITS

Abbreviations and Acronyms

Abbreviation / Acronym	Definition
2020 MLWC HGS model	HydroGeoSphere Model
AAG	Aboriginal Advisory Group
DO	dissolved oxygen
e.g.,	for example
EIA	Environmental Impact Assessment
EFDC+	Environmental Fluid Dynamics Code
FHEC	Fort Hills Energy Corporation
FHUC	Fort Hills Upland Complex
Fort Hills Project	Fort Hills Oil Sands Project
HRA	Hydrologic Response Area
i.e.	that is
ITK	Indigenous Traditional Knowledge
MLWC	McClelland Lake Wetland Complex
NED	North External Dump
NOP	North Outwash Plain
OP	Operational Plan
R0	no development in the MLWC watershed
R1	development scenario with no implementation of water management design features
S1	development scenario with implementation of the selected water management design features
SC	Sustainability Committee
TAG	Technical Advisory Group
TDS	total dissolved solids

Units

Unit	Definition
%	percent
cm	centimetre
m	metre
m/m	metres per metre
masl	metres above sea level
m bgs	metres below ground surface
mg/L	milligrams per litre
mm	millimetre
mm/year	millimetres per year
µS/cm	microsiemens per centimetre