NORTHERN EXPERIMENTAL PASSIVE TREATMENT FACILITY: TECHNICAL DESIGN REPORT

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Table of Contents

1. Introduction

Passive treatment systems offer a low cost and low maintenance means of remediating water contaminated by a variety of industrial and domestic factors. Natural wetlands demonstrate an innate ability to remove contaminants derived from mining/industrial operations, agricultural systems, and domestic sewage. Passive treatment systems are an artificial construct that utilize these natural processes to maximize their effectiveness for increased removal efficiencies. These systems have been utilized globally, but are particularly successful in temperate regions where high rates of primary productivity and moderate winters prevail. Under such climates, the chemistry, biology, and hydrology of wetlands are well understood, resulting in constructed systems with high removal efficiencies that are effective for an array of contaminant regimes.

While the operation of passive treatment systems are well understood in temperate regions, there is a growing need to understand how they operate in Artic and subarctic climate conditions. As resource extraction pushes farther north, remediation systems capable of operating in remote locations with little maintenance or human intervention are becoming a necessity. Considering the colossal scope and timeframe of these projects and the potential for severe environmental contamination, long term remediation plans must be guaranteed to succeed. While active treatment is an option, it is expensive and time consuming. Given that the time frame of these extraction operations can exceed 100 years, accounting for construction, mineral extraction, and remediation, active treatment quickly becomes impractical. By contrast, passive treatment systems have low long term costs and require only occasional monitoring and maintenance, providing a feasible method of contaminant remediation.

Significant components of northern passive treatments remain poorly understood, limiting their long term effectiveness. Indeed, Ness et al., (2013) address fundamental research questions within the foundational knowledge of how passive treatment systems function in northern climates, raising questions such as: “how does seasonal variation alter removal efficiency?”; “how do wintertime abiotic factors, such as freeze-thaw cycles, influence metal attenuation?”; “how do varying endemic plant species and local substrates differ in their ability to host diverse microbial communities?”; and “how does cold climate impact the expected lifetime of passive treatment systems?”.

A northern experimental treatment wetland facility offers an opportunity to increase our understanding of the fundamental factors influencing wetlands and passive treatment systems under cold climate conditions. Current facilities such as the Loxahatchee Impoundment Landscape Assessment (LILA, Florida, USA), the Wetland Research Centre (WRC, Halmstad, Sweden), and the International Institute for Sustainable Development Experimental Lakes Area (IISD ELA, Ontario, Canada), allow for macrocosm scale research on factors influencing everglade marshes, constructed wetlands, and freshwater lakes on the Precambrian Shield, respectively. With an improved understanding of the basic functionality of passive treatments in northern climates, more robust remediation schemes will be ensured. Similar to LILA, WRC, and the ELA, this technical report proposes a design for a research facility capable of addressing present and future knowledge gaps concerning the effectiveness of passive treatment systems under cold climate conditions.

2. Design Objectives:

1) To serve as a controlled, long-term, and adaptive experimental facility responsible for addressing research questions on how passive treatment wetlands function in a northern climate environment.
2) To provide researchers, regulators, and industry stakeholders with a facility enabling them to address concerns and find plausible solutions to mitigate and remediate contamination and meet industry/government environmental standards.
3) To be used as a teaching resource to educate and train the public, industrial stake holders, and future employers of this technology.
4) To provide opportunities for discussion between regulatory and industry representatives at a neutral facility run by an unbiased organization.

3. Design Overview

3.1 Summary

Located in the Territorial capital of Whitehorse for maximum accessibility, and proximal to active, inactive and proposed resource extraction sites; this facility offers the opportunity to unite researchers, industry stakeholders, and regulators under one roof to better address passive treatment performance questions. This design is intended to serve as an experimental vehicle addressing research questions on the performance of passive treatment wetlands in northern climates. As such, it maximizes adaptability to provide the utmost control and customization of variables within an experimental design. The four primary cells of the system are coupled with four separate holding tanks, facilitating independent operation for up to four separate treatments. Furthermore, utilization of the cells in a sequentially paired orientation accommodates hybrid treatments running parallel to the other sequential pair. Weir channels at the base of each holding cell allow for independent control over the water level within each cell, to adapt conditions to specific vegetation or treatment types (surface, subsurface, bioreactor, etc). An array of multi parameter sensors and wireless telemetry offer real time observations of water quality change progressively through the system.

3.2 Location

An approved area has been allocated to this project measuring approximately 441m^2. The area is located behind the Centre for Northern Innovation in Mining which is currently in construction on the Yukon College campus (see Figure 1 and 2). The chosen site is bordered by the Trans-Canada

Trail system on its north and east borders and an access road on its western border. Given its location on the edge of campus and its proximity to a trail system, it is advised that the entire area be fenced for safety and security reasons.

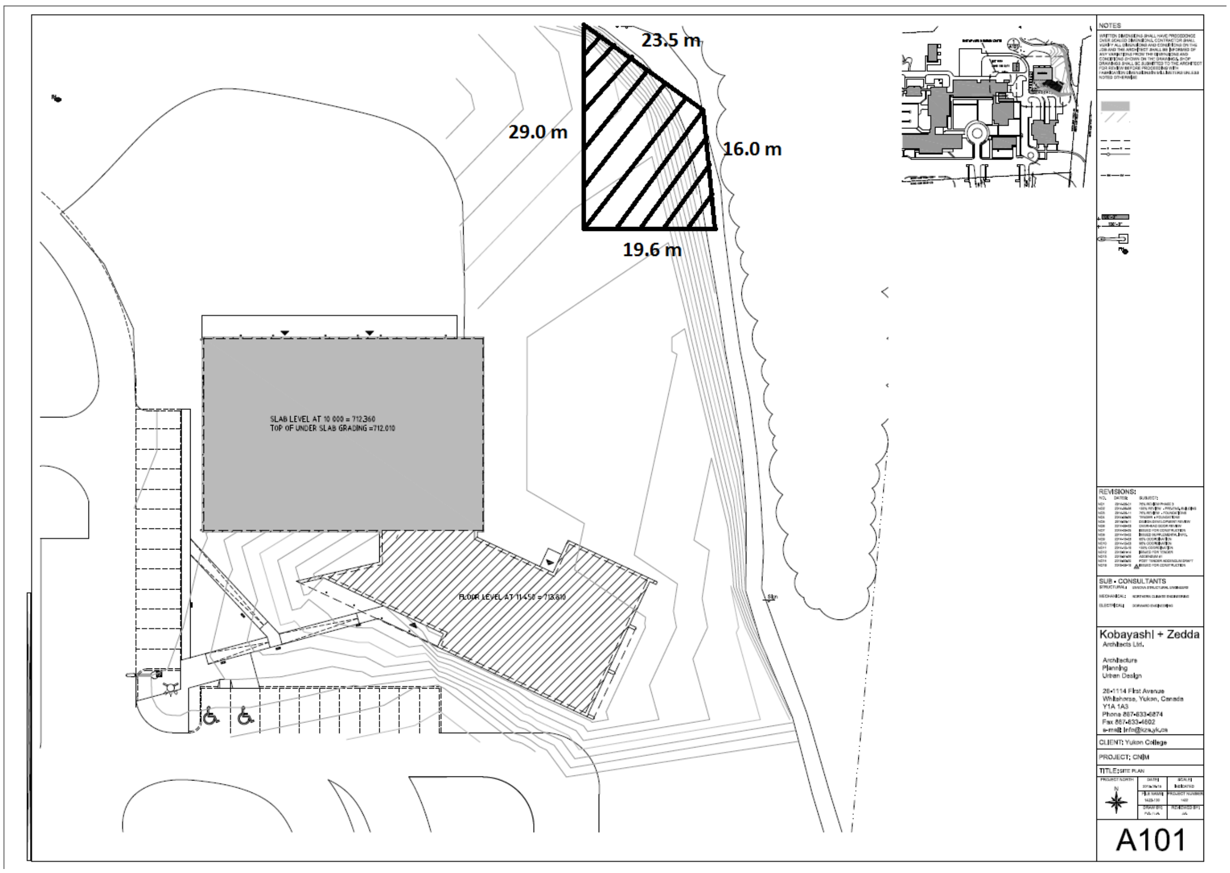


Figure 1: Site plan for the Centre for Northern Innovation in Mining with area allocated for passive treatment research facility highlighted in black.

Figure 2: Photograph of proposed site. Photograph was taken utilizing panorama and thus proportions may not be to scale.

3.3 Regulatory Considerations and Post Treatment Water Remediation

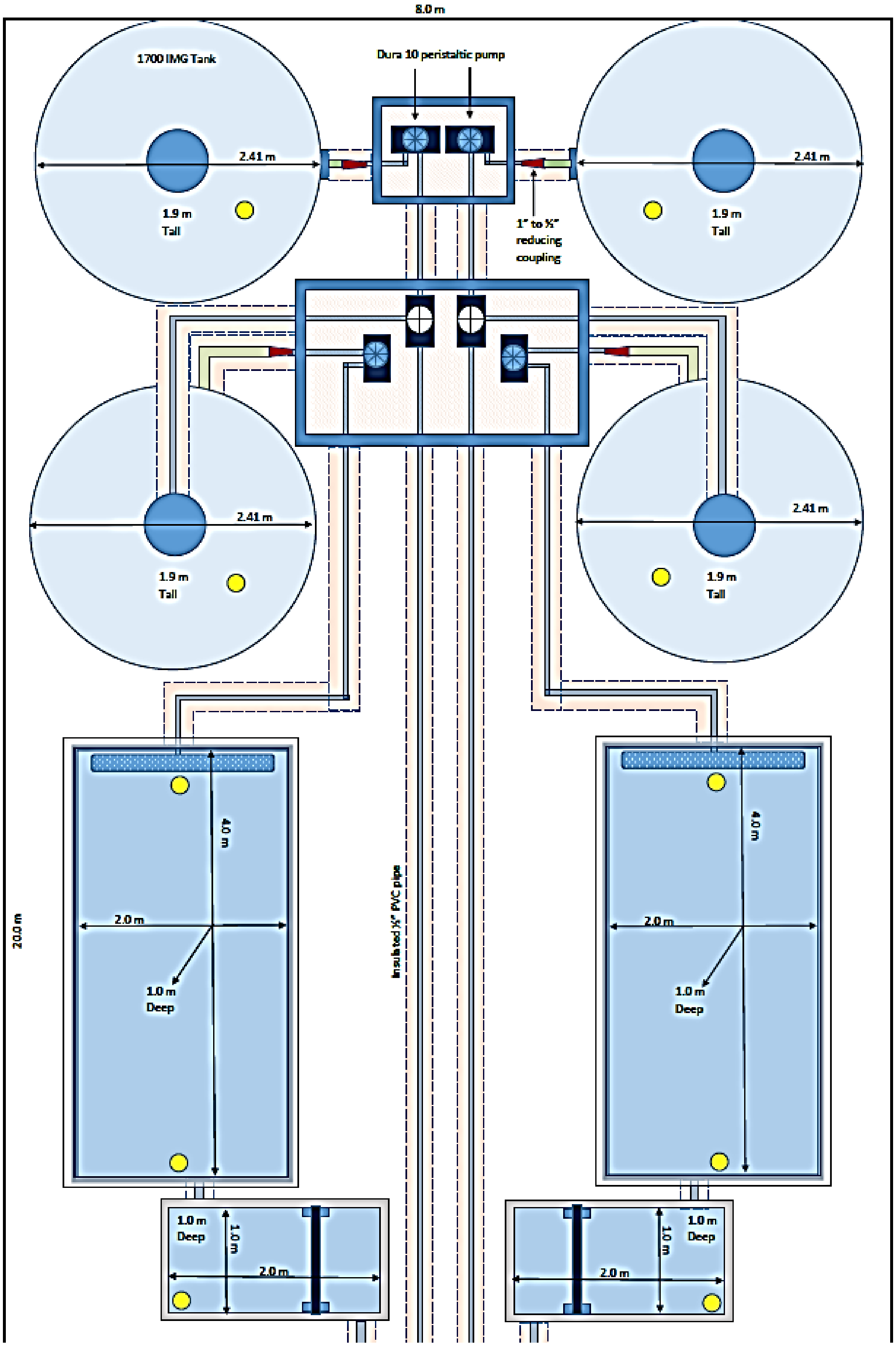
Specific considerations concerning hazardous amendments to water and/or utilizing mine influenced waste water have been considered in accordance with Yukon Water Board regulations. However, so long as the site maintains complete isolation from the surrounding environment, water releasing regulations will not apply (Yukon Water Board, 2016, pers. comm., April 5).

To maintain isolation, holding tanks serve as sources and a terminal holding pond will capture post-experimentation water for further remediation, should it be above regulatory limits for release to the environment. Following communication with the Yukon Water Board, it has been determined that the remediation of water significantly contaminated with metals requires specialized treatment and likely transportation to facilities outside of the territory. A potential solution is to transport post-experiment waste water back to the mine site from which it was sourced and remediate using on-site methods.

3.4 Site Preparation and Excavation

The chosen site for the research facility requires grading and site preparation to ensure precise placement of tanks, basins, and pipes. A significant amount of excavation will be required for placement of the concrete basins, weir channels, and the terminal holding pond. The excavation bases will require additional grading with sand or gravel to ensure that the cells do not shift. It is vital that the cells are identically graded for consistent flow paths to exist within all treatment cells. Previous guides recommend that basins be gently sloped (0.1-1.0%) to allow for an even water depth throughout and a consistent flow (Lesikar, 1999; EPA, 2000; Sobolewski, 2003).

3.5 Design Schematic



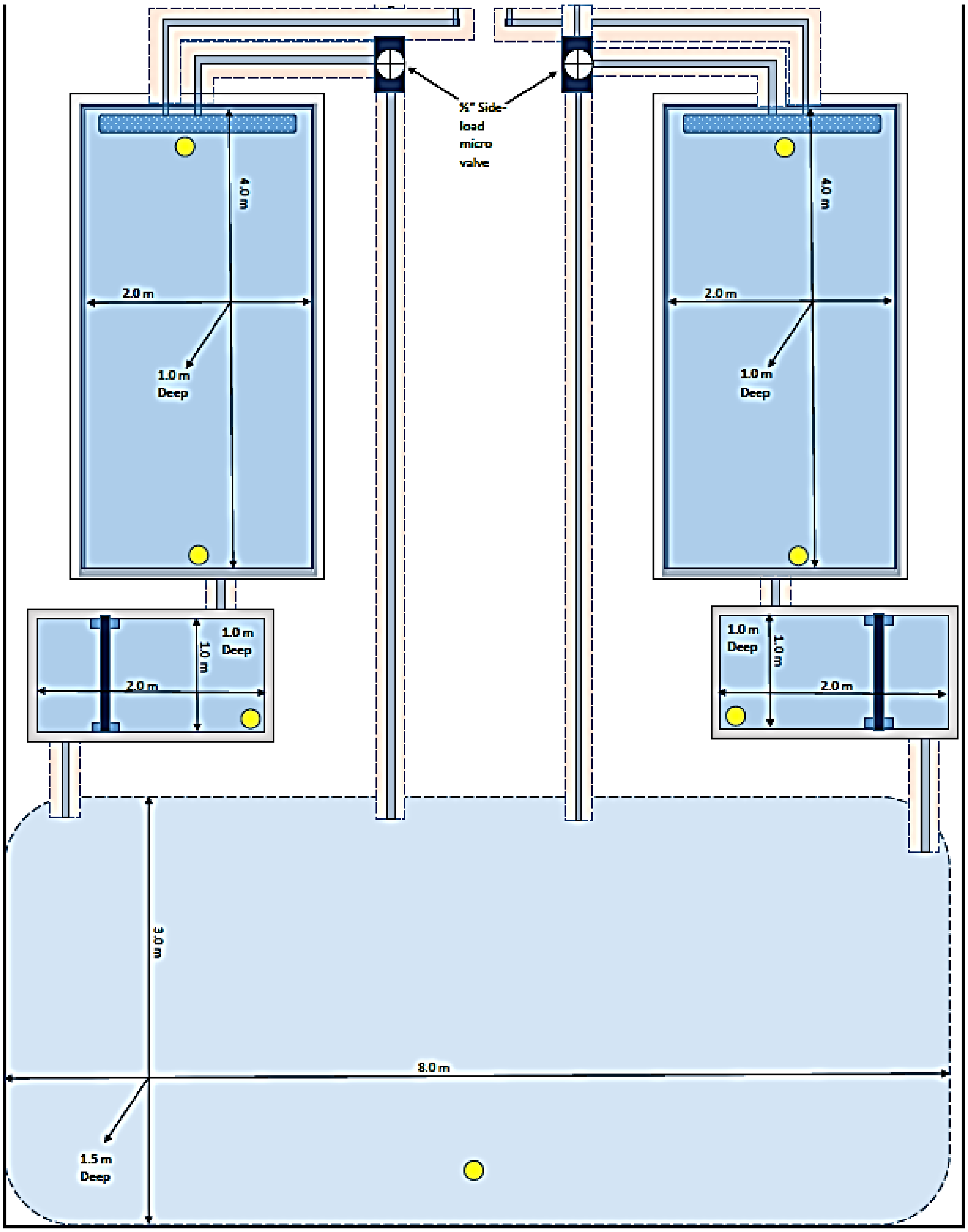


Figure 3: Design for northern passive treatment research facility with sizes. Yellow circles indicate potential placement areas for multi parameter sondes.

3.6 Initial Holding Tanks

The input into most treatment wetlands is derived from a pre-existing source, be it a large holding area of mine influenced water or a contaminated stream. However, given the constraints of the building site and the operational requirements of an enclosed system, water holding tanks are necessary. Through basic calculations (see Appendix 1.1), each cell will require a holding container with a volume ≥1700 imperial gallons (IMG). This accommodates a variable residence time of between 1 and 10 days in each wetland cell, while allowing for weekly or bi-weekly recharges of each tank. Each treatment cell is assigned an initial holding tank allowing for independent treatments in each wetland cell to be conducted. However, the design also features the ability to link two of the holding tanks together, thereby doubling the amount of influent and allowing for the use of two treatment cells in conjunction as a hybrid treatment (See Figure 3). It is necessary to determine the cost of water transport to and from the facility when calculating an overall estimate of long-term operational costs for a business proposal.

3.7 Cell Design

A major consideration in the creation of a wetland cell is the basin morphology, which has implications for the hydraulic efficiency and residence time. The cells in this design measure 2 meters wide by 4 meters long by 1 meter deep, and are designed to operate individually or as a pair in series, dependant on the experimental design requirements (See Figure 4). The long cell dimensions have been selected to maintain an appropriate hydraulic efficiency, particularly when paired with significant vegetation and an initial evenly distributed flow. By contrast, S-shaped cells produce the highest hydraulic efficiency initially, but promote channelization, (much like a river channel) where differing velocities on the inside and outside of the channel will cause erosion of the substrate (Haakensen, 2016, pers. comm., March 9). This will quickly reduce the hydraulic residence time and the treatment efficiency of the wetland cell. However, should differing cell shapes be required for experimental purposes, the concrete basin can be filled with a substrate, such as sand, and the desired morphology molded prior to inlaying the impermeable liner.

Several options for the treatment cell liner are available for use with the design, such as the Rhino Mat 750 (Interwrap, Vancouver, Canada), a robust impermeable liner, which has been utilized in other systems. Due to the potential abrasive effects of removing substrate and vegetation over several periods of experimentation, an impermeable membrane will be utilized in conjunction with a durable basin to stop contamination of the underlying soil. Pre-cast concrete basins will house and maintain a rigid cell body, while a geomembrane will further enhance impermeability. Though concrete is not completely impermeable, it is highly resistant to the mechanical strain of the removal and addition of vegetation and can maintain its structure, despite climatic conditions such as frost heave and contraction. Concrete, therefore, will allow for precise observations on volume, flow and residence time within each cell.

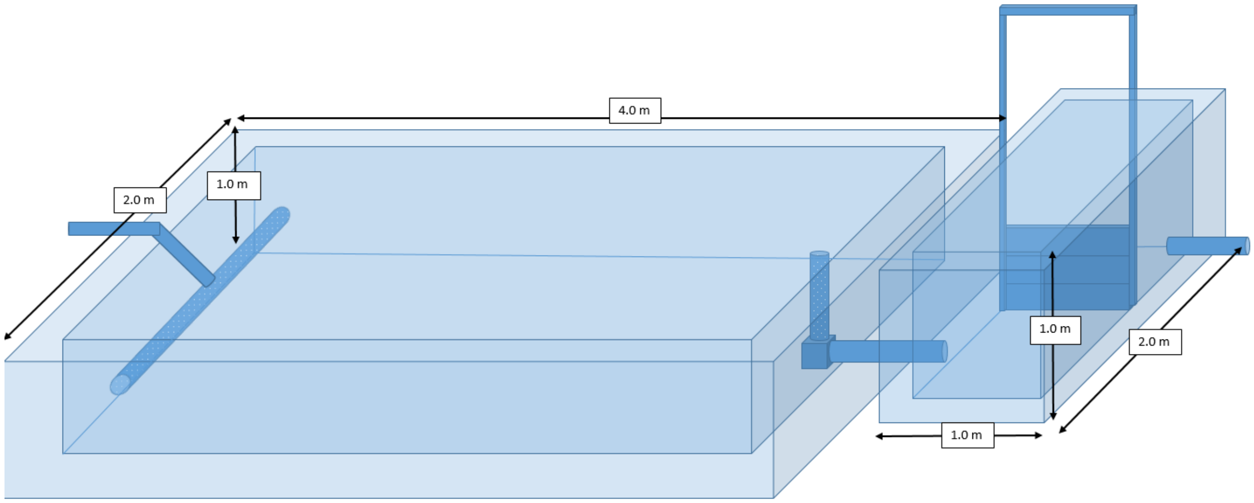


Figure 4: Proposed cell and weir channel construction with measurements

3.8 Flow

A means of inducing and controlling flow is vital in the function of a passive treatment system. According to reviewed literature maintaining a constant flow is an effective means of preventing freezing within pipes and water courses (Akyurt *et al.*, 2002). This report proposes the implementation of mechanical pumps despite the potential for added cost and increased power consumption. As a research facility primarily concerned with addressing knowledge gaps and accommodating precise experimental design, the most efficient way to maintain an accurate, minimum and constant flow rate in the system is through the installation of mechanical pumps.

Mechanical pumps require less monitoring of water levels and permit the accurate setting of flow rates, leading to more precise experimental design in future research initiatives. Furthermore, due to intermittent access to water on site, forced flow rates through a pump fed system will maintain a constant flow rate regardless of the water level within the tank. The DURA 10 peristaltic pump

(DO00032, ProMinent, Guelph, Canada) has been selected for use in the overall design due to its precision and variable flow rate between 5 to 53 liters per hour (see Supplementary Information for further specifications and information). Each pump has a draw of over 12 V so alternative energy sources are not viable currently. In addition, the pumps must be housed in an insulated pump house and maintained above 0 °C. Insulated housing will be created using plywood board and panel insulation containing the pumps and small heaters/heat trace run on a thermostat to conserve energy should the internal temperature drop below 0 °C.

To accommodate a reduced budget, a gravity fed system would eliminate the need for power and would be less costly than implementing pumps. However, gravity fed systems are only applicable if a hydraulic head is maintained in the holding tanks. This would require continuous observation and maintenance of a significant head height within the tank. Indeed, the lower the head height in the water tank the lower the flow rate through the pipes, and therefore the greater risk that the system could freeze. This would also limit the precision of the flow rate, and would be detrimental for the determination of residence times within the cells. A passive gravity fed system would be much more applicable in-situ at a mine site where a consistent flow rate from a groundwater or surface source is possible.

3.9 Piping

Pipe material is an important consideration when investigating the susceptibility of a pipe to freezing. Taking Table 1 into account, PVC or plastic will be used. Metal is durable but expensive and, with a high thermal conductivity, susceptible to freezing. PVC offers satisfactory resistance to saturated aqueous solutions common to mine water contaminants such as arsenic, cadmium, copper, iron, magnesium, manganese, mercury, silver, lead, and zinc, though it can be degraded or interact with chemicals, particularly acids, and thus care should be taken to consult a chemical performance chart prior to experimentation (See Supplementary Information).

Piping	**Material**	**Thermal Conductivity (W/mK)**
Steel	Carbon Steel	54
Copper	Copper	401
PEX	Cross-linked high-density Polyethylene	0.51
CPVC	Chlorinated Polyvinyl Chloride	0.14
PE	Polyethylene	0.38
PVC	Polyvinyl Chloride	0.19

Table 1: *Thermal Conductivity of Tubing Materials* (Adapted from Manufactures Monthly, 2009, Thermal Conductivity of Some Common Materials, 2005, EMCO Industrial Plastics, 2009)

As previously stated, maintaining a minimum flow rate of water is a key factor in reducing the potential for freeze-up of pipes. Regardless of pipe material, insulation reduces the minimum flow rate required. Figure 5 demonstrates a method of insulating the water pipe to contain insulation and guard against moisture. Given the residence time of 1-10 days required for the treatment system, the volume of the cells, and the minimum flow rate required to prevent pipes from freezing; it is recommended that piping transporting water be a half inch (½”) in diameter.

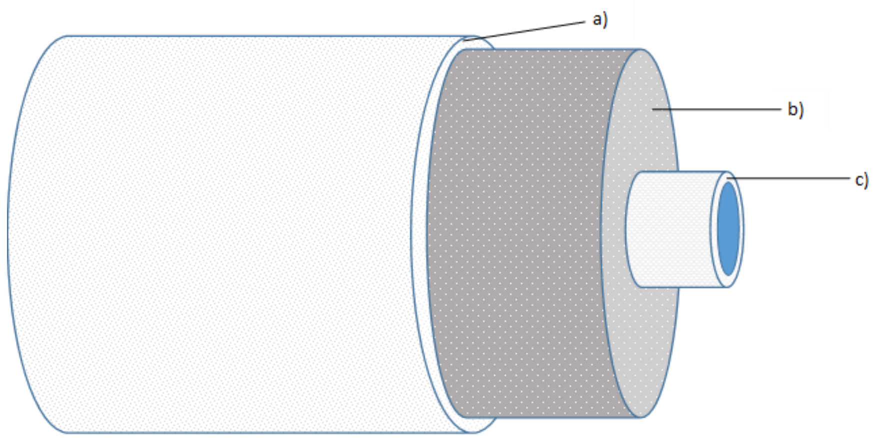


Figure 5 - Illustration of potential pipe insulation to guard against cold and precipitation. Note a) outer PVC pipe, b) pipe insulation, and c) inner PVC pipe accommodating the flow of water.

Depending on the experimental design, whether it requires two cells in series or four separate treatments, ½” side loading valves will shunt water to different areas of the treatment facility. These side loading valves direct water from one tank to another (as seen in Figure 3) and allow for the combination of two 1700 IMG tanks for use in an experiment requiring two wetland cells operating in series. If four separate treatments (and therefore, four separate cells) are required, side loading valves will be manipulated to ensure that each holding tank feeds an individual wetland cell.

3.10 Instrumentation

A significant component of this research facility is the installation of multi parameter sensors connected to wireless telemetry that broadcast remotely to the Yukon Research Centre Laboratory. This installation permits the real time quantification of various water quality measurements, including temperature, pH, conductivity, oxidation-reduction potential (ORP), and dissolved oxygen (DO), pre and post passive treatment in the system. Currently two providers source the instrumentation and telemetry required, Campbell Scientific Corp. (Edmonton) and Aquatic Life Ltd. (Manitoba). Costing for instrumentation and telemetry is based on information received from Campbell Scientific, due to the comprehensiveness of their sales quote. The sales quote for Aquatic Life Ltd. is included in Supplementary Information.

Figure 3 displays the potential placement of sensors (yellow circles) within the treatment system for best sampling practices. It is conservatively estimated that the system would require nine sensors; two for each of the four treatment cells and one for the terminal holding pond. The pair of sensors in each cell monitor water quality as water enters the cells and following treatment. The sensor mounted within the terminal holding pond monitors the overall contaminant load prior to post treatment removal and transport. This may be necessary for health and safety considerations.

Online monitoring of the passive treatment system requires the installation of a remote monitoring radio station within the treatment wetland, to log and transmit data generated from the sensors. A base station and relevant software will intercept the radio transmissions and display the logged data. All sensors and the remote monitoring station would be powered by 12V solar panels in order to reduce electricity consumption.

3.11Water Level Control

Maintaining a consistent water level is key to the survival of many wetland plant species and for the optimum operation of a treatment wetland. This design utilizes a secondary smaller cell to serve as a weir channel to adjust the height of the water level within the preceding treatment cell, allowing the cell to be flooded or drained depending on experimental requirements (see Figure 6). Furthermore, the weir could open fully to allow for the complete drainage of the cell when routine maintenance or removal/implementation of substrate and vegetation is required. A v-notch is optional to calculate the flow rate of water leaving the cell.

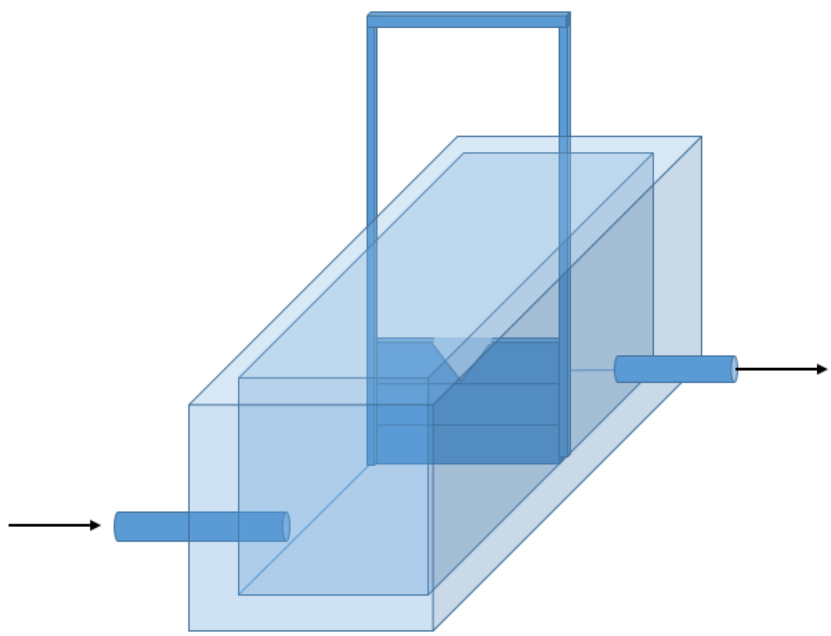


Figure 6: Proposed design for V-notched weir to control water level in preceding cell and determining flow rate.

3.12 Terminal Holding Pond

Following experimentation, contaminant concentrations cannot be guaranteed to be below minimum regulatory standards. Therefore, it is imperative that waste water is contained, transported, and treated elsewhere to ensure appropriate remediation. A final holding pond is required to contain the effluent from all four tanks, as well as any other surface water inputs (i.e. precipitation). Considering each initial tank holds 1700 IMG of water, a pond with a capacity of ≥6800 IMG is required. This is the equivalent to approximately 31 cubic meters. Additional space is required to accommodate any external inputs as well as potential delays in water drainage/transport to ensure experimentation is not disrupted. Given the potential for water to be significantly contaminated post treatment, it is advised that the holding pond has no substrate and that margins remain un-vegetated. This renders the holding cell unappealing to colonization by wildlife and vegetation, mitigating the potential biotic uptake of contaminants.

4. Budget

Table 2 provides an estimated cost for materials and services for the implementation of the project. Where possible, local sources of material and labour are considered. However, due to the complexity of the project and a requirement for customized materials, some out of territory sources are unavoidable. Labour, unless otherwise included in a sales quote, has been omitted due to uncertainty over the timeframe of construction. However, implementation on Yukon campus offers the opportunity for cooperative interdepartmental initiatives to alleviate labour expenses (i.e. carpentry program assists with pump house construction, pipefitting program installs pipe system, etc.). Furthermore, prior to approval and construction, it is recommended that the designs are ratified by an engineer, likely at additional cost, to ensure design feasibility and efficient implementation.

Item	Supplier	Catalogue Number	Quantity	Rate	Total
Tanks					
1700 IMG 95" D 75" H	Hurlburt Enterprises Inc.	C1700	4	$2,175.00	$8,700.00
Piping					
1/2" PVC 10'	Home Hardware	3262-123	14	$8.29	$116.06
1" PVC 10'	Home Hardware	3262-141	1	$17.49	$17.49
1/2" Flexible pipe 20'	Home Hardware	3298-149	1	$4.39	$4.39
2" PVC 10'	Home Hardware	3262-178	16	$23.99	$383.84
Pipe Insulation 1/2" x 3' L	Home Hardware	5510-164	74	$1.39	$102.86
1/2" Elbow joint	Home Hardware	3262-882	16	$1.29	$20.64
2" Elbow joint	Home Hardware	3262-873	16	$3.49	$55.84
1/2" Side load micro valve 300	Hurlburt Enterprises Inc.	LV050SLV	4	$21.47	$85.88
1/2" T joint	Home Hardware	3262-953	4	$1.29	$5.16
2" Ball valve	Home Hardware	3282-913	4	$24.99	$99.96
Pipe tracing heat cables 18'	Home Hardware	5513-553	4	$44.99	$179.96
Pumps					
Verderflex DURA 10 Peristaltic Pumps	ProMinent	DO00032	4	$2,985.00	$11,940.00
Motor and Variable Frequency Drive Assembly	ProMinent	DO00032	4	$1,452.00	$5,808.00
Spare hose	ProMinent	7903732	4	$219.99	$879.96
1L Container Verderlube	ProMinent	7903714	2	$39.99	$79.98

Table 2: Estimated budget of materials and services required for implementation excluding additional labor fees, site grading, and long term operational and maintenance costs.

Item	Supplier	Catalogue Number	Quantity	Rate	Total
Pump housing					
2"x2" x 8' L	Home hardware	2805-399	2	$2.59	$5.18
4'x8' 1/2" OSB board	Home Hardware	2814-861	14	$18.99	$265.86
15"x32' Insulation	Home Hardware	2648-328	2	$22.99	$45.98
3 Heat settings heated blanket 50"x60"	Home Hardware	3814-952	4	$64.99	$259.96
Hinges - 2x 8" black strap hinges	Home Hardware	2373-700	3	$21.99	$65.97
Gap and crack low expanding foam 850g	Home Hardware	2030-961	1	$19.99	$19.99
Lock - 2-7/8" shrouded	Home Hardware	5438-332	2	$24.99	$49.98
100 Pack 1-5/8" #6 green square deck screws	Home Hardware	2182-388	1	$7.69	$7.69
Liner					
Cells - RhinoMat 750 at $0.23 per ft^2	Interwrap	Custom order	4	$89.13	$356.50
Settling pond - Rhino Mat 750 at $0.23 per ft^2	Interwrap	Custom order	1	$215.39	$215.39
Concrete					
Precast basin walls 8'x12'x4'	Langley Concrete Group	Custom order	4	$7,155.30	$28,621.20
Precast basin bottom 8'x12'	Langley Concrete Group	Custom order	4	$7,030.00	$28,120.00
Precast Type 1 oil interceptor (weir channel)	Langley Concrete Group	Custom order	4	$1,050.00	$4,200.00
Borehole drilling (per inch, 2" holes)	Langley Concrete Group	Custom order	24	$25.00	$600.00
Freight - Concrete basins	Langley Concrete Group	Custom order	1	$9,000.00	$9,000.00
Weir	Armtec	Custom order	4	$13,323.91	$53,295.64
Freight - Weirs	Armtec	Custom order	4	$2,000.00	$8,000.00

Table 2 Continued: Estimated budget of materials and services required for implementation excluding additional labor fees, site grading, and long term operational and maintenance costs.

Item	Supplier	Catalogue Number	Quantity	Rate	Total
Fence					
Chain link 5-6' per foot	Contractor Estimate	Job quote	249	$30.00	$7470.00
20' Swinging Gate	Contractor Estimate	Job quote	2	$800.00	$1,600.00
Landscaping					
Landscaping - grading and digging	Arctic Backhoe Services Ltd.	Job quote			Pending
Electrical Work					
Subpanel Installation (Jason, Jaytech Ltd.)	Jaytech	Job quote	1	$5,000.00	$5,000.00
Online Monitoring					
Remote Station Components					
Datalogger with 512K RAM Memory	Campbell Scientific	CR206X	3	$1,255.00	$3,765.00
Interface Cable USB-to9-Pin Males RS-232 Cable (6 foot)	Campbell Scientific	L17394	1	$40.00	$40.00
Battery Rechargeable Lead Acid 12 Volt 42 Ahr w/PS100 Connector	Campbell Scientific	BP42	3	$740.00	$2,220.00
Mount Kit Quick Deploy Wiring Cover for 12/14-ENC 14/16	Campbell Scientific	C1529	1	$24.19	$24.19
Solar Panel 30 Wat 12 Volt with Mount and Regulator	Campbell Scientific	MSX30R	3	$910.00	$2,730.00
Enclosure Fiberglass 12 Inch x 14 inch White	Campbell Scientific	ENC 12/14	3	$645.00	$1,935.00
Enclosure Mount Kit for Tower and Mast Mount	Campbell Scientific	ENC MOUNT	3	$142.00	$426.00
OTT Pressure Level Sensor with SDI Output	Campbell Scientific	PLS-L	1	$2,165.00	$2,165.00
Hydrolab HL Series Multi parameter Instrument	Campbell Scientific	HL4	8	$13,055.00	$104,440.00
Hydrolab Cable HL Series 5 m	Campbell Scientific	Cz005	8	$970.00	$7,760.00
Hydrolab Accessory HL series SDI-12 communication module	Campbell Scientific	H9039600	8	$370.00	$2,960.00

Table 2 Continued: Estimated budget of materials and services required for implementation excluding additional labor fees, site grading, and long term operational and maintenance costs.

Item	Supplier	Catalogue Number	Quantity	Rate	Total
Terminal Expander Components					
Connector Terminal Acc 5" Din-Rail Mounting Kit	Campbell Scientific	L25458	3	$31.33	$94.00
Connector Terminal Acc End Plate for Terminal Block Rail Wago 279-339	Campbell Scientific	L15907	6	$1.83	$10.97
Connector Terminal Acc Horizontal Jumper for Din Rail Connector Wago 279-402 ROHS	Campbell Scientific	L15909	9	$2.00	$18.00
Connector Terminal 3-Pin 4mm Spring Loaded Din Rail Connector Wago 279-681 ROHS	Campbell Scientific	L15920	18	$5.79	$104.25
Remote Station Radio Components and Tripod					
Coax Antenna Cable Reverse Polarity	Campbell Scientific	COAX RPSMA	3	$45.00	$135.00
Omni Antenna 3 dBd Gain w/mounts	Campbell Scientific	L14221	3	$295.00	$885.00
Tripod 7-10' Adjustable Galvanized Steel with Grounding kit	Campbell Scientific	CM106B	3	$1,300.00	$3,900.00
CM106B Guy Kit 15 ft cables	Campbell Scientific	L29813	3	$530.00	$1,590.00
Base Station Radio and Wireless Network Interface					
Enclosure Fiberglass 10x12" White	Campbell Scientific	ENC 10/12	1	$555.00	$555.00
Enclosure Mount Kit for Tower and Mast Mount	Campbell Scientific	ENC MOUNT	1	$142.00	$142.00
Tripod/Mast Assembly 1.5m	Campbell Scientific	L16776	1	$136.60	$136.60
Wireless Network Link Interface	Campbell Scientific	NL240	1	$740.00	$740.00
Interface Cable	Campbell Scientific	L10873	1	$7.00	$7.00
Spread Spectrum Radio	Campbell Scientific	RF401A	1	$915.00	$915.00
Omni Antenna 3 dBd Gain w/mounts	Campbell Scientific	L14221	1	$295.00	$295.00
Coax Antenna Cable Reverse Polarity	Campbell Scientific	COAX RPSMA	1	$45.00	$45.00
Power Supply Adaptor AC	Campbell Scientific	L15966	2	$45.00	$90.00

Table 2 Continued: Estimated budget of materials and services required for implementation excluding additional labor fees, site grading, and long term operational and maintenance costs.

Item	Supplier	Catalogue Number	Quantity	Rate	Total
Software					
Datalogger Support Software - Loggernet	Campbell Scientific	LOGGERNET	1	$590.00	$590.00
Consulting and Installation Estimated Expenses					
Project Support Time - For datalogger programing, testing, etc.	Campbell Scientific	Consulting	5	$130.00	$650.00
Travel Expenses - Excluding meals	Campbell Scientific	Travel	1	$2,211.00	$2,211.00
Travel Expenses - Meals	Campbell Scientific	Meals	1	$321.50	$321.50
Consulting Support Time - Travel time	Campbell Scientific	Consulting	14	$130.00	$1,820.00
Consulting Support Time - On-site installation	Campbell Scientific	Consulting	24	$130.00	$3,120.00
Consulting Support Time - On-site training	Campbell Scientific	Consulting	8	$130.00	$1,040.00
TOTAL					**$323,559.87**

Table 2 Continued: Estimated budget of materials and services required for implementation excluding additional labor fees, site preparation, and long term operational and maintenance costs.

5. **Appendix**

5.1 Calculations

Mathematical calculations were used to estimate size requirements for initial holding tanks, pipes, and the terminal holding pond as well as pump flow rates requirements. These calculations are based on hypothetical needs of a research group and should thus be revaluated prior to experimentation.

5.1.1 Cell Volume

An estimated average volume of water for each cell, during a given treatment, was calculated using a cell that was half filled with water, assuming no substrate:

$$Volume\ (V) = LWD = (4\ m) \cdot (2\ m) \cdot (0.5\ m) = 4\ m^3 \quad (1)$$

$$4m^3 = 880\ IMG\ per\ cell \quad (2)$$

5.1.2 Pump Flow Rates

To make an appropriate estimate of pumps required for the design, the flow rate (*Q*), in m^3/day was calculated using an equation from Crites *et al.*, (2014):

$$Q = \frac{LWDn}{t} \quad (3)$$

Where, *LWD* is equivalent to *V* (m^3) as shown in (1); *n* is the porosity of the cell, as a percentage, where fully vegetated is 0.65-0.75 and open water is 1.0 (E.P.A, 2000); and *t* is the hydraulic residence time (days). To achieve a median hydraulic residence time of 5 days in a fully vegetated cell, the following calculations must be made:

$$Q = \frac{4\ m^3 \cdot 0.75}{5\ days} = 0.6\ m^3\ day^{-1} \tag{4}$$

$$0.6\ m^3\ day^{-1} = 41.7\ L\ hr^{-1} \tag{5}$$

As demonstrated above in (4) and (5), a flow rate of 41.7 $L\ hr^{-1}$ will be required, justifying the use of the DURA 10 peristaltic pump, with variable flow rate of 5 to 55 $L\ hr^{-1}$, previously recommended.

5.1.3 Initial Holding Tank Volume

An important consideration of the design is the initial holding tank volume. An oversized tank may be unsuited to the available area and could further shadow and inhibit plant growth and solar collection. However, water transport to and from the research facility is a potential long-term operating cost which could be reduce with a greater initial tank volume. Given the previously calculated flow rate (4) and a reasonable time between refills being 10 days, an initial tank volume can be inferred:

$$0.6\ m^3\ day^{-1} \cdot 10\ days = 6\ m^3 \tag{6}$$

$$6\ m^3 = 1320\ IMG \tag{7}$$

Given a hypothetical experimental design, the calculated volume in equation 7, an initial holding tank with a volume of 1700 IMG would provide ample time between refills.

5.2 Options to Mitigate Cell Freezing

5.2.1 Minimum Flow Rate

Utilizing a memo by Stephenson (1964) it is possible to estimate the minimum flow rate of water to prevent pipes from freezing. The calculations listed in the previously named memo include pipe material, insulation material, insulation thickness, ambient temperature, and wind speed as factors influencing potential freezing. Maintaining a consistent minimum flow is vital to ensuring the continued operation of the passive treatment facility during winter months.

5.2.2 Ice-Air Insulation

Pipes utilized in the facility design are insulated and protected from the ambient conditions, however, the surface of the treatment cells will be open and relatively unprotected. Given the long retention time and slow flow rates of water, there is potential for the cell to freeze, disrupting treatment efficiency to varying degrees dependant on the ice thickness. One potential solution is to implement an ice-air layer (Figure 7) when average outside temperatures fall below zero. By flooding the wetland during initial sub-zero temperatures, a layer of ice forms over each cell. After a sufficient ice thickness has accumulated, the water level is dropped, creating a barrier of ice and air, insulating the flowing water beneath. Accumulation of snow over this ice layer serves as further insulation to the cell below. The treatment cell may operate at a reduced capacity, but will likely remediate water regardless.

Following a significant accumulation of snow, interference from wildlife, or warming temperatures; the ice layer may be prone to failure. In a method similar to that used in the creation of ice roads, an ice layer could further be prevented from collapse by reinforcing it with a layer of mesh or rebar during formation (Hastaoglu and Hakim, 1996; Makkonen, 2004; Government of Canada, 2006). As Figure 7 demonstrates, this could provide crucial structural stability to mitigate failure from the factors previously listed. Several studies suggest that structural support be incorporated as soon as possible into the bottom of ice formation, in order to maximize the reinforcing effects (Makkonen, 2004; Treasury Board of Canada Secretariat, 2006). Retention of detritus both within the ice and over top of the water surface could provide additional insulation and structural support.

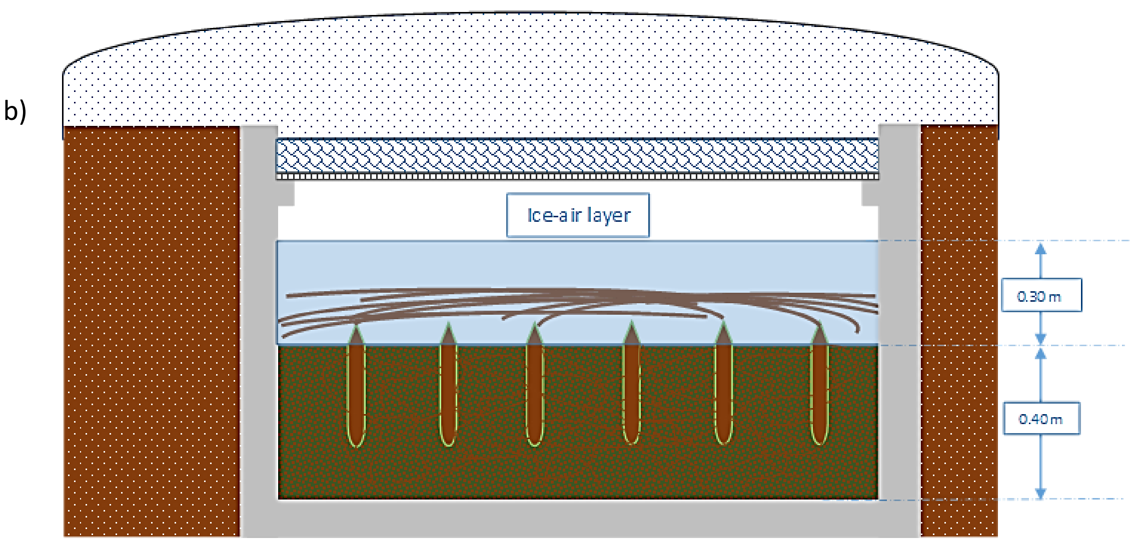


Figure 7: Implementation of ice-air layer to increase insulation of wetland cells. Note a) demonstrates flooding of the cell and placement of reinforcing metal mesh just prior to sub-zero temperatures and b) demonstrates the formation of a reinforced metal-ice layer following a decrease in cell water level.

5.2.3 Burial and Heat Tracing

Another potential method for protecting and insulating pipes and cells from freezing temperatures is through burial. Along with a minimum flow rate and additional insulation, this could protect pipes from freezing and bursting. However, burial requires added excavation costs and reduces accessibility to pipes should maintenance be required. The experimental cells will be sunk to 0.75 – 1 meter below ground level in order to provide some external insulation and reduce the surface area exposed to the ambient air temperature and wind. Should complete isolation of the water surface within the cell be required, a horizontal subsurface orientation is advised during winter. Used in conjunction with the ice-air boundary layer and detritus, this cell orientation would allow for greater resistance to freezing than a surface flow cell orientation.

As needed, heat tracing tape can be implemented in conjunction with a thermostat for particularly susceptible sections of pipe. This is a common method used throughout the territory to keep septic systems and water wells from freezing during winter months. The thermostat ensures that heat tracing would only be activated at a given temperature thereby reducing the energy demand of the facility.

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