

# **Template for Pilot/Field-Testing of Bentonite Amendment of Tailings**

Prepared for  
PolyMet Mining, Inc.

April 2017



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## 1.0 Introduction/Background

PolyMet submitted a draft NorthMet Dam Safety Permit Application - Flotation Tailings Basin to the Minnesota Department of Natural Resources for review and comment (Reference (1)). The permit application referenced the NorthMet Project Flotation Tailings Management Plan (Reference (2)) which states that during construction the exterior face of Flotation Tailings Basin (FTB) dams will be amended with a bentonite layer ( see Section 7.1). The objective of the bentonite layer is to limit oxygen infiltration into the Flotation Tailings. Bentonite amendment will also reduce rainwater infiltration into the dams, which has a small benefit in terms of an increased slope stability safety factor. Reference (2) also states that exposed beach areas on the interior of the basin will be amended with bentonite to limit oxygen infiltration into the Flotation Tailings. Finally, Reference (2) also states that the pond bottom will be amended with bentonite as described in the NorthMet Project Adaptive Water Management Plan (Reference (3)). The bentonite-amended pond bottom will reduce the percolation from the FTB Pond, thereby maintaining a permanent pond that will provide an oxygen barrier and reduce oxidation and resultant production of chemical constituents in the underlying tailings. It will also reduce the amount of water collected by the FTB Seepage Containment System and the South Seepage Management System that will require treatment.

In summary, the design, operation, and closure of the FTB will include three separate but related applications of bentonite amendment:

- During construction of FTB dams, the exterior face of the dams will be amended with a bentonite layer
- In closure, exposed beach areas on the interior of the basin will be amended with a bentonite layer
- In closure, the pond bottom will be amended with bentonite

Attachment G - Template Construction Specifications - Section 03100 of Reference (2) requires that pilot/field-testing of bentonite amendment of soils (tailings) be performed, and this requirement is anticipated to be a condition of the Dam Safety Permit required for the FTB. This document is a template of the proposed pilot/field-test program.

## 2.0 Pilot/Field-Test Objectives

The objectives of bentonite amendment of the FTB dams, beaches, and pond bottom are to:

- limit oxygen infiltration through the FTB dams into the Flotation Tailings
- limit oxygen infiltration through FTB beaches into the Flotation Tailings
- limit oxygen infiltration through the FTB pond area by reducing the average areal percolation through the FTB pond bottom, thereby maintaining a permanent pond that will limit oxygen infiltration into the Flotation Tailings (and also reduce the amount of water collected by the FTB seepage capture systems and requiring treatment)

The performance of bentonite amendment of FTB dams and beaches to limit oxygen infiltration into the Flotation Tailings will be a function of the success with which a continuous areal (horizontal) zone of saturation can be established and maintained. The current plan calls for establishment of such a zone by constructing an 18-inch thick layer of bentonite-amended tailings covered by 30-inches of revegetated tailings. The 30-inch cover on the dams will consist of LTV Steel Mining Company (LTVSMC) Coarse Tailings and the 30-inch cover on the beaches will consist of Flotation Tailings. The bentonite layer will consist of 3% granulated bentonite mixed with LTVSMC Coarse Tailings or Flotation Tailings for the dams and beaches, respectively.

Therefore the **primary objectives of the dams and beaches pilot/field-test** will be to:

1. assess and demonstrate systematic and repeatable means and methods of earthwork construction to consistently create (i.e., mix bentonite and tailings) and place the bentonite layer in conformance to engineering specifications
2. assess the consistency/variability in the maintenance of a continuous areal zone of saturation within the 18-inch thick layer of compacted bentonite-amended tailings throughout the pilot/field-test<sup>1</sup>
3. observe the potential for other factors to inhibit, interfere or degrade the sustained maintenance of a continuous areal zone of saturation within an 18-inch thick layer of bentonite-amended tailings related to:
  - a. desiccation cracking of the bentonite-amended tailings layer during dry weather
  - b. post-construction differential settlement and/or erosion of overlying tailings
  - c. deep plant root penetration below the 30-inch cover layer

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<sup>1</sup> This does not mean to imply 18-inches of saturation, rather that there will be a continuous zone of saturation within the bentonite-amended tailings layer. The vertical dimension of the saturated zone will be determined in the pilot/field test.

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- d. freeze-thaw degradation of the bentonite-amended tailings layer
  - e. pond water chemistry along the beaches of the FTB
  - f. ice scour damage along the shoreline of the FTB Pond
  - g. other factors that could adversely affect the maintenance of saturation within a bentonite-amended tailings layer

The performance of bentonite amendment of the FTB pond bottom to reduce percolation from the pond and thus maintain a permanent pond will be a function of inducing a permanent positive water balance for the pond by reducing the areal average hydraulic conductivity of the pond bottom relative to pre-closure conditions. Unlike the bentonite amendment of the FTB dams and beaches, bentonite amendment of the pond bottom can be easily repeated if necessary through a series of approximations to reduce the average areal hydraulic conductivity of the pond bottom to sustain a permanent pond.

Therefore, the **primary objectives of the pond bottom pilot/field-test** will be to:

1. demonstrate systematic and repeatable means and methods of introducing bentonite to the pond bottom in a relatively uniform manner, which may include:
  - a. broadcasting of granular or pelletized bentonite from a GPS route controlled barge
  - b. injection/mixing of bentonite with pond bottom from a GPS route controlled barge
  - c. placement of geosynthetic clay liner over the pond bottom from a GPS route controlled barge
2. assess the performance of bentonite introduction in achieving a positive pond water balance

It is important to note that to achieve a positive pond water balance, bentonite amendment of the pond bottom may not be required at all. The hydraulic conductivity of the deposited flotation tailings without bentonite amendment may be as low as needed to maintain a positive pond water balance.

## 3.0 Pilot/Field-Test – Preliminary Concepts

### 3.1 Dams Pilot/Field-Test

Pilot/field-testing of bentonite amendment of dams will be performed on Cell 2W to demonstrate systematic and repeatable means and methods of earthwork construction to consistently create and place the bentonite layer in conformance to engineering specification (see Dams and Beaches Objective 1 above). The materials used in the pilot/field-test will be representative of LTVSMC Coarse Tailings borrow and the bentonite that will be used in Cell 1E/2E dam construction. The means and methods for construction of test section dams will be consistent with Construction Specifications (Attachment A and Attachment G of Reference (2)). The location of the test section dams will be along the north interior crest of Cell 2W to provide a southern exposure aspect to the test section while also providing good accessibility (Figure 3-1). A southern exposure aspect should provide an increased stress related to solar radiation effects such as elevated temperatures, evapotranspiration and soil moisture deficit. Each of these effects will tend to be adverse to the maintenance of a zone of saturation within the 18-inch thick layer of bentonite-amended tailings.

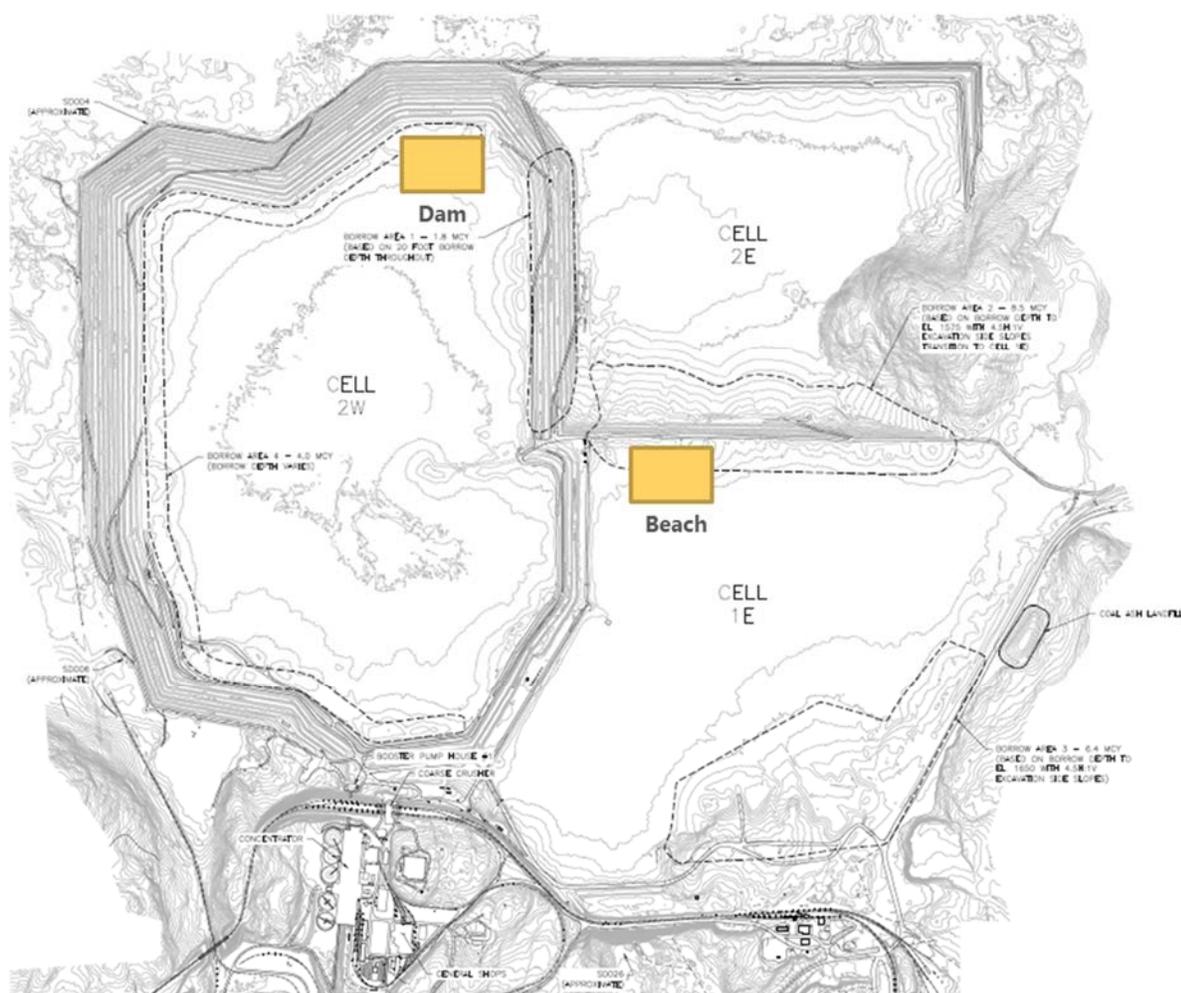


Figure 3-1 Probable Locations of Dam and Beach Pilot/Field-Test Areas

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Numerous methods are available to assess the consistency/variability in the maintenance of a continuous areal zone of saturation within the 18-inch thick layer of bentonite-amended tailings throughout the pilot/field-test (see Dams and Beaches Objective 2 above and Reference (4), Reference (5), Reference (6)). These methods include a variety of choices for volumetric, tensiometric, gravimetric and redox indicator soil water monitoring. Each method offers certain advantages and drawbacks for application in the pilot/field-test. Important considerations for this pilot/field-test include:

- reading range that includes a saturated state
- acceptable accuracy to support test plan objectives (e.g., +/- 1% or 1 cbar)
- durability and permanence of installation (i.e., minimal need to revisit/disturb the test section)
- minimal maintenance requirements (i.e., minimal need to revisit/disturb the test section)
- minimally affected by solutes/salinity
- minimal sensitivity to soil temperature
- compatibility with clay soils
- easy and stable soil-specific calibration
- easy monitoring at multiple soil depths

It will also be desirable if the monitoring method will accommodate data logging capability and provide ease of installation.

Several methods appear to be compatible with the conditions/constraints of the pilot/field-test and will largely accommodate the considerations listed above (exceptions are noted):

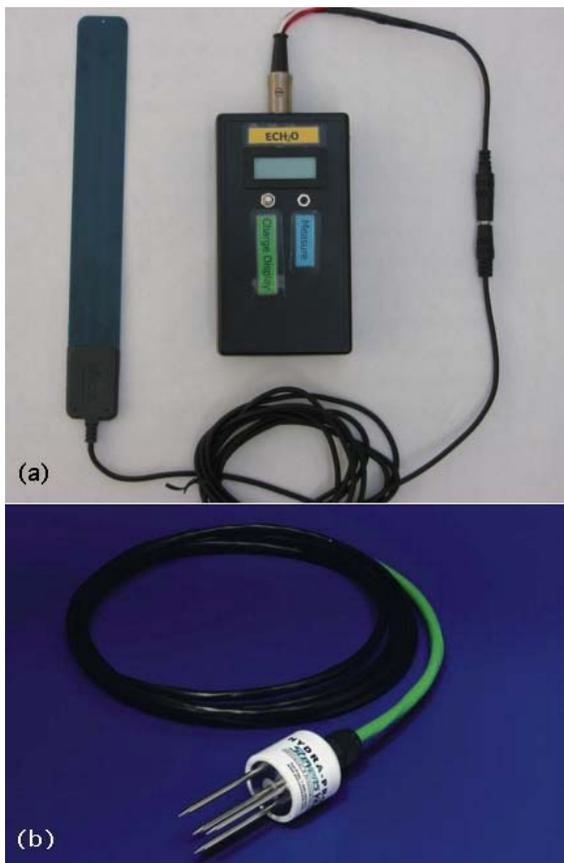
- Frequency domain (FD) probes such as (Figure 3-2):
  - capacitance plates embedded in a silicon board
  - capacitance rods

Careful installation of FD probes is necessary to avoid air pockets and the devices easily accommodate multiple sampling depths; temperature influence will need to be evaluated.

- Amplitude domain reflectometry (ADR) probe (Figure 3-3):  
The device will easily accommodate multiple sampling depths; soil-specific calibration is necessary to maintain accuracy and careful installation is required to avoid air pockets.
- Tensiometer (Figure 3-4):  
Custom modification is necessary to accommodate data logging, device may require ongoing

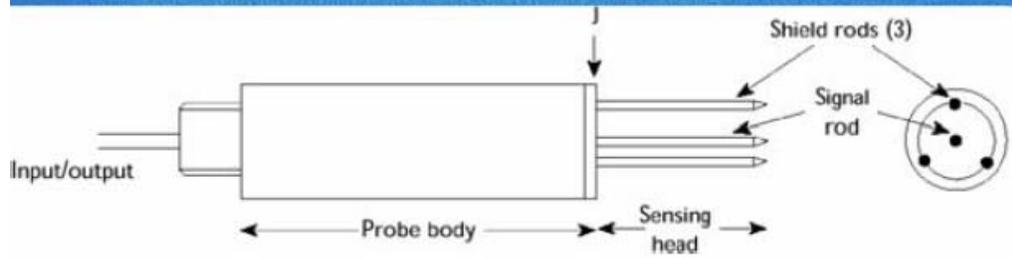
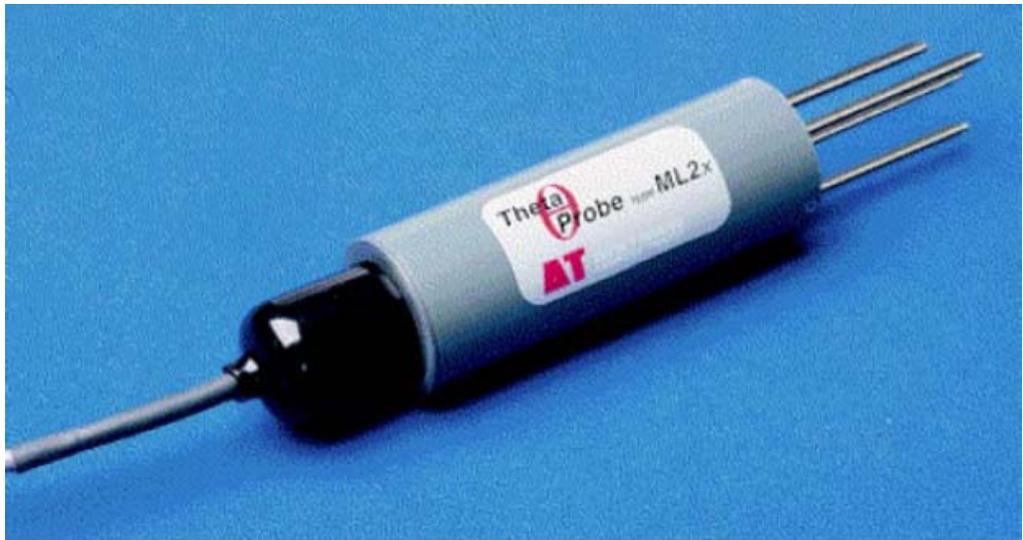
maintenance, will require seasonal maintenance and/or replacement, and device is more fragile than other devices described above.

- Mild Steel Rods as described in Reference (5):  
Lack of available oxygen in saturated soils prevents rust of mild steel rods that have been driven into the soil; saturated soil will yield rust-free rod below depth of saturation. An indirect sampling method that is cheap and easy to install, compatible with assessment of gradients along transects, gives strong measure of depth of saturation, low cost allows intensive grid sampling to assess the consistency of saturation over an area; oxygen may infiltrate along the rod/soil contact.
- Gravimetric as described in Reference (6):  
An established and standardized method of measuring soil saturation by collection of soil samples, determining wet weight, dry weight, determining moisture content by difference and comparing to an established saturated baseline moisture content. Drawbacks include: physical sampling (extraction of soil at depth) must be repeated at each sampling event, sampling will cause disturbance of soils and vegetation.



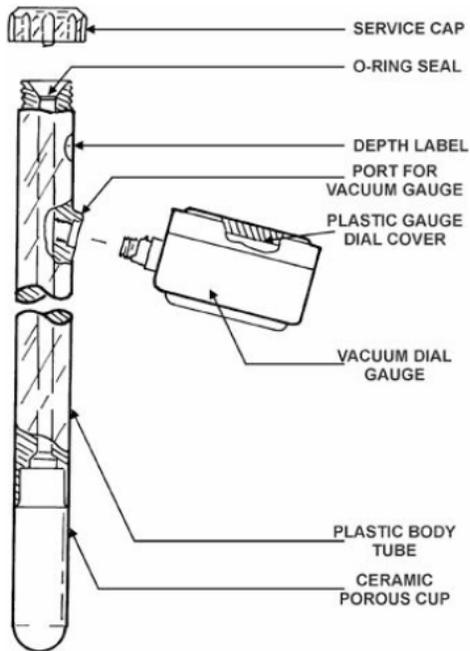
(Reference (4))

Figure 3-2 Frequency Domain (FD) Probes: a) Capacitance (plates embedded in a silicon board)



(Reference (4))

Figure 3-3 Amplitude Domain Reflectometry (ADR) Probe



(Reference (4))

Figure 3-4 Tensiometer

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The number of sample locations and frequency/timing of monitoring events (or continuous monitoring) will reflect the combination of soil moisture monitoring methods incorporated into the pilot/field-test. A minimum of three replicates of each type of monitoring will be implemented at each of three depths of monitoring (3-inches, 9 inches and 15 inches) into the 18-inch bentonite-amended zone. Frequency of monitoring will vary by method, likely monthly during the growing season (April 1 and October 1). Gravimetric sampling will likely be limited to three events per growing season (to minimize test area disturbance) and yet allow a means to calibrate/confirm monitoring results from other methods.

Monitoring to observe the potential for other factors to inhibit, interfere with, or degrade the construction and sustained maintenance of a continuous areal zone of saturation (see Dams and Beaches Objective 3 above) in an 18-inch thick layer of bentonite-amended tailings in tailings dams will be accomplished through the use of the "observe and investigate" method and/or designed mini-experiments as follows:

- Observe and Investigate – The following factors that could inhibit, interfere with, or degrade the zone of saturation in FTB dams can be easily observed in the dam test sections and potentially in the existing LTVSMC dams during routine dam inspection activities:
  - post construction erosion of overlying tailings
  - deep plant root penetration of 30-inch cover layer

If post construction erosion is observed, methods of investigation (e.g., excavation, measurement, and photo documentation) can be used to deduce potential engineering/design or operational modifications to avoid and minimize the adverse effects of this factor. If in the collection of gravimetric soil moisture samples (see above), plant roots are observed below a 20 -inch depth in the cover soils, samples of such soil can be retained and sieved to quantify the prevalence of root mass with depth to 30 -inches. Depending on the findings, future sampling and/or investigation can be designed and implemented to assess the significance of root penetration of the bentonite-amended layer; e.g., as part of post-test section demolition.

- Mini-Experiments – The following factors that could inhibit, interfere with, or degrade the zone of saturation in FTB dams would be best assessed through designed experiments with comparison controls (exclusion of the factor):
  - desiccation cracking of the bentonite-amended layer during dry weather
  - freeze-thaw degradation of the bentonite-amended layer

Such experiments could be implemented in the field with small test microcosms designed to isolate and maximize the effect of the factor and accommodate ready observation. For example, wood frame structures could be built/used to evaluate desiccation cracking or freeze-thaw degradation of the bentonite-amended layer through use of observation panels (i.e., windows) in the side of the wood structure. Soil core samples could also be collected and examined. Irrigation and heating can be used to exclude the stress of dry weather and freezing on the control microcosms.

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## 3.2 Beaches Pilot/Field-Test

Pilot/field-testing of bentonite amendment of beaches will be performed along select portions of the south side crest of the Cell 1E/2E splitter dam (Figure 3-1) to demonstrate systematic and repeatable means and methods of earthwork construction to consistently create and place the bentonite layer in conformance to engineering specifications (see Dams and Beaches Objective 1 above and Attachment A and Attachment G of Reference (2)). A limited volume of Flotation Tailings will be spigoted along the south side crest of the Cell 1E/2E splitter dam for use as a pilot/field-test area prior to the merging of Cells 1E and 2E. The materials used in the pilot/field-test will be representative of Flotation Tailings and the bentonite that will be used in construction of the bentonite amendment layer on Cell 1E/2E beaches. Test sections of beach will be constructed in the spigoted tailings using the means and methods for construction consistent with Construction Specifications (Attachment A and Attachment G of Reference (2)). Construction of the test section will be on the south side crest of the Cell 1E/2E splitter dam to provide a southern exposure aspect to the test section. A southern exposure aspect should provide an increased stress related to solar radiation effects such as elevated temperatures, evapotranspiration and soil moisture deficit. Each of these effects will tend to be adverse to the maintenance of a zone of saturation within the 18-inch thick layer of bentonite-amended tailings.

Methods for monitoring consistency/variability in the maintenance of a continuous areal zone of saturation within the 18-inch thick layer of bentonite-amended tailings in the test section beaches (see Dams and Beaches Objective 2 above) will be similar to the methods described for monitoring test section dams (see above). However, because the monitoring of dam test sections will take place prior to the monitoring of the beach test sections, there will be an opportunity to apply “lessons learned” to improve monitoring outcomes and efficiencies for the beach test section.

Monitoring to observe the potential for other factors to inhibit, interfere or degrade the sustained maintenance of a continuous areal zone of saturation (see Dams and Beaches Objective 3 above) within an 18-inch thick layer of bentonite-amended tailings in FTB beaches will be accomplished through the use of the “observe and investigate” method and/or designed mini-experiments as follows:

- Observe and Investigate – The following factors that could inhibit, interfere with, or degrade the zone of saturation in FTB beaches can be easily observed in the beach test sections and potentially in the existing LTVSMC beaches during routine FTB inspection activities:
  - post construction differential settlement
  - deep plant root penetration of 30-inch cover layer
  - ice scour damage along the shoreline of the FTB Pond

If post construction differential settlement or ice scour damage along the shoreline of the FTB Pond is observed, methods of investigation (e.g., excavation, measurement, and photo documentation) can be used to deduce potential engineering/design or operational modifications to avoid and minimize the adverse effects of the factors. If in the collection of gravimetric soil moisture samples (see above), plant roots are observed below a 20 -inch depth in the cover soils, samples of such soil can be retained and

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sieved to quantify the prevalence of root mass with depth to 30 -inches. Depending on the findings, future sampling and/or investigation can be designed and implemented to assess the significance of root penetration of the bentonite-amended layer; e.g., as part of post-test section demolition.

- Mini-Experiments – The following factors that could inhibit, interfere or degrade the zone of saturation in FTB beaches would be best assessed through designed experiments with comparison controls (exclusion of the factor):
  - desiccation cracking of the bentonite-amended layer during dry weather
  - freeze-thaw degradation of the bentonite-amended layer
  - pond water chemistry along the beaches of the FTB

Such experiments could be implemented in the field with small test microcosms designed to isolate and maximize the effect of the factor and accommodate ready observation. These experiments could be designed in a manner similar to that described for evaluation of potential adverse factors effecting FTB dams. It is entirely likely that results of the experiments to assess desiccation cracking and freeze-thaw degradation of the bentonite-amended layer for the FTB dams will be equally applicable to the FTB beaches. The effects of pond water chemistry on the zone of saturation could be assessed in field microcosms that allowed the introduction of pond water to stress the bentonite layer. The control (comparison) microcosms will exclude introduction of pond water and substitute collected rain water.

### 3.3 Pond Bottom Field-Test

As described in the Adaptive Water Management Plan (Reference (3)), a field-testing and demonstration program of bentonite amendment of the pond bottom will be performed (see Pond Bottom Objective 1 above). The program will be conducted to evaluate the efficacy of the proposed method of bentonite amendment and to select a method that is effective, efficient, and economical. By this test method the hydraulic conductivity of the bentonite-amended Flotation Tailings can first be estimated in the laboratory and necessary bentonite application rates can then be confirmed in the field. The combined hydraulic conductivity and bentonite layer thickness will be specified to achieve performance requirements. Then, as part of the initial FTB Pond reclamation work in combined Cell 1E/2E, the selected construction contractor will be required to demonstrate the means and methods for bentonite application to the pond bottom that will yield the desired uniformity of bentonite application as dictated by pre-application laboratory test results.

As described previously, methods of introducing bentonite to the pond bottom in a relatively uniform manner has been proposed along with two alternate methods of introduction (Figure 3-5 through Figure 3-7):

- broadcasting of bentonite from a GPS route controlled barge (proposed)
- injection/mixing of bentonite with pond bottom from a GPS route controlled barge

- placement of geosynthetic clay liner over the pond bottom from a GPS route controlled barge

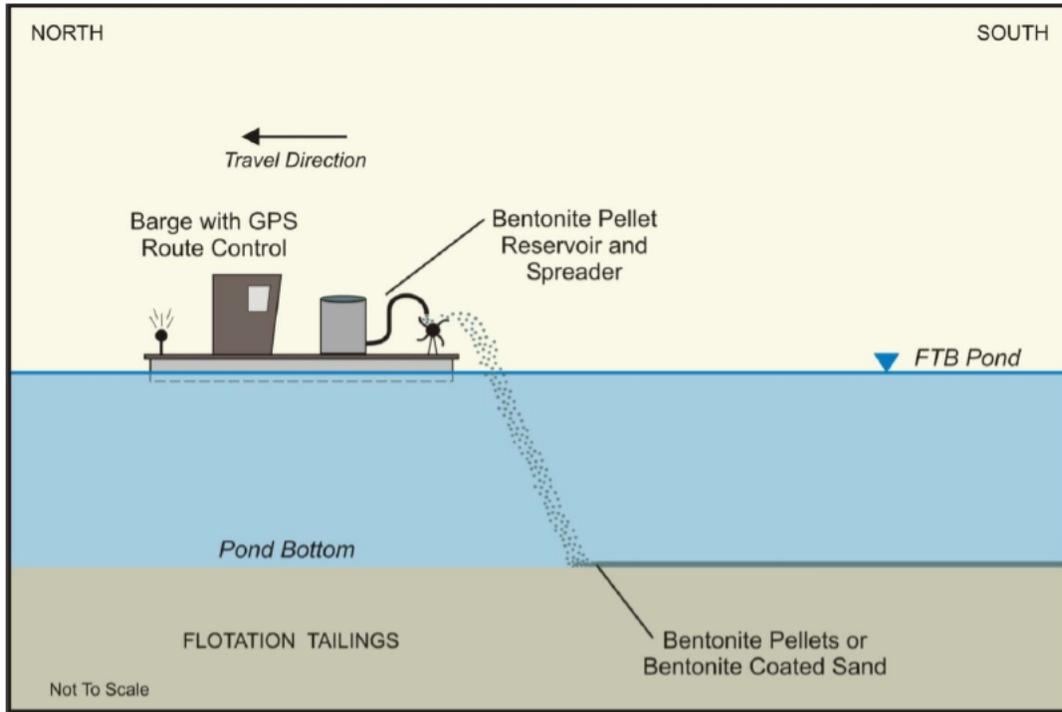


Figure 3-5 Bentonite Broadcasting

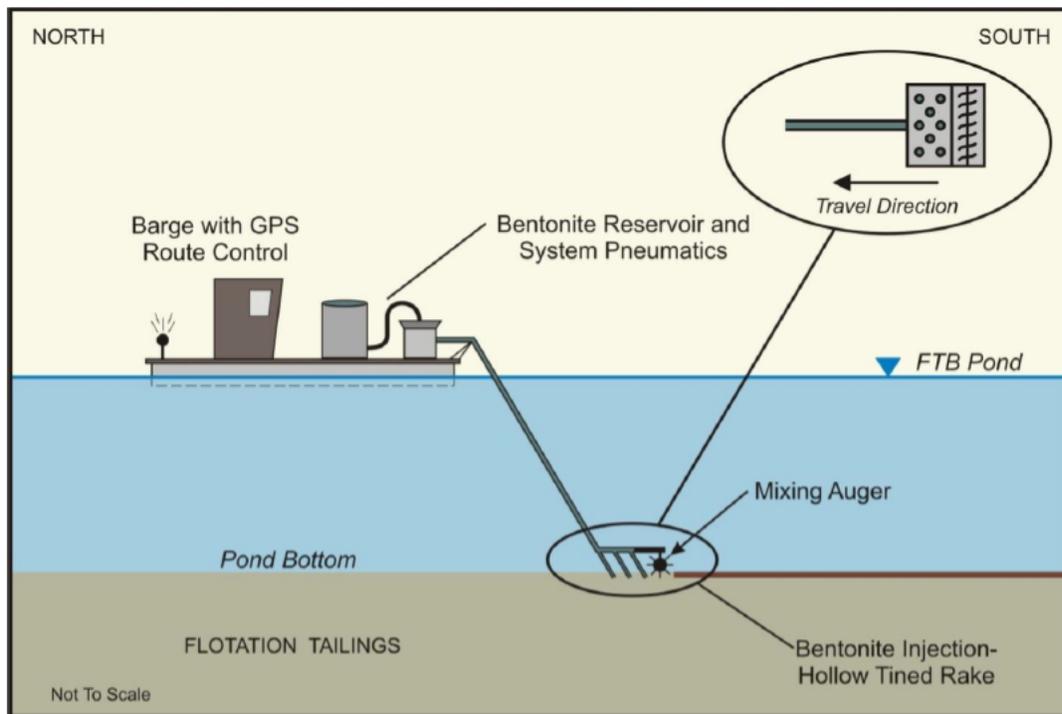
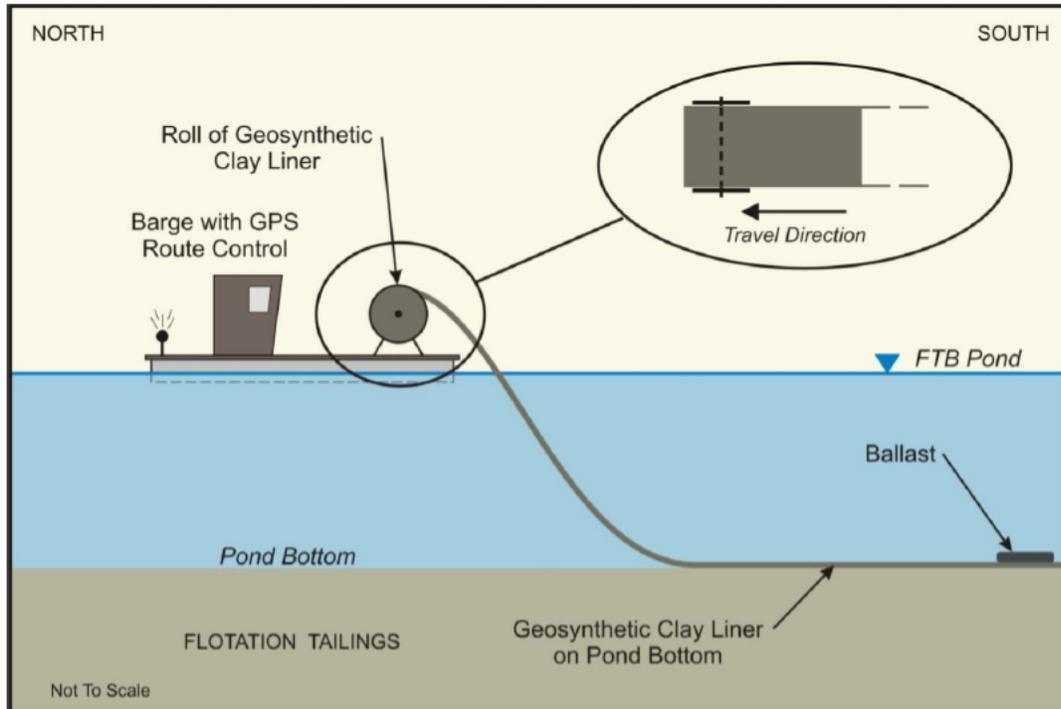


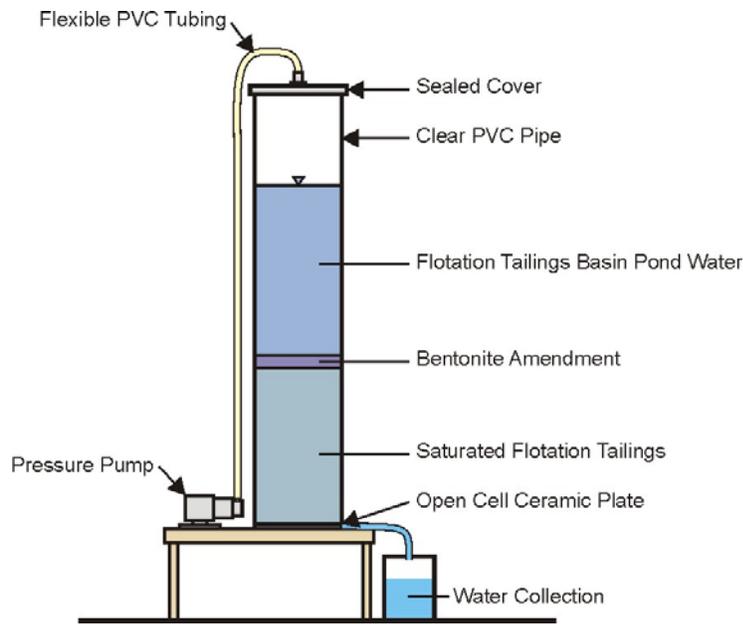
Figure 3-6 Bentonite Injection



**Figure 3-7 Geosynthetic Clay Liner**

With the proposed method, bentonite will subsequently settle to the pond bottom where it will hydrate, swell, and due to its inherently low hydraulic conductivity, reduce percolation from the pond bottom. In the second method of bentonite application, the amendment will be mixed with the pond bottom where it will also hydrate, swell, and due to its inherently low hydraulic conductivity, reduce percolation from the pond bottom. Bentonite placed as a geosynthetic clay liner over the pond bottom would similarly hydrate, swell and reduce the percolation from the pond bottom.

All of these methods of bentonite amendment can be simulated in the laboratory using replicated clear PVC columns (Figure 3-8) filled with Flotation Tailings, and FTB pond water. This will allow an evaluation of the performance of varying rates and uniformity of introduction of bentonite amendment via broadcasting and mixing. In addition, air pressure can be applied to the tops of the columns to simulate the hydraulic head of varying pond depths on bentonite amendment performance. The performance metric for evaluation of bentonite amendment would be measured reduction in pond bottom percolation.



**Figure 3-8 Schematic of Laboratory Column and Ceramic Plate to Assess Performance of Bentonite Amendment**

Using these lab methods, the volume of water collected from the bottom of the columns over a specified time can be used to calculate the hydraulic conductivity of various methods of bentonite introduction as well as modification of the rates and uniformity of bentonite amendment as compared to control columns (w/o bentonite amendment). Finally, at the conclusion of the simulation, the columns can be disassembled and samples of the bentonite-amended layer can be collected for measurement of bentonite layer thickness.

The combined hydraulic conductivity and bentonite layer thickness will be specified (most likely in pounds per acre) to achieve the performance requirement of sustaining a stable pond level consistent with Reference (2). These specifications will then be used by the contractor to perform a field demonstration of the means and methods necessary to achieve the specifications.

During closure, indirect monitoring methods will be used to confirm the efficacy of the introduction of bentonite into the pond bottom to reduce the percolation from the FTB Pond. Indirect monitoring will include monitoring of the pond level using a continuous recording instrument to confirm achievement of a positive pond water balance (see pond bottom Objective 2 above). If pond level monitoring indicates that an inadequate reduction of pond bottom percolation has been accomplished, bentonite amendment of the pond bottom can be easily repeated if necessary through a series of approximations to reduce the average areal hydraulic conductivity of the pond bottom to sustain a positive pond water balance.

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Monitoring to observe the potential for other factors to inhibit, interfere with, or degrade the sustained maintenance of a continuous areal zone of saturation within the bentonite-amended pond bottom tailings will be accomplished through the use of the “observe and investigate” method as follows:

- Observe and Investigate – Factors that could inhibit, interfere with, or degrade bentonite amendment of pond bottom include:
  - post construction differential settlement and/or erosion of shallow pond areas
  - ice scour damage along the shoreline of the FTB Pond

Inspection of the pond bottom could include observation from the pond shoreline or through use of an underwater camera attached to a shallow draft watercraft or attached to a remotely operated underwater drone. If post construction differential settlement, erosion of pond shallows or scour damage along the underwater shoreline of the FTB Pond is observed, methods of investigation (e.g., excavation, measurement, and photo documentation) can be used to deduce potential engineering/design or operational modifications to avoid and minimize the adverse effects of the factors.

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## 4.0 Testing Schedule

Pilot/field testing of bentonite amendment on dams, beaches and pond bottoms will be performed upon receipt of the necessary permits and initiation of the project. The schedule for performing each type of bentonite pilot/field test is described below. Construction Specifications Section 03100 will be updated as necessary with completion of each Pilot/Field-Test.

### 4.1 Dams Pilot/Field-Test

Pilot/field-testing of bentonite amendment on dams (as described above) will begin in an area on Cell 2W after permits are issued; and before or concurrent with construction of the first lift of the Cell 2E dam, which will begin to be constructed upon receipt of the necessary permits and initiation of the project. The available pilot/field-test time window will be on the order of two years to accomplish the test section construction and initial monitoring prior to construction of the second FTB dam lift. However, the test section will be maintained for three additional years to evaluate longer term environmental effects on test section performance.

### 4.2 Beaches Pilot/Field-Test

Pilot/field-testing of bentonite amendment of beaches cannot occur until a section of Flotation Tailings beach can be established on the south crest of the Cell1E/2E splitter dam (tentatively during year-3 of FTB operations). This will provide sufficient time for PolyMet operations personnel to establish and fine-tune their basin operation activities. Once the test zone is established, the available pilot/field-test window to accomplish the pilot/field-test objectives prior the merging of Cells 1E/2E will be about four years.

### 4.3 Pond Bottom Field-Test

Field demonstration of the bentonite amendment of the pond bottom (as described above) will be focused on demonstrating a systematic and repeatable means and method of introducing bentonite to the pond bottom in a relatively uniform manner. This demonstration will necessarily be delayed until FTB Pond closure so as not to interfere with tailings basin operations during the life of the project, and so that the demonstration can be performed by the contractor selected for the bentonite amendment activities at closure.

Testing of bentonite amendment can be simulated in the laboratory as soon as an adequate volume of representative tailings samples from the FTB pond bottom can be collected from the FTB, possibly in Mine-Year 2.

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## 5.0 References

1. **Barr Engineering Co.** NorthMet Dam Safety Permit Application - Flotation Tailings Basin. May 2017.
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