Technical Memorandum

To: WSP Canada Group Ltd.	**Project:** CVRD Liquid Waste Management Plan
From: Doug Grimes, Norman Joyal, Michelle van der Pouw Kraan, and Jason Yeung	
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Revision Log

Revision No.	Date	Revision Description
A	July 29, 2019	Initial Draft Issued to WSP Canada Group Ltd.
B	August 23, 2019	Updated Draft Issued to WSP Canada Group Ltd.
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1.0 Introduction

WSP Canada Group Limited (WSP), has been retained by the Comox Valley Regional District (CVRD) to complete an alignment evaluation to replace an aging sewer forcemain in Comox, BC. The work is part of preparation of an updated Liquid Waste Management Plan. As part of the study, WSP identified specific sections of the route that encountered elevation gains where a trenchless option was a way of avoiding these constraints. WSP retained McMillen Jacobs Associates (McMillen Jacobs) to undertake a conceptual trenchless study and constructability assessment including rough order cost estimates. The conceptual trenchless sections include trenchless crossings of Comox Road Hill and Lazo Road Hill.

2.0 Background and Key Assumptions

2.1 General

The following inputs were provided by WSP for use in this concept study:

- Google Earth .kmz file of the current preliminary force main alignment
- Google Earth .kmz file of the auger hole locations that were drilled near the Lazo hill
- Topographic profile of the current preliminary force main alignment
- The alignment elevations will be optimized in conjunction with the groundwater study to maximize the trenchless crossing length and depth with respect to the hydraulic grade line and hydraulic requirements
- Technical Memo titled “CVRD Liquid Waste Management Plan – Preliminary Hydrogeological Assessment of Tunnel Options” (GW Solutions Inc., 2019)
- Technical Report titled “Geotechnical Assessment Report – Pre-Implementation Phase, Proposed Comox No.2 Pump Station, Comox, BC” (Exp Services Inc., 2018).

2.2 Geotechnical and Hydrogeology

A brief search of online records for geotechnical and hydrogeology information of the area identified the following applicable references:

- Humphrey, 2000. Regional District of Comox-Strathcona Aquifer Classification Project Report.
- EBA Engineering Consultants Limited (EBA), 2005. Geotechnical Desktop Study – Proposed Sewer Line Realignment Courtenay/Comox, BC.
- Water well drill hole logs within the Lazo Hill area from the BC Water Resources Atlas. Three water well drill hole logs were provided in 2019 within the Comox Hill from the BC Water Resource Atlas.

The following geotechnical and hydrogeology information was provided by WSP:

- Technical Report titled "Geotechnical Assessment Report – Pre-Implementation Phase, Proposed Comox No.2 Pump Station, Comox, BC" (Exp Services Inc., 2018).
- Technical Memo titled "CVRD Liquid Waste Management Plan – Preliminary Hydrogeological Assessment of Tunnel Options" (GW Solutions Inc., 2019).

These references provide useful regional and local geological information which is summarized below.

<u>Surficial Geology - Regional</u>

Humphrey (2000) contains a good summary of the regional surficial geology as described below.

- The area has an extensive history of glaciation with deposits from numerous glacial and interglacial periods represented.
- Bedrock in the area consists largely of shale, sandstone, coal and conglomerate of the Nanaimo Group (late Cretaceous).
- Quadra Sediments overly bedrock in most areas and consist of 3 layers (in order of oldest to youngest): marine clays; silt, sand and gravel; and white sand.
- Vashon Till overlies Quadra Sediments in most areas and consists of dense silt, clay and gravel mixtures.
- Marine/Glacio-Marine Veneer overlies Vashon Till in most areas and consists of stoney clay.
- Capilano Sediments overly the Marine/Glacio-Marine Veneer in most areas and consists of silt, sand and gravel. The sediments are post-glacial in origin and represent deposition in fluvial, lacustrine, deltaic, shoreline and eolian environments. As a result, the composition of this unit varies greatly. The unit is present at surface in most areas of the region and is the material that is expected to be intersected in the proposed open cut and trenchless sections of the sewer force main.

<u>Surficial Geology - Local</u>

EBA (2005) undertook a site visit and inspection of local soil exposures along Torrence Road and Lazo Road in the vicinity of Lazo Hill subject area and noted the following:

- There is no indication that bedrock would be intersected in the proposed trenchless alignment in the Lazo Hill.

- Cut slopes exposed primarily sand or sand and gravel with trace silt.
- Surficial materials appear to be well drained with no indication of a regional groundwater table at the elevation of trenchless alignment in this study. However, localized perched water tables could be encountered during trenchless construction.

EXP Services Inc (2018) conducted auger hole drilling within the Lazo Hill vicinity. The auger holes generally showed that the soil stratigraphy beyond surficial fill generally consisted of sand, silty sand, gravelly sand, sandy silt, and silty clay.

<u>Hydrogeology</u>

A series of 6 water well records were obtained within the Lazo Hill area and while the logs were highly variable (likely related in part to varying logging skills amongst drillers) they generally concur with the above summary. The depth of the successful wells was in the range of 20 – 50 m with one dry hole to 80 m. The key holes along the conceptual alignment were drilled to aquifers at 45 m (Well 12611) and 43 m (Well 74280) depth which supports our assumption that the elevation of the proposed trenchless installation is above the regional water table. Not all water well record logs recorded elevations for the Lazo Hill area; however, for the logs that had this information recorded, it was recorded as exactly 0 meters above sea level, which may lend to the indication that the recorded elevation may not be accurate.

McMillen Jacobs was only able to obtain 3 water well records (#12296, #77172, and #77100) that are within the Comox Hill Area from BC Resource Atlas. The bottom depths of the wells ranged from approximately 2.5 m to 12.5 m from ground surface. Only one water well log (#12296) had the ground surface elevation surveyed. Based from this record, the ground surface was approximately 4.6 m above sea level and the well depth was 2.5 m, providing a bottom of well elevation of 2.1 m t above sea level.

Our findings are consistent with the 2019 hydrological assessment conducted by GW Solutions, which concludes:

- Groundwater in wells drilled northeast of Hawkins Road in the Quadra Sand Aquifer (#408) is greater than 40 m and as much as 60 m below ground level, and therefore groundwater is not expected to exceed above 14 m elevation in the Lazo Hill area based on cross section provided by GW Solutions (See Figure 1 below). The area northeast of Hawkins Road is the approximate location of where the Lazo Hill trenchless alignment is located.
- The depth to groundwater in wells southwest of Hawkins Road is relatively shallow, typically less than 10 m below surface. Only a small portion of the alignment is located southwest of Hawkins Road and so assumed to be above the ground water table since it is the start of the alignment and will be at relatively shallow depth from ground surface.

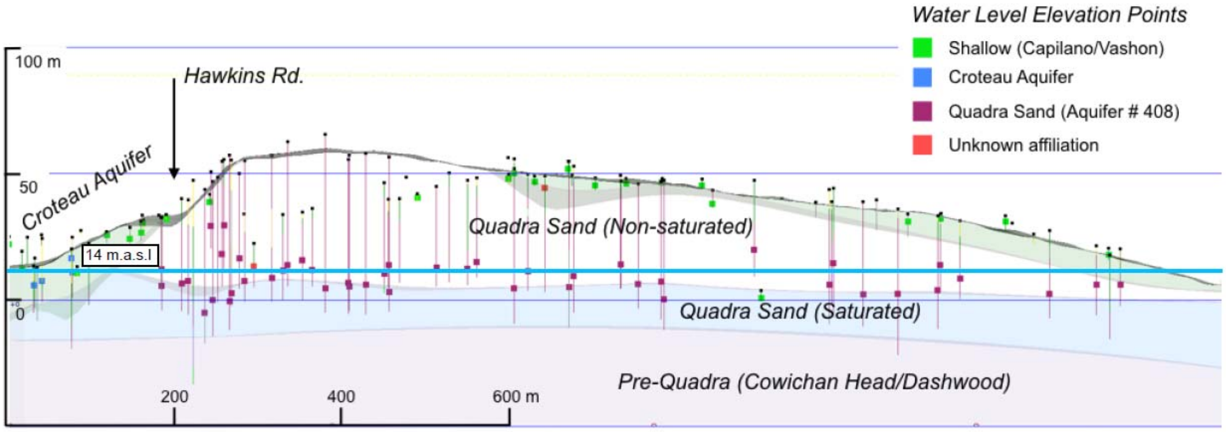

Figure 1: Hydrogeological profile provided by GW Solutions. Blue line shows the interpreted high point of the water table in the Quadra Sand Aquifer at 14 m elevation.

2.3 Key Assumptions

For this study, based on the previous discussion we assume that the trenchless alignments in the Comox and Lazo hills are above the water table in primarily cohesionless ground with the intermittent presence of fine-grained silts and clays. Perched groundwater conditions would be realistic to expect, with a short duration initial flush flow followed by formational "bleeding". The expectation is that any perched groundwater encountered along the alignments can be handled with routine use of sumps or drainage by gravity.

Considering the varied depositional environments described, the presence of cobbles and boulders cannot be ruled out. The trenchless construction approach should anticipate their presence and provide flexibility for their removal or dealing with them, if encountered.

3.0 Assessment of Conceptual Trenchless Options

3.1 Design Criteria

The following are the key criteria (or objectives) that would drive the concept design:

- Make the alignment as short as possible to minimize cost, while also considering the hydraulic requirements and costs associated with pumping.
- Straight, sloped trenchless alignments will simplify pipe installation and optimize hydraulic performance.
- Emphasis on work areas and portal sites with flexible access and staging configurations.

No consideration has been made of property ownership or right of way. We understand such considerations will be considered in future phases of this study.

3.2 Conceptual Alignment

Figure 2 shows the conceptual alignment profile for the trenchless crossings within the current preliminary topography along the entire Comox Force Main Upgrade project. The trenchless alignment elevation and length may be lowered and lengthened while remaining above the water table to benefit hydraulic pumping requirements. Based on our understanding of the groundwater conditions and topography, the elevation of trenchless alignments can be dropped to as low as 20 m. In Figure 2, the green shading along the trenchless alignment profile shows where ground elevation is above elevation 20 m and is considered feasible for trenchless construction.

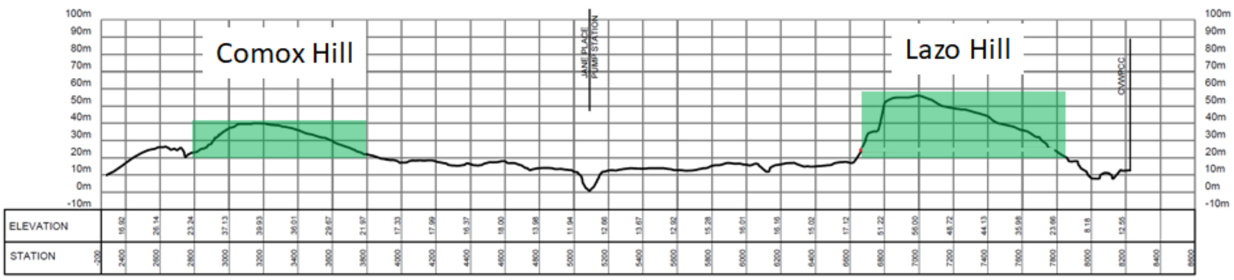

Figure 2: Topographic profile of the trenchless sections. Green shading represents feasible elevations of the trenchless alignments based on current understanding of groundwater conditions.

3.3 Trenchless Construction Methods

Three methods are identified that could be applicable: shield tunneling, microtunneling, and horizontal directional drilling (HDD). The pipe diameter is such that these various trenchless methods could be considered.

The anticipated geology (Section 2) consists of sand with gravel and silt at an elevation above the water table, except for possible perched water conditions. Based on a preliminary assessment of anticipated ground conditions, the trenchless construction methods will have to address:

- Measures to address short standup time due to ground behaviours ranging from raveling and running ground.
- Stabilizing the boring face in ground conditions ranging from raveling and running ground, and to allow access to the boring face in the instance boulders need to be removed (for shield tunneling and microtunneling).
- An expeditious installation of an initial support system.
- Ground disturbance during the removal of boulders, if encountered.
- Provide borehole or face support with an engineered drilling fluid in the case of HDD or slurry microtunneling, respectively.

A high-level description of each trenchless method is provided below. Refer to the following subsections for further information on each method.

<u>Shield Tunneling</u>: Shield tunneling involves advancing a tunnel shield forward by pushing off an initial support system. The shield is transported and maneuvered through the ground by hydraulic jacks and typically pushes off the previously installed initial ground support nearest the face of excavation. Shield tunneling can use a range of different excavation methods, ranging from hand to mechanical excavation. Shield tunneling is typically a two-pass method where the product pipe is installed inside an initial ground support system and grouted in place.

<u>Slurry Microtunneling</u>: is a mechanized, remote-controlled, slurry-based, pipe jacking tunneling method where a microtunnel boring machine (MTBM) is advanced through the ground by means of a main jacking station that jacks the machine and pipe string forward by successively adding pipe or casing segments. Drilling fluid is used throughout the tunneling process to counterbalance hydrostatic pressure and provide nominal face support, and to transport the cutting-laden slurry back to the surface for processing. Slurry microtunneling can be a one or a two-pass method, where the product pipe is either installed directly behind the MTBM (one-pass), or a casing is installed behind MTBM and the product pipe is subsequently pushed or pulled through (two-pass).

<u>HDD</u>: is a trenchless construction method where a small diameter pilot hole is drilled along an inverted-U profile between surface entry and exit points. The pilot hole is enlarged by a reamer attached to one end of the drill string which is pulled or pushed through the pilot hole to enlarge the hole diameter. Multiple passes of reaming will occur until the designated diameter of borehole is reached. Drilling slurry is constantly pumped throughout the drilling process to transport cuttings out of the borehole. The drilling fluid also stabilizes the borehole with hydrostatic pressure generated by the engineered drilling fluid whose density is greater than that of water. After the diameter of the borehole has been reached, the product pipe is pulled back in a continuous string from one end.

3.3.1 Shield Tunneling

Shield tunneling involves advancing a tunnel shield forward by pushing off an initial support system which can consist of steel ribs and lagging, or a segmental lining made of steel liner plate or precast concrete. For the 1.2m diameter pipe that is being considered, a shield on the order of 2.2 m diameter would likely be needed to overcome the anticipated ground conditions and to provide room for tunnel workers, ventilation, muck equipment, utilities, and pipe installation. If beneficial, the extra space in the tunnel could be outfitted with other smaller pipe for future use or operational flexibility.

The initial ground support is assembled in the tail of the shield and would likely consist of steel ribs and lagging, or bolted liner plate. Shield tunneling can utilize a variety of mechanical excavation methods, face support configurations, and tunnel face access to remove boulders.

Figure 3: Example of steel ribs and lagging (left), and bolted liner plates (right)

Shield tunneling includes the following methodologies:

- Digger shield with natural face support: This type of shield relies on firm ground support at the face under natural conditions. The natural angle of repose or the self-supporting properties of the ground maintains the face stability. Excavation methods within the shield can consist of hand picks, an excavator boom with bucket, or small road headers (see Figure 4).
- Digger shield with partial face support with sand shelves or pie shaped doors: This type of shield is suitable in loose sandy material and features horizontal plates that act as shelves to support the ground. Excavation methods within the shield can consist of hand picks, an excavator boom with bucket, and road headers (see Figure 4).
- Partial face rotary cutting shields: This type of a shield features a partial face cutting head that is rotated using a hydraulic or electric motor incorporated within the shield. The motors provide the required torque to excavate the ground.
- Full face rotary cutting shields: This type of shield is similar to the partial face shield but offers mechanical support to the ground for the entire face. This shield features hydraulically or manually adjustable doors within the cutting head that allow the operator to control the rate of excavation and access to break and remove boulders.

Figure 4: Example of a digger shield with partial face support and an excavator boom (left), and a digger shield with a road header excavator (right).

A digger shield with partial face support is considered the most suitable method for excavating the tunnel considering safety and the flexibility criteria in the event curves can optimize the alignment. A digger shield also typically has shorter lead times for procurement and a modest assembly process compared to other shield tunneling methods.

Tunnel boring machines (TBMs) are a more sophisticated type of single tunnel shield that have features such as a more robust cutting head and greater power. TBM's are more complex versions of rotary cutting shields listed in the last two bullet points above. Compared to simpler digger shields, TBMs have a higher capital costs, require longer lead times, and involve assembly time on site. The use of a TBM is considered a low possibility for the 1.2 m pipe diameter because the TBM would have to be advanced by pipe jacking and the distances impose limitations to that approach. A TBM would require the product pipe to be pulled or pushed through after installation of the initial casing since the minimum diameter feasible for TBM is larger than the conceptual 1.2 m product pipe diameter.

A minimum tunnel diameter of 2.2 m should be considered to promote tunnel efficiency for this smaller product pipe diameter and make up for tunnel volume lost to air ducts, muck carts and rails, and other utilities coming in and out of the tunnel. This should provide enough room at the face for the removal of boulders if encountered. Once the tunnel is constructed, it is conceivable that the product pipe could be pulled into the tunnel as one continuous pipe if there is enough space to layout, weld and test each pipe section. Otherwise, the pipe could be pulled into the tunnel as predetermined strings that are assembled during pullback or as individual pieces. An open tunnel complete with the initial liner provides flexibility for the material of the product pipe.

3.3.2 Slurry Microtunnelling

Slurry microtunneling is a trenchless construction method that uses a microtunneling boring machine (MTBM) to excavate a circular opening through the ground (see Figure 5). The excavated ground is transported from the face to the surface by a drilling fluid, where it's processed in a slurry separation plant, before returning to the face. Slurry microtunneling can counterbalance hydrostatic pressure and apply nominal pressure to maintain a stable face The MTBM is launched from the jacking shaft (see

Figure 6) and excavates along the proposed alignment until it breaks through into the receiving shaft. Each segment of the jacking pipe is coupled or welded in the jacking shaft and is jacked into the tunnel one at a time. The jacking pipe is typically reinforced concrete, steel, fiberglass reinforced pipe or polymer concrete pipe. Microtunnelling can install carrier pipe in one-pass or with a two-pass approach where the carrier pipe is installed in the jacked pipe. The MTBM method has a navigation system and can provide high line and grade accuracy in suitable ground conditions. Microtunnelsf can have curved alignments (horizontal or vertical) but this adds to the complexity of the execution and may limit the number of eligible contractors. MTBM is a similar method to using a tunnel boring machine (TBM), however microtunneling is smaller in diameter, the MTBM and pipe are advanced by pipe jacking methods, it is remotely controlled from surface, and an engineered drilling fluid plays a significant role in the mining process especially when it comes to counterbalancing hydrostatic pressure in cohesionless ground.

Figure 5: Example microtunnel boring machines. The cutter face is designed to suit the anticipated ground conditions.

Figure 6 - Typical microtunnelling setup in jacking shaft. The direction of drive is to the top of the picture. The jacking equipment is the red and yellow frame surrounding the MTBM.

MTBM is feasible in a wide array of ground conditions, including below the groundwater table. The MTBM provides constant face pressure to counterbalance earth and groundwater pressures by pumping engineered drilling fluid (e.g. bentonite slurry) into the MTBM face. The slurry is pumped to the surface to a slurry separation plant for cleaning, then returned to the face. However, microtunnelling in soft ground conditions can be challenging as machines are prone to settle in soft ground, and steering can be difficult to initiate as the ground is too weak to provide the necessary reaction to steering adjustments.

Microtunneling is best in ground conditions below the groundwater because it is slurry based, so the face and groundwater can be supported with pressure. This would be an absolute must for the cohesionless ground conditions. The slurry must be an engineered drilling fluid to control systemic settlement and not water-only for which settlement of unknown magnitude is all but guaranteed. The drive distance would also necessitate a fully lubricated and pressurized annular space and intermediate jacking stations. The advantage is that a one-pass direct installation of the carrier pipe could be done with microtunneling. Concrete, fiberglass, or polymer-concrete pipe could be considered. The drawback for a direct install of a 1.2 m pipe, is the drive length and machine demand for torque that can only be provided by a machine larger than 1.2 m, but a larger diameter could impact hydraulic flows.

Other considerations for microtunnel at the proposed tunnel length are degradation of the laser over distance (e.g. due to dust), but more importantly tool survivability if the ground conditions are abrasive. Being above the groundwater, the MTBM can be designed for face access to replace tooling if needed, but that could require a machine diameter greater than 2.2 m to accommodate that access. Nevertheless, ground abrasivity will be an important characteristic to investigate in the design process.

3.3.3 Horizontal Directional Drill (HDD)

HDD is a three-step construction method using a horizontal directional drill. The process consists of drilling a pilot hole usually in an inverted-U profile to maintain drilling fluid in the hole for stability, reaming the pilot hole to the required diameter, and pulling through a continuous string of carrier pipe. See Figure 7 below.

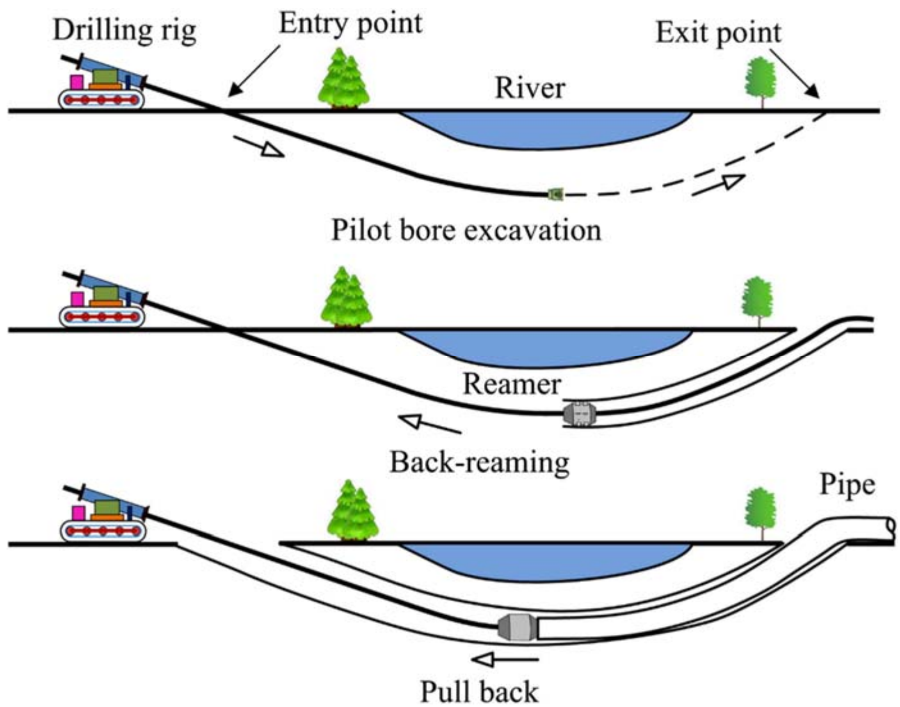

Figure 7 – Pipe installation by HDD is a three-step process: 1) the pilot hold is drilled, 2) the hole is reamed to the required diameter, and 3) the product pipe is pulled into the hole in one continuous string (Yang et al, 2014).

The pilot hole is excavated using a steerable guided drill bit along the prescribed design alignment. The hole starts at ground surface that is angled into the ground between 5 to 12 degrees (see Figure 8). A small pit at surface is dug around the hole to contain drilling fluids (e.g. bentonite slurry). When weak ground conditions are present, a surface casing is often used to isolate the soft materials from the hydraulic fluid pressure needed for HDD that otherwise would be prone to “frac-out” because the soft ground lacks strength to overcome the hydraulic pressure.

Once the pilot hole is drilled through to the exit point, the hole is incrementally reamed to a larger diameter with several passes back and forth along the hole, until the required borehole diameter is achieved. During the drilling and reaming process, the borehole is filled with bentonite slurry with a unit weight heavier than water to provide borehole stability by hydraulic counterbalancing of the water and ground via the drilling fluid. After the hole has been reamed to the required size (in this case about 1.6 m for a 1.2 m OD pipe), the assembled product pipe is pulled through the borehole in one continuous operation, see Figure 9. The annular space between the borehole wall and the outside of the pipe remains backfilled with the bentonite slurry which gains strength over time and ultimately reverts to a weak clay material surrounding the pipe.

This method is feasible below the groundwater table as the engineered slurry prevents water ingress into the excavation. However, for HDD to be considered, typically an arcuate-shaped profile would be required to maintain fluid in the borehole to maintain borehole stability. For the flat trajectory profile depicted, the primary challenge to overcome will be maintaining a fluid-filled borehole. Depending on the elevation difference between the high and low points, a pit could be excavated on the low side such the fluid can equilibrate between the high and low points to maintain a fluid-supported borehole.

Figure 8: Example of HDD drill rig and supporting equipment.

Figure 9- Example of product pipe layout for pullback into the reamed borehole.

3.4 Order of Magnitude Cost Estimate

The conceptual cost estimate presented below is based on the following:

- Two trenchless alignments (Comox Hill and Lazo Hill)
- Three construction methodologies.

The cost estimates are equivalent to AACE Class 5 using unit price costs derived on a cost per inch diameter per foot of the alignment (diameters shown in Table 1 below). The unit costs used reflects pricing on US projects to which we applied a 1.33 currency conversion factor (i.e. $0.75 USD for every $1.00 CAD).

Table 1: Comparative Cost Estimate

Excavation Method			Digger Shield	Microtunnel	HDD
Minimum Tunnel Diameter			**2.2 m**	**1.2 m**	**1.6 m**
Item	**Qty**	**Unit**	**Base Cost ($)**	**Base Cost ($)**	**Base Cost ($)**
Portal/Site Development	4	ea	1.6	1.6	0.8
Comox Hill Excavation and Lining	1000	m	11.5	9.5	5.0
Lazo Hill Excavation and Lining	1000	m	11.5	9.5	5.0
Mobilization and Site Work	1	ea	2.0	2.0	0.5
Total Base Cost			26.0	22.6	11.3
Total Cost Range			13.3 to 34.6	11.3 to 29.4	5.7 to 14.7

Note: All values in $M, Canadian currency, 2019 rates and exclusive of contingency, engineering, pipe, and Owner's costs. Costs were developed based on the Minimum Tunnel Diameter

The costs presented in Table 1 are Contractor's costs only. Typical additional costs that an Owner could expect over and above these are:

- 15% Owner's Engineer and Construction Manager
- 10% Owners staff (PM etc.)
- 30% Contingency

With regards to duration, for the digger shield approach the project duration is estimated to be approximately 10 months for a single section. For both sections this would be increased to 18 months, but the method can accommodate two headings which can almost halve the duration. For microtunneling, it is anticipated that each drive would take approximately 5 – 6 months. Similarly, for HDD, it is anticipated that each bore would take 6 – 7 months to complete.

Based on the above, it is apparent that there are significant cost advantages to the HDD approach if the feasibility can be confirmed in subsequent phases of this project.

3.5 Summary of Advantages and Limitations of Conceptual Trenchless Options

Table 2 below summarizes the advantages and limitations for the three conceptual trenchless construction methods.

Table 2: Trenchless Method Comparison

Category	Trenchless Method		
	Shield Tunneling (two pass)	Microtunneling (one pass)	Horizontal Directional Drilling (one pass)
Steering Capability	Uses jacks/articulation to navigate. Can complete straight or curved bores	Has a navigation system. High accuracy in line and grade control. Can bore curved alignment, but only with concrete pipe	Has a highly accurate navigation system. Drills curved alignment primarily, but straight alignments possible if drilling fluid pressure can be controlled.
Minimum Slope	0.1%	0.05%	1% - 2%
Product Pipe Material	Steel, concrete, FRP, Clay, HDPE, PVC, Polymer Concrete	Steel, concrete, FRP, Polymer Concrete	Steel, HDPE
Ability to Maintain Line and Grade During Excavation	High level of control	High level of control, however weight of machine may cause it to settle leading to steering difficulties in very soft ground.	High level of control, can experience steering issues in very soft ground.
Groundwater/ Face Control	No hydrostatic counterbalancing. Not designed to work below the water table	Continuous face support and hydrostatic counterbalancing with slurry. Can operate above and below the water table.	Borehole annulus supported with slurry. Can operate above and below the water table.
Staging Area Requirements	Method is compact, has small surface footprint	Larger area required for staging due to supporting equipment (e.g. slurry plant), shafts required.	Larger area required for HDD equipment and long linear pipe laydown area. Surface to surface method with shallow pits.

Shaft and Pits	Requires surface portal for ground ingress and egress, otherwise shafts may be necessary.	Requires jacking shaft to accommodate equipment. Requires receiving shaft. May require ground improvement for jacking force development and at launch and receipt portals.	Requires small surface pits at both bore ends or a shallow shaft on the downstream end to maintain a fluid-filled borehole, and space for drilling fluid system.
Settlement and Risk to Stakeholders	Casing provides ground support, face control variable, depth of alignment not likely to produce measurable surface settlement.	Machine/Pipe and engineered drilling fluids provides continuous ground support and hydrostatic counterbalancing.	Slurry provides continuous ground support and hydrostatic counterbalancing prior to pipe installation. Surface casing may be used for shallow section. Borehole slurry reverts to weak clay over time.
Typical Diameters Installed	2.2 m or larger	0.5 m to 2.7 m	0.1 m to 1.5 m
Typical Length Installed	No limitations	Installed lengths are typically in the range of 600 m, however 1100 m has been installed before	Less than 1,500 m
Impact / Mitigation if boulder encountered	Relatively little impact – primarily reduction in advance rate for hand-removal of boulder through tunnel	Moderate to significant time impact depending on boulder diameter, tunnel diameter affords limited access to face for removal, advance could be stopped days to a week or two	Low to moderate impact, varies if HDD is able to drill through boulder or if drill path needs altering to get around boulder, hours to a day or two of schedule delays, significant impact if frequent or nested.
Cost Estimate based on current conceptual alignment length	\$13.3 M to \$34.6 M	\$11.3 M to \$29.4 M	\$5.7 M to \$14.7 M

FRP – Fiberglass Reinforced Pipe, HDPE – High Density Polyethylene, PVC – Polyvinyl Chloride

4.0 Discussion

Based on our evaluation, the ground conditions appear favorable for trenchless crossings through the Lazo and Comox hills, and allows for consideration of three different trenchless methodologies, each with advantages and disadvantages. For example, if schedule was a constraint, simple shield machines could be used to advance two headings at the same time. There would not be a lot of lead time needed for machine and liner procurement such that construction could begin in relatively short order. Although faster at the outset with respect to the start of boring, the efficiency diminishes over distance, especially if shield tooling is not mechanized. Alternatively, it may take longer to deploy a mechanized shield, but the production will be faster than a plain shield as length increases, albeit at the sacrifice of only one heading. To highlight flexibility that can reduce schedule, one heading could be done with a plain over-sized shield from one direction while a mechanized shield is procured and launched from another heading. The two machines would be driven towards each other until they intersect. The plain shield would be sacrificed in the name of ground support and the machine would be brought out through the ground support installed behind the over-sized shield tunnel.

In reviewing the alignment profile, the flows will be pumped up to the trenchless alignment elevation to traverse the topographical high points. If the ground conditions remain favorable (i.e. groundwater levels remain well below the installation), from our perspective there is no reason that the alignment across those topographical high points could not be lowered, possibly to elevation 20 m, to lower the hydraulic head needed to pump across the topographic rise, thereby lower pumping costs. Granted, this would lengthen the trenchless alignment, but that additional cost could be far outweighed by reductions in pumping costs for only the incremental cost of longer tunnels. Longer tunnels (shield and microtunneling) increase the risk profile with respect to tooling/cutterwheel survivability, additional shafts to keep drives shorter to manage jacking forces, and machine breakdown, but not so much with HDD, except for finding the room to lay out one pipe string or multiple sections if needed.

We would expect that revisions and refinements to the conceptual design and cost estimate may be required when additional information becomes available.

Based on our current level of information, a microtunnel option that installs the carrier pipe in a one-pass would be feasible, but the method only becomes cost competitive when an alignment is below groundwater. Using microtunneling for installations above groundwater means paying for a methodology whose ground control attributes (e.g., hydrostatic counterbalancing) are not needed. If just a TBM is considered, it is constrained by the need to dig a larger tunnel just to accommodate the umbilicals needed for mining.

From a cost perspective, HDD appears to offer significant cost advantages over the other methods provided borehole stability can be maintained. This can be achieved by developing a shallow inverted-U profile to maintain drilling fluid in the bore hole at all times. If a low point in the alignment is not desirable, a straight HDD is feasible by incorporating provisions to maintain drilling fluid in the borehole at all times. The primary drawback to HDD is the laydown room needed to fuse a pipe string long enough for one continuous pullback or to fuse two or three sections that are welded together during pullback.

5.0 Recommendations

Additional design input information is required to advance the design from the conceptual stage. The key data gaps are:

- Detailed information on the geotechnical and groundwater conditions along the alignment, specifically within the Comox Hill proximity.
- Availability of land for staging areas and portal construction. This is a critical for assessing the feasibility of HDD construction because a laydown the length of the fully strung out product pipe

is highly desirable, or a laydown area half or one-third of the alignment length to build up two or three pipe sections for welding during pullback.

- Constraints on trenchless alignment associated with permitting.
- Constraints on alignment associated with right of way acquisition including for private property.

Additionally, further geotechnical investigations will be required within both the Lazo Hill and Comox Hill trenchless alignment areas. The current geotechnical investigation consists of shallow auger holes and provides a general appreciation of the surface conditions, however does not provide insight to the soil conditions within the range of elevations for feasible trenchless construction. A geotechnical investigation is recommended where boreholes are drilled to the range of elevations where the trenchless alignment is being assessed to gain more insight as to the ground conditions.

During drilling, soil samples should be taken for subsequent lab testing. In addition to soil index testing for identifying the soil types within the boreholes, lab tests should be carried out to assess the strength and design parameters of the cohesive and non-cohesive soils within the stratigraphy with specific focus on the soil unit the trenchless alignment may be located in. The parameters obtained from this investigation can be used to carry out the design calculations and assist with reducing the number of assumptions.

We recommend continuing with hydrogeological studies to gain a better appreciation for the ground water regime, specifically in the Comox Hill area. Current records show only a limited number of water wells from public databases, and the most recent hydrogeology from GW Solutions has a specific focus on the Lazo Hill area, only.

In addition to the above, we recommend completing a site visit to better understand the project area and the geologic conditions. Based on a review of Google Earth imagery it appears that the topographic high along Lazlo and Balmoral Roads, which requires the trenchless application, extends to the shoreline to the east and forms the Willimar Bluffs. An inspection of these bluffs would likely yield useful geological information.

6.0 References

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