REPORT

Observations of Soil and Rock Particles in Well Water

North Kent Wind 1, Chatham-Kent, Ontario

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1.0 INTRODUCTION

The North Kent Wind 1 wind turbine facility (the “Project”), has recently been constructed in the Municipality of Chatham-Kent, Ontario. During project development, concerns were raised regarding the potential for driving pile steel pile foundations into the ground to influence water wells in the area. As a result, vibration monitoring was completed for two initial test piles and later for all piles driven for turbine foundation construction. Monitoring of residential water well casings for vibrations was also completed during construction pile driving. Vibration monitoring was undertaken since ground vibrations are a measurable manifestation of the energy delivered to the ground by construction processes, the dissipation of this energy over distances, the effects of such construction energy, regulatory thresholds and published case histories.

A total of 16 water well interference complaints were received during and after the months of 2017 when piles were driven for the foundations of 34 wind power turbines constructed as part of the Project. The principal complaints were associated with visible particles within the water or flow rate reductions as summarized in Table 1 (provided following the report text). Water well complaints were investigated by AECOM Canada Ltd. (AECOM) and documented in multiple reports (listed at the conclusion of this report). After completion of well complaint investigations, AECOM and Golder Associates Ltd. (Golder) determined that the conditions associated with the well complaints were not related to construction of the turbine foundations. This report summarizes various factors related to the interaction of geotechnical, hydrogeological and ground-vibration conditions and reported observations of particles within water wells or poor water flow rates in the area of the Project. Based on the evidence gained during the work carried out for the Project and published information, an opinion is provided regarding the suspected cause(s) of particles being entrained in groundwater drawn from the local domestic water wells.

For mineral particles such as sand, silt, clay and similar size fragments of the bedrock (excluding organic matter) to enter the flow of a pumped well, two principle conditions must be present:

- a source of particles must exist; and
- a mechanism for the particles to enter the water flow must exist.

Each of these principal conditions are addressed below preceded by a summary of the local subsurface conditions and the conditions of the local domestic water wells. A series of laboratory demonstrations was also completed to visually illustrate various mechanisms related to the introduction and suspension of soil and rock particles in well water.

2.0 BACKGROUND

2.1 Subsurface Soil and Rock Conditions

Subsurface conditions at each turbine site were explored, tested and summarized by AMEC (2016)[1]. In general, the subsurface conditions are described as follows:

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[1] AMEC 2016. Geotechnical Investigation Report, Proposed North Kent Wind 1 Project, Municipality of Chatham-Kent, Ontario. AMEC Foster Wheeler Environment and Infrastructure, Report No. SWW167102, July 19, 2016.

- Topsoil and tilled farmlands were commonly encountered at the ground surface. In some areas, deposits of sand and silt existed ranging in total thickness between nil and 8.2 metres (m) with an average thickness of 1.7 m.
- Below the sand and silt, where present, the majority of the soils consisted of a regionally extensive deposit of very soft to firm silty clay, ranging in thickness from about 10 to 20 m with an average thickness of 13.2 m. In most areas, below the top m or two, the silty clay is of a dark grey colour and includes small fragments of the local black shale bedrock as a result of the local geologic history[2]. This layer confines the underlying water-bearing glacial deposits and bedrock (also referred to as a "contact aquifer").
- At various turbine sites, sand and gravel soils with varying proportions of silt and clay, either representing ice-contact outwash or basal glacial till soils, were commonly found between the overlying silty clay deposits and the underlying bedrock. These soils represent part of the local contact aquifer and are as much as 10.4 m thick with an average thickness of about 2.2 m. These materials also include bedrock fragments of varying sizes as a result of the geologic history of the region. Engineering characteristics of the aquifer soil materials are summarized in Table 2, below.
- Fine-grained and black shale bedrock of the Kettle Point Formation was encountered beneath the glacial till at all turbine sites in boreholes within which rock coring was completed by AMEC (2016), during pile driving and during foundation anchor drilling. Rock quality designation values[3], being a measure of rock fracturing observed in rock cores, varied from a 10th percentile value of about 52 per cent to a 90th percentile of about 97 per cent, with an average of about 83 per cent based on data reported by AMEC (2016). The broken rock at the soil/rock interface also forms part of the contact aquifer.
- Gas of natural origin, consisting predominantly of methane, has repeatedly been encountered and reported in the Project area (see Figure 1):
  - during drilling of domestic water wells in the Project area as documented in Ontario Ministry of the Environment and Climate Change (MOECC) Water Well Information System (WWIS)[4] records;
  - as noted in research conducted over the last 25 years in the Kettle Point Formation region and Project area[5, 6, 7, 8, 9, 10];
  - during exploratory drilling at eight turbine sites (AMEC, 2016);
  - during pile construction for the Project (summer and fall 2017); and

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[2] Soderman, L. G. and Kim, Y. D. 1970. Effect of groundwater levels on stress history of the St. Clair till deposit. Canadian Geotechnical Journal, 7(2): 173-193.

[3] For definition of the rock quality designation, see ASTM D6032, Standard Test Method for Determining Rock Quality Designation (RQD) of Rock Core. American Society for Testing and Materials (ASTM International), West Conshohocken, PA, 2017,

[4] https://www.ontario.ca/data/well-records

[5] Intera Technologies Ltd. 1992. Hydrogeological Study of the Freshwater Aquifer and Deep Geologic Formations, Sarnia, Ontario. Volume 1, prepared for Ontario Ministry of the Environment.

[6] Weaver, T.R. 1994. Groundwater flow and solute transport in shallow Devonian bedrock formations and overlying Pleistocene units, Lambton County, southwestern Ontario. Ph.D. Thesis, University of Waterloo, Waterloo, ON.

[7] Béland Otis, C. 2013. Gas assessment of the Devonian Kettle Point Formation; Ontario Geological Survey, Open File Report 6279, 63p.

[8] Hamilton, S.M. 2011. Ambient groundwater geochemistry data for southwestern Ontario, 2007–2010; Ontario Geological Survey, Miscellaneous Release—Data 283. http://library.mcmaster.ca/maps/geospatial/ambient-groundwater-geochemistry-data-southwestern-ontario-2007-2010

[9] McIntosh, J.C., Grasby, S.E., Hamilton, S.M. and Osborn, S.G. 2014. Origin, distribution and hydrogeochemical controls on methane ccurrences in shallow aquifers, southwestern Ontario, Canada. Applied Geochemsitry, Elsevier, Vol. 50, 37 – 52.

[10] Hamilton, S.M., Grasby, S.E., McIntosh, J.C. and Osborn, S.G. 2015. The effect of long-term regional pumping on hydrochemistry and dissolved gas content in an undeveloped shale-gas-bearing aquifer in southwestern Ontario, Canada. Hydrogeology Journal (2015) 23: 719–739

- as observed by Golder discharging from the outside tap at one of the wells that formed part of the construction-phase pile driving vibration monitoring program (Well 11).

Natural gas pressures in the Kettle Point Formation and overlying permeable soils, trapped by the regionally-extensive silty clay soils, are sufficient to cause audible and visible bubbling in exploratory boreholes, observation wells and domestic water wells. In the 1990s, while drilling in the Sarnia area for a Golder assignment, gas encountered near the bedrock surface readily discharged through boreholes (see Photograph 1). Natural gas in soil pore water is also known to be a problem with respect to soil strength and behaviour[11]. In 2006, while Golder staff were supervising drilling at a different site north of the Project, gas pressures at the Kettle Point Formation bedrock surface were sufficient to lift approximately 30 m of steel drilling rods about 20 m, indicating a gas pressure of at least 360 kPa, and gas vented for several days before the borehole could be sealed. During drilling of exploratory boreholes for the Project, AMEC (2016) observed gas pressures sufficient to force groundwater out of the boreholes at the ground surface at the locations of T11 and T37. At T37, the gas pressure was sufficient to spray water to a height of 12 m above the ground surface and likely in excess of about 174 kPa. Golder commonly experiences similar instances of methane gas occurring at and near the interface of the glacial deposits and underlying Kettle Point Formation throughout the region. In two documented instances, natural gas pressures in the region were sufficient to breach the ground surface at either the bottom of an excavation[12] or the bottom of a shallow pond and surrounding creek floodplain[13]. In these cases, gas pressures at the bedrock level were likely in excess of 300 kPa (equivalent to a water pressure head of about 30.6 m or more). Sand and silt seams or lenses within the overlying clay deposit and low topographic elevations are considered contributors to gas pressures breaching the ground surface in these instances.

Concentrations of methane dissolved in the groundwater in the area bound by Chatham, Thamesville and Port Lambton, Ontario, range between about 9 and 134 milligrams per litre (mg/l) with an average of about 40 mg/l. Dissolved methane saturation[14] at the bottom of the sampled wells was as much as 117 per cent during measurements taken between 2007 and 2010[8]. For water samples collected from wells installed into the Kettle Point Formation or overlying glacial till contact aquifer throughout the wider southwest Ontario area, dissolved gas concentrations were as much as 248 mg/l (with in situ saturation of as much as 414 per cent). The higher saturation values were suspected of being associated with gas bubble entrainment during sampling[9].

Hydrogen sulfide, or sulfurous water[15], and sulfate have been noted in wells in the region[16]. According to at least three historic records for wells located within the Project area, the water was also reported to demonstrate a “sulphur” odour based on the MOECC WWIS and odours associated with the water were also noted in the water well complaints investigated by AECOM.

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[11] Dittrich, J.P., Rowe, R.K., Becker, D.E. and Lo, K.Y. 2010. Influence of Exsolved Gases on Slope Performance at the Sarnia Approach Cut to the St. Clair Tunnel. Canadian Geotechnical Journal, 47(9): 971-984.

[12] Rowe, R.K. and Mabrouk, A. 2015. Forensic numerical analysis of gas venting in Southwestern Ontario. Engineering Geology 151 (2012) 47–55.

[13] http://blackburnnews.com/sarnia/sarnia-news/2015/06/17/natural-gas-leak-under-investigation/

[14] Per cent saturation is the relative measure of the amount of a material (gas in this case) that can be dissolved in a liquid (water in this case) where 100 per cent defines the maximum concentration of dissolved gas at a given pressure and temperature except under special circumstances where supersaturated conditions can occur.

[15] As indicated by a characteristic rotten egg odour and/or presence of sulfates and sulfides in groundwater where sulfate reducing bacteria reduce sulfate to sulfide.

[16] Singer, S.N., Cheng, C.K., and Scafe, M.G. 2003. The Hydrogeology of Southern Ontario, Second Edition. Ontario Ministry of the Environment, Toronto.

Table 2: Summary of Engineering and Hydrogeologic Parameters for Contact Aquifer Soils

Parameter	10th Percentile	50th Percentile	90th Percentile
Thickness (m)	0.8	1.7	3.6
Standard Penetration Test N Value, Uncorrected, Automatic Hammer (blows/0.3 m)	10	50	106
Vertical permeability, k_v (m/s)[a]	$1x10^{-6}$	$1x10^{-4}$	$1x10^{-3}$
Horizontal permeability, k_h (m/s)[a]	$2x10^{-6}$	$2x10^{-4}$	$2x10^{-3}$
Water content (% by weight)	8	14	20
Saturated Density, γ_{sat} (Mg/m^3)	2.10	2.23	2.39
Voids Ratio, e	0.22	0.38	0.54
Porosity, n	0.18	0.27	0.35
Lower Bound, Estimated Shear Wave Velocity (m/s)	170	225	250
Key Grain Size Distribution Characteristics			
D_{85} (mm)[b]	5.8	11.0	18.2
D_{60} (mm)	0.4	2.3	10.2
D_{50} (mm)	0.12	0.53	6.28
D_{30} (mm)	0.019	0.085	2.05
D_{15} (mm)	0.005	0.0115	0.437
D_{10} (mm)	0.003	0.0065	0.092
Gravel (%)	18.2	29.6	56.6
Sand (%)	24.9	33.5	39.7
Silt (%)	6.1	22.6	37.5
Clay (%)	3.6	6.0	9.3
Finer than 0.075 mm “fines” (%)	9.4	29.6	46.7

Notes: a) Based on grain size distribution characteristics as reported by AMEC (2016) and values reported in published literature;
b) Screen size opening and effective particle diameter D for which the subscript indicates the percentage of the sample by weight smaller than the indicated size;

2.2 Water Well Conditions

Information provided within the MOECC WWIS database indicates that the following typical conditions are known about domestic water wells in the Project area:

- of 436 unique records for wells more than 10 m deep, 31 per cent of these were abandoned because of water quality ("cloudy"), insufficient quantity ("dry") or other unspecified reason;
- water quality at the time of drilling was recorded in 288 of these wells and, of these, more than 16 per cent indicated "cloudy" water at the time pumping tests were carried out, and some of the wells were abandoned because the "cloudy" water could not be cleared over a period of hours to days;
- more than 80 per cent of the well casings were about 102 mm diameter;
- more than 70 per cent of the wells were drilled into the Kettle Point Formation black shale bedrock, and the other drilled or bored wells terminated in the glacial till materials immediately overlying bedrock;
- nearly 90 per cent of the wells were drilled using cable tool percussion methods;
- more than 40 per cent of the wells were drilled prior to 1970 and more than 80 per cent were drilled prior to 1990, when Ontario regulations for construction of water supply wells were implemented;
- most wells were installed without screens when they were originally drilled;
- the average water column height with the wells (static water level to bottom of well) was about 15 m;
- vertical open hole lengths (open to the aquifer being rock or overburden) range between 0 (open only at the casing bottom) and about 2 m;
- drawdown during initial pumping tests ranged from about 0.3 to 10 m, with an average of about 4 m; and
- pumping rates, as recommended by the driller, for 80 per cent of the wells, ranged from about 9 to 45 litres per minute (about 2.4 to 12 U.S. gallons per minute) with an average of about 26 litres per minute (6.8 U.S. gallons per minute).

Simplified illustrations of well construction in the Project area are provided on Figure 2 along with notes taken from the respective MOECC WWIS records.

Well pumps in the area often consist of one or two-line shallow well jet pumps or older mechanical lift and piston pumps. The shallow well jet pumps (1/2 to 1 horsepower) typically pump at rates of 20 to 40 litres per minute, when running.

2.3 Well Casing Vibrations Measured during Construction

Monitoring of ground vibrations was carried out during foundation construction for the project. At the turbine sites, maximum ground surface and bedrock vibration velocities were less than 20 mm/s at a distance of 10 m from pile driving diminishing to less than 1 mm/s at a distance of 100 m. The largest of the peak well casing vibrations directly attributable to pile driving on the glacial till and bedrock were 0.037 mm/s or less (Golder, 2017)[17] for monitored wells between about 570 m to 680 m from the pile driving with vibration magnitudes diminishing to less

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[17] Golder Associates Ltd., "North Kent 1, Construction Vibration Monitoring Report," Report No. 1668031-2000-R02, December, 2017.

than 0.02 mm at a distance of 920 m from pile driving. The largest measured vibration velocity directly attributable to pile-driving (0.037 mm/s) was associated with an acceleration magnitude of less than $1x10^{-3}$ times the gravitational acceleration parameter *g* (where *g* = 9.81 m/s^2) and ground or well casing response frequencies typically varied between about 35 and 40 Hertz (Hz). For the purposes of this evaluation, a peak vibration velocity at the well casings of 0.04 mm/s in any of the three orthogonal directions (i.e., vertical, longitudinal or transverse) was used as a basis for analyses.

2.4 Well and Pump Conditions Observed during Complaint Investigations

Of the hundreds of wells within the project area, a total of 16 complaints were reported during the course of the pile driving and vibration monitoring programs, as summarized in Table 1. The nature of the complaints included particulates in the water discharged from faucets, sediments in filters, increased turbidity and loss of or reduced flow. Details of the inspections completed by AECOM are provided in the reports referenced at the conclusion of this report. During the AECOM investigations of the complaints, the following conditions were also noted:

- several of the residents also reported gas discharge from the wells or well odours and AECOM personnel observed gas bubbles in water discharged from sampling points;
- filtration systems were improperly connected between the pump and pressure tanks resulting in either relatively rapid on-off cycles or prolonged pumping and stressed pumping systems;
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- many of the well casings, particularly those for the 100 mm diameter wells with jet pumps, were sealed (with some cover bolts corroded shut) and some were inaccessible for inspection because the well heads were buried; and
- sediments were noted in varying degrees by AECOM personnel, but typically not to the extent as reported by the well owners and reference should be made to the AECOM well complaint investigation reports for more information.

3.0 PARTICLE SOURCES

The primary sources of particles that could enter these wells are:

1) soil or rock materials in the side walls of the open portion of the well hole and any annular gap that might exist between well casings and the surrounding soils and rock;
2) particles adhering to the inside walls of the steel well casings;
3) particles existing within rock fractures in the side walls or bottom of the well entering through improperly-sized well screens or from the walls and bottom of open well holes; and
4) sediment or drilling cuttings existing at the bottom of the well.

For each of these particle sources, mechanisms by which particulates might enter the well water and their relative importance are addressed below, grouped by location within the well.

3.1 Well Side Walls

Mechanisms that could result in particles being dislodged and transported from the side walls of the well where the natural ground is exposed (i.e., below the casing) might include:

- lateral flow of water through granular soils (e.g., silt, sand and gravel soils) and/or bedrock fractures;
- flow of water within any annular gap that exists at the boundary between the well casing and surrounding ground; and
- side wall instabilities.

Following initial well drilling, wells are commonly "developed" to remove cuttings and deliberately mobilize and remove fine particles from the surrounding soil and/or rock. In this context, well "development" addresses the two principle water well objectives: *"1) repair damage done to the formation by the drilling operation so that the natural hydraulic properties are restored, and 2) alter the basic physical characteristics of the aquifer near the borehole so that water will flow more freely to a well."*[18] Many methods are available for well development and maintenance including[18, 19, 20]:

- Over-pumping – pumping the well at a higher rate than the formation can withstand under normal operations (e.g., pumping a well at a rate of 40 litres per minute when its rated flow is 10 litres per minute based on a pumping test and the natural characteristics of the aquifer);
- Backwashing – repeatedly reversing the flow direction to progressively break down bridging between soil particles followed by pumping in the normal direction to remove fine particles;
- "Rawhiding" – repeatedly using the well pump to lift water to the surface and then immediately turning off the pump to surge the well with unstable flow rates and directions;
- Mechanical surging – mechanical surging is accomplished using a close-fitting block, or "plunger", that is repeatedly raised and lowered into the well to produce rapid cycling of water flow directions and pressures (i.e., rapidly raising and lowering the water level within the well by several metres or more);
- Air development – air is injected into the well intermittently to lift the water surface and subsequently allow the water to fall back when air flow stops and, in this case, the multi-phase fluids (air and water) rise to the top of the casing carrying soil particles and flushing them from the well; and
- Air and water jetting – high velocity air and water are injected horizontally through well screens into the water-bearing formation to mechanically dislodge fine particles, entraining them in the returning air and water streams for subsequent removal.

These techniques are also commonly employed periodically throughout the life of the well to *"…maintain or even improve the original yield and drawdown conditions"* [18, 20]. In general, well development is used to result in *"sand free water"* which, for practical purposes, can be considered as having less than 5 mg/l[21] of sand, silt or clay particles for residential systems[18]. Even following well development, however, *"…it is impractical to assume that all sediment transport can be eliminated, even by the most powerful development methods."*[18] Each of the

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[18] Driscoll, F.D. 1986. Groundwater and Wells, Second Edition. Johnson Filtration Systems, Inc., St. Paul, Minnesota, pp. 434, 500.

[19] Water Well Driller's Beginning Training Manual, National Water Well Association, Columbus, Ohio 1979.

[20] NGWA 2017. Residential Well Cleaning, Best Suggested Practices. NGWA The Ground Water Association, Westerville, OH.

[21] Equivalent to between 4 and 30 grains of sand per litre of water with the grain size ranging from 0.5 to 1 mm diameter.

techniques summarized above are designed and implemented to deliberately disturb fine soil and rock particles for their subsequent removal and, by design, exceed water flow rates associated with normal well use. Deliberate disturbance, dislodgement and removal of fine particles from the aquifer formation, to the degree practicable, is undertaken during initial well development to form a natural filter around the well where (paraphrased from Driscoll, 1986):

1) in the zone just outside the well screen (if and when present), water pumping removes most particles smaller than the screen openings, leaving only the coarsest materials in place;
2) a little farther out, some medium-sized grains remain mixed with the coarse sediment (by progressively lodging against formation pore spaces smaller than the grain size);
3) beyond that zone, the material gradually grades back to the original character of the water-bearing formation (through progressive blocking of grains of smaller and smaller sizes);
4) fine particles initially brought into the screen in this process are removed by continued pumping (development);
5) development work is continued until the movement of fines from the soil and/or rock formation becomes negligible; and
6) by creating this succession of progressively fining particle size zones around the well, development stabilizes the formation and prevents further movement of sediment into the well under normal operating conditions.

Photograph 2 illustrates these conditions near a well screen. Wells without a screen, however, are more susceptible to long-term movement of ground particles into the well bore and continued outward propagation of filter-zone distances under both normal and high operational flow rate conditions.

During and after well development, water exits the ground and enters the well at a velocity governed by the pumping rate. This entrance velocity plays a critical role in determining whether particles are dislodged and also enter a well. Considering the typical water well characteristics defined above (50th percentile values provided in Table 2), common relationships for radial flow to a well[22], and assuming a 1 m vertical intake length (vertical zone of uncased well bore), estimated flow velocities at the well bore wall are summarized in Table 3, below. In cases where well intake vertical lengths are greater than 1 m, the well entrance velocities could be smaller for the same pumping rate. In cases where the well intake area is limited to the bottom open end of the well casing (i.e., the casing extends fully to the bottom of the well, see Figure 2, well diagram B for example), entrance velocities for equivalent pumping rates can be significantly larger and exceed those indicated for the mean casing flow velocity. Approximate mean flow velocities within the well casings themselves are also shown in Table 3, assuming a 100-mm diameter casing (casing outside diameters in the vicinity of the Project typically range from about 102 to 140 mm) with the pump intake set high in the well casing. Given the typical pumping rates of 20 to 40 litres per minute and a well casing length of 18 m, the full water volume of the casing could be removed during 3 to 8 minutes of pumping. If water flows in an annular gap between the casing and ground, the flow velocity will depend on the opening size and the proportion of the total well flow through of the gap; however, the range of flow velocities in Table 3, below, likely represent a reasonable range for such conditions.

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[22] Bennett, G.D., Reilly, T.E. and Hill, M.C. 1990. Technical Training Notes in Ground-Water Hydrology: Radial Flow to a Well. US. Geological Survey, Water Resources Investigations Report 89 4134. U.S. Geological Survey, Office of Ground Water, Reston, Virginia.

Table 3: Well Entrance and Casing Water Velocities

Constant Pumping Rate in Litres Per Minute (U.S. Gallons Per Minute)	Approximate Well Entrance Water Velocity^a (mm/s)	Approximate Mean Flow Velocity in Casing^b	
		mm/s	m/minute
1.5 (0.4)	0.3	3	0.06
5.0 (1.3)	1.0	10	0.6
20.0 (5.3)	3.9	40	2.4
40.0 (10.5)	7.9	80	4.8
80.0 (21.0)	15.7	160	9.6

Notes: a) based on aquifer porosity of 0.27 and horizontal hydraulic conductivity of $2x10^{-4}$ m/s; b) based on inside diameter of 100 mm; c) influences of well screen are not included or considered; and d) well entrance water velocities are applicable to radial flow to vertical side walls of a cylindrical well cavity.

Based on published experiments and research related to the movement of fine particles near well screens[23, 24] and the range of aquifer characteristics summarized in Table 3, above, the water flow velocities required to initiate movement of fine particles into wells would be expected to range from about 0.02 to 0.55 mm/s. Water flow velocities required to *"…ensure (with a certain safety) removal of movable fine grains from the vicinity of the screen…"* [23] would likewise be expected to range from about 0.50 to about 5 mm/s. Therefore, under normal pumping conditions, movement of fine particles within the aquifer surrounding the well bore would be expected, though the quantities entering any given well would be highly variable, reflecting the variability in local aquifer grain size distribution (for porous materials), degree to which the well was initially developed after drilling, pumping rates and whether or not a screen was present to limit movement of the coarser particles and therefore create a natural filter around the well.

Uncased boreholes and wells drilled into poorly-graded[25] saturated sand deposits are typically unable to be self-supporting, the sand quickly flows and the holes cave once drilling tools are removed. Any water supply wells within the Project area drilled by cable tool rigs into saturated sand deposits with unsupported well intake lengths (i.e., no casing or screen) would be subject to the same fate (i.e., uncontrolled flow of particles into the well). Where the aquifer includes a variety of particle sizes, drilling and well development could have resulted in progressive removal of fine-grained particles until a coarse-grained skeleton of gravel and broken rock fragments remained that is then capable of sustaining an open hole through particle-to-particle contact (i.e., through effective stresses and arching). Subsequent pumping and flow could then have removed fine materials progressively from larger radial distances away from the opening without necessarily inducing collapse. In cases where the stability of the uncased well section relies upon inter-particle bonding within fine-grained or more broadly graded materials, long-term and progressive removal of particles could result in delayed collapse of the uncased section.

The glacial till aquifer materials in the Project area are composed of a wide variety of grain sizes, being composed of about 9 to 47 per cent, by weight, silt and clay size particles and about 25 to 40 per cent sand-size particles.

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[23] Kovacs, G. and Ujfaludi, L. 1983. Movement of fine grains in the vicinity of well screens. Hydrological Sciences Journal, 28, 247-260.

[24] Blackwell, I. M., Howsam, P. and Walker, M. J. 1995. Borehole performance in alluvial aquifers: particulate damage. Quarterly Journal of Engineering Geology, 28, S151-S162.

[25] tending toward uniformity of grain sizes whereas "well graded" soils exhibit a broad range of grain sizes

Silt and sand, being the more erodible material, comprise about 42to 77 per cent of the total mass. Therefore, there is both a supply of fine particles around the wells and water velocities necessary to mobilize fine particles into the wells, particularly for those without well screens.

The soil (glacial till) and bedrock interface can be gradational, transitioning over centimetres to metres from mixtures of gravel, sand silt, clay and broken rock to fractured rock. Spaces between fragments of rock at and near this boundary can be filled with sediments created by grinding of the rock fragments beneath glacial ice sheets as well as weathering products of the shale bedrock itself (i.e., breakdown of the rock into minerals over millennia of exposure to water and dissolved gasses). Shale, unlike limestone, is not susceptible to karstic weathering that creates open networks of joints and fractures. In some areas, bedrock shear zones and fractures can occur from glacio-tectonic stresses, faulting systems associated with the basement rock or, in the case of the northern areas of the Kettle Point Formation, subsidence due to loss of salt from underlying formations[26]. These fractures can also be filled with a wide variety of particle sizes derived from shearing of the bedrock and, near the interface with overlying glacial till, with sediments derived from glacial action.

Where the well draws water only from fractured rock, flow velocities through the fractures and sediments or weathering products within these (infill) will depend on aperture sizes, their distribution and interconnection, and the permeability of the infilling materials. As compared to the estimated well entrance and casing flow velocities summarized in Table 3 for flow through a 1 m long, 100 mm diameter well bore through porous soils, well entrance velocities through rock fractures and their infill for the same pumping rates will likely be higher except in the unlikely cases of fractures having a cumulative cross-sectional area greater than the cumulative openings of a porous soil material. Migration of fine particles from rock fracture infilling materials follows the same principles governing migration of fines from porous aquifers, though total volumes of fine particles may be less and removal of these from the fractures may be quicker because of higher flow velocities as compared to granular aquifers.

In addition to the exposed wall of the open well hole, materials may collect on the inside of steel well casings. In order for particles to collect on the inside of the well casings, however, they must either originate from residues resulting from initial well drilling, be suspended within the water drawn up through the casing by pumping or gas bubbles, by introduction from the surface, by bacterial growth within the well water or by corrosion of the well casing itself. Thus, other than by corrosion and bacterial growth, materials that collect on the inside of the well casings must originate from the well itself, its construction and the ground through which the water is drawn.

3.2 Bottom of Well

Most of the wells in the Project area were drilled using cable-tool systems. This drilling method uses a weighted steel cutting bit that is raised by a winch and dropped down the hole to chop soil and rock formations into small fragments that become mixed with water and are removed from the hole using a bailing tool that uses a simple check valve for removal of water and cuttings[18, 27]. Given the methods of drilling, it is impossible to fully remove all cuttings from the well bore using a bailer, particularly with some bailer designs (e.g., flapper valves, dart valves, etc.). Attempting to fully remove all cuttings would require use of air-lift methods or suction pumps with intakes operating at the base of the well. Cuttings (sediments) left in the well during drilling will be composed of rock and soil fragments consistent with the materials through which the well was drilled.

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[26] Armstrong, D.K. and Carter, T.R. 2010. The Subsurface Paleozoic Stratigraphy of Southern Ontario, Ontario Geological Survey Special Volume 7. Queen's Printer for Ontario.

[27] Water Wells & Ground Water Supplies in Ontario. 1994. Ministry of Environment and Energy Ontario.

As described above, initial pump testing, well development, and normal pump operations can mobilize sediment particles from the aquifer materials surrounding the well. Sediments entering the well from these mechanisms will be composed of rock and soil particles consistent with the surrounding soil and rock formations into which the well was installed. If the well has no screen, the size of the particles mobilized into the well water will only be limited by water flow velocities, particle-to-particle attraction (adhesion/cohesion and other bonding forces), particle-to-particle interference (i.e., small particles being blocked from flow due to insufficient opening sizes between larger particles), friction forces, and gravitational forces. Any mineral soil particle (i.e., excluding biogenic particulates) and other debris that exists within the well will settle to the bottom of the well under quiescent conditions. Depending on the concentration of particles in the water and their electro-chemical charges, especially as related to clay-size particles, small particles may also flocculate and therefore settle more rapidly as groups. A summary of settling velocities for different particle sizes is provided in Table 4, below[28, 29, 30].

Table 4: Approximate Settling Velocities for Particles in Water

Particle Diameter	Estimated Settling Velocity	
	mm/s	m/hour
0.075 mm < Sand Particle Diameter < 4.75 mm Sieve Opening Size		
10	430	All velocities >20
1	120	
0.5	66	
0.1	6	
Silt and Clay Particle Diameter ≤ 0.075 mm Sieve Opening Size		
0.075	3.5	12.6
0.050	1.6	5.8
0.010	0.07	0.25
0.005	0.017	0.06
0.001	0.0007	0.025

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[28] Standard Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis. American Society for Testing and Materials Standard D7928 – 17, ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA, USA

[29] Camenen, B. 2007. Simple and general formula for the settling velocity of particles. Journal of Hydraulic Engineering, 133(2), 229 – 233.

[30] Song, Z., Wu, T., Xu, F., and Li, R. 2008. A simple formula for predicting settling velocity of sediment particles. Water Science and Engineering, Vol. 1, No. 1, 37-43.

Sediments that are drawn into the well by well development and operational pumping, as described above, that are not pumped out of the well during normal use will accumulate at the bottom of the well along with debris from biological activity[18, 20, 31]. For example, the “sand free” threshold of 5 mg/l (as referenced above) could be converted to mm/year of sediment accumulating in the bottom of a well, assuming that none is suspended, re-suspended and subsequently removed through the pump and pipes. For a typical daily water use by two individuals, each drawing 250 litres per day[32], over the course of one year, 5 mg/l of sediment would result in 50 to 70 mm of sediment accumulating in the base of a 100-mm diameter well (assuming a voids ratio on the order of 0.3 to 0.5 for the settled sediment). Over the period of at least 27 years since 1990, reflecting the minimum age of more than 80 per cent of the wells in the project area, the accumulated sediment could be on the order of a metre or more thick for this example “sand free” sediment concentration, assuming that none was removed through normal pumping and discharged via the residential water supply system or removed during maintenance of the well.

4.0 INFLUENCES OF PILE DRIVING

In general, the effects or consequences of ground vibrations (oscillatory displacement or motion) are dependent upon the magnitude of the displacements and frequencies at which they occurs[33, 34, 35, 36]. Strong ground motions caused by seismic events typically occur at dominant frequencies of less than 10 Hz and, for evaluation of damage to infrastructure from strong ground motions, complex ground-structure interaction analyses are required that also consider the dynamic responses of the infrastructure. For evaluation of the effects of blasting, which involves far less energy than strong-motion seismic events, the typical allowable particle velocity to avoid damage to buildings (e.g., cracking of plaster walls) is about 5 mm/s at a frequency of 1 Hz and up to 50 mm/s at a frequency of 30 Hz[34], though other thresholds may be set by various agencies[37, 38]. These same principles apply to vibrations caused by construction[35, 36] that, depending on distance, are typically at the low end of the ground energy spectrum and often less than 1/100th of the energy delivered to the ground by even small blasting operations[36]. Typical ground velocity frequency responses to impact pile driving are in the range of 10 to about 70 Hz[36, 39]. For the purposes of this report, well-known principles developed for estimating ground shear stresses and strains, liquefaction and groundwater pressure changes induced by blasting or seismic events are used since these result in conservative (i.e., adverse or “worst case”) estimations of the long-distance effects of low energy, small magnitude vibrations induced by the impact hammer pile driving used for the North Kent Wind 1 project.

4.1 Well Side Walls

If the well casings and corresponding ground vibration measured during distant pile driving were to fully manifest in differential velocity between aquifer particles and water[40] it would be less than 1/50th of the flow velocity induced

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[31] OSMRE. Common Single Dwelling Water Supply Systems in the Appalachian Coalfields. United States Department of the Interior, Office of Surface Mining Reclamation and Enforcement, undated document, https://www.arcc.osmre.gov/about/techDisciplines/hydrology/docs/techGuidance/2014/tsd-wggb-Common_Single_Dwelling_Water_Supply_Systems_in_Appalachian_Coalfields.pdf

[32] https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/residential-water-use.html

[33] Kramer, S.L. 1996. Geotechnical Earthquake Engineering. Prentice Hall, NJ.

[34] Siskind, D.E., Stagg, M.S., Kopp, J.W., and Dowding, C.H. 1985. Structure Response and Damage Produced by Ground Vibration from Surface Mine Blasting, Report of Investigations 8507, United States Bureau of Mines.

[35] Wiss, J.F. 1981. Construction vibrations: State-of-the-Art. Journal of the Geotechnical Engineering Division, ASCE, 107(2), 167 – 181.

[36] Dowding, C.H. 1996. Construction vibrations. Prentice-Hall. Englewood Cliffs, NJ.

[37] Toronto Municipal Code, Chapter 363, Building Construction And Demolition, 363-1 August 28, 2014, Chapter 363, Building Construction and Demolition, 363-3.6. Construction vibrations.

[38] Publication NPC-119 - Blasting. Model Municipal Noise Control By-Law - Final Report. August 1978. Ontario Ministry of the Environment.

[39] Brandenberg, S.J., Coe, J., Nigbor, R., Tanksley, K. Different Approaches for Estimating Ground Strains from Pile Driving Vibrations at a Buried Archeological Site. Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 135(8), 1101 – 1112.

[40] i.e., the soil moving with the water remaining stationary, or water and soil moving in opposite directions due to oscillatory motion, inertia and low water viscosity

by normal pumping at the low end of the operational range of 20 to 40 litres per minute (see Table 3 for water flow velocities), and is therefore unlikely to be a significant factor in dislodging particles internal to the structure of granular aquifer materials at or near the well boundary.

Depending on relative magnitudes, shear stresses and strains in the ground associated with ground vibrations might affect the overall stability of the well sidewall. Measured vibrations at the residential well casings in the Project area were on the order of 0.1 per cent of normal gravitational acceleration (i.e., $1x10^{-3}g$) with a peak velocity less than about 0.04 mm/s. The peak particle velocity and acceleration, in this case, however, are negligible with respect to generation of shear strains that could cause mechanical shear failure, settlement or liquefaction. Shear strains induced at the wells by the pile-induced vibrations would also be less than 1/50th of the threshold value considered applicable to inducing settlement or development of excess pore water pressures in granular soils[41, 42 43, 44].

Ground vibrations associated with causes such as close-proximity pile driving, blasting and earthquakes are accompanied by elevated pore water pressures depending on the magnitude and duration of the vibrations[45 46, 47, 48] and distance from the energy source. Even in the case of sustained vibrations (hundreds or thousands of cycles) of a constant magnitude consistent with the peak pile-induced transient vibrations at the monitored well casings, the maximum estimated excess pore water pressure associated with these vibrations is equivalent to a change in water surface elevation of less than 30 mm, far less than changes induced by normal well pumping and less than about 0.2 per cent of the water pressure at the aquifer level for the typical conditions in the Project area.

In the immediate vicinity of driven piles, pore water pressures can be effected by the displacement of the ground and surrounding the pile and the changes can be significant, resulting in negative or positive pressure changes, depending on the character of the surrounding ground[49, 50, 51, 52, 53] and distance from the pile. As noted in pile design guidance, however, *"the induced excess pore pressures decrease rapidly with distance from the pile and generally dissipate very rapidly."*[54] These pile-driving induced excess pore water pressure changes typically become nil within a distance of about 50 times the pile diameter or less in the most severe cases in low-permeability ground. In this case, the pile diameter is about 410 mm and, therefore, dissipation of severe excess pore water pressures from pile driving would dissipate to nil within about 21 m under the worst-case assumptions. In ground of higher permeability, excess pore water pressures caused by pile driving are typically not as severe as in clay soils and dissipate more rapidly.

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[41] Dobry et al. (1982) and Mohamed and Dobry (1987) defined a strain threshold as the value of cyclic shear strain below which densification of dry granular soils or pore pressure build-up in water-saturated granular soil will not occur and, for most sand materials, this value is on the order of 0.1.

[42] Dobry, R. Ladd, R. S., Yokel, F. Y., Chung, R. M. and Powell, D. J. 1982. Prediction of pore pressure buildup and liquefaction of sands during earthquakes by the cyclic strain method. Building Science Series 138, U. S. Nat. Bureau of Standards, Washington, D. C.

[43] NCEER 1997. Proceedings of the NCEER Workshop on Evaluation of Liquefaction Resistance of Soils. T. Leslie Youd and Izzat M. Idriss. Editors, National Center for Earthquake Engineering Research, Buffalo, N.Y. 1997.

[44] Massarsch, K. R., 2000. "Settlements and damage caused by construction-induced vibrations". Proceedings, Intern. Workshop, Wave 2000, Bochum, Germany, 299 – 315.

[45] Seed, H.B., Idriss, I.M. and Arango, A. 1981. Evaluation of Liquefaction Potential Using Field Performance Data. Journal of Geotechnical Engineering, ASCE, 109(3), 458 – 482.

[46] U.S. Bur. Rec. (1985). Review of Present Practices Used in Predicting the Effects of Blasting on Pore Pressure, Report GR-85-9. Engineering and Research Center, U.S. Department of the Interior, Bureau of Reclamation, Division of Research and Laboratory Services, Geotechnical Branch, Denver, Colorado, USA.

[47] van Court, W.A.N. and Mitchell, J.K. 1994. Explosive Compaction: Densification of loose, saturated, cohesionless soils by blasting, Geotechnical Engineering Report No. UCB/GT/94-03. University of California, Berkeley.

[48] Charlie, W. A., Lewis, W. A., and Doehring, D.O. 2001. "Explosive Induced Pore Pressure in a Sandfill Dam," Geotechnical Testing Journal, GTJODJ, Vol. 24, No. 4, 391 – 400.

[49] Bjerrum, L., and Johannessen, I.L. 1960. Pore pressures resulting from driving piles in soft clay. Conference on Pore Pressure and Suction in Soil, pp. 14-17.

[50] Milligan, V., Soderman, L. and Rutka, A. 1962. Experience with Canadian varved clays. Proc. American Society of Civil Engineers, Vol. 88, SM4, pp. 32-67.

[51] Farrel, E., Lehane, B. and Looby, M. 1998. An instrumented driven pile in Dublin boulder clay. Proceedings of the Institution of Civil Engineers, Geotechnical Engineering, Vol. 131, 233 – 241.

[52] Lo, K.Y. and Stermac, A.G. 1965. Induced Pore Pressures during Pile-Driving Operations. Proceedings of the

[53] Randolph, M. F., Carter, J.P. and Wroth, C.P. 1979. Driven piles in clay-the effects of installation and subsequent consolidation. Geotechnique 29(4), 361-393.

[54] Poulos, H.G. and Davis, E.H. 1980. Pile Foundation Analysis and Design. John Wiley and Sons, NY.

Water pressures in wells installed into fractured rock have been observed to be influenced by low-frequency strong vibratory motions during earthquake events[55, 56]. Research has suggested that seismically-induced increases or drops in water pressure may be associated with temporary or long-term opening or closing of blockages in fractures caused by colloid-size or larger rock particles[57]. Water level changes on the order of centimetres were observed coincident with vibration velocities on the order of millimetres per second at low frequencies in some published cases. For the North Kent Wind 1 case, where peak vibration velocities associated with pile driving were on the order of 0.04 mm/s, water level responses to seismic vibrations of an equivalent magnitude would be expected to be less than 100 mm and, therefore, significantly less than typical drawdown induced by normal pumping and less than 0.7 per cent of the water pressure at the aquifer level for the typical conditions in the Project area.

Where the open hole sections of wells in the Project area are formed fully within the Kettle Point Formation, pile-induced vibrations would be inconsequential as related to the strength of intact rock materials and could not cause overall instability of the well openings.

With respect to materials that may collect on the inside of well casings, inter-particle molecular, electrostatic, capillary, double-layer repulsion forces and acid-base interactions that attract particles to one another and to surfaces are well-known, though can be difficult to quantify precisely[58, 59, 60, 61]. Fine soil (mineral) particles, typically of the silt and clay size fraction (<75 μm), are more difficult to remove from solid surfaces since the relative surface area to mass of the particle is far greater than for larger particles (e.g., sand and gravel) and the forces of attraction are related to surface area interactions between the solids and/or their adsorbed layers of water. Studies of methods used to remove particles from surfaces have measured these attraction forces in some respects. Methods of removal included high pressure air and liquid jets, surfactants, solvents and vibrations. For vibrations to be effectively used to measure and overcome attraction forces and, therefore, optimize vibrations as a means for removing fine particles, frequencies in the range of 1,000 to 1 million Hz were required with accelerations on the order of 10^3 to 10^6g[61]. Cleaning well casings usually requires the use of brushes, water jetting and chemicals (e.g., acids, chlorination, bio-dispersants, etc.)[18, 20]. Vibratory acceleration necessary for effective removal of fine particles (silt and clay size fractions) from solid surfaces, even in the presence of water, are one million times or more larger than the well casing accelerations measured during pile driving for the North Kent Wind 1 project with frequencies 25 to 25,000 times faster than those measured in the field.

While particles associated with corrosion and bacterial influence will loosen by decay, and in some case be in an incipient state of detachment, these processes are independent of vibration issues and will occur and continue to occur from time to time in accordance with the natural corrosion processes and decay. Vibrations of the magnitudes and frequencies associated with pile driving are unlikely to hasten such a process, particularly when these particles are exposed to water flow velocities from pumping.

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[55] Roeloffs, E.A. 1998. Persistent water level changes in a well near Parkfield, California, due to local and distant earthquakes. Journal of Geophysical Research, Vol. 103, B1, 869 – 889.

[56] Bower, D.R. and Heaton, K.C. 1978. Response of an aquifer near Ottawa to tidal forcing and the Alaskan earthquake of 1964. Canadian Journal of Earth Sciences, 15, 331-340.

[57] Brodsky, E. E., Roeloffs, E., Woodcock, D., Gall, I. and Manga, M. 2003. A mechanism for sustained groundwater pressure changes induced by distant earthquakes. Journal of Geophysics Research, 108(B8), 7-1 – 7-10.

[58] Rosenqvist, I.T. 1955. Investigations in the clay electrolyte water system. Norwegian Geotechnical Institute, Publication 9.

[59] Rosenqvist, I.T. 1963. The influence of physico-chemical factors upon the mechanical properties of clays. Norwegian Geotechnical Institute, Publication 54.

[60] Santamarina, J.C. 2001. Soil Behavior at the Microscale: Particle Forces. Proc. Symp. Soil Behavior and Soft Ground Construction, in honor of Charles C. Ladd - October 2001, MIT

[61] Ranade, M.B. 1987. Adhesion and Removal of Fine Particles on Surfaces. Aerosol Science and Technology, Taylor and Francis, 7:2, 161-176.

Based on the evaluation of the potential effects of vibrations on ground stresses and pore water pressures, it is our professional option that vibrations induced by pile driving for this project could not have caused the observed appearance of sediments in the water wells that are the subjects of complaints.

4.2 Bottom of Well

Comparing the well entrance and casing flow velocities associated with pumping, as summarized in Table 3, to the settling velocities summarized in Table 4, above, the upward flow velocities within the well casing or well bore and toward the pump intake exceed settling velocities for sediments with fine sand or smaller particle sizes. Therefore, if sediment enters the flow it can be carried upward. The size of particles that then enter the well pump intake will depend on the degree to which the velocity of pump-induced flow exceeds the settling velocity, the duration of pumping and number of pumping cycles during the time otherwise required for the particles to settle. For example, a cycling well pump could turn on and mobilize and lift particles from the well bottom, switch off, and then before the particles fully settle, the pump switches on again and lifts the particles again. The cumulative effect of repeated cycling can result in progressive increases in the concentration of particles within the water stream in the well. Well pump intakes located close to the bottom of the well can exacerbate this condition.

Vibratory motion of the water within the well casing, whether horizontal (lateral or transverse) or vertical, if caused by pile driving, would be two directional (oscillatory). Regarding the effect of oscillatory motion of fluid columns on settling velocities of various particle sizes, Nielsen (1984) stated *"The analysis of first-order effects…shows that in a pure wave motion, such effects are purely oscillatory and therefore without net effect on the settling velocity. Oscillatory flow can, however, reduce the settling velocity if the grain is so large that the drag force is non-linear…"*[62] Further, later research confirmed this condition whereby *"It is easily derived…that the temporally averaged settling velocity of spheres in a sinusoidally oscillating fluid is equal to that in a still fluid as long as the fluid drag obeys Stoke's law."*[63] Thus, in this case, the effects of vibrations on the settling velocity of fine particle sizes within the wells would be negligible.

As noted above, the peak vibration velocities and accelerations measured at the well casings associated with pile driving are insufficient to induce liquefaction of the aquifer, insufficient to result in pore water pressure changes of any significance, insufficient to influence settling velocities of the fine particles and insufficient to cause particle movement based on water flow. Further, peak accelerations associated with these same vibrations are less than 0.1 per cent of gravitational acceleration. In this case, then, the effects of distant pile driving are therefore insufficient to result in generating sufficient disturbance within or displacement of the sediments existing at the bottom of the well and could not force particles into suspension or maintain fine particles in suspension.

4.3 Other Considerations

Comparisons of factors associated with mobilization of soil and rock particles as discussed above are simplified and neglect factors such as inter-particle attraction or repulsion forces such as van der Waals forces and electro-chemical forces (i.e., inter-particle bonding or cementation, adhesion, cohesion, etc.) except as these influence adhesion to the insides of well casings. Research has, for example, demonstrated that water flow velocities required to erode fine clay-size particles from the beds of natural water courses are significantly greater than flow

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[62] Nielsen, P. 1984. On the Motion of Suspended Sand Particles. Journal of Geophysical Research, Vol. 89, No. C1, 616 – 626.

[63] Ikeda, S. and Yamasaka, M. 1989. Fall velocity of single spheres in vertically oscillating fluids. Fluid Dynamics Research, Japanese Society of Fluid Mechanics, Vol. 5, 203 – 216.

velocities required to overcome settling velocities[64, 65, 66, 67, 68]. Similar factors are also relevant for detachment of very fine (e.g., colloid-size) particles from within porous natural formations[69]. Therefore, the conclusions made above with respect to the relative magnitudes of water flow rates and pressures are most relevant to the more critical condition where inter-particle bonding has already been overcome by drilling actions and more severe well pumping events (e.g., during development or particularly demanding pumping rates).

5.0 INFLUENCES OF GAS

Natural gas, dissolved in water or occurring in its gaseous phase, is known to cause problems with water wells such as:

- *"spurting household water taps, milky color to the water which lasts only a few seconds"* and *"Malfunctioning pump (gas-locking)"* [70]
- *"…methane can be flammable and explosive when mixed with air, and it can displace oxygen if released into a confined space…"* and *"…can also cause problems with the operation of the well pump and water system."* [71]
- "*In many cases, gas invasion merely induces effervescence in the water column, which can cause fine sediment in the bottom of the well to become suspended and generate turbid water. Under the most extreme circumstances, pressure may be great enough to dislodge the entire well casing and pump assembly. At lower pressure, the water column can be gas lifted, dislodge the well seal, and promote artesian flow. It is not unusual to detect significant, yet short-lived, temporal changes in water quality during such events, resulting from the invasion of deeper aquifer fluids into shallow aquifer regimes."*[72]

When the total gas pressure exceeds the hydrostatic pressure plus bubble initiation pressure (relatively small component), degassing will occur. Gas within the saturated zone can then subsequently migrate upwards through a process of ebullition. Subsurface gas migrates from areas of high to low pressure and, where it is not otherwise confined, the gas will migrate upward and escape to the ground surface and atmosphere. In the case of water wells, pressure differentials will also be caused as groundwater pressures are reduced when the well is pumped. Factors that influence the amount of gas entering a well and the degree to which dissolved gas comes out of solution and into a well casing and emerges in subsequent water supply components include[73, 74, 75]:

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[64] Hjulstrøm, F. 1935. Studies of the morphological activity of rivers as illustrated by the River Fyris. Bulletin of the Geological Institute , 25 , 221–527. University of Uppsala.

[65] Hjulstrøm, F. (1939). Transportation of debris by moving water, in Trask, P.D., ed., Recent Marine Sediments. A Symposium: Tulsa, Oklahoma, American Association of Petroleum Geologists, (pp. 5-31). Tulsa, Oklahoma.

[66] Shields, A. (1936). Anwendung der Aehnlichkeitsmechanik und der Turbulenzforschung auf die Geschiebebewegung. Mitteilung der Preussischen Versuchsanstalt fur Wasserbau und Schiffbau, Heft 26, Berlin. Belin.

[67] Sundborg, A. (1956). The River Klarålven: Chapter 2. The morphological activity of flowing water erosion of the stream bed. Geografiska Annaler, 38, 165-221.

[68] Miedema, S.A., "Constructing the Shields curve, a new theoretical approach and its applications". WODCON XIX, Beijing China, September 2010.

[69] Ryan, J.N. and Elimelech, M. 1996. Colloid mobilization and transport in groundwater. Colloids and Surfaces A: Physicochemical and Engineering Aspects 107, 1-56.

[70] Module 7 — Troubleshooting Water Well Problems. Alberta Ministry of Agriculture and Forestry,

[71] Methane in Well Water. Well Management Section Environmental Health Division, Minnesota Department of Health.

[72] NGWA 2017. Reduce and Mitigate Problematic Concentrations of Methane in Residential Water Well Systems, Best Suggested Practices. NGWA The Ground Water Association, Westerville, OH.

[73] Edwards, J.S. 1991. Potential hazards resulting from the presence of methane dissolved in groundwater. Proceedings, 4th International Mine Water Congress, Ljubljana, Slovenia, International Mine Water Association, 223-231.

[74] OSMRE 2001. Technical Measures for the Investigation and Mitigation of Fugitive Methane Hazards in Areas of Coal Mining. United States Department of the Interior, Office of Surface Mining Reclamation and Enforcement, 129 pp.

[75] Kappel, W.A. and Nystrom, E.A. 2012. Dissolved Methane in New York Groundwater. United States Geological Survey Open-File Report 2012–1162, United States Department of the Interior, United States Geological Survey.

- availability of gas in the soil and bedrock formations from which water is drawn by the well;
- degree to which the gases are confined by overlying low permeability “capping” layers;
- temperature gradients (within the aquifers and wells);
- magnitude and frequency of pressure differentials and flow rates caused by pumping;
- magnitude and frequency of atmospheric (barometric) pressure changes; and
- degree to which the well casing and water supply components are sealed.

Given the regionally-extensive capping layer of soft, low-permeability silty clay that overlies the contact aquifer and gas-bearing Kettle Point Formation shale bedrock, conditions within the Project area are ideally suited for gas to be discharged from the local water wells as clearly documented by the Ontario Ministry of the Environment, as encountered in exploratory boreholes and as observed emanating from open faucets, as described above (see Figure 1). Older wells without appropriate or functional venting systems (e.g., buried wells, fully or partially sealed wells) are also susceptible to poor control over gas releases[31] and some of the wells noted in the complaint reports were buried and inaccessible. Reported concentrations of dissolved methane in the local and regional groundwater[8] within water wells is typically above action thresholds defined for in-line samples (obtained at the point of use)[71, 72, 74, 75]. Reported dissolved methane concentrations in the local groundwater, reported instances of methane discharge from wells and boreholes in the Project area and broad indications of gas pressures summarized in Section 2.0, above, along with reported effervescence or bubbling and odours during well complaint investigations by AECOM, demonstrate that methane and hydrogen sulphide are problematic more widely in the region and at specific wells in the Project area.

The maximum concentration of dissolved methane (i.e., saturation equal to 100 per cent) in well water at the well bottom can be estimated by the methods summarized by the Office of Surface Mining Reclamation and Enforcement (OSMRE)[74]. Under typical water pressure heads at the bottom of wells in the Project area, the maximum concentration of dissolved methane would be about 69 mg/l. During a typical 4 m drawdown, the saturation concentration would progressively drop to about 58 mg/l resulting in about 11 mg/l of methane coming out of solution. For typical pumping rates and water inflow rates in the area wells, such a condition could result in 100 ml or more of gaseous methane being liberated from solution per minute of pumping. Likewise, dissolved methane could exist within the aquifer at conditions less than full saturation and lowering of water pressures by pumping could readily and rapidly result in dissolved methane concentrations exceeding the saturation concentration. While pumping rates, water drawdown distances and concentrations of dissolved methane will vary throughout the project area, this example illustrates the relatively rapid off-gassing of dissolved methane into water wells that could occur when only considering water pressure changes from pumping and ignoring the potential migration of subsurface gaseous methane into wells and barometric pressure changes. Given the range of reported dissolved methane concentrations and saturation levels, typical methane discharge rates associated with pumping could commonly range between about 2 and 20 ml/minute for wells in the Project area.

Phenomena related to the interaction of gas bubbles (air, methane, and others), fluids, and their effects on particle suspensions have also been recognized and utilized for many applications (e.g., air-lift well cleaning[18, 76] and bubble column reactors[77]). As indicated by the National Ground Water Association[72], natural gas can periodically

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[76] Powers, J. P., Corwin, A.B, Schmall, P.C., Kaeck, W.E. 2007. Construction Dewatering, New Methods and Applications, Third Edition. John Wiley & Sons, New York.

[77] Imafuku, K., Wang, T-T, Koide, K. and Kubota, H. 1968. THE BEHAVIOR OF SUSPENDED SOLID PARTICLES IN THE BUBBLE COLUMN", Journal of Chemical Engineering of Japan, 1(2), 153 – 158.

result in well sediments becoming suspended or re-suspended in well water, generating turbidity and significant but short duration changes in water quality.

Hydrogen sulfide is also known to exist in water wells in the region and has been reported for water wells within the Project area. Hydrogen sulfide, characterized by it noxious "rotten egg" odour, can result in severe pitting and corrosion of metal well components, the sulfate-reducing bacteria produce slime, and it can, in sufficient quantities, presents a health and safety risk[76]. It is also known that hydrogen sulfide and the related bacteria can produce other undesirable problems in water wells such as promotion of other bacterial slime growths (e.g., as related to iron bacteria) that can also clog wells and plumbing systems, and black staining on metal well and plumbing parts[78, 79].

The conditions described above are known consequences of natural gas (predominantly methane in this case) and hydrogen sulfide within water wells. The natural and observed well conditions that have been recorded in the area years or decades prior to the Project are known to cause well problems including sediment appearing in water from time-to-time and in different concentrations. Black or grey sediment originating from the black shale into which the wells have been drilled, black particulates from hydrogen sulfide corrosion and staining of metals, bacterial slime growth, foul or noxious odours, clogging of well systems and fine filters and discolouration of well water, all of which are the basis of the water well complaints made during the course of the Project, should not be considered unusual given these natural conditions, typical well construction information and common well operations in the Project area.

6.0 ILLUSTRATION OF VIBRATION AND GAS INFLUENCES ON SEDIMENT SUSPENSION

A series of simple laboratory-scale demonstrations were completed to visually illustrate the effects of vibrations and gas on sediments in wells as described above. The methods used for these demonstrations are summarized below.

Samples of the glacial till deposits overlying the Kettle Point Formation black shale bedrock were obtained during drilling in December 2017 to install instruments for the long-term subsurface vibration monitoring program that is to be implemented for the operational phase of the Project. Three installations were completed as "mock wells" to mimic the construction of residential water wells in the project area and these were designated T23MW, T41MW and T51MW. Copies of drilling records are provided in Appendix A. As illustrated on these records, a hole was drilled to bedrock, conventional split spoon[80] and thin-wall tube[81] samples of the soil were obtained at various depths and the rock was cored[82] to confirm that the monitoring instruments would be seated within rock. A 128 mm inside diameter steel casing, similar to many area well casings, was installed by forcing the casing into the slightly smaller diameter drilled hole to ensure intimate contact with the surrounding ground. Once in place, the hole was flushed, instruments were cemented into place and a surface seal of bentonite grout was installed in the

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[78] http://www.health.state.mn.us/divs/eh/wells/waterquality/hydrosulfide.html

[79] Technical Support Document for Ontario Drinking Water Standards, Objectives and Guidelines, PIBS 4449e01. 2006

[80] ASTM D1586 – 11. 2011. Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils. American Society for Testing and Materials (ASTM International), West Conshohoken, PA.

[81] ASTM D1587. 2015. Standard Practice for Thin-Walled Tube Sampling of Fine-Grained Soils for Geotechnical Purposes, American Society for Testing and Materials (ASTM International), West Conshohocken, PA.

[82] ASTM D2113-14. 2014. Standard Practice for Rock Core Drilling and Sampling of Rock for Site Exploration, American Society for Testing and Materials (ASTM International), West Conshohocken, PA.

top 12 to 15 feet, similar to modern wells. The long-term monitoring plan design and implementation are addressed in other documents prepared for this project and are not discussed in further detail in this report.

Four soil specimens were used in the demonstrations to represent different variations of sediment grain size distribution and illustrate the influence of particle size on re-suspension of the sediments in water by either vibrations or gas. The specimens included a portion of Sample 4 from Well T23MW and three specimens were prepared from a composite of T41MW Sample 3 and T51MW Sample 5. The composite sample was prepared to provide sufficient masses when the sample was then split into different grain size distribution fractions. All samples were subject to standard mechanical[83] and hydrometer[84] grain size distribution determinations. Test reports for the grain size distributions are provided in Appendix B. Following grain size distribution testing for the composite T41MW/T51MW sample, the total mass of soil was sieved with the gravel, sand and “fines” (silt and clay-size fraction) separated. Grain size distributions prepared on the basis of these separations are also provided in Appendix B. Characteristic grain sizes for these separated samples are illustrated by Photographs 3 through 7. Of note, the oven-drying process, used during the standard mechanical sieve analysis, resulted in some oxidization of the fine materials resulting in a more brown than grey or black appearance to the overall specimen mass. Each of the four specimens was blended into a slurry, poured into the water column in separate glass hydrometer test cylinders and allowed to settle.

Dispersant, while normally used in the standard hydrometer test, was not used for either the demonstration conditions or the grain size distribution tests. Eliminating the use of dispersant, while it might result in fine particles that remain bonded or flocculated, was judged to be more consistent with the conditions in the water wells. In all cases, the water level was filled to the standard 1,000 ml line used in the hydrometer test to provide a visual cue for any movements of the water surface. Once the particles had settled, the hydrometer test cylinder was gently moved to a separate laboratory bench for vibration testing, air bubble testing and filming.

For each vibration condition, an Instantel Minimate Plus (Series III) geophone monitoring system was placed next to the hydrometer cylinder. Two small sandbags were placed on top of the geophone to mimic the total cumulative mass of the glass cylinder, sediment and water (total of about 1.5 kg), thus approximating the gravitational coupling of the hydrometer to the laboratory bench. Clocks on the geophone monitoring system and video camera were synchronized to within about 1 second. When subjected to vibrations, in either vertical or horizontal directions, the vibrations were generated by manually striking the bench, using a hard rubber mallet, 500 mm away from the hydrometer cylinder. Vibrations were first generated by using the wooden mallet handle tapping on the bench, followed by firmly hitting the desk, followed by hard pounding on the desk at a rate of about 1 strike per second with the intent of generating transient vibrations of different magnitudes. After striking the bench with vertical movements, the process of striking the bench was repeated except in the horizontal direction by striking the end of the bench. Each demonstration condition was subject to both vertical and horizontal vibrations and the total duration of vibrations was on the order of 4 minutes. Samples T41MW/T51MW gravel and sand fractions were each subjected to two instances of vertical hammering since the first instance was severe enough after 1 minute to result in dislodging the photography light bulbs and after securing the bulbs the demonstrations were restarted. After being subjected to vertical and horizontal vibrations the sediments were allowed to rest for a period of 2 to 6 hours, except for the T41MW/T51MW gravel sample which rested for 1.5 hours after the vibrations. Records of vibration measurements taken during each condition are included in Appendix C. In these demonstration, vibrations generated by hammering on the laboratory bench occurred in all three orthogonal

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[83] ASTM D422. 2007. Standard Test Method for Particle-Size Analysis of Soils. American Society for Testing and Materials (ASTM International), West Conshohocken, PA

[84] ASTM D7928. 2017. Standard Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis. American Society for Testing and Materials (ASTM International), West Conshohocken, PA.

directions (vertical, longitudinal and transverse) with the vertical hammering producing the most severe responses, likely because of the particular construction details of the bench. Horizontal hammering was not as well controlled with respect to the position for striking the bench because of rounding of the bench edge and the details of the bench edging.

Simple simulations of gas emergence through well bottom sediments were subsequently undertaken by installing a small, 3.2 mm (1/8 inch) inside diameter pipe to the bottom of the sediment. The pipe passed through a cylinder cap with a second short length of identical pipe to act as a vent. Insertion of the pipe was accomplished without coupling (sealing) to the air injection system to allow equilibration of water and outside air pressures within the pipe as it was being inserted. The pipe was fitted with a small diameter rod with a curved end that fit into the open hole to prevent it from being plugged by compressed fine sediment or larger particles. Once inserted, the air pipe was retracted slowly so that the opening was suspended 20 mm from the bottom of the hydrometer cylinder, taking care not to disturb the sediments. After installing and retracting the pipe, the sediments were allowed to rest for at least one hour. Two specimens, T23MW and T41MW/T51MW (sand) were also subject to diffuse air injection using a Hagen 960 air stone. In these cases, the samples were thoroughly mixed with the water in the hydrometer, the pipe with the air stone was installed to the bottom of the cylinder while the sediments were suspended and the sediments were allowed to settle around the air stone. After each gas infusion demonstration, the sediments were mechanically mixed to fully suspend the sediments in the water and remove any influences of the prior gas bubbling demonstration.

A Harvard Apparatus Standard Infuse/Withdraw PHD ULTRA™ 4400 Programmable Syringe Pump was used to force air through the pipe under controlled volumetric rates while at the same time measuring pressures using a Keyence 12SK 100kPa in-line pressure transducer and an AP-V80W readout. Volumetric air injection rates of 3 ml/minute with a maximum total volume of 5 ml per infusion, 10 ml/minute to a maximum volume of 20 ml and 50 ml/minute to a total of 20 ml were used to illustrate the influence of different gas emergence rates compatible with potential field conditions in the Project area. Air pressures under the pre-set flow rates were also measured in both free air and when submerged in water. For the pipe-only system, air pressures resulting only from flow through the system were insignificant and, when submerged in water, the pressures required to cause emergence of the bubble matched calculated hydrostatic pressures at the pipe tip. When the diffuser was used, net air pressures from flow resistance when the system was in free air were about 0.1 kPa. When the diffuser was submerged, a net pressure of about 6.6 kPa was required to result in the first formation of bubbles when under a head of water of about 347 mm. For the two demonstrations using the diffuser, the injection rate and total volume of air were set to 3 ml/minute and 10 ml total volume and 10 ml/min and 20 ml total for T23MW and T41MW/T51MW (sand), respectively, since the diffuser system required a higher volume of air to fill the diffuser prior to air reaching the sediment. Readings associated with changes in the ambient air pressure in the laboratory fluctuated to as much as 0.2 kPa.

Each of the demonstrations was video recorded. Equipment used in these demonstrations are shown in Photographs 8 through 12. Still images from the video recordings are provided in Photographs 13 to 46 as examples to illustrate the outcome of these demonstrations[85].

These simple demonstrations illustrate key elements of mechanisms that cause suspension of sediments in well water as described above:

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[85] The electronic version of this report also includes video examples.

- None of the vibration trials exhibited re-suspension of the bottom sediments into the well water, despite being subjected to vibration velocities of more than 40 mm/s and 100 mm/s in the horizontal and vertical directions, respectively. During the hammering, the vibrations were sufficient to move the demonstration apparatus to the extent that the pressure measuring readout (used for later experiments) was bouncing and, in some cases, by the end of the testing, the bean bag weights and photography light tent were visibly displaced. Vibrations measured during these examples were more than 1,000 and 2,500 times the largest well casing vibrations measured during pile driving, respectively.

- Use of the 3.2 mm diameter pipe opening to introduce the air produced bubbles emerging from the sediment that ranged between about 0.1 to 0.5 ml in volume (5.9 to 9.6 mm diameter) with an average of about 0.3 ml (average diameter of about 8.2 mm). Use of the diffuser produced hundreds of bubbles every second (depending on infusion rate), on the order of 1 mm diameter.

- Introduction of air, at all rates used in this demonstration, did not affect the gravel sample, with the exception of re-suspending part of the minor quantities of very fine (i.e., dust) particles that remained after the mechanical sieve sample separation.

- Bubbles passing through the mixed grain size distribution of the T23MW sample produced the most turbid (i.e., cloudy, most suspended sediments) conditions at the conclusion of the air infusion, regardless of the infusion rate, based on visual evidence. The suspended sediment load in each of the tests, ranked from least to most, follows:

    - T41MW/T51MW – Gravel exhibited little suspended sediment and only a minor concentration of very fine particles (remnants of the mechanical sieve separation) were suspended in the water near the bottom of the water column;

    - T41MW/T51MW – Silt and Clay was resistant to sediment resuspension on account of the cohesion between the fine particles comprising the majority of the specimen;

    - T41MW/51MW – Sand reacted rapidly to emergence of bubbles, as compared to the silt and clay specimen, with sand-size sediment readily being forced and carried upward into the water column;

    - T23MW – the mixed grain size distribution produced the most turbid conditions of all samples, regardless of infusion rate or bubble size.

    - Net air pressures, after accounting for flow resistance through the diffuser tip, required to generate bubbles that emerged from the sediment exceeded the hydrostatic pressure at the infusion point by less than 10 per cent (average of about 6 per cent). In all cases, once the first bubbles emerged from the sediment, the air pressure required to generate bubbles dropped slightly to match the hydrostatic pressure at the point of infusion.

- The faster air infusion rates suspended more sediments within the water column, based on visual evidence, likely because of higher turbulence and bubble-particle interaction overcoming particle settling velocities more frequently.

- In each of the bubbling cases, small jets of water emerged from the sediments as the water within the injection pipe, diffuser and sediment pores was displaced by the air, until the first air bubble was of sufficient pressure to break through the overlying sediment (see Photographs 45 through 48).

- During initial sedimentation for all tests, a coating of fine particles formed on the walls of the hydrometer cylinder, influencing the clarity of visibility during the tests. This fine film of particles could not be dislodged or altered by vibrations or the bubbles. Severe agitation of the sediments and water between tests did not remove this fine film of particles. Photographs 49 and 50 illustrate that only after physically wiping the inside of the cylinder could this particulate coating be partially removed. For the series of demonstrations using dispersed air the side walls of the hydrometer cylinder were scraped with a plastic spatula during agitation to remove the film from previous tests, resulting in better viewing conditions through the glass (see Photograph 51).

In these demonstrations, sediments were readily re-suspended in the water by emergence of bubbles whereas vibrations far in excess of field measurements did not re-suspend sediments. In field conditions, upward water flow toward a well pump intake would exacerbate the re-suspension of particles by gas bubbles and also carry them higher in the water column. While these demonstrations were relatively simple bench-scale models of the well system, they provide tangible and measurable examples of sediment suspension (or re-suspension) mechanisms and their relative importance for the conditions in the North Kent Wind 1 project area.

7.0 SUMMARY

Evaluations of the natural conditions, characteristics of pile driving and its effects on ground and water, water flow velocities and pressures, and conditions within domestic water wells in the Project area, as described above, can be summarized as follows:

- The local domestic water wells were drilled into the Kettle Point Formation black shale and/or glacially-deposited materials immediately above the Kettle Point Formation shale bedrock. The glacially-derived materials are also known to include fragments of the black shale. Sediments composed of black shale fragments should therefore be expected within the wells.
- Natural soil and rock particles of a wide spectrum of sizes exist within and immediately surrounding the wells. The most likely source for such particles being in the wells is from cuttings remaining from initial well drilling and fine-grained natural materials drawn into the well by water flow during initial well development, long-term pumping, and over-pumping events that form a deposit of sediment at the bottom of the well. Accumulations of sediment composed of black Kettle Point Formation shale should be expected in these wells, independent of any other influences, simply on account of the wells being installed into these formations and pumped.
- Water flow velocities through the aquifer at the boundary of the well hole and in the well casing induced by pumping are sufficient to transport and suspend fine sand and smaller particles and overcome their settling velocities. Therefore, the appearance of fine sand, silt and clay-size particles in well water should be expected independent of any other influences.
- The effects of distant pile driving were not sufficient by one or more orders of magnitude (i.e., 1/10th, 1/100th, 1/1000th, etc.) to result in any:
  - dynamically-induced pore water pressures that meaningfully contribute to differential flow velocities at or within the wells;
  - liquefaction of the ground;
  - disturbance and remobilization/suspension of fine particles within the well water column;

  - dynamically-induced shear stresses of any significance related to well bore instability;
  - influences on the settling velocity or suspension of fine sand and smaller sediment particles in the wells; or
  - dislodging of particles adhering to the inside of the well casing.
- Natural gas (predominantly methane) exists in sufficient quantities and pressures within water wells in the wider region and within the Project area to result in suspension of sediments within wells from time to time as it comes out of solution or emanates from the rock in a gaseous phase as the wells are pumped.
- Naturally-occurring hydrogen sulfide is a likely contributor to observations of black particles within the well water and its accompanying characteristic unpleasant odour, biogenic slimes and water discolouration.

As but one example, the Alberta Ministry of Agriculture and Forestry[86], in its guidance for troubleshooting water well problems, notes that the appearance of sediment in wells can be caused by multiple and common factors including:

- improper well design or construction;
- insufficient well development after construction;
- continuous over-pumping of well;
- corrosion of well casing, liner or screen causing holes; and
- failure of the annular or casing seal.

All available information for the Project area, including known geologic conditions and recorded well histories, and a significant body of published research and water well operation and maintenance guidance indicate that the reported troublesome well conditions are no different than the well-known causes described above. It is Golder's opinion that the likely cause of the reported well problems and observed sediments are associated with:

- well-bottom sediments originating from initial well drilling and development;
- periodic over-pumping of the low-yield aquifer that contributes to well-bottom sediments;
- lack of appropriate well screens and sand packs that allows continued extraction of fine particles from the aquifer during normal pumping and contribution to well-bottom sediments;
- erratic pump cycling caused by improper configurations of pumps, pressure tanks and filters;
- poorly vented well casings that permit uncontrolled build-up and release of gas pressures;
- re-suspension of well-bottom sediments by water flow in wells where the sediments have accumulated to the point of blocking water flow into the well (i.e., filling up into the casing);
- re-suspension of well-bottom sediments by gas bubbles (methane and/or hydrogen sulphide from sulfate-reducing bacteria);
- the presence of hydrogen sulfide and sulfate-reducing bacteria in the wells; and

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[86] Module 7 — Troubleshooting Water Well Problems. Alberta Ministry of Agriculture and Forestry,

- in the most severe cases, uncased well bore collapses may have occurred as a result of prolonged removal of aquifer particles from pumping.

Pile driving more than 500 meters away from water wells cannot be rationally justified as a cause of the reported water well problems based on the available historic water well records, local geology, scientific and engineering research, and published knowledge regarding water well conditions and field measurements. The natural methane and hydrogen sulfide in the region and local water wells are, however, consistent with and known to cause the conditions reported by the well owners. It is Golder’s professional opinion that the problems reported by the well owners are the result of natural conditions coupled with well construction, age and operation and such problems should be expected from time to time in the future. Published advisory resources are available to well owners suffering such problems and the Best Suggested Practices produced by The Groundwater Association and referenced in this report could provide appropriate guidance for the owners and licensed water well specialists in resolving their water supply issues.

Signature Page

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Unless otherwise stated, the suggestions, recommendations and opinions given in this report are intended only for the guidance of the Client in the design of the specific project. The extent and detail of investigations, including the number of test holes, necessary to determine all of the relevant conditions which may affect construction costs would normally be greater than has been carried out for design purposes. Contractors bidding on, or undertaking the work, should rely on their own investigations, as well as their own interpretations of the factual data presented in the report, as to how subsurface conditions may affect their work, including but not limited to proposed construction techniques, schedule, safety and equipment capabilities.

Soil, Rock and Groundwater Conditions: Classification and identification of soils, rocks, and geologic units have been based on commonly accepted methods employed in the practice of geotechnical engineering and related disciplines. Classification and identification of the type and condition of these materials or units involves judgment, and boundaries between different soil, rock or geologic types or units may be transitional rather than abrupt. Accordingly, Golder does not warrant or guarantee the exactness of the descriptions.

Special risks occur whenever engineering or related disciplines are applied to identify subsurface conditions and even a comprehensive investigation, sampling and testing program may fail to detect all or certain subsurface conditions. The environmental, geologic, geotechnical, geochemical and hydrogeologic conditions that Golder interprets to exist between and beyond sampling points may differ from those that actually exist. In addition to soil variability, fill of variable physical and chemical composition can be present over portions of the site or on adjacent properties. The professional services retained for this project include only the geotechnical aspects of the subsurface conditions at the site, unless otherwise specifically stated and identified in the report. The presence or implication(s) of possible surface and/or subsurface contamination resulting from previous activities or uses of the site and/or resulting from the introduction onto the site of materials from off-site sources are outside the terms of reference for this project and have not been investigated or addressed.

Soil and groundwater conditions shown in the factual data and described in the report are the observed conditions at the time of their determination or measurement. Unless otherwise noted, those conditions form the basis of the recommendations in the report. Groundwater conditions may vary between and beyond reported locations and can be affected by annual, seasonal and meteorological conditions. The condition of the soil, rock and groundwater may be significantly altered by construction activities (traffic, excavation, groundwater level lowering, pile driving, blasting, etc.) on the site or on adjacent sites. Excavation may expose the soils to changes due to wetting, drying or frost. Unless otherwise indicated the soil must be protected from these changes during construction.

Sample Disposal: Golder will dispose of all uncontaminated soil and/or rock samples 90 days following issue of this report or, upon written request of the Client, will store uncontaminated samples and materials at the Client’s expense. In the event that actual contaminated soils, fills or groundwater are encountered or are inferred to be present, all contaminated samples shall remain the property and responsibility of the Client for proper disposal.

Follow-Up and Construction Services: All details of the design were not known at the time of submission of Golder’s report. Golder should be retained to review the final design, project plans and documents prior to construction, to confirm that they are consistent with the intent of Golder’s report.

During construction, Golder should be retained to perform sufficient and timely observations of encountered conditions to confirm and document that the subsurface conditions do not materially differ from those interpreted conditions considered in the preparation of Golder’s report and to confirm and document that construction activities do not adversely affect the suggestions, recommendations and opinions contained in Golder’s report. Adequate field review, observation and testing during construction are necessary for Golder to be able to provide letters of assurance, in accordance with the requirements of many regulatory authorities. In cases where this recommendation is not followed, Golder’s responsibility is limited to interpreting accurately the information encountered at the borehole locations, at the time of their initial determination or measurement during the preparation of the Report.

Changed Conditions and Drainage: Where conditions encountered at the site differ significantly from those anticipated in this report, either due to natural variability of subsurface conditions or construction activities, it is a condition of this report that Golder be notified of any changes and be provided with an opportunity to review or revise the recommendations within this report. Recognition of changed soil and rock conditions requires experience and it is recommended that Golder be employed to visit the site with sufficient frequency to detect if conditions have changed significantly.

Drainage of subsurface water is commonly required either for temporary or permanent installations for the project. Improper design or construction of drainage or dewatering can have serious consequences. Golder takes no responsibility for the effects of drainage unless specifically involved in the detailed design and construction monitoring of the system.

Table 1: Summary of Complaints

Complaint	Well Depth[a] (m)	Well Intake Length[b] (m)	Pump Intake Depth[c] (m)	Pump Type	Q_R[e] (l/m)	Nature of Complaint	Filtration Notes[f]	Other[g]
1	20.7	0.9	14.0/U	S	13.3	“sediment inundation”, low flow	screen at clay/ gravel interface, multiple filter systems	coliforms
2	21	U	U	J	U	reduced flow, sediment in filters	multiple filters between pump and tank	gas
3	14.0	U	12.2	M	U	“sediment filling filters”, loss of pressure	filter between pump and tank	
4	14.9	0	9.1	J	19	“black sediment”	filter > 8 years old	multiple nearby wells abandoned due to cloudy or insufficient water
5	See Complaint 2, above							
6	14.5	0	12.8	J	1	“cloudy water”, sediment in tank	filter within pump house	coliforms, well “dry” at time of completion, other wells on property, 1 lpm, water noted as “slight haze” on records
7	U	U	U	J	U	sediment in trap		well head buried
8	U	U	U	J	U	“black specs” in sediment trap, reduced flow		gas, well head buried
9	21.9	U	21.9	P	U	“filters plugged”, “increased rust colouring”	multiple filters installed recently	well head buried
10	U	U	U	J	U	sediment in filters, “more gas” noticed, pump “choked out”	filter between pump and tank	gas

Complaint	Well Depth[a] (m)	Well Intake Length[b] (m)	Pump Intake Depth[c] (m)	Pump Type	Q_R[e] (l/m)	Nature of Complaint	Filtration Notes[f]	Other[g]
11	18.9	0.6	7.6	J	26.5	sediment in water, low flow	well screen, filter between pump and tank	iron
12	U	U	U	J	U	sediment		well head buried
13	19.2	0.3	15.2	J	15.2	flow stopped	none	gas, IRB, coliforms, nearby well abandoned due to lack of supply
14	16.2	1.2	9.1	P	15.2	sediment, low flow	recent filter systems	two other wells on property abandoned due to being “dry”
15	15.2 to 18.3	U	U	J	U	sediment, no water	recent filter system	
16	U	U	U	J on all	U	sediment		IRB, coliforms at one well, complaint related to 3 wells, well heads buried on two wells, gas noted at all 3 wells, orange-red coloured water at one well

Notes: a) depth as recorded on MOECC WWIS records or as provided by owner, U = unknown/undocumented;
b) intake length as taken from MOECC WWIS record being difference between casing length and total well depth and where 0 length indicates casing installed to bottom of well and, therefore, water drawn through bottom of well only;
c) recommended pump intake depth as noted on MOECC WWIS record but not confirmed in field due to limited access;
d) pump type J = jet, U=unknown, M = mechanical lift pump, S = submersible;
e) Q_R = flow rate recommended by well installer as indicated on MOECC WWIS record;
f) “screen” noted where MOECC WWIS record or owner indicated that a well screen was installed;
h) IRB = iron-related bacteria.

AECOM COMPLAINT INVESTIGATION REPORTS:

1) "North Kent Wind 1 (Chatham-Kent, ON), Well Water Impact Complaint Investigation – Updated v.2, Brooks, Paul & Jessica – PIN 007460069, 9597 Brook Line (Dresden, ON)", dated November 15, 2017, AECOM Project No. 60343599

2) "North Kent Wind 1 (Chatham-Kent, ON), Well Water Impact Complaint Investigation – Updated v.2, Brooksbank, Scott – PIN 007500008, 9757 Countryview Line (Dresden, ON)", dated November 15, 2017, AECOM Project No. 60343599

3) "North Kent Wind 1 (Chatham-Kent, ON), Well Water Impact Complaint Investigation – Updated v.2, Brooksbank, Wayne – PIN 007500067, 9459 Countryview Line (Dresden, ON)", dated November 15, 2017, AECOM Project No. 60343599

4) "North Kent Wind 1 (Chatham-Kent, ON), Well Water Impact Complaint Investigation – Updated v.2, Moir, Mark – PIN 7500065, 9567 Countryview Line (Dresden, ON)", dated November 22, 2017, AECOM Project No. 60343599

5) See Complaint 2, above.

6) "North Kent Wind 1 (Chatham-Kent, ON), Well Water Impact Complaint Investigation – Updated v.2, Robson, Dwayne & Decan-Robson, Susan – PIN 007530115, 8811 Union Line (Dresden, ON)", dated November 22, 2017, AECOM Project No. 60343599

7) "North Kent Wind 1 (Chatham-Kent, ON), Well Water Impact Complaint Investigation – Updated v.2, LeClair, Jack & Carole – PIN 007490092, 9073 Countryview Line (Dresden, ON)", dated November 22, 2017, AECOM Project No. 60343599

8) "North Kent Wind 1 (Chatham-Kent, ON), Well Water Impact Complaint Investigation – Updated v.2, Poland, Kevin & Laura – PIN 007530061, 9293 Greenvalley Line (Dresden, ON)", dated November 22, 2017, AECOM Project No. 60343599

9) "North Kent Wind 1 (Chatham-Kent, ON), Well Water Impact Complaint Investigation - Updated, Meyerink, Larry & Janice – PIN 007530004, 8610 Greenvalley Line", dated November 30, 2017, AECOM Project No. 60343599

10) "North Kent Wind 1 (Chatham-Kent, ON), Well Water Impact Complaint Investigation – Updated v.3, DeFraeye, Donald & Lucille – PIN 007490086, 9372 Union Line", dated December 14, 2017, AECOM Project No. 60343599

11) "North Kent Wind 1 (Chatham-Kent, ON), Well Water Impact Complaint Investigation, Aitken, William & Betty – PIN 007530054,8902 Bush Line (Tupperville, ON)", dated December 6, 2017, AECOM Project No. 60343599

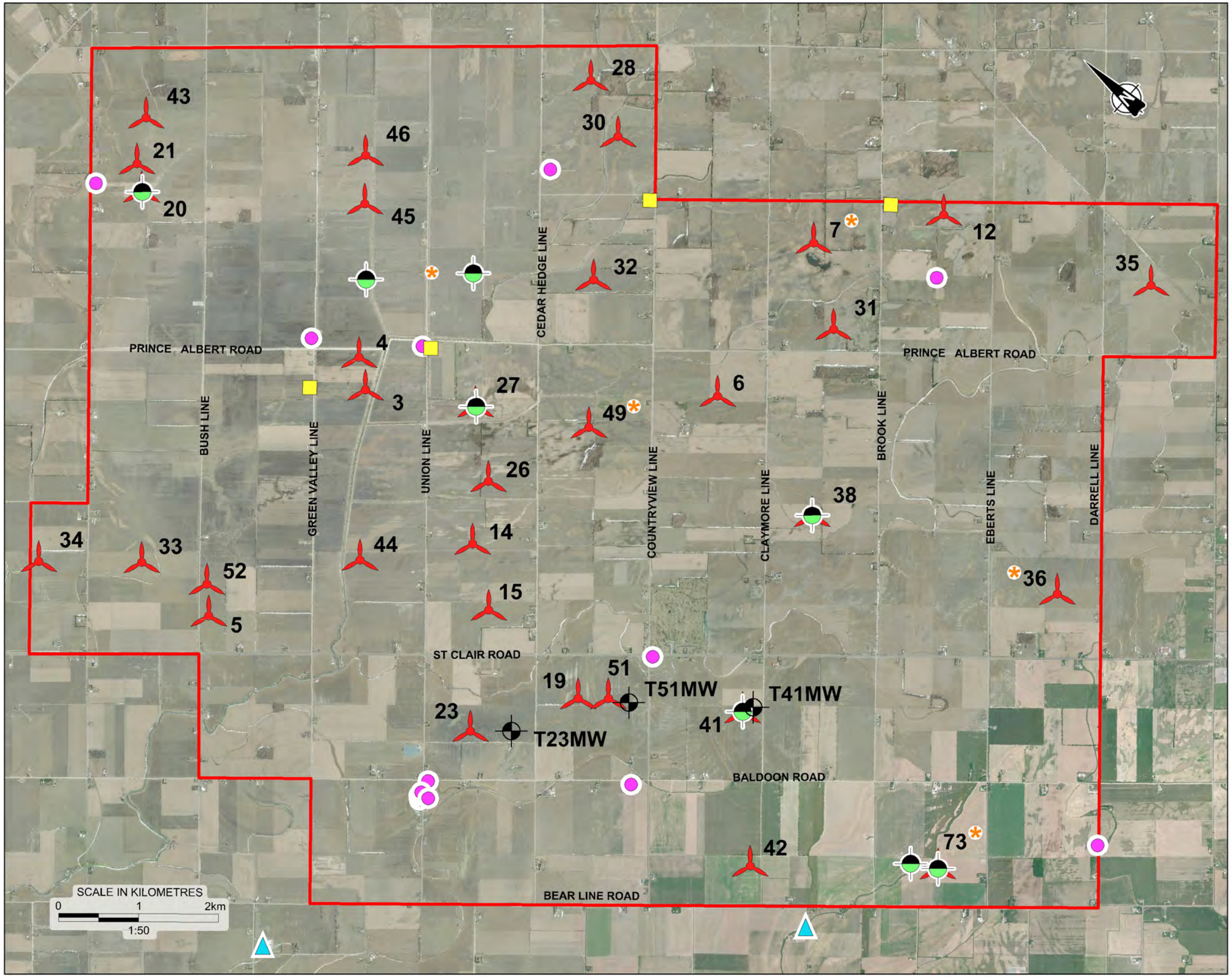
12) "North Kent Wind 1 (Chatham-Kent, ON), Well Water Impact Complaint Investigation - Revised, Simmons, Calvin & Tina – PIN 007530036, 9387 Greenvalley Line (Dresden, ON)", dated January 23, 2017[8], AECOM Project No. 60343599

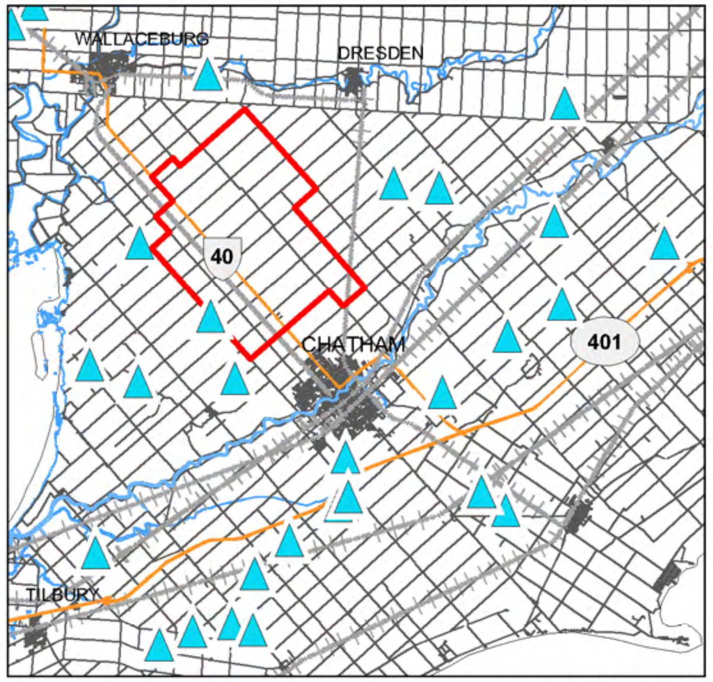
13) "North Kent Wind 1 (Chatham-Kent, ON), Well Water Impact Complaint Investigation, Blonde, Daniel & Bailey, Kathryn – PIN 7420039, 24850 Caledonia Rd. (Dresden, ON)", dated December 8, 2017, AECOM Project No. 60343599

14) “North Kent Wind 1 (Chatham-Kent, ON), Well Water Impact Complaint Investigation, Lusk, Dave – PIN 007530030, 9127 Greenvalley Line (Dresden, ON)”, dated January 25, 2017[8], AECOM Project No. 60343599

15) “North Kent Wind 1 (Chatham-Kent, ON), Well Water Impact Complaint Investigation, Laevens, Henry & Marjorie – PIN 007420011, 24364 Caledonia Rd. (Dresden, ON)”, dated January 25, 2017[8], AECOM Project No. 60343599

16) “North Kent Wind 1 (Chatham-Kent, ON), Well Water Impact Complaint Investigation, Stallaert, Eric – PIN 007530023, 26457 St. Clair Rd. & 26347 St. Clair Rd. (Dresden, ON)”, dated January 25, 2018, AECOM Project No. 60343599





KEY PLAN

LEGEND

- ⊕ VIBRATION MONITORING MOCK WELL
- ● HISTORIC WATER WELL RECORD WITH GAS NOTED, MOECC WATER WELL INFORMATION SYSTEM (1973-2011)
- ⊕ GAS OBSERVED IN AMEC BOREHOLE/MONITORING WELL (2016)
- ▲ METHANE CONCENTRATIONS IN WELL WATER MEASURED BY HAMILTON (2007 – 2011)
- ⅄ TURBINE
- ■ RESIDENCE FOR WHICH GAS NOTED IN WELL OR WATER DISCHARGE (2017)
- * GAS OBSERVED DURING CONSTRUCTION
- — PROJECT STUDY AREA BOUNDARY

REFERENCE

DRAWING BASED ON BING IMAGERY (IMAGE DATE UNKNOWN) AS OF NOVEMBER 30 - 2017;
"FOUNDATION PLAN", ENTUITIVE, PROJECT No. C017-0190, DWG No. S002;
MOECC WATER WELL RECORDS AS OF 2016; AND
HAMILTON, S.M. 2011. AMBIENT GROUNDWATER GEOCHEMISTRY DATA FOR SOUTHWESTERN ONTARIO, 2007–2010; ONTARIO GEOLOGICAL SURVEY, MISCELLANEOUS RELEASE—DATA 283.

NOTES

THIS DRAWING IS SCHEMATIC ONLY AND IS TO BE READ IN CONJUNCTION WITH ACCOMPANYING TEXT.
BING IMAGERY USED FOR ILLUSTRATION PURPOSES ONLY AND NOT TO BE USED FOR MEASUREMENTS.
ALL LOCATIONS ARE APPROXIMATE.

PROJECT

NORTH KENT 1

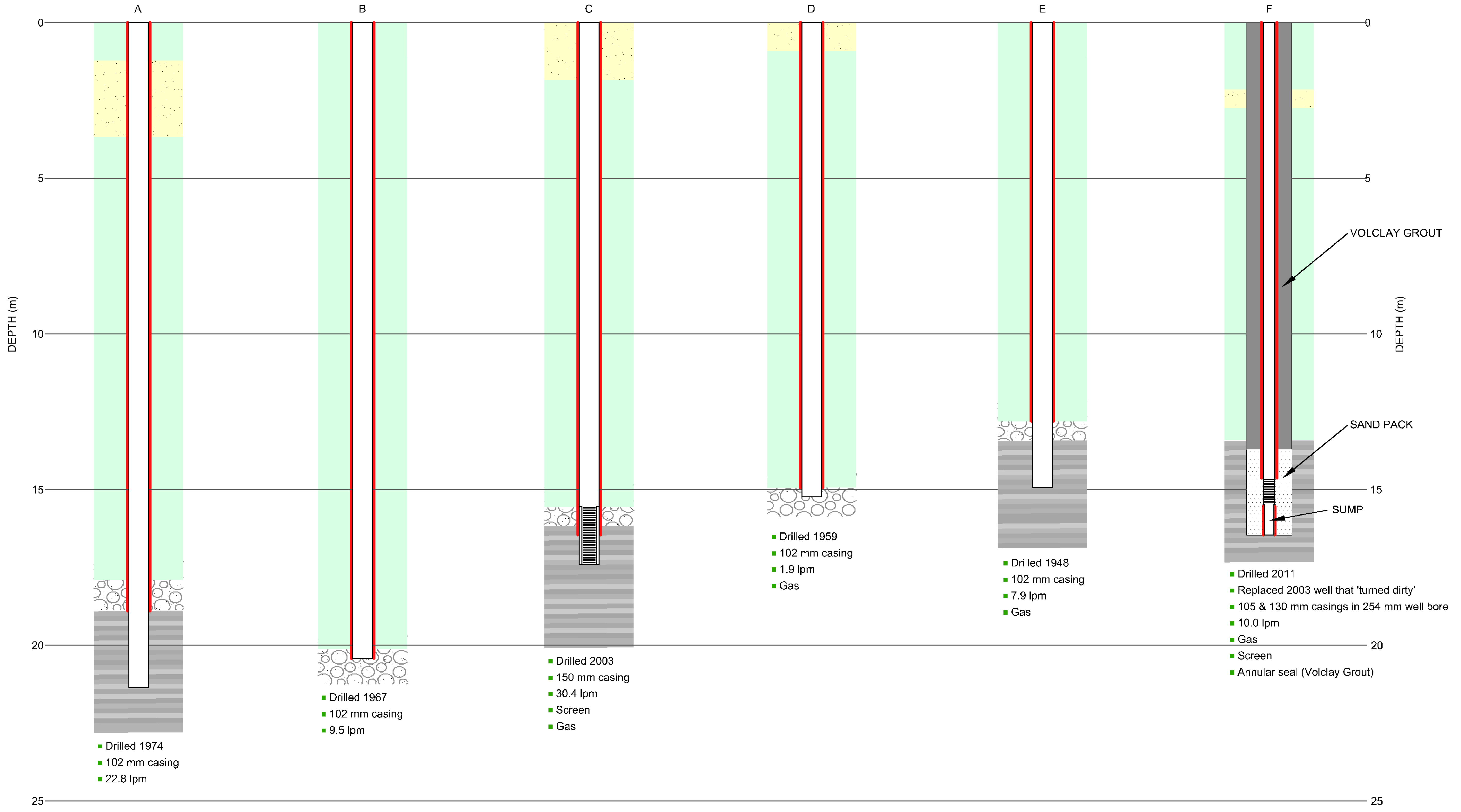
TITLE

SITE LOCATION PLAN

Golder Associates

PROJECT No.		1668031	FILE No. 1668031–2000–R03001	
			SCALE AS SHOWN	REV.
CADD	DCH/ZJB	May 4/18	FIGURE 1	
CHECK	SJB			

Drawing file: 1668031–2000–R03001.dwg May 04, 2018 – 11:36am



A
- Drilled 1974
- 102 mm casing
- 22.8 lpm

B
- Drilled 1967
- 102 mm casing
- 9.5 lpm

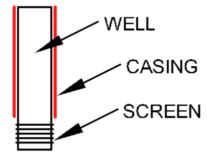
C
- Drilled 2003
- 150 mm casing
- 30.4 lpm
- Screen
- Gas

D
- Drilled 1959
- 102 mm casing
- 1.9 lpm
- Gas

E
- Drilled 1948
- 102 mm casing
- 7.9 lpm
- Gas

F
- Drilled 2011
- Replaced 2003 well that 'turned dirty'
- 105 & 130 mm casings in 254 mm well bore
- 10.0 lpm
- Gas
- Screen
- Annular seal (Volclay Grout)

LEGEND



lpm : LITRES PER MINUTE, RECOMMENDED PUMPING RATE AT TIME OF DRILLING

▨	SAND & SILT
🟩	SILTY CLAY
▨	VARIOUS MIXTURES OF GRAVEL, SAND, SILT & CLAY (GLACIAL TILL)
▨	BEDROCK, KETTLE POINT FORMATION

REFERENCE

DRAWING BASED ON MOECC WATER WELL INFORMATION SYSTEM RECORDS.

NOTES

THIS DRAWING IS SCHEMATIC ONLY AND IS TO BE READ IN CONJUNCTION WITH ACCOMPANYING TEXT.

ALL LOCATIONS ARE APPROXIMATE.

PROJECT

NORTH KENT 1

TITLE

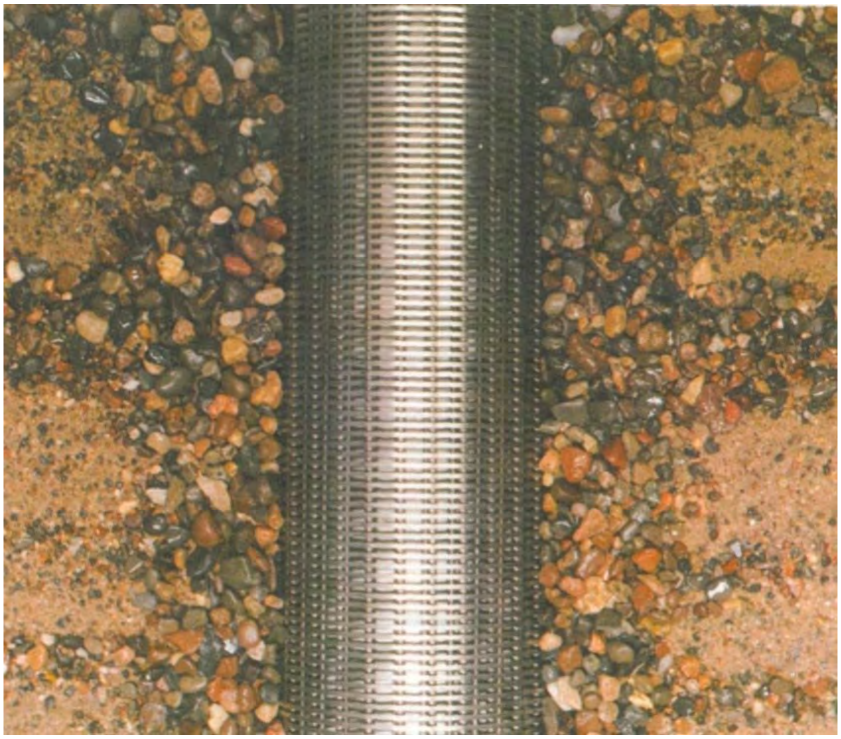
TYPICAL WATER WELL DETAILS

Golder Associates

PROJECT No.		1668031	FILE No. 1668031–2000–R03001	
			SCALE AS SHOWN	REV.
CADD	DCH/ZJB	May 4/18	FIGURE 2	
CHECK	SJB			

Drawing file: 1668031–2000–R03001.dwg May 04, 2018 – 11:18am

Photograph 1: Example of gas discharge from borehole drilled to top of Kettle Point Formation black shale (ca. 1990 – 1992).

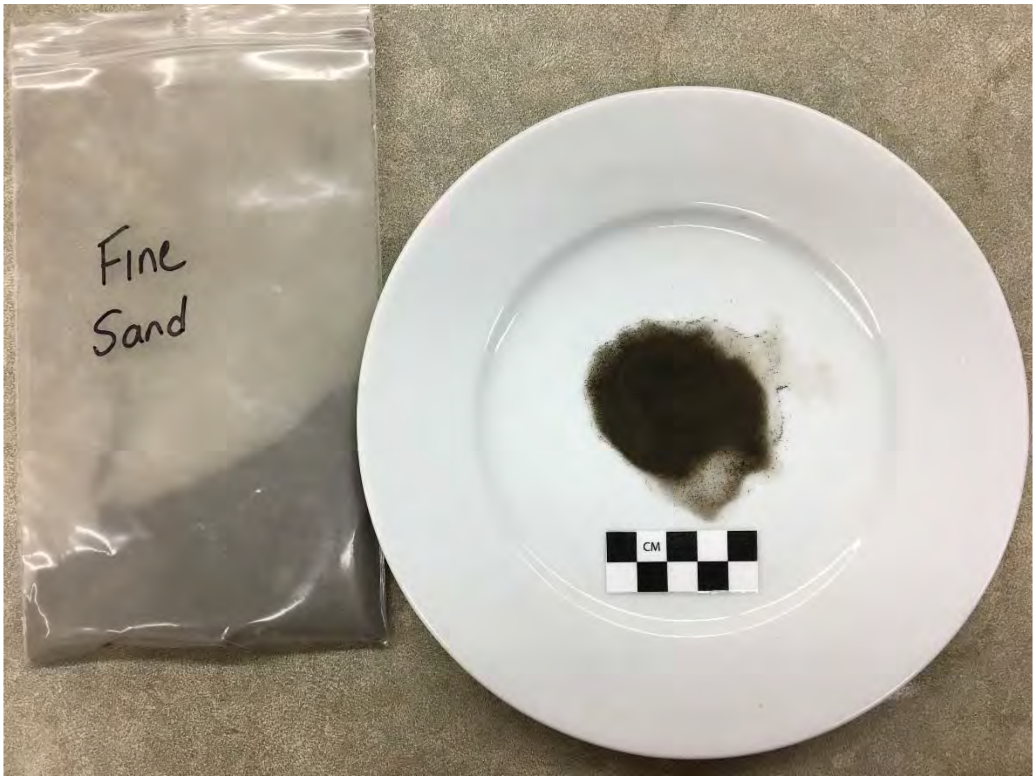


Photograph 2: Illustration of natural filter formation around a well screen (from Driscoll, 1986, Figure 15.3).

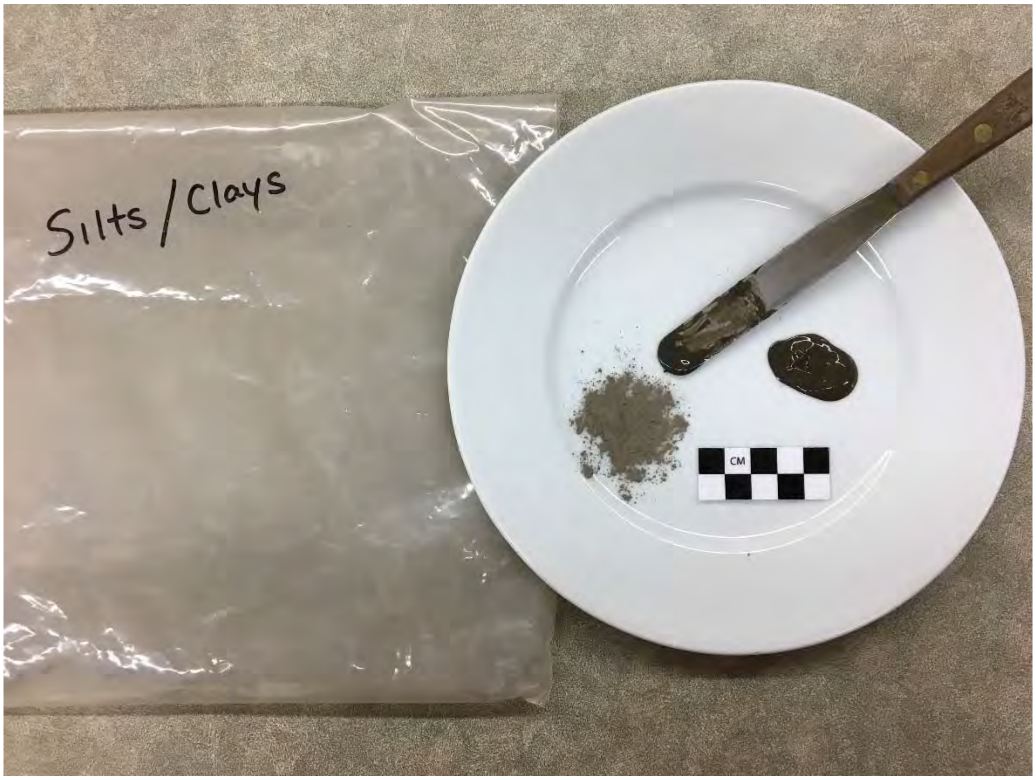
Photograph 3: Example grains of fine to coarse gravel obtained from composite sample T41MW/T51/MW.

Photograph 4: Example grains of coarse sand obtained from composite sample T41MW/T51/MW.

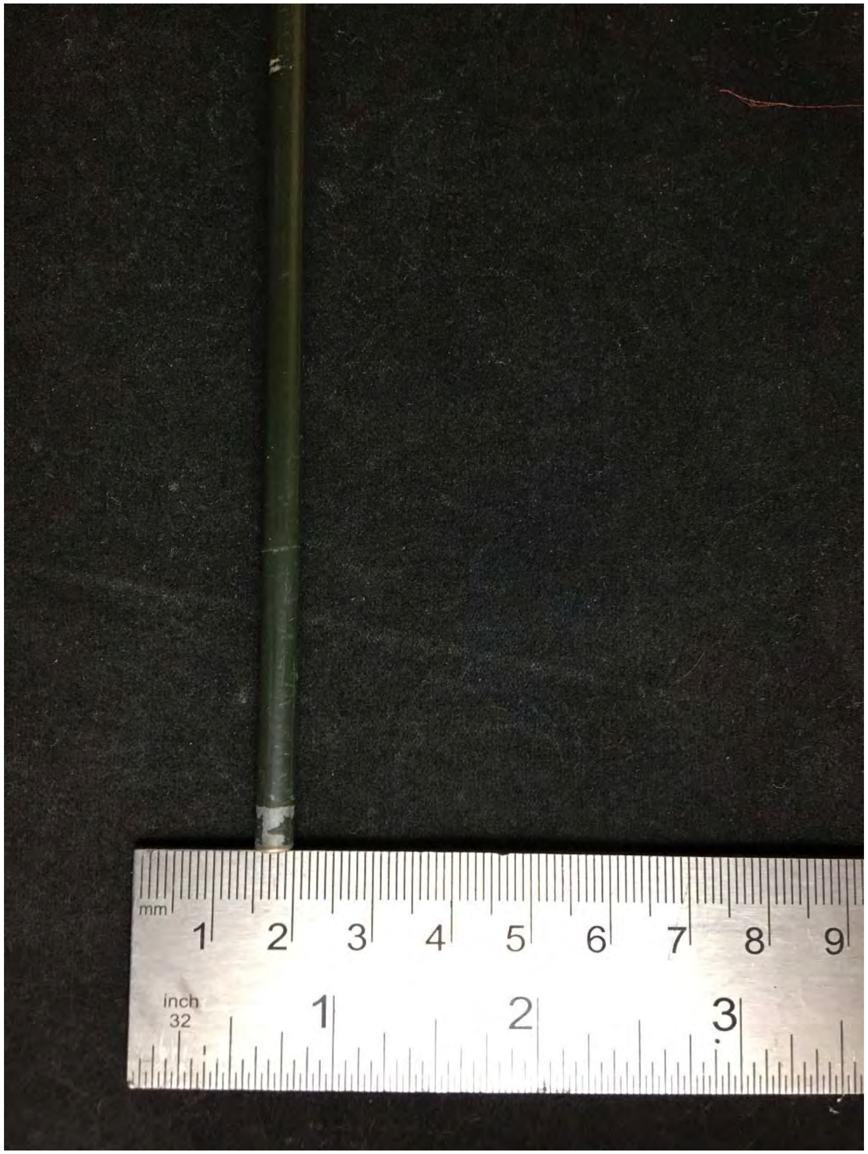
Photograph 5: Example grains of medium sand obtained from composite sample T41MW/T51/MW.



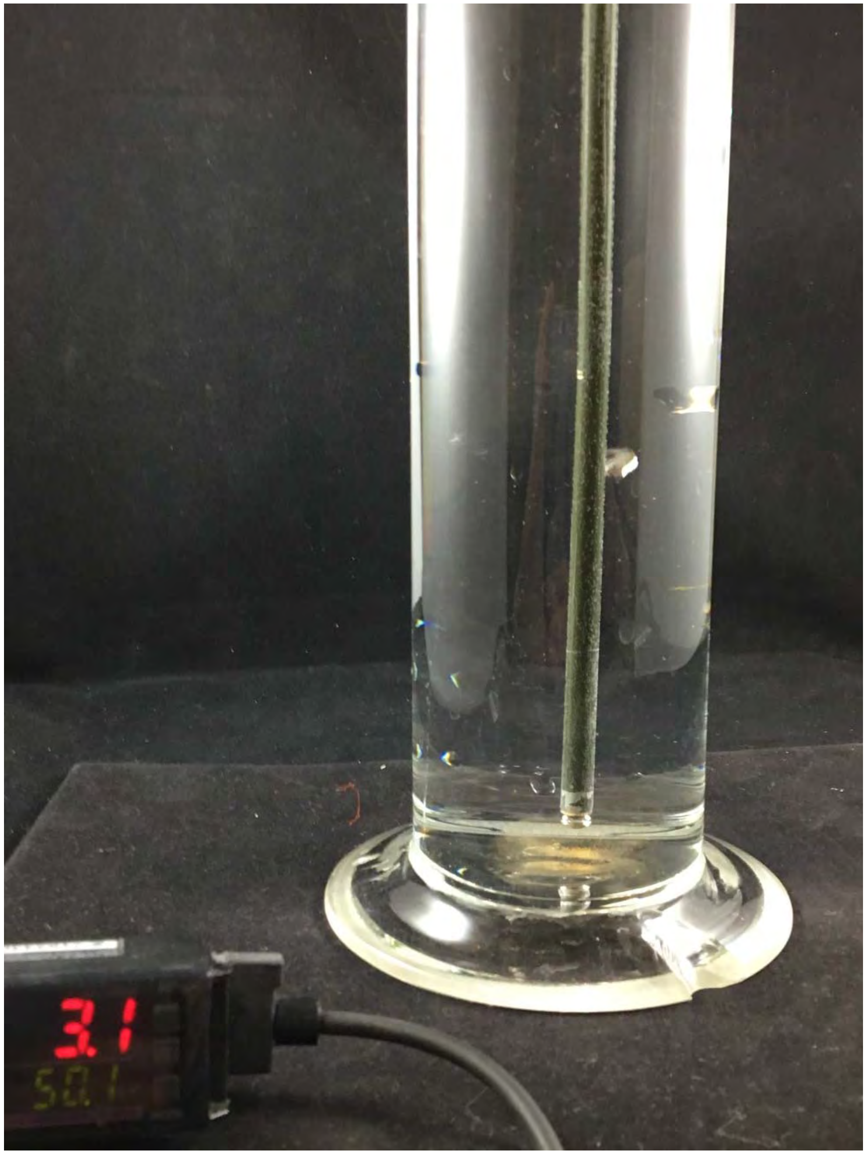
Photograph 6: Example grains of fine sand obtained from composite sample T41MW/T51/MW.



Photograph 7: Example grains of silt and clay obtained from composite sample T41MW/T51/MW, showing in both dry form (powder at left) and blended with water and shown sticking to metal mixing blade (at right).



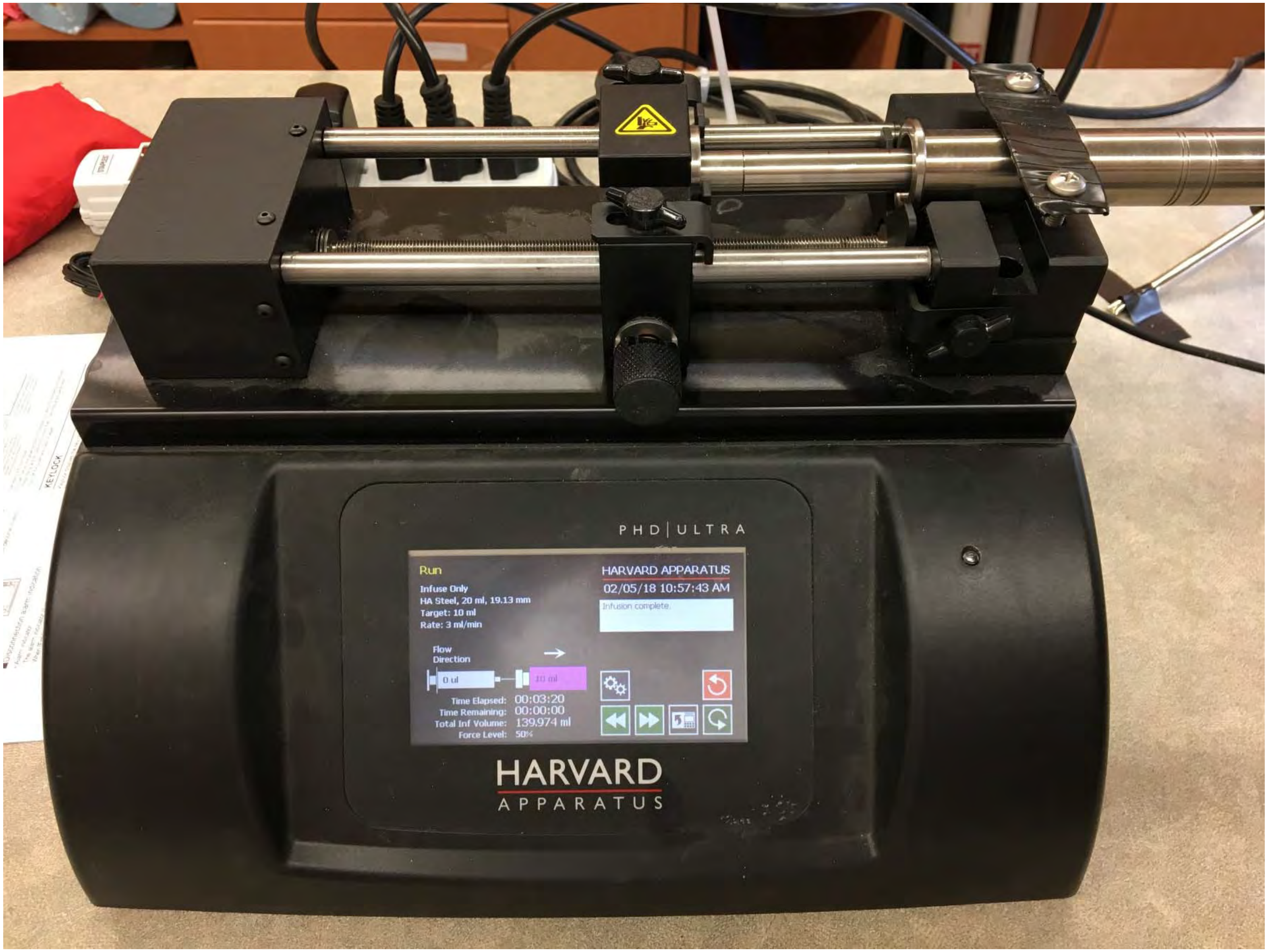
Photograph 8: Air infusion pipe and opening.



Photograph 9: Air bubbles from infusion pipe only.

Photograph 10: Air diffuser tip.

Photograph 11: Air bubbles from diffuser.



Run

Infuse Only
HA Steel, 20 ml, 19.13 mm
Target: 10 ml
Rate: 3 ml/min

HARVARD APPARATUS
02/05/18 10:57:43 AM

Infusion complete.

Flow Direction →

0 ul
10 ml

Time Elapsed: 00:03:20
Time Remaining: 00:00:00
Total Inf Volume: 139.974 ml
Force Level: 50%

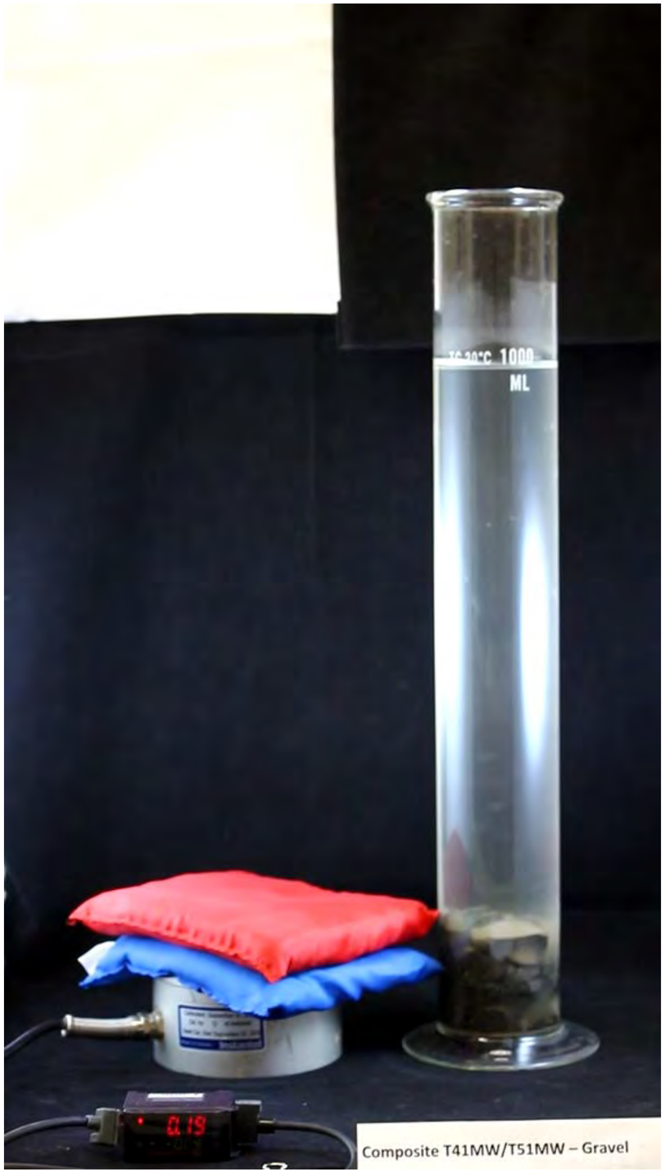
Photograph 12: Programmable infusion pump.

Photograph 13: Conditions at start of vertical hammering for subjecting Sample T23MW (full grain size distribution) to vibrations.

Photograph 14: Conditions at conclusion of vertical hammering for subjecting Sample T23MW (full grain size distribution) to vibrations.

NOTE: Air pressure gauge readings reflect changes in ambient air pressures only.

Photograph 15: Conditions at start of horizontal hammering for subjecting Sample T41MW/T51MW (gravel) to vibrations.



Photograph 16: Conditions at conclusion of horizontal hammering for subjecting Sample T41MW/T51MW (gravel) to vibrations.

NOTE: Air pressure gauge readings reflect changes in ambient air pressures only.

Photograph 17: Conditions at start of vertical hammering for subjecting Sample T41MW/T51MW (sand) to vibrations.

Photograph 18: Conditions at conclusion of vertical hammering for subjecting Sample T41MW/T51MW (sand) to vibrations.

NOTE: Air pressure gauge readings reflect changes in ambient air pressures only.

Video: Conditions during vertical hammering for subjecting Sample T41MW/T51MW (sand) to vibrations.

Photograph 19: Conditions at start of vertical hammering for subjecting Sample T41MW/T51MW (silt & clay) to vibrations.

Photograph 20: Conditions at conclusion of vertical hammering for subjecting Sample T41MW/T51MW (silt & clay) to vibrations.

NOTE: Air pressure gauge readings reflect changes in ambient air pressures only.

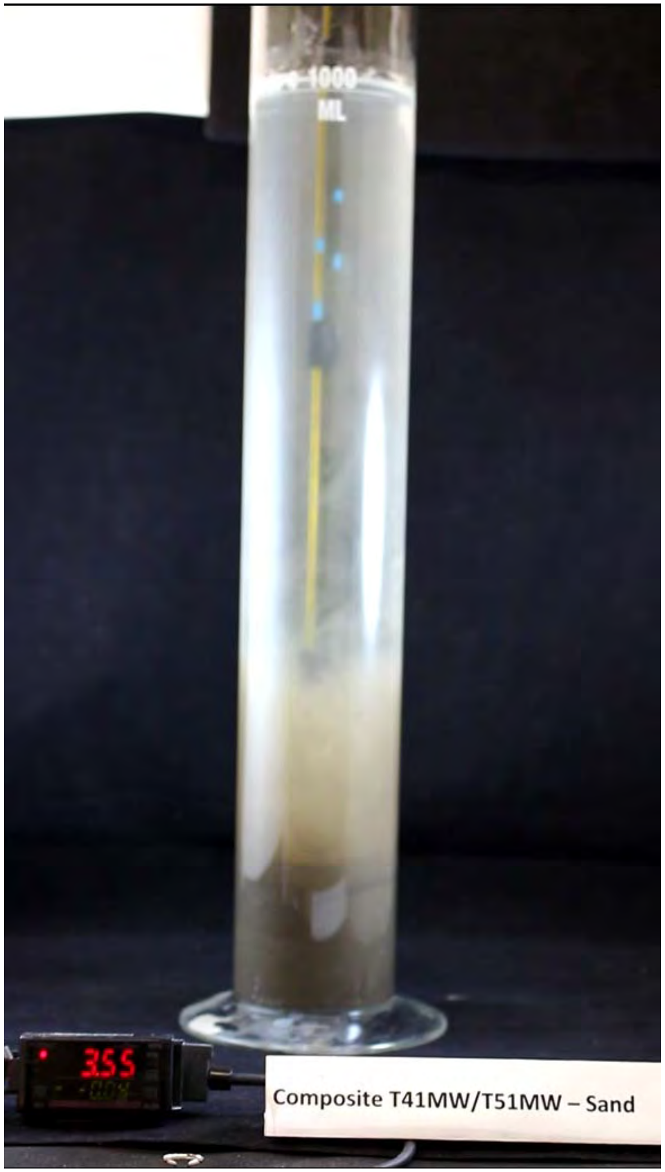
Photograph 21: Conditions at formation of first bubble during air infusion at 10 ml/minute, Sample T23MW (full grain size distribution).

Photograph 22: Conditions at conclusion of 20 ml of air infusion at 10 ml/minute, Sample T23MW (full grain size distribution).

Photograph 23: Conditions at formation of first bubble during air infusion at 50 ml/minute, Sample T41MW/T51MW (gravel).

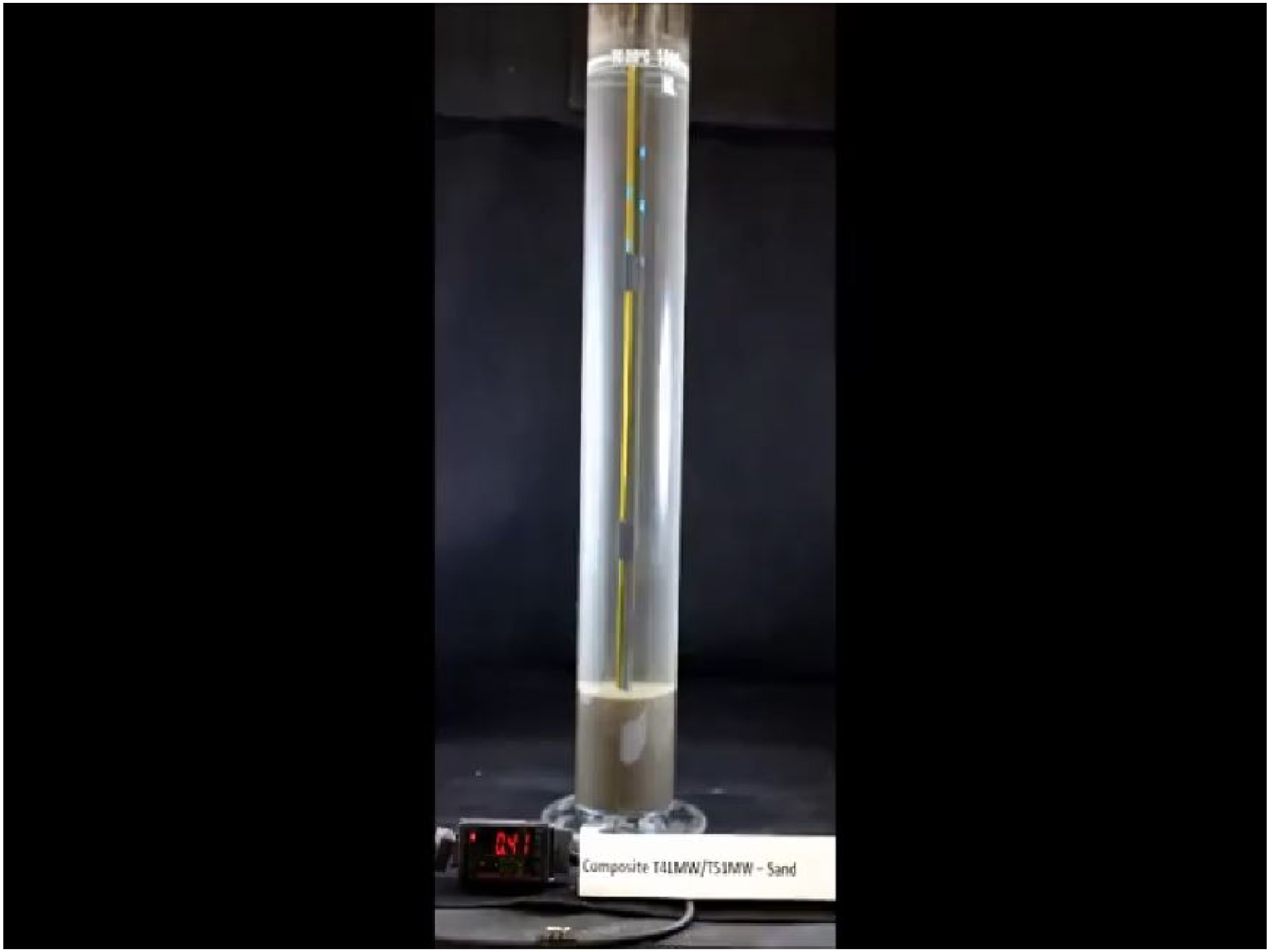
Photograph 24: Conditions at conclusion of 20 ml of air infusion at 50 ml/minute, Sample T41MW/T51MW (gravel).

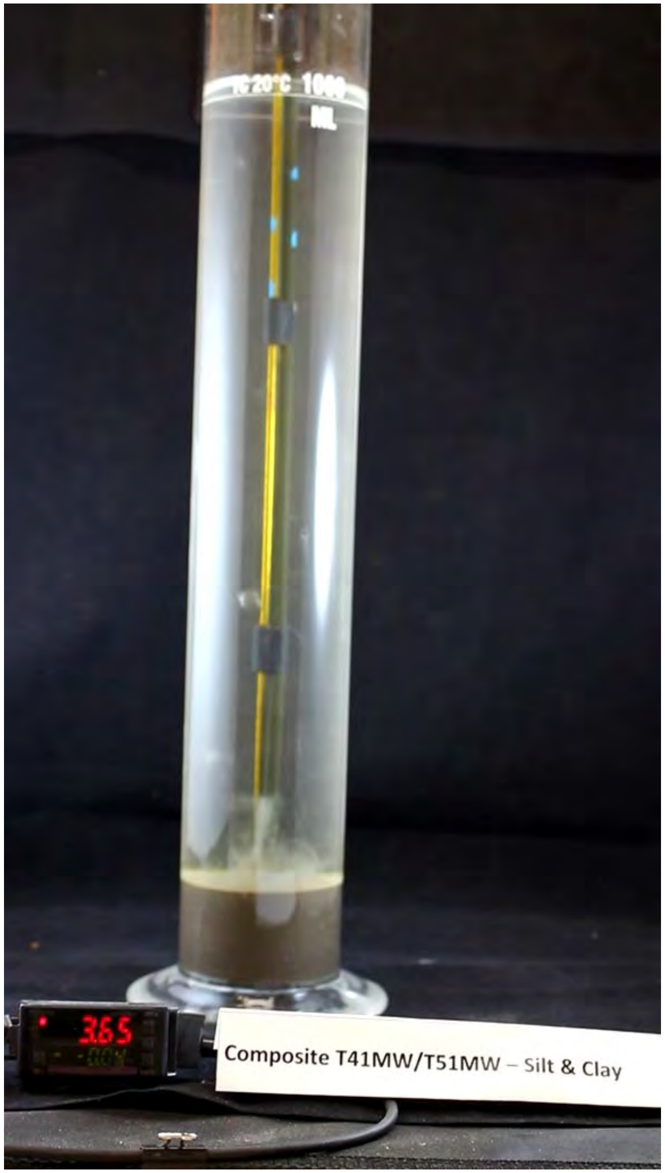
Photograph 25: Conditions at formation of first bubble during air infusion at 3 ml/minute, Sample T41MW/T51MW (sand).



Photograph 26: Conditions at conclusion of 5 ml of air infusion at 3 ml/minute, Sample T41MW/T51MW (sand).

Video: Conditions during infusion of 20 ml of air at 10 ml/minute, Sample T41MW/T51MW (sand).

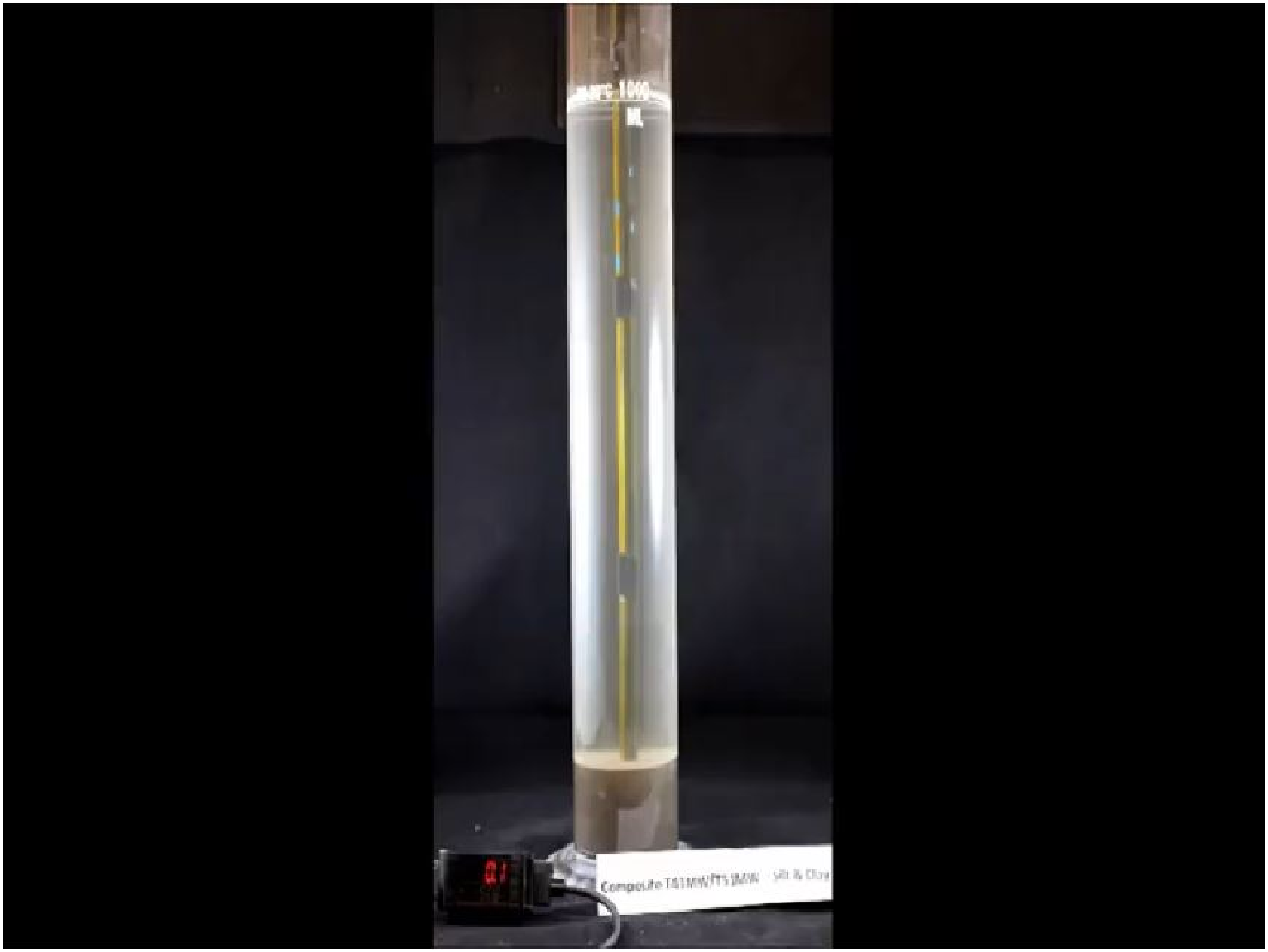




Photograph 27: Conditions at formation of first bubble during air infusion at 10 ml/minute, Sample T41MW/T51MW (silt & clay).

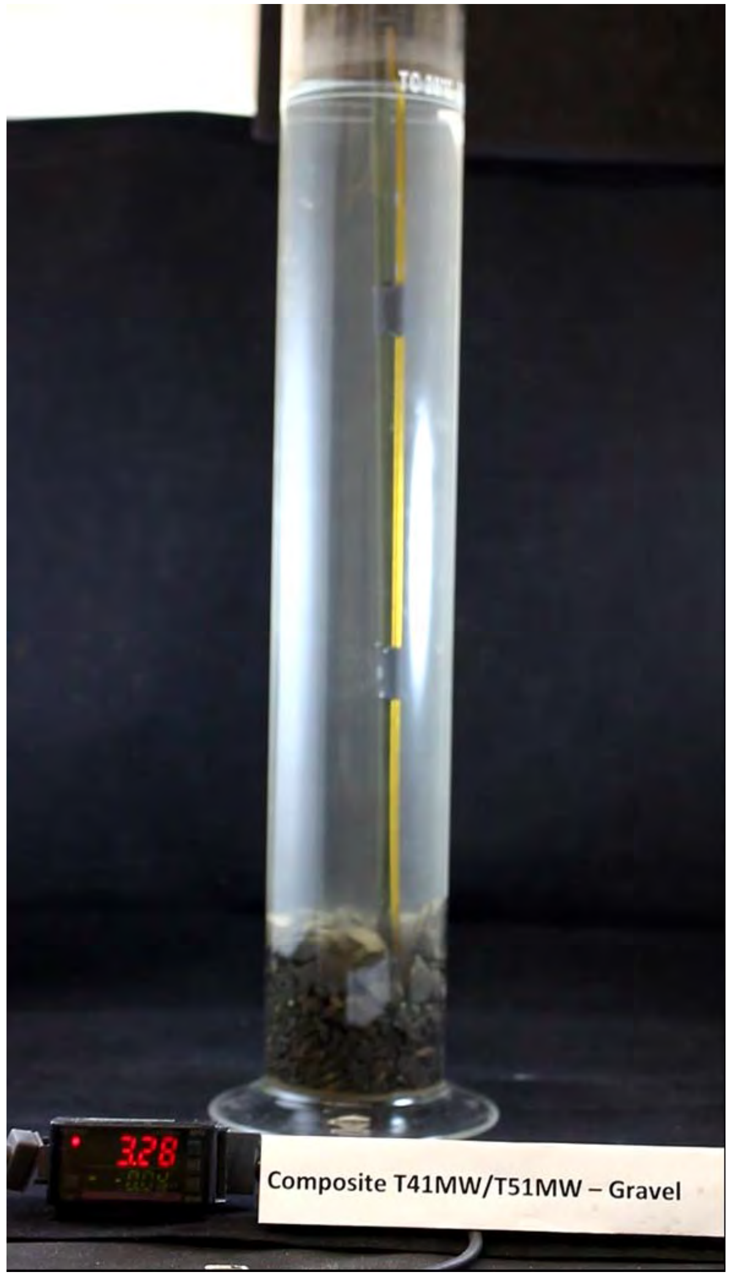
Photograph 28: Conditions at conclusion of 20 ml of air infusion at 10 ml/minute, Sample T41MW/T51MW (silt & clay).

Video: Conditions during infusion of 20 ml of air at 50 ml/minute, Sample T41MW/T51MW (silt and clay).

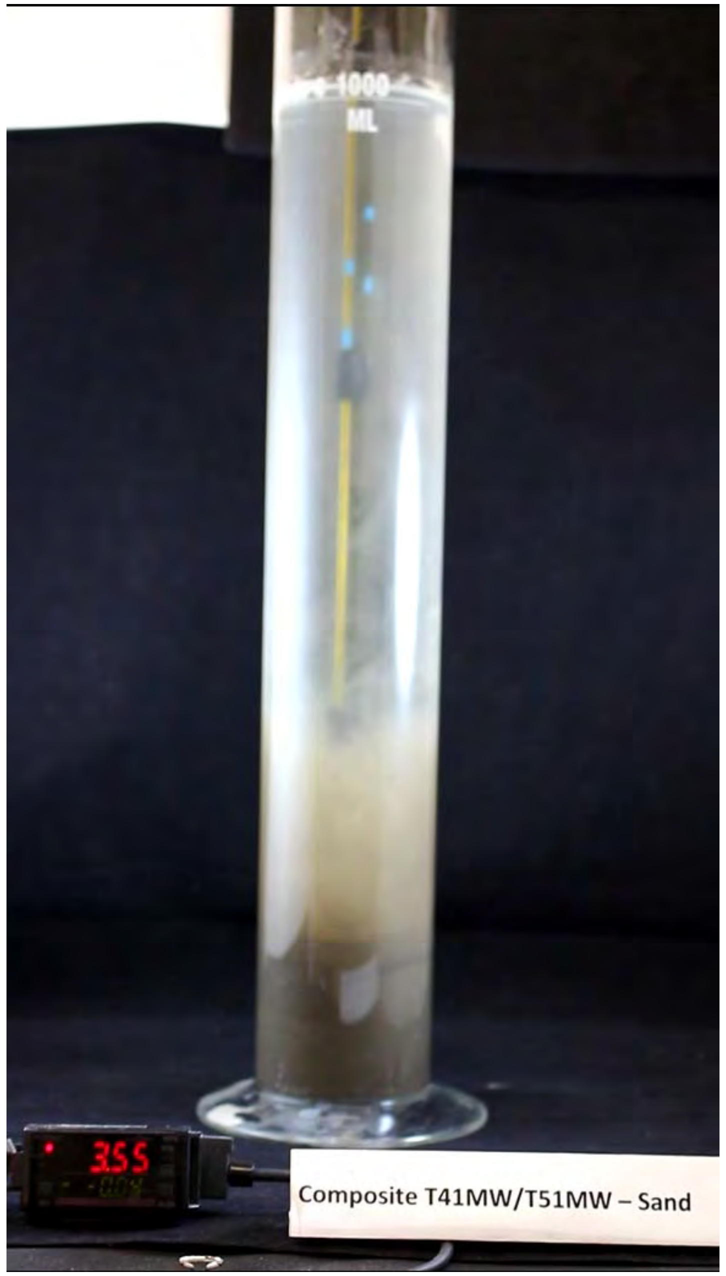


Video: Conditions during infusion of 20 ml of air at 10 ml/minute through diffuser, Sample T41MW/T51MW (sand).

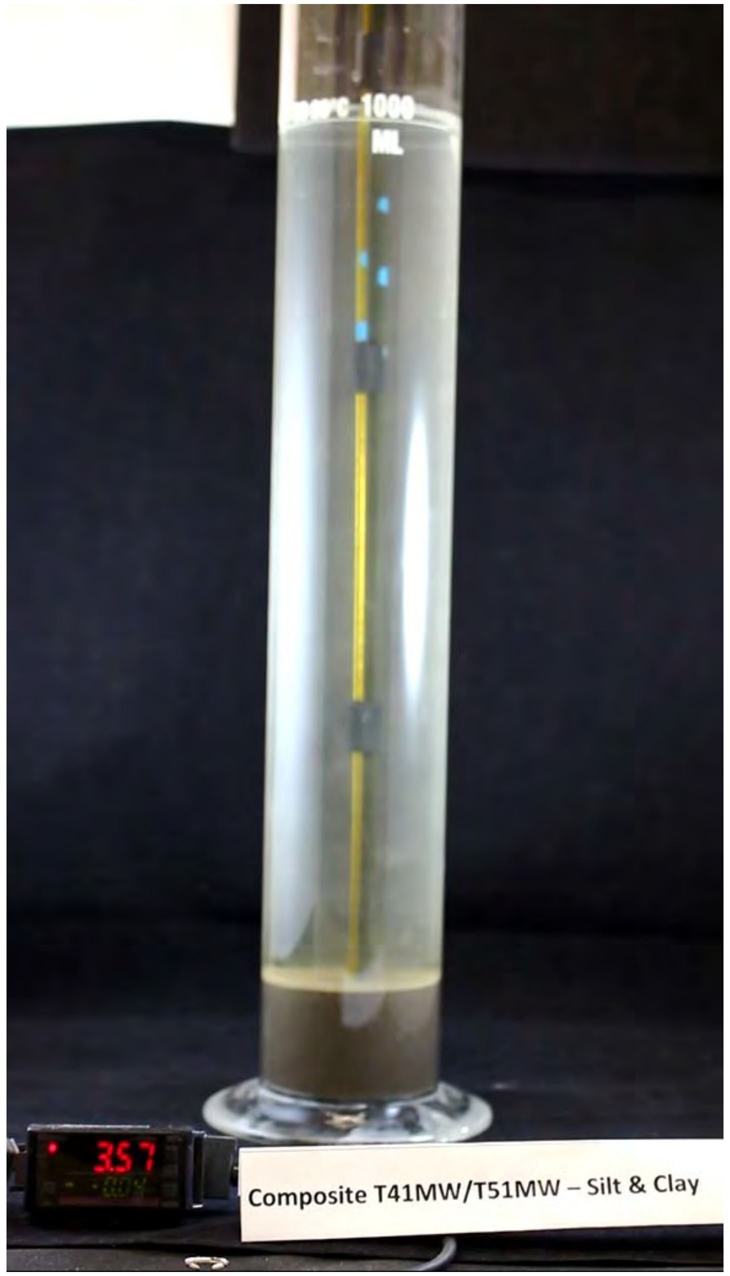
Photograph 29: Conditions after air infusion of 5 ml at 3 ml/minute, Sample T23MW (full grain size distribution).



Photograph 30: Conditions after air infusion of 5 ml at 3 ml/minute, Sample T41MW/T51MW (gravel).



Photograph 31: Conditions after air infusion of 5 ml at 3 ml/minute, Sample T41MW/T51MW (sand).



Photograph 32: Conditions after air infusion of 5 ml at 3 ml/minute, Sample T41MW/T51MW (silt & clay).

Photograph 33: Conditions after air infusion of 20 ml at 10 ml/minute, Sample T23MW (full grain size distribution).

Photograph 34: Conditions after air infusion of 20 ml at 10 ml/minute, Sample T41MW/T51MW (gravel).

Photograph 35: Conditions after air infusion of 20 ml at 10 ml/minute, Sample T41MW/T51MW (sand).

Photograph 36: Conditions after air infusion of 20 ml at 10 ml/minute, Sample T41MW/T51MW (silt & clay).

Photograph 37: Conditions after air infusion of 20 ml at 50 ml/minute, Sample T23MW (full grain size distribution).

Photograph 38: Conditions after air infusion of 20 ml at 50 ml/minute, Sample T41MW/T51MW (gravel).

Photograph 39: Conditions after air infusion of 20 ml at 50 ml/minute, Sample T41MW/T51MW (sand).

Photograph 40: Conditions after air infusion of 20 ml at 50 ml/minute, Sample T41MW/T51MW (silt & clay).

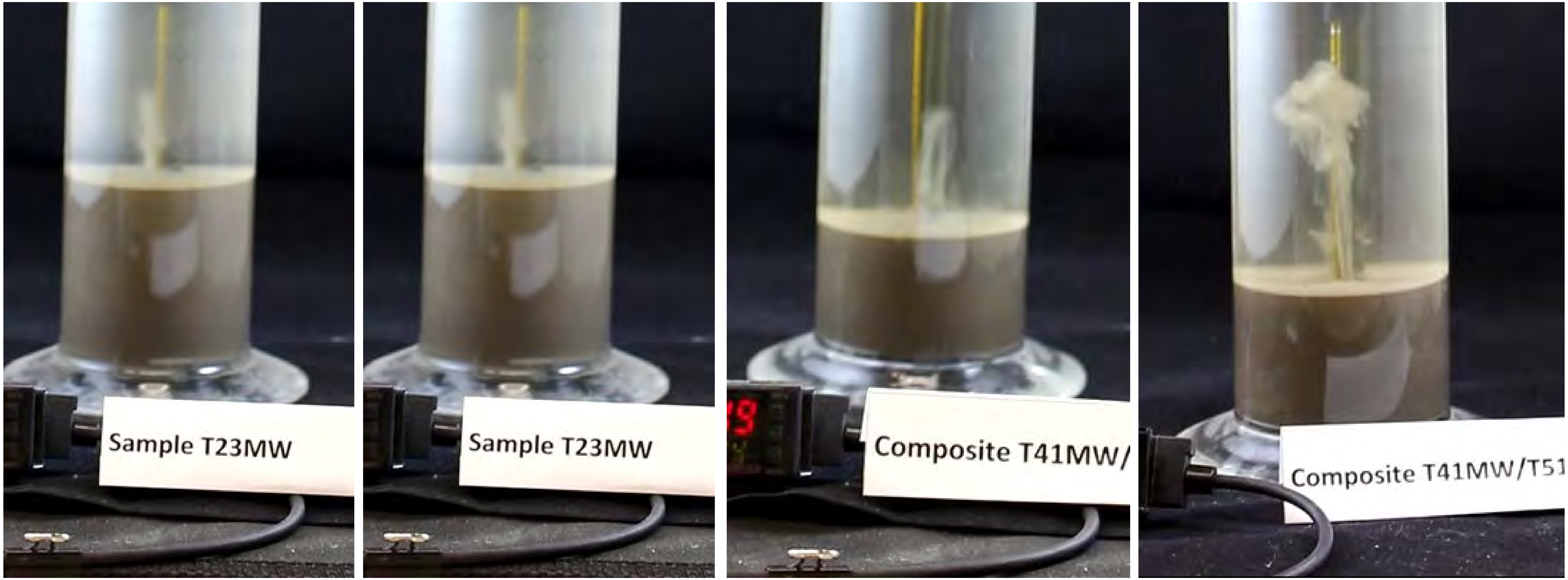
.

Photograph 41: Conditions at first bubbles during infusion of 10 ml of air at 3 ml/minute through diffuser, Sample T23MW (full grain size distribution).

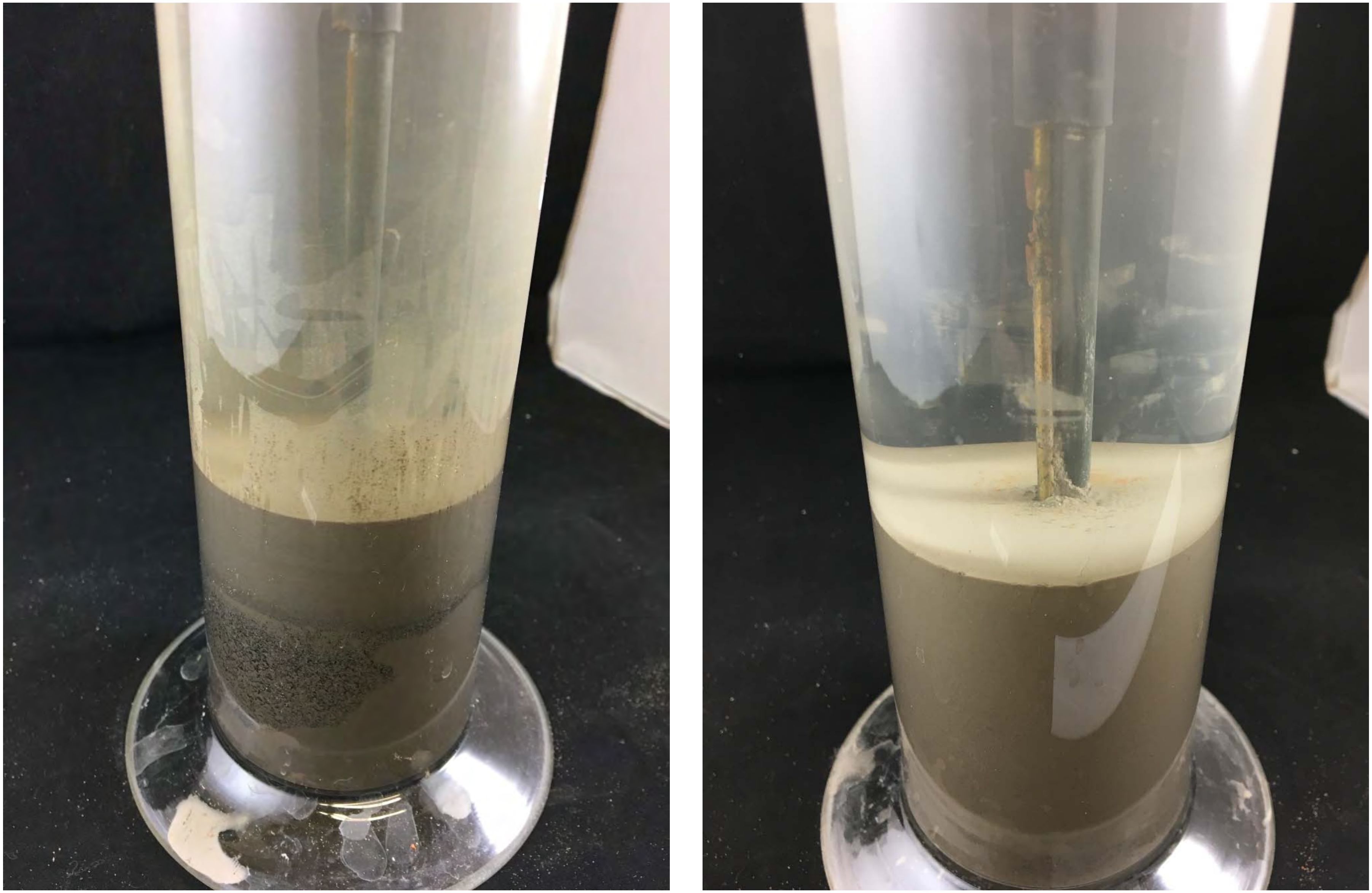
Photograph 42: Conditions after infusion of 10 ml of air at 3 ml/minute through diffuser, Sample T23MW (full grain size distribution).

Photograph 43: Conditions at first bubbles during infusion of 20 ml of air at 10 ml/minute through diffuser, Sample T41MW/T51MW (sand).

Photograph 44: Conditions after infusion of 20 ml of air at 10 ml/minute through diffuser, Sample T41MW/T51MW (sand).



Photograph 45: Examples of water jets emerging through sediments before emergence of bubbles.



Photograph 46: Examples of the film of fine particles adhering to inside of glass hydrometer cylinders, illustrating where mechanical removal using a plastic scraper was only partially successful in removing the coating.

APPENDIX A

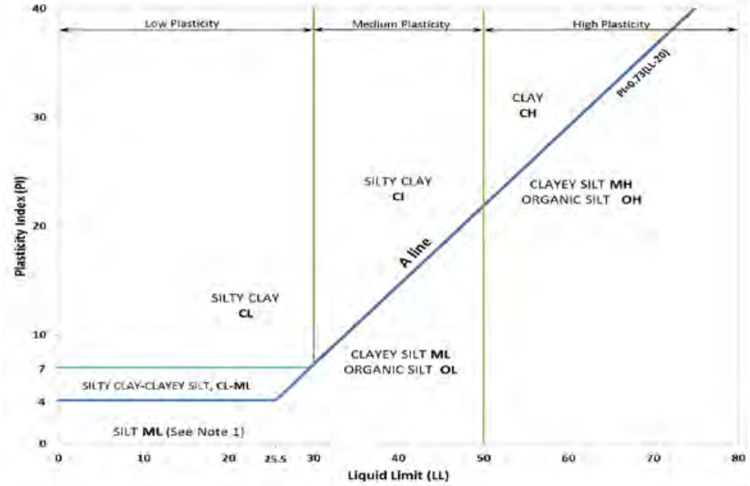
Records Of Instrumentation Mock Well Drilling

METHOD OF SOIL CLASSIFICATION

The Golder Associates Ltd. Soil Classification System is based on the Unified Soil Classification System (USCS)

Organic or Inorganic	Soil Group	Type of Soil		Gradation or Plasticity	$Cu = \frac{D_{60}}{D_{10}}$	$Cc = \frac{(D_{30})^2}{D_{10} x D_{60}}$	Organic Content	USCS Group Symbol	Group Name
INORGANIC (Organic Content ≤30% by mass)	COARSE-GRAINED SOILS (>50% by mass is larger than 0.075 mm)	GRAVELS (>50% by mass of coarse fraction is larger than 4.75 mm)	Gravels with ≤12% fines (by mass)	Poorly Graded	<4	≤1 or ≥3	≤30%	GP	GRAVEL
				Well Graded	≥4	1 to 3		GW	GRAVEL
			Gravels with >12% fines (by mass)	Below A Line	n/a			GM	SILTY GRAVEL
				Above A Line	n/a			GC	CLAYEY GRAVEL
		SANDS (≥50% by mass of coarse fraction is smaller than 4.75 mm)	Sands with ≤12% fines (by mass)	Poorly Graded	<6	≤1 or ≥3		SP	SAND
				Well Graded	≥6	1 to 3		SW	SAND
			Sands with >12% fines (by mass)	Below A Line	n/a			SM	SILTY SAND
				Above A Line	n/a			SC	CLAYEY SAND

Organic or Inorganic	Soil Group	Type of Soil	Laboratory Tests	Field Indicators					Organic Content	USCS Group Symbol	Primary Name
				Dilatancy	Dry Strength	Shine Test	Thread Diameter	Toughness (of 3 mm thread)			
INORGANIC (Organic Content ≤30% by mass)	FINE-GRAINED SOILS (≥50% by mass is smaller than 0.075 mm)	SILTS (Non-Plastic or PI and LL plot below A-Line on Plasticity Chart below)	Liquid Limit <50	Rapid	None	None	>6 mm	N/A (can't roll 3 mm thread)	<5%	ML	SILT
				Slow	None to Low	Dull	3mm to 6 mm	None to low	<5%	ML	CLAYEY SILT
				Slow to very slow	Low to medium	Dull to slight	3mm to 6 mm	Low	5% to 30%	OL	ORGANIC SILT
			Liquid Limit ≥50	Slow to very slow	Low to medium	Slight	3mm to 6 mm	Low to medium	<5%	MH	CLAYEY SILT
				None	Medium to high	Dull to slight	1 mm to 3 mm	Medium to high	5% to 30%	OH	ORGANIC SILT
		CLAYS (PI and LL plot above A-Line on Plasticity Chart below)	Liquid Limit <30	None	Low to medium	Slight to shiny	~ 3 mm	Low to medium	0% to 30% **(see Note 2)**	CL	SILTY CLAY
			Liquid Limit 30 to 50	None	Medium to high	Slight to shiny	1 mm to 3 mm	Medium		CI	SILTY CLAY
			Liquid Limit ≥50	None	High	Shiny	<1 mm	High		CH	CLAY
HIGHLY ORGANIC SOILS (Organic Content >30% by mass)		Peat and mineral soil mixtures							30% to 75%	PT	SILTY PEAT, SANDY PEAT
		Predominantly peat, may contain some mineral soil, fibrous or amorphous peat							75% to 100%		PEAT



Note 1 – Fine grained materials with PI and LL that plot in this area are named (ML) SILT with slight plasticity. Fine-grained materials which are non-plastic (i.e. a PL cannot be measured) are named SILT.

Note 2 – For soils with <5% organic content, include the descriptor "trace organics" for soils with between 5% and 30% organic content include the prefix "organic" before the Primary name.

Dual Symbol — A dual symbol is two symbols separated by a hyphen, for example, GP-GM, SW-SC and CL-ML.

For non-cohesive soils, the dual symbols must be used when the soil has between 5% and 12% fines (i.e. to identify transitional material between "clean" and "dirty" sand or gravel.

For cohesive soils, the dual symbol must be used when the liquid limit and plasticity index values plot in the CL-ML area of the plasticity chart (see Plasticity Chart at left).

Borderline Symbol — A borderline symbol is two symbols separated by a slash, for example, CL/CI, GM/SM, CL/ML.

A borderline symbol should be used to indicate that the soil has been identified as having properties that are on the transition between similar materials. In addition, a borderline symbol may be used to indicate a range of similar soil types within a stratum.

ABBREVIATIONS AND TERMS USED ON RECORDS OF BORHEOLES AND TEST PITS

PARTICLE SIZES OF CONSTITUENTS

Soil Constituent	Particle Size Description	Millimetres	Inches (US Std. Sieve Size)
BOULDERS	Not Applicable	>300	>12
COBBLES	Not Applicable	75 to 300	3 to 12
GRAVEL	Coarse Fine	19 to 75 4.75 to 19	0.75 to 3 (4) to 0.75
SAND	Coarse Medium Fine	2.00 to 4.75 0.425 to 2.00 0.075 to 0.425	(10) to (4) (40) to (10) (200) to (40)
SILT/CLAY	Classified by plasticity	<0.075	< (200)

MODIFIERS FOR SECONDARY AND MINOR CONSTITUENTS

Percentage by Mass	Modifier
>35	Use 'and' to combine major constituents (*i.e.,* SAND and GRAVEL)
> 12 to 35	Primary soil name prefixed with "gravelly, sandy, SILTY, CLAYEY" as applicable
> 5 to 12	some
≤ 5	trace

PENETRATION RESISTANCE

Standard Penetration Resistance (SPT), N:
The number of blows by a 63.5 kg (140 lb) hammer dropped 760 mm (30 in.) required to drive a 50 mm (2 in.) split-spoon sampler for a distance of 300 mm (12 in.).

Cone Penetration Test (CPT)
An electronic cone penetrometer with a 60° conical tip and a project end area of 10 cm^2 pushed through ground at a penetration rate of 2 cm/s. Measurements of tip resistance (q_t), porewater pressure (u) and sleeve frictions are recorded electronically at 25 mm penetration intervals.

Dynamic Cone Penetration Resistance (DCPT); N_d:
The number of blows by a 63.5 kg (140 lb) hammer dropped 760 mm (30 in.) to drive uncased a 50 mm (2 in.) diameter, 60° cone attached to "A" size drill rods for a distance of 300 mm (12 in.).

PH:	Sampler advanced by hydraulic pressure
PM:	Sampler advanced by manual pressure
WH:	Sampler advanced by static weight of hammer
WR:	Sampler advanced by weight of sampler and rod

SAMPLES

AS	Auger sample
BS	Block sample
CS	Chunk sample
DD	Diamond Drilling
DO or DP	Seamless open ended, driven or pushed tube sampler – note size
DS	Denison type sample
FS	Foil sample
GS	Grab Sample
RC	Rock core
SC	Soil core
SS	Split spoon sampler – note size
ST	Slotted tube
TO	Thin-walled, open – note size
TP	Thin-walled, piston – note size
WS	Wash sample

SOIL TESTS

w	water content
PL , w_p	plastic limit
LL , w_L	liquid limit
C	consolidation (oedometer) test
CHEM	chemical analysis (refer to text)
CID	consolidated isotropically drained triaxial test[1]
CIU	consolidated isotropically undrained triaxial test with porewater pressure measurement[1]
D_R	relative density (specific gravity, Gs)
DS	direct shear test
GS	specific gravity
M	sieve analysis for particle size
MH	combined sieve and hydrometer (H) analysis
MPC	Modified Proctor compaction test
SPC	Standard Proctor compaction test
OC	organic content test
SO_4	concentration of water-soluble sulphates
UC	unconfined compression test
UU	unconsolidated undrained triaxial test
V (FV)	field vane (LV-laboratory vane test)
γ	unit weight

1. Tests anisotropically consolidated prior to shear are shown as CAD, CAU.

NON-COHESIVE (COHESIONLESS) SOILS

Compactness[2]

Term	SPT 'N' (blows/0.3m)[1]
Very Loose	0 - 4
Loose	4 to 10
Compact	10 to 30
Dense	30 to 50
Very Dense	>50

1. SPT 'N' in accordance with ASTM D1586, uncorrected for overburden pressure effects.
2. Definition of compactness terms are based on SPT-'N' ranges as provided in Terzaghi, Peck and Mesri (1996) and correspond to typical average N_{60} values. Many factors affect the recorded SPT-'N' value, including hammer efficiency (which may be greater than 60% in automatic trip hammers), groundwater conditions, and grainsize. As such, the recorded SPT-'N' value(s) should be considered only an approximate guide to the compactness term. These factors need to be considered when evaluating the results, and the stated compactness terms should not be relied upon for design or construction.

Field Moisture Condition

Term	Description
Dry	Soil flows freely through fingers.
Moist	Soils are darker than in the dry condition and may feel cool.
Wet	As moist, but with free water forming on hands when handled.

COHESIVE SOILS

Consistency

Term	Undrained Shear Strength (kPa)	SPT 'N'[1,2] (blows/0.3m)
Very Soft	<12	0 to 2
Soft	12 to 25	2 to 4
Firm	25 to 50	4 to 8
Stiff	50 to 100	8 to 15
Very Stiff	100 to 200	15 to 30
Hard	>200	>30

1. SPT 'N' in accordance with ASTM D1586, uncorrected for overburden pressure effects; approximate only.
2. SPT 'N' values should be considered ONLY an approximate guide to consistency; for sensitive clays (e.g., Champlain Sea clays), the N-value approximation for consistency terms does NOT apply. Rely on direct measurement of undrained shear strength or other manual observations.

Water Content

Term	Description
w < PL	Material is estimated to be drier than the Plastic Limit.
w ~ PL	Material is estimated to be close to the Plastic Limit.
w > PL	Material is estimated to be wetter than the Plastic Limit.

LIST OF SYMBOLS

Unless otherwise stated, the symbols employed in the report are as follows:

I. GENERAL

π	3.1416
ln x	natural logarithm of x
$\log_{10}$	x or log x, logarithm of x to base 10
g	acceleration due to gravity
t	time

II. STRESS AND STRAIN

γ	shear strain
Δ	change in, e.g. in stress: $\Delta\ \sigma$
ε	linear strain
ε_v	volumetric strain
η	coefficient of viscosity
υ	Poisson's ratio
σ	total stress
σ'	effective stress ($\sigma' = \sigma$ - u)
σ'_{vo}	initial effective overburden stress
$\sigma_1, \sigma_2, \sigma_3$	principal stress (major, intermediate, minor)
σ_{oct}	mean stress or octahedral stress $= (\sigma_1 + \sigma_2 + \sigma_3)/3$
τ	shear stress
u	porewater pressure
E	modulus of deformation
G	shear modulus of deformation
K	bulk modulus of compressibility

III. SOIL PROPERTIES

(a) Index Properties

$\rho(\gamma)$	bulk density (bulk unit weight)*
$\rho_d(\gamma_d)$	dry density (dry unit weight)
$\rho_w(\gamma_w)$	density (unit weight) of water
$\rho_s(\gamma_s)$	density (unit weight) of solid particles
γ'	unit weight of submerged soil ($\gamma' = \gamma - \gamma_w$)
D_R	relative density (specific gravity) of solid particles ($D_R = \rho_s / \rho_w$) (formerly G_s)
e	void ratio
n	porosity
S	degree of saturation

* Density symbol is ρ. Unit weight symbol is γ where $\gamma = \rho g$ (i.e. mass density multiplied by acceleration due to gravity)

(a) Index Properties (continued)

w	water content
w_l or LL	liquid limit
w_p or PL	plastic limit
I_p or PI	plasticity index = ($w_l - w_p$)
w_s	shrinkage limit
I_L	liquidity index = $(w - w_p) / I_p$
I_C	consistency index = $(w_l - w) / I_p$
e_{max}	void ratio in loosest state
e_{min}	void ratio in densest state
I_D	density index = $(e_{max} - e) / (e_{max} - e_{min})$ (formerly relative density)

(b) Hydraulic Properties

h	hydraulic head or potential
q	rate of flow
v	velocity of flow
i	hydraulic gradient
k	hydraulic conductivity (coefficient of permeability)
j	seepage force per unit volume

(c) Consolidation (one-dimensional)

C_c	compression index (normally consolidated range)
C_r	recompression index (over-consolidated range)
C_s	swelling index
C_α	secondary compression index
m_v	coefficient of volume change
c_v	coefficient of consolidation (vertical direction)
c_h	coefficient of consolidation (horizontal direction)
T_v	time factor (vertical direction)
U	degree of consolidation
σ'_p	pre-consolidation stress
OCR	over-consolidation ratio = σ'_p / σ'_{vo}

(d) Shear Strength

τ_p, τ_r	peak and residual shear strength
ϕ'	effective angle of internal friction
δ	angle of interface friction
μ	coefficient of friction = tan δ
c'	effective cohesion
c_u, s_u	undrained shear strength (ϕ = 0 analysis)
p	mean total stress $(\sigma_1 + \sigma_3)/2$
p′	mean effective stress $(\sigma'_1 + \sigma'_3)/2$
q	$(\sigma_1 - \sigma_3)/2$ or $(\sigma'_1 - \sigma'_3)/2$
q_u	compressive strength $(\sigma_1 - \sigma_3)$
S_t	sensitivity

Notes: 1 $\tau = c' + \sigma' \tan \phi'$

2 shear strength = (compressive strength)/2

PROJECT: 1668031

RECORD OF BOREHOLE T23MW

SHEET 1 OF 2

LOCATION: REFER TO LOCATION PLAN

BORING DATE: December 12 - 14, 2018
DRILLING CONTRACTOR: WALKER DRILLING

DATUM: GEODETIC

HAMMER TYPE: Auto Hammer

DEPTH SCALE METRES	BORING METHOD	SOIL PROFILE DESCRIPTION	ELEV. / DEPTH (m)	SAMPLES NUMBER	TYPE	BLOWS/0.3m	ELEVATION	INSTALLATION AND GROUNDWATER OBSERVATIONS T23MW
							178	128 mm I.D. Casing
0	HOLLOW STEM AUGER 159mm ID HOLLOW STEM	GROUND SURFACE	177.59					
		TOPSOIL, silty sand; grey	0.00					244.5mm O.D. Auger Hole
		(SP) **SAND**, fine, some silt; brown	177.29 0.30				177	
1							176	
2							175	
3		(CI) **SILTY CLAY**; grey	174.85 2.74	1	AS			
4	MUD ROTARY DRILLING PQ CASING						174	128mm I.D. Casing
5							173	Bentonite grout
6				2	TO	PH	172 171	
7							170	
8							169	
9		--- CONTINUED NEXT PAGE ---						

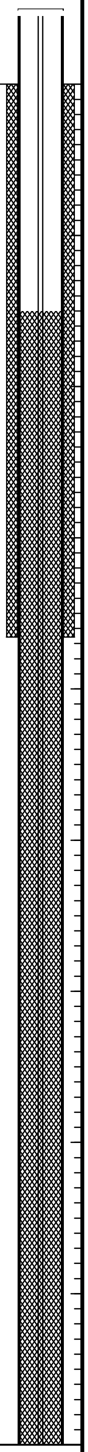
DYNAMIC PENETRATION RESISTANCE, BLOWS/0.3m: 20 40 60 80

SHEAR STRENGTH Cu, kPa: nat V. + Q - ● rem V. ⊕ U - ○ 20 40 60 80

HYDRAULIC CONDUCTIVITY, k, cm/s: 10^{-6} 10^{-5} 10^{-4} 10^{-3}

WATER CONTENT PERCENT: Wp ⊢—○W—⊣ Wl 10 20 30 40

ADDITIONAL LAB. TESTING



LDN_BHS_07 1668031.GPJ GLDR_LON.GDT 07/05/18 14:00 DATA INPUT: ZJB

DEPTH SCALE
1 : 50

Golder Associates

LOGGED: MA
CHECKED: SSB

PROJECT: 1668031

RECORD OF BOREHOLE T23MW

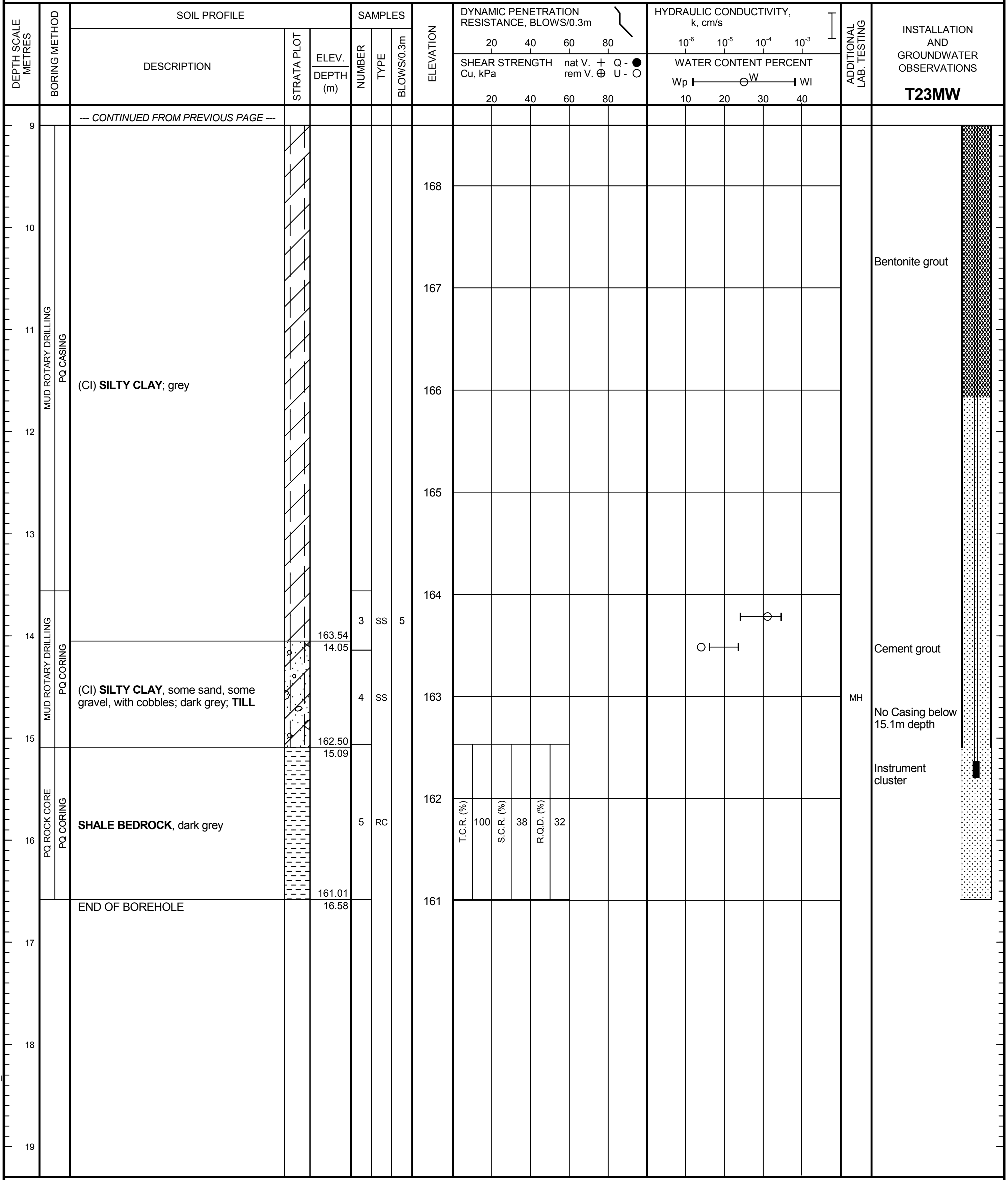
SHEET 2 OF 2

LOCATION: REFER TO LOCATION PLAN

BORING DATE: December 12 - 14, 2018
DRILLING CONTRACTOR: WALKER DRILLING

DATUM: GEODETIC

HAMMER TYPE: Auto Hammer



DEPTH SCALE METRES	BORING METHOD	SOIL PROFILE DESCRIPTION	ELEV. DEPTH (m)	SAMPLES NUMBER	SAMPLES TYPE	BLOWS/0.3m	ADDITIONAL LAB. TESTING	INSTALLATION AND GROUNDWATER OBSERVATIONS T23MW
		--- CONTINUED FROM PREVIOUS PAGE ---						
9	MUD ROTARY DRILLING PQ CASING	(CI) **SILTY CLAY**; grey	163.54 14.05	3	SS	5		Bentonite grout
14	MUD ROTARY DRILLING PQ CORING	(CI) **SILTY CLAY**, some sand, some gravel, with cobbles; dark grey; **TILL**	162.50 15.09	4	SS		MH	Cement grout No Casing below 15.1m depth
15	PQ ROCK CORE PQ CORING	**SHALE BEDROCK**, dark grey	161.01 16.58	5	RC	T.C.R. (%) 100 S.C.R. (%) 38 R.Q.D. (%) 32		Instrument cluster
		END OF BOREHOLE						

LDN_BHS_07 1668031.GPJ GLDR_LON.GDT 07/05/18 14:00 DATA INPUT: ZJB

DEPTH SCALE
1 : 50

Golder Associates

LOGGED: MA
CHECKED: SSB

PROJECT: 1668031

RECORD OF BOREHOLE T41MW

SHEET 1 OF 3

LOCATION: REFER TO LOCATION PLAN

BORING DATE: December 17, 2018
DRILLING CONTRACTOR: WALKER

DATUM: GEODETIC

HAMMER TYPE: Auto Hammer

DEPTH SCALE METRES	BORING METHOD	SOIL PROFILE DESCRIPTION	ELEV. / DEPTH (m)	SAMPLES NUMBER	TYPE	BLOWS/0.3m
0		GROUND SURFACE	178.39 0.00			
0 – 1.52	HOLLOW STEM AUGER 159mm ID HOLLOW STEM	(CL) sandy **SILTY CLAY**, trace gravel; brown, **TILL**	176.87 1.52			
1.52 – 3.66	HOLLOW STEM AUGER 159mm ID HOLLOW STEM	**SANDY SILT TO SILTY SAND**; brown	174.73 3.66	1	AS	
3.66 – 9	HOLLOW STEM AUGER 159mm ID HOLLOW STEM (to 4.6) MUD ROTARY DRILLING PQ CASING	(CI) **SILTY CLAY**, some sand, trace gravel; grey				

--- CONTINUED NEXT PAGE ---

ELEVATION: 179, 178, 177, 176, 175, 174, 173, 172, 171, 170

DYNAMIC PENETRATION RESISTANCE, BLOWS/0.3m: 20, 40, 60, 80

SHEAR STRENGTH Cu, kPa: nat V. + Q - ● rem V. ⊕ U - ○: 20, 40, 60, 80

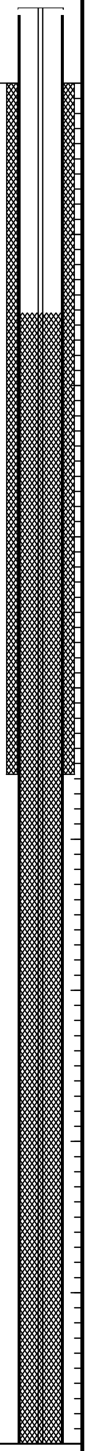
HYDRAULIC CONDUCTIVITY, k, cm/s: 10^{-6}, 10^{-5}, 10^{-4}, 10^{-3}

WATER CONTENT PERCENT: Wp ⊢—○W—⊣ Wl: 10, 20, 30, 40

ADDITIONAL LAB. TESTING

INSTALLATION AND GROUNDWATER OBSERVATIONS

T41MW



Elevation	Installation and groundwater observations
about 178.7	128mm I.D. Casing
178.39	244.5mm O.D. Auger Hole
about 173.7	128mm I.D. Casing
about 173.2	Bentonite grout

DEPTH SCALE
1 : 50

Golder Associates

LOGGED: SM
CHECKED: SSB

PROJECT: 1668031

RECORD OF BOREHOLE T41MW

SHEET 2 OF 3

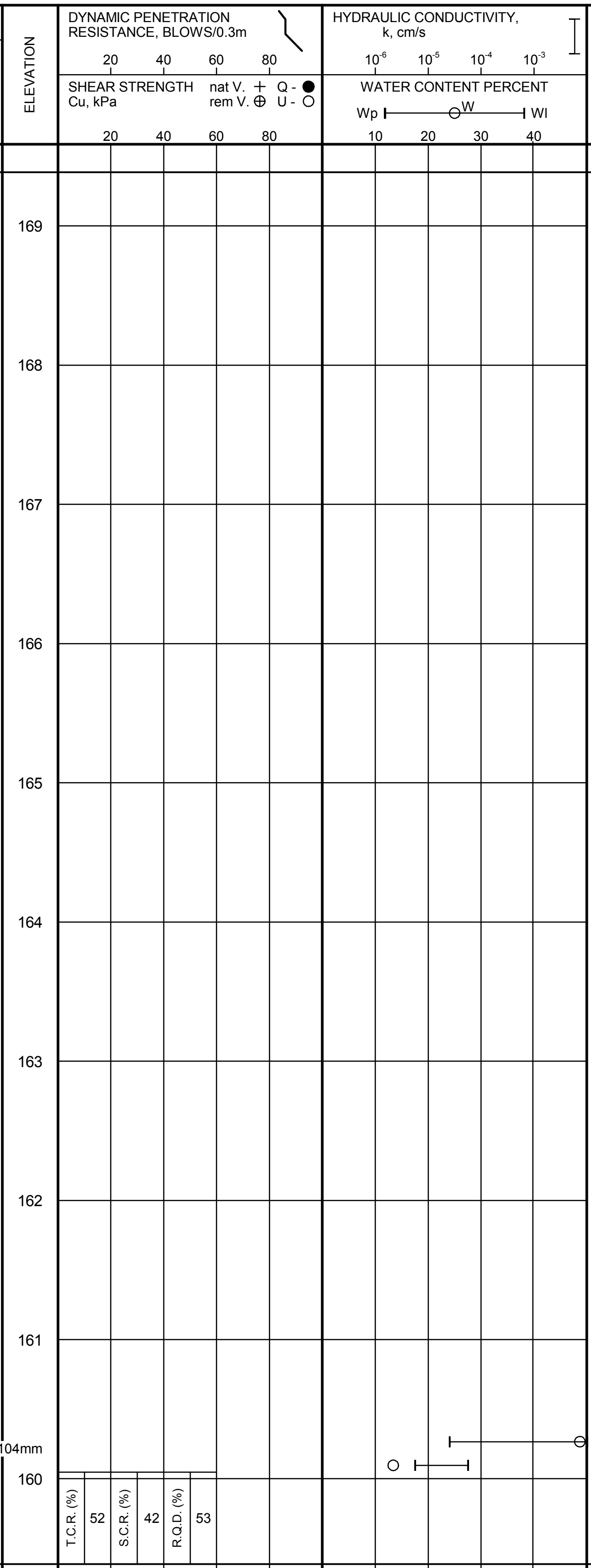
LOCATION: REFER TO LOCATION PLAN

BORING DATE: December 17, 2018
DRILLING CONTRACTOR: WALKER

DATUM: GEODETIC

HAMMER TYPE: Auto Hammer

DEPTH SCALE METRES	BORING METHOD	SOIL PROFILE: DESCRIPTION	ELEV. DEPTH (m)	SAMPLES: NUMBER	SAMPLES: TYPE	SAMPLES: BLOWS/0.3m	ADDITIONAL LAB. TESTING	INSTALLATION AND GROUNDWATER OBSERVATIONS T41MW
		--- CONTINUED FROM PREVIOUS PAGE ---						
9 – 18	MUD ROTARY DRILLING PQ CASING	(CI) **SILTY CLAY**, some sand, trace gravel; grey						Bentonite grout
12				2	TO	PH		
								Cement grout
18	PQ ROCK CORE PQ CORING		160.15 18.24	3	SS	50/104mm	51 MH	
		(SC) **GRAVELLY SAND**, clayey; grey; very dense	159.90 18.49					
19		**SHALE BEDROCK**, black		4	RC	T.C.R. (%) 52 S.C.R. (%) 42 R.Q.D. (%) 53		Instrument cluster
		--- CONTINUED NEXT PAGE ---						



DEPTH SCALE
1 : 50

LOGGED: SM
CHECKED: SSB

PROJECT: 1668031

RECORD OF BOREHOLE T41MW

SHEET 3 OF 3

LOCATION: REFER TO LOCATION PLAN

BORING DATE: December 17, 2018
DRILLING CONTRACTOR: WALKER

DATUM: GEODETIC

HAMMER TYPE: Auto Hammer

DEPTH SCALE METRES	BORING METHOD	SOIL PROFILE DESCRIPTION	SOIL PROFILE STRATA PLOT	SOIL PROFILE ELEV. DEPTH (m)	SAMPLES NUMBER	SAMPLES TYPE	SAMPLES BLOWS/0.3m	ELEVATION	DYNAMIC PENETRATION RESISTANCE, BLOWS/0.3m (20 40 60 80) SHEAR STRENGTH Cu, kPa nat V. + Q - ● rem V. ⊕ U - ○ (20 40 60 80)	HYDRAULIC CONDUCTIVITY, k, cm/s (10^{-6} 10^{-5} 10^{-4} 10^{-3}) WATER CONTENT PERCENT Wp ⊢—○W—⊣ Wl (10 20 30 40)	ADDITIONAL LAB. TESTING	INSTALLATION AND GROUNDWATER OBSERVATIONS **T41MW**
		--- CONTINUED FROM PREVIOUS PAGE ---										
19	PQ ROCK CORE PQ CORING	**SHALE BEDROCK**, black		158.71	4	RC		159	T.C.R. (%) 52 S.C.R. (%) 42 R.Q.D. (%) 53			Cement grout
		END OF BOREHOLE		19.68								
20												
								158				
21												
22												
23												
24												
25												
26												
27												
28												
29												

LDN_BHS_07 1668031.GPJ GLDR_LON.GDT 07/05/18 14:00 DATA INPUT: ZJB

DEPTH SCALE
1 : 50

Golder Associates

LOGGED: SM
CHECKED: SSB

PROJECT: 1668031

RECORD OF BOREHOLE T51MW

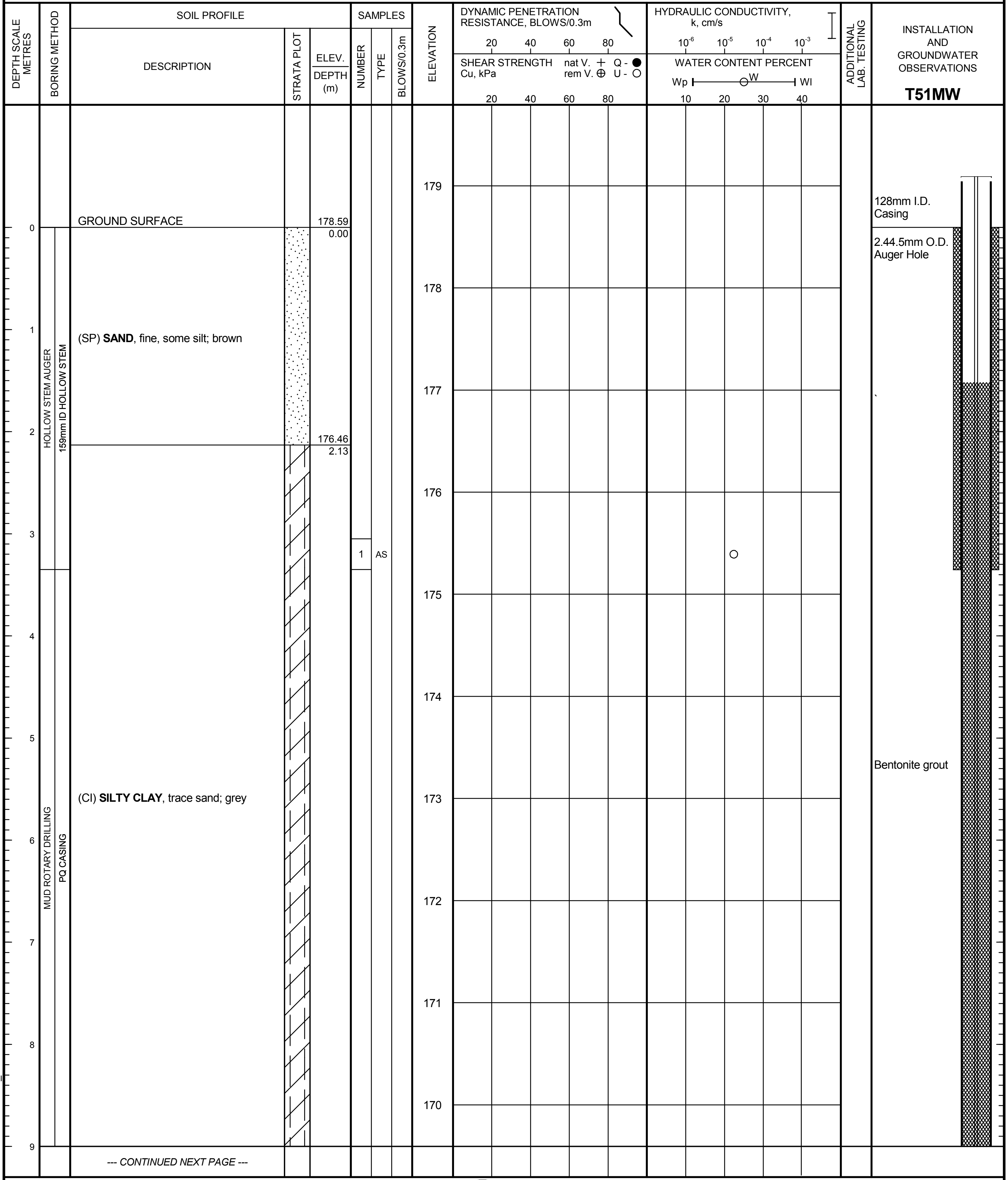
SHEET 1 OF 2

LOCATION: REFER TO LOCATION PLAN

BORING DATE: December 15, 2018
DRILLING CONTRACTOR: WALKER

DATUM: GEODETIC

HAMMER TYPE: Auto Hammer



DESCRIPTION	ELEV. / DEPTH (m)	NUMBER	TYPE
GROUND SURFACE	178.59 0.00		
(SP) **SAND**, fine, some silt; brown	176.46 2.13		
(CI) **SILTY CLAY**, trace sand; grey		1	AS

--- CONTINUED NEXT PAGE ---

DEPTH SCALE

1 : 50

Golder Associates

LOGGED: MA/SM

CHECKED: SJB

LDN_BHS_07 1668031.GPJ GLDR_LON.GDT 07/05/18 14:00 DATA INPUT: ZJB

PROJECT: 1668031

RECORD OF BOREHOLE T51MW

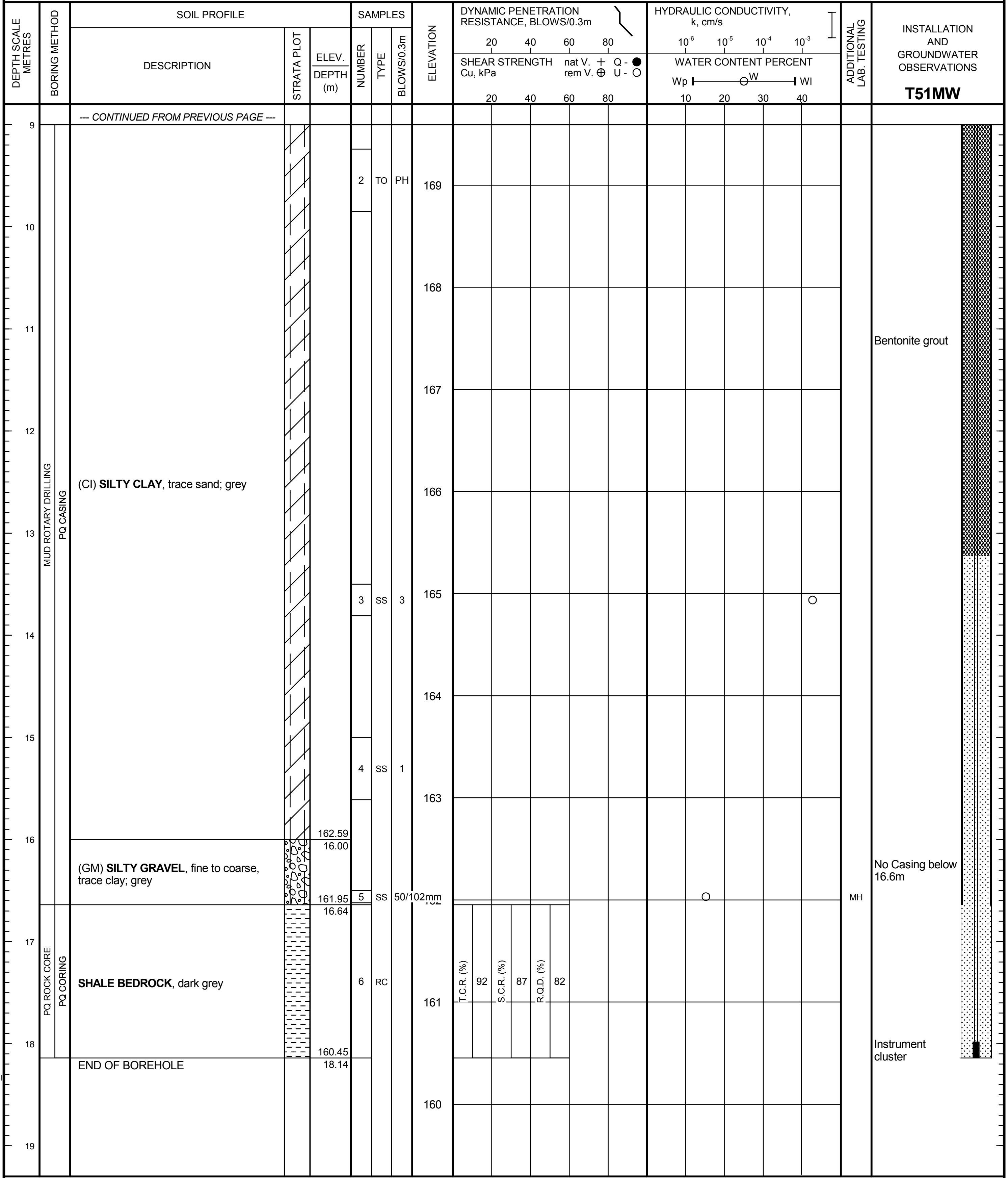
SHEET 2 OF 2

LOCATION: REFER TO LOCATION PLAN

BORING DATE: December 15, 2018
DRILLING CONTRACTOR: WALKER

DATUM: GEODETIC

HAMMER TYPE: Auto Hammer



DESCRIPTION	ELEV. / DEPTH (m)
(CI) **SILTY CLAY**, trace sand; grey	162.59 16.00
(GM) **SILTY GRAVEL**, fine to coarse, trace clay; grey	161.95 16.64
SHALE BEDROCK, dark grey	160.45 18.14
END OF BOREHOLE	

NUMBER	TYPE	BLOWS/0.3m	T.C.R. (%)	S.C.R. (%)	R.Q.D. (%)	ADDITIONAL LAB. TESTING
2	TO	PH				
3	SS	3				
4	SS	1				
5	SS	50/102mm				MH
6	RC		92	87	82	

Bentonite grout

No Casing below 16.6m

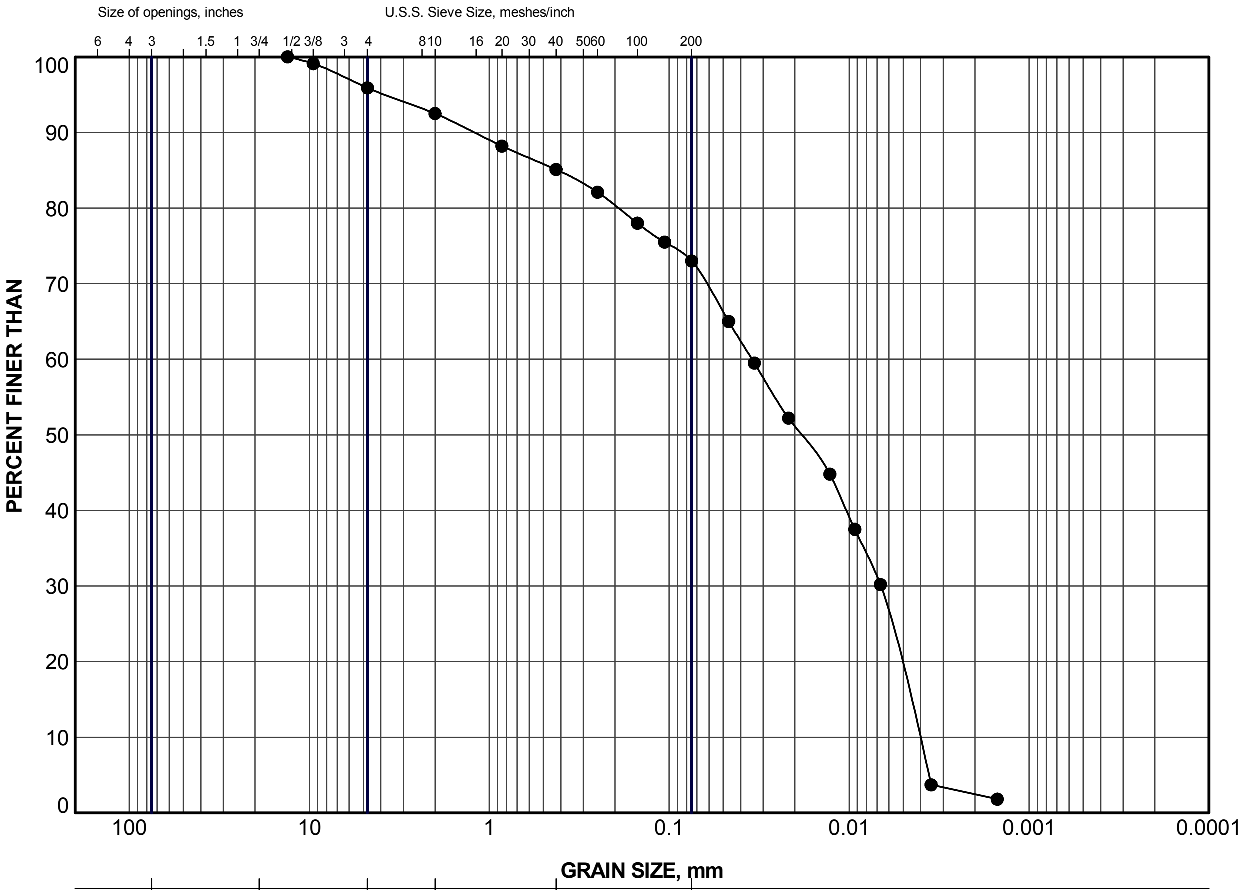
Instrument cluster

DEPTH SCALE
1 : 50

LOGGED: MA/SM
CHECKED: SSB

APPENDIX B

Grain Size Distribution Test Reports



Cobble Size	coarse	fine	coarse	medium	fine	SILT AND CLAY
	GRAVEL SIZE		SAND SIZE			

LEGEND

SYMBOL	BOREHOLE	SAMPLE	DEPTH (m)
●	T23MW	4	14.6

PROJECT

NORTH KENT 1

TITLE

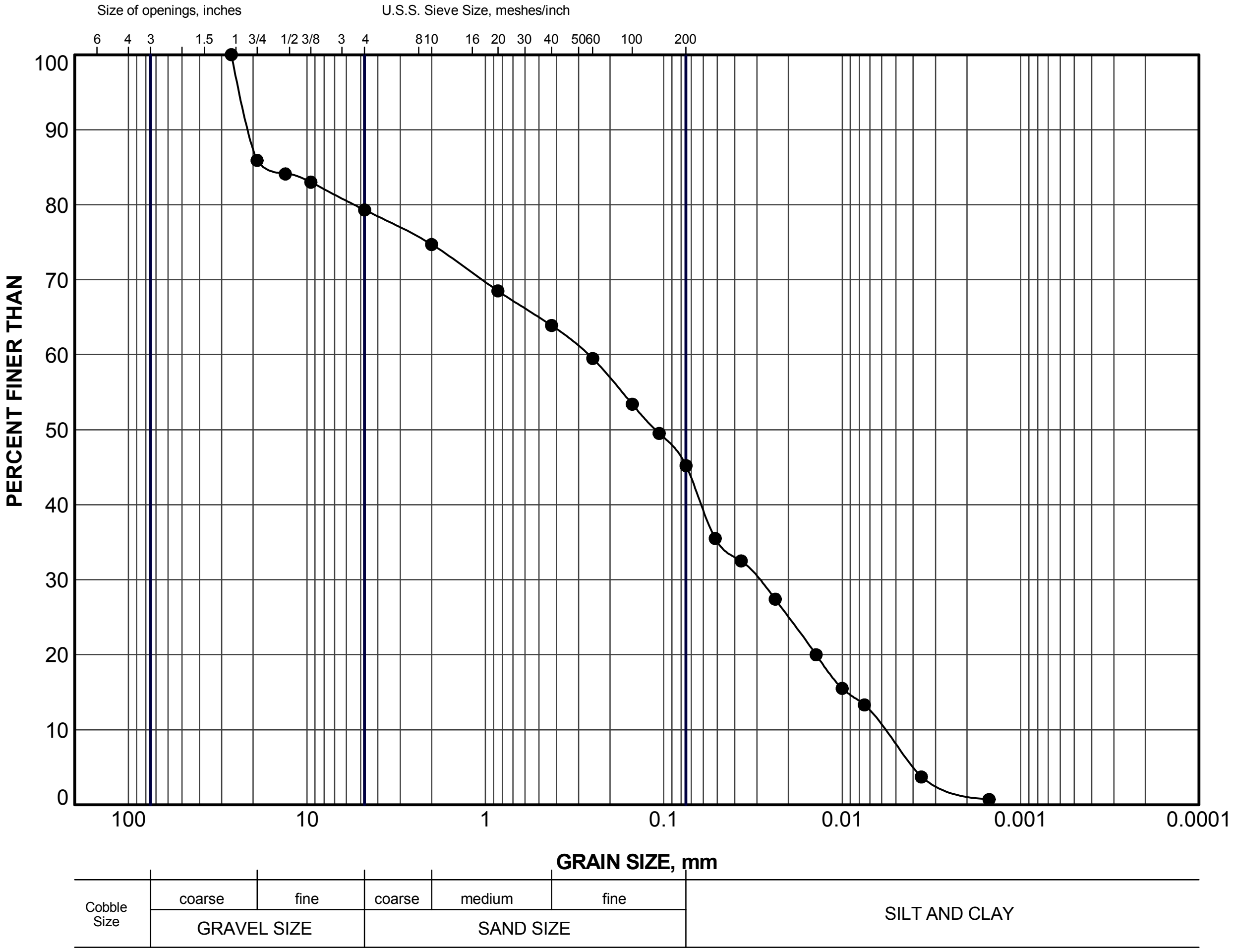
GRAIN SIZE DISTRIBUTION

SILTY CLAY TILL

Golder Associates

PROJECT No.		1668031	FILE No.	1668031-3000-R030B1
			SCALE N/A	REV.
DRAWN	ZJB	Feb 16/18	**FIGURE B-1**	
CHECK	SSB			

LDN_GSD GLDR_LDN.GDT 16/02/18 12:10



LEGEND

SYMBOL	BOREHOLE	SAMPLE	DEPTH (m)
●	T41MW	3B	18.4

PROJECT

NORTH KENT 1

TITLE

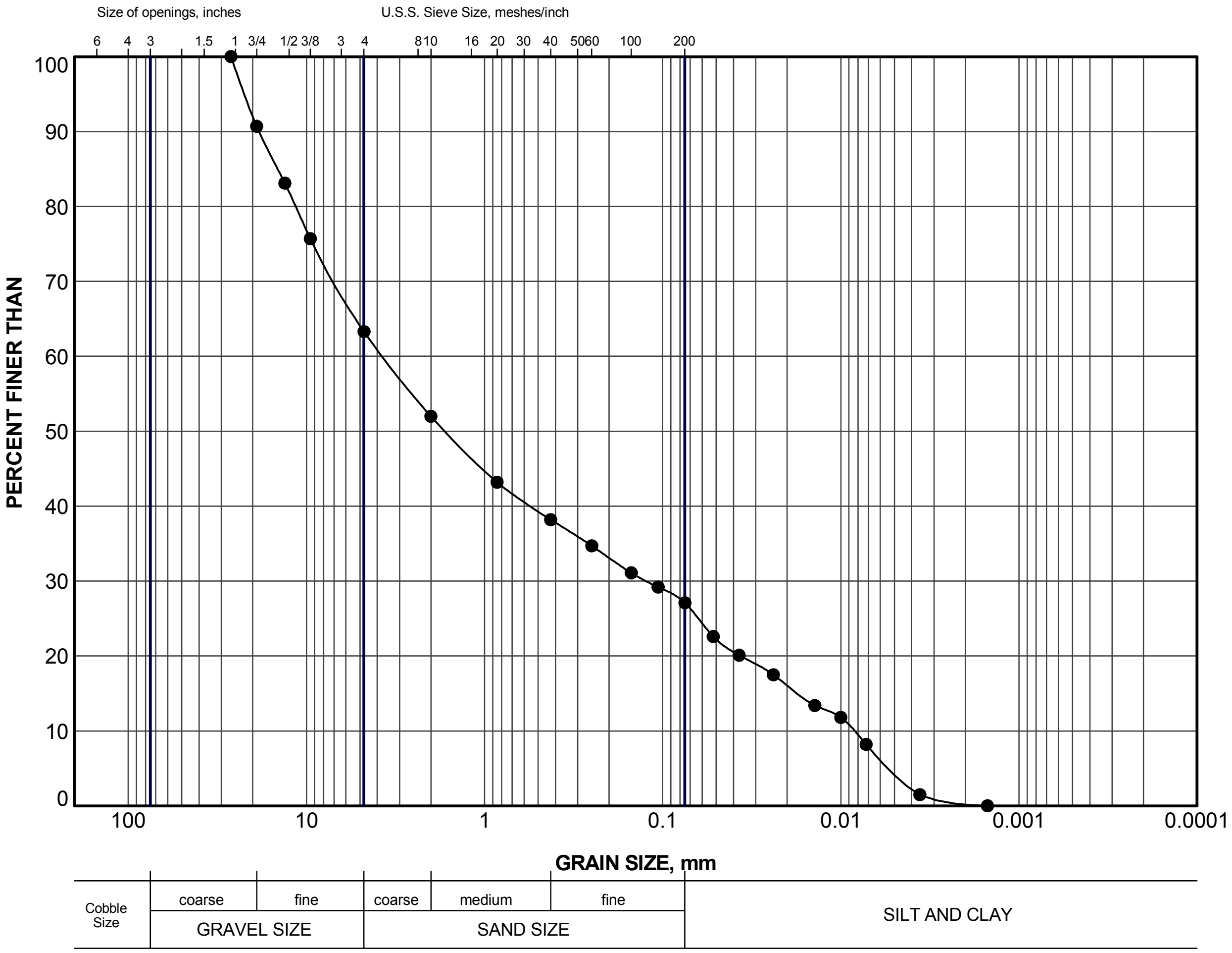
GRAIN SIZE DISTRIBUTION

GRAVELLY SAND

Golder Associates

PROJECT No.		1668031	FILE No.	1668031-3000-R030B2
			SCALE	N/A REV.
DRAWN	ZJB	Feb 16/18	**FIGURE B-2**	
CHECK	SSB			

LDN_GSD GLDR_LDN.GDT 16/02/18 12:11



LEGEND

SYMBOL	BOREHOLE	SAMPLE	DEPTH (m)
●	T51MW	5	16.5

PROJECT

NORTH KENT 1

TITLE

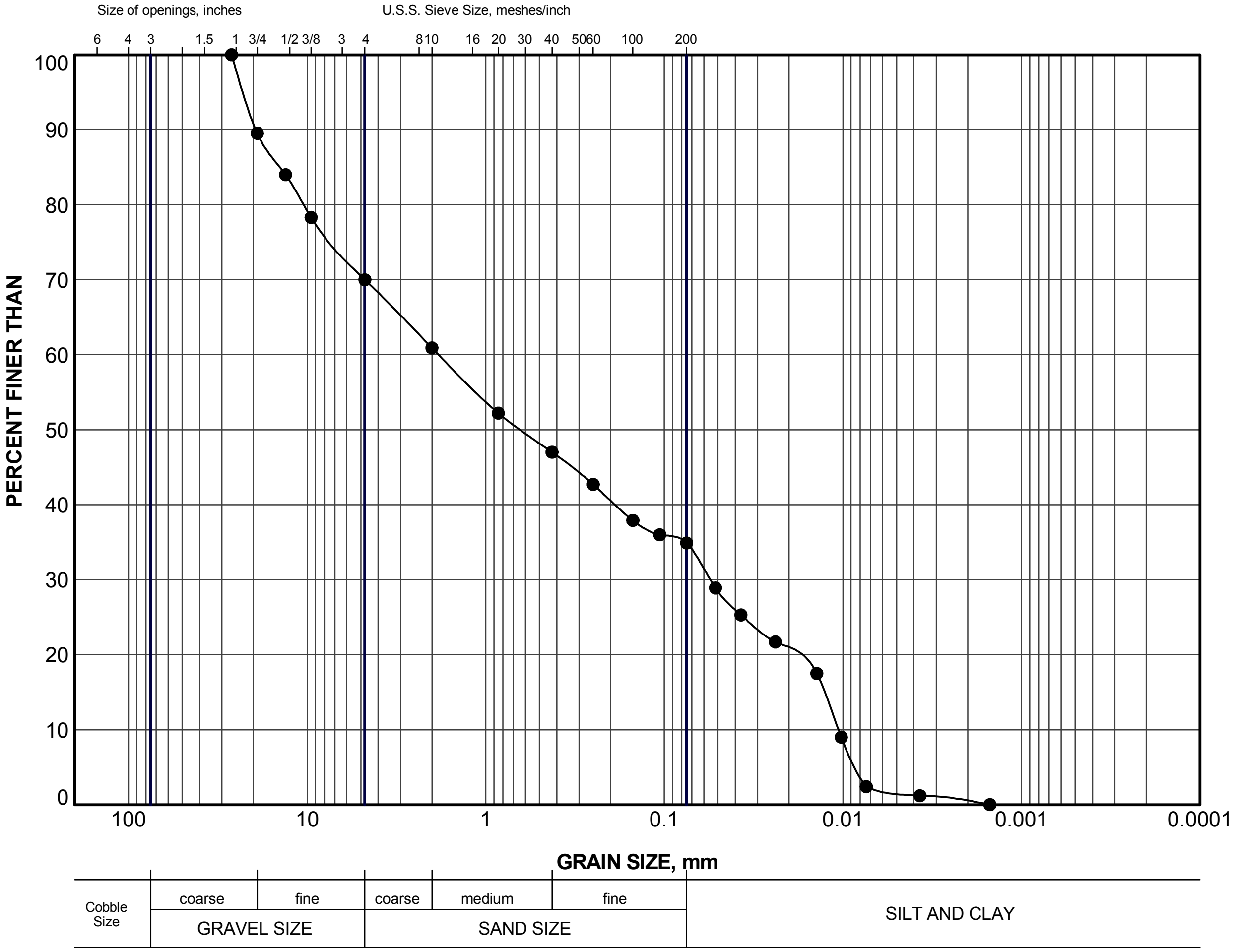
GRAIN SIZE DISTRIBUTION

SILTY GRAVEL

Golder Associates

PROJECT No.		1668031	FILE No.	1668031-3000-R030B3
			SCALE N/A	REV.
DRAWN	ZJB	Feb 16/18	**FIGURE B-3**	
CHECK	SJB			

LDN_GSD GLDR_LDN.GDT 16/02/18 12:11



PROJECT

NORTH KENT 1

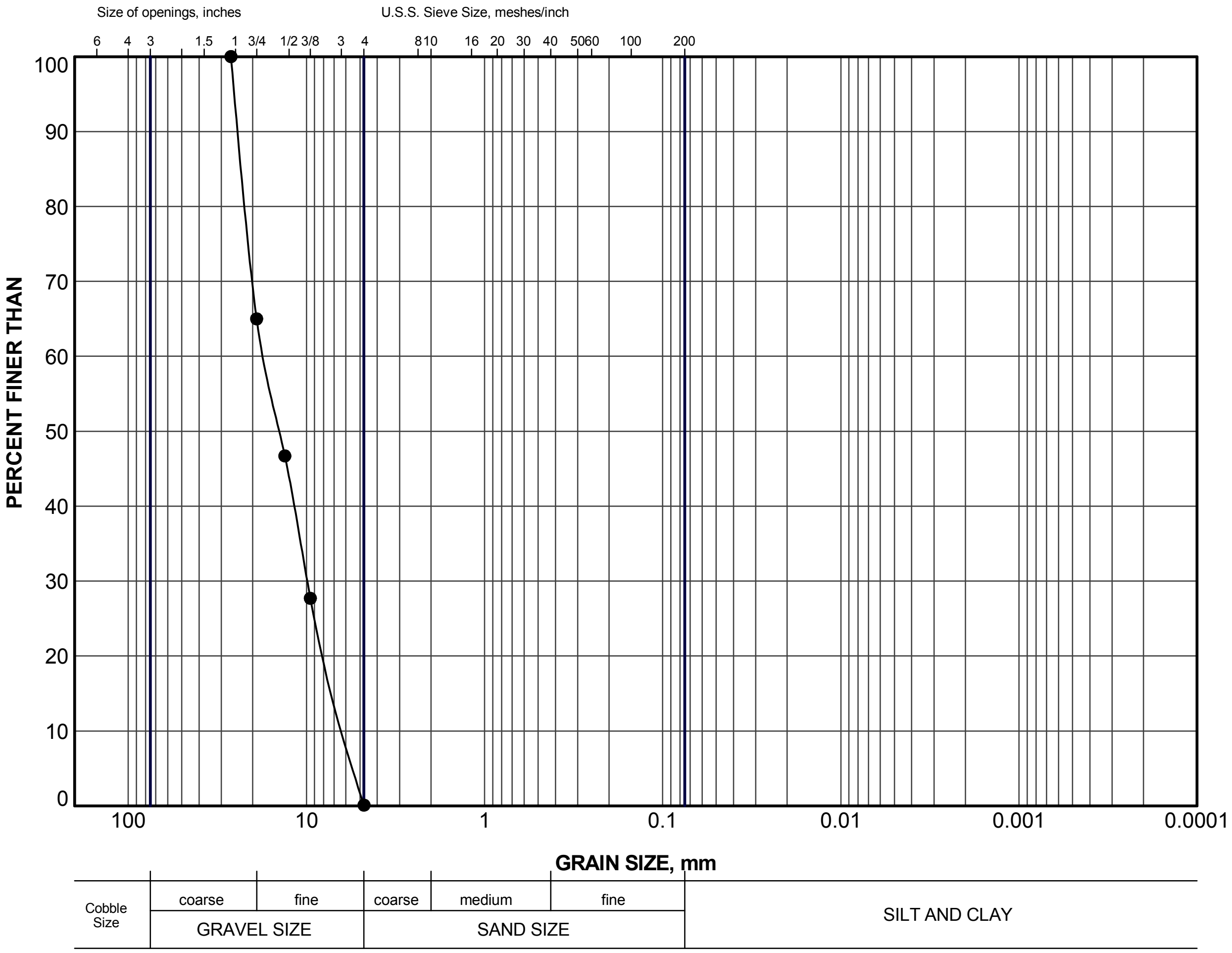
TITLE

GRAIN SIZE DISTRIBUTION
COMPOSITE SAMPLE

Golder Associates

PROJECT No.		1668031	FILE No.	1668031-3000-R030B4
			SCALE N/A	REV.
DRAWN	ZJB	Feb 16/18	**FIGURE B-4**	
CHECK	SJB			

LDN_GSD GLDR_LDN.GDT 16/02/18 12:11



PROJECT

NORTH KENT 1

TITLE

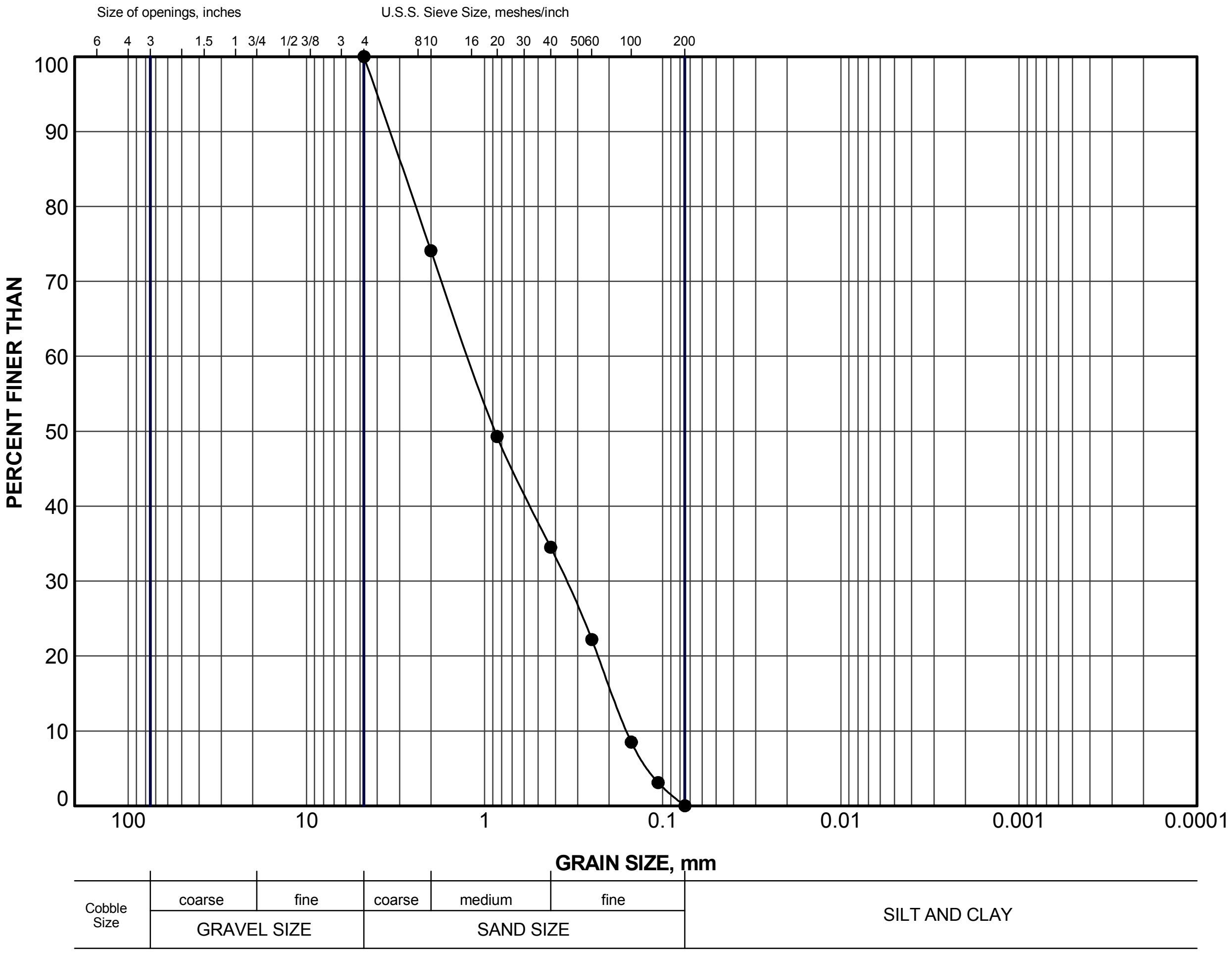
GRAIN SIZE DISTRIBUTION

COMPOSITE SAMPLE - GRAVEL

Golder Associates

PROJECT No.		1668031	FILE No.	1668031-3000-R030B5
			SCALE N/A	REV.
DRAWN	ZJB	Feb 16/18	**FIGURE B-5**	
CHECK	SSB			

LDN_GSD GLDR_LDN.GDT 16/02/18 12:12



PROJECT

NORTH KENT 1

TITLE

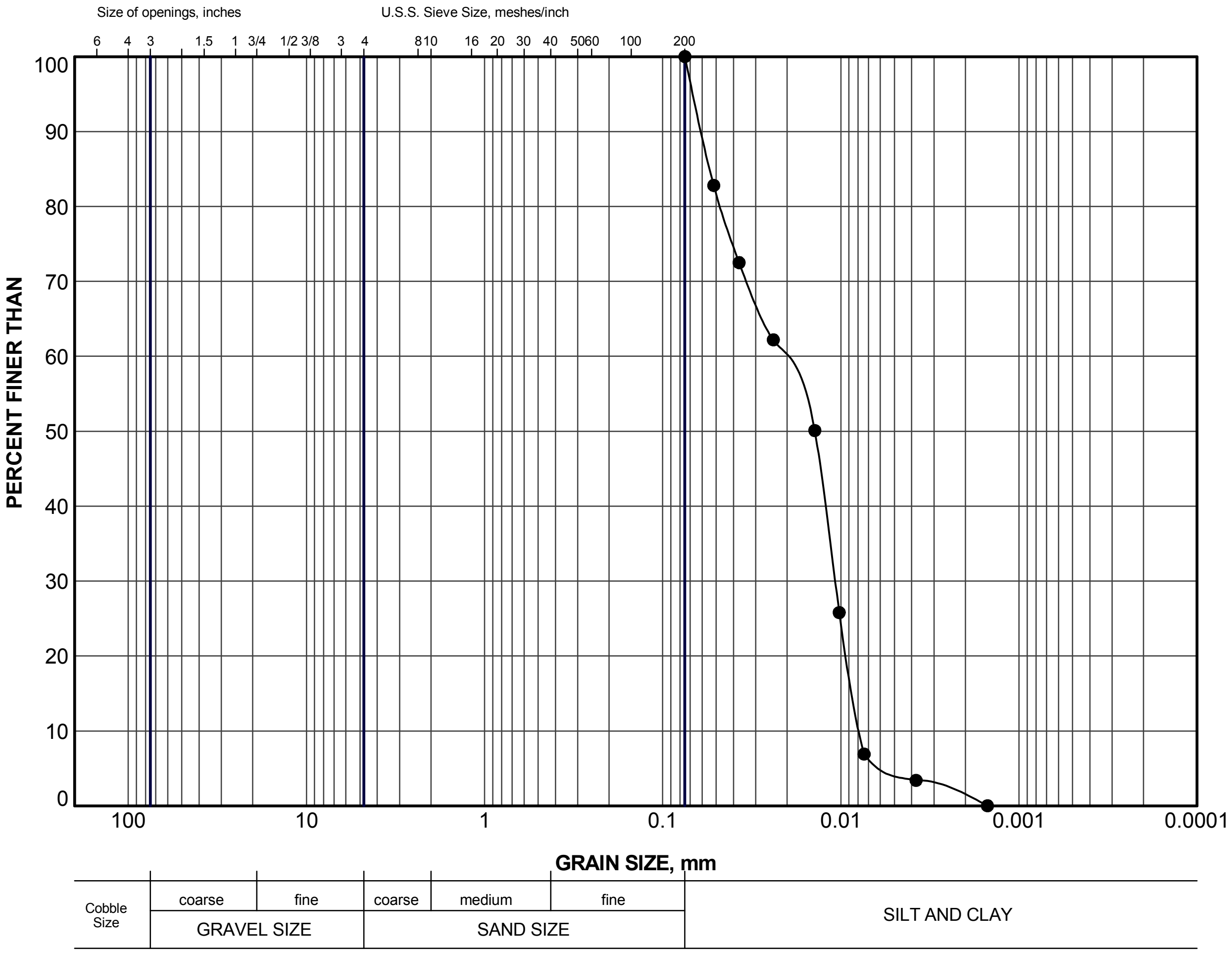
GRAIN SIZE DISTRIBUTION

COMPOSITE SAMPLE - SAND

Golder Associates

PROJECT No.		1668031	FILE No.	1668031-3000-R030B6
			SCALE N/A	REV.
DRAWN	ZJB	Feb 16/18	**FIGURE B-6**	
CHECK	SJB			

LDN_GSD GLDR_LDN.GDT 16/02/18 12:12



PROJECT

NORTH KENT 1

TITLE

GRAIN SIZE DISTRIBUTION

COMPOSITE SAMPLE - SILT AND CLAY

Golder Associates

PROJECT No.		1668031	FILE No.	1668031-3000-R030B7	
			SCALE	N/A	REV.
DRAWN	ZJB	Feb 16/18	**FIGURE B-7**		
CHECK	SSB				

LDN_GSD GLDR_LDN.GDT 16/02/18 12:12

APPENDIX C

Vibration Monitoring Reports

Instantel

Event Report

Sample T23MW - Horizontal Hammering

Histogram Start Time	10:29:01 January 29, 2018
Histogram Finish Time	10:31:11 January 29, 2018
Number of Intervals	65.00 at 2 seconds
Range	Geo:254.0 mm/s
Sample Rate	1024sps

Serial Number	BE18695 V 10.72-8.17 MiniMate Plus
Battery Level	6.3 Volts
Unit Calibration	February 22, 2017 by Instantel
File Name	T695H9H1.4D0

Notes

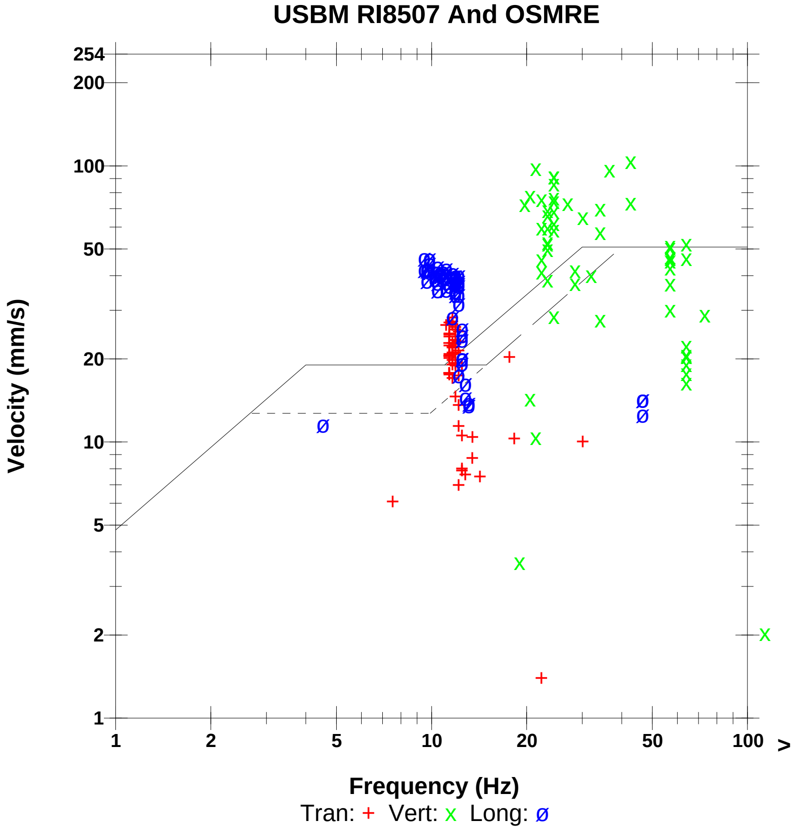
Location:	Demonstration 1
Client:	
User Name:	Golder Associates Ltd.
General:	

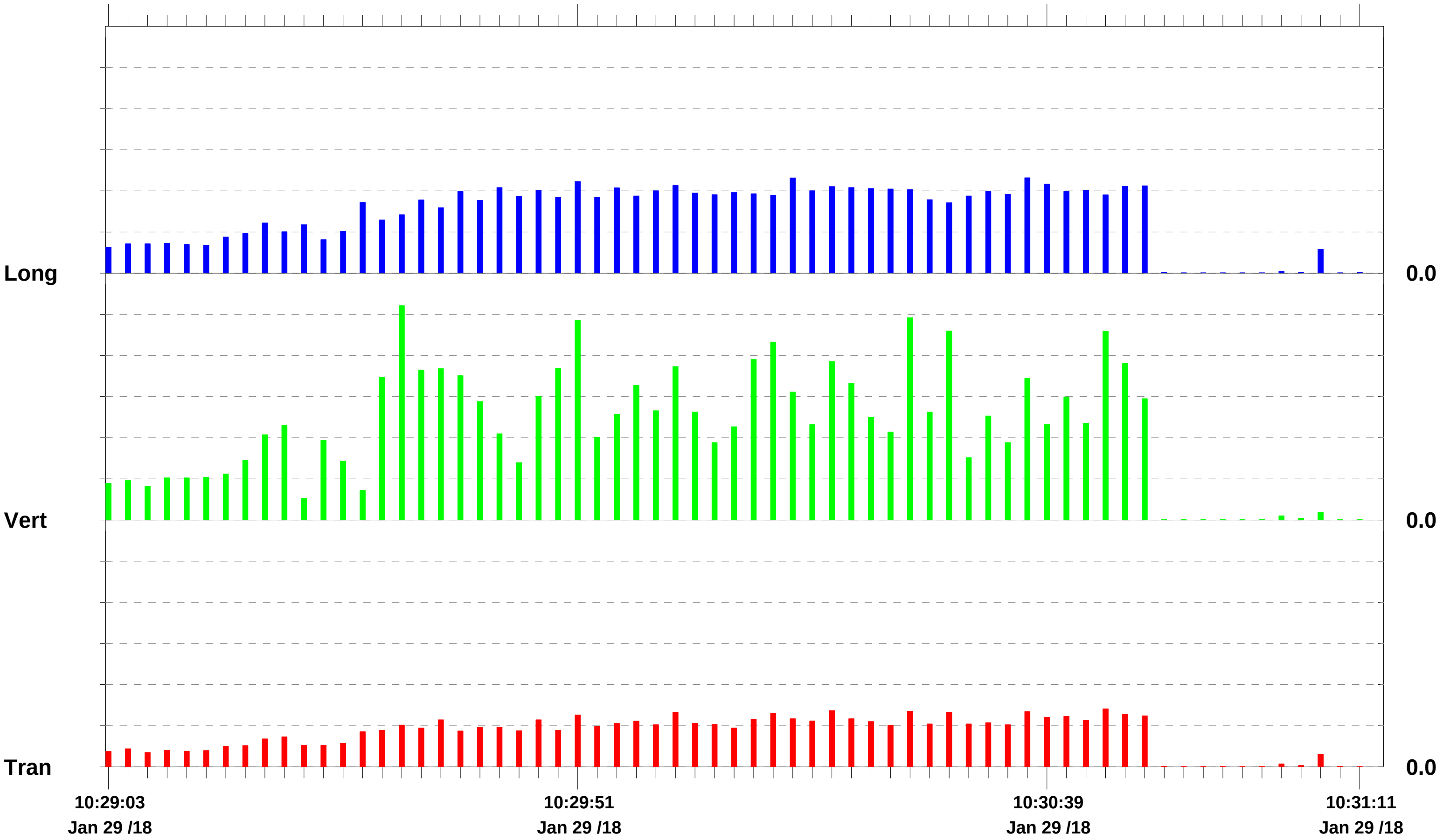
Extended Notes

Geophone weighted to same surface as test cylinder.

	Tran	Vert	Long	
PPV	28.19	104.1	46.35	mm/s
ZC Freq	12	43	9.5	Hz
Date	Jan 29 /18	Jan 29 /18	Jan 29 /18	
Time	10:30:45	10:29:33	10:30:37	
Sensor Check	Passed	Passed	Passed	

Peak Vector Sum 104.2 mm/s on January 29, 2018 at 10:29:33


USBM RI8507 And OSMRE



Time Scale: 2 seconds /div **Amplitude Scale:** Geo: 20.00 mm/s/div

Event Report

Sample T23MW - Vertical Hammering

Histogram Start Time	10:24:38 January 29, 2018
Histogram Finish Time	10:26:53 January 29, 2018
Number of Intervals	67.00 at 2 seconds
Range	Geo:254.0 mm/s
Sample Rate	1024sps

Serial Number	BE18695 V 10.72-8.17 MiniMate Plus
Battery Level	6.3 Volts
Unit Calibration	February 22, 2017 by Instantel
File Name	T695H9H0.X20

Notes

Location: Demonstration 1
Client:
User Name: Golder Associates Ltd.
General:

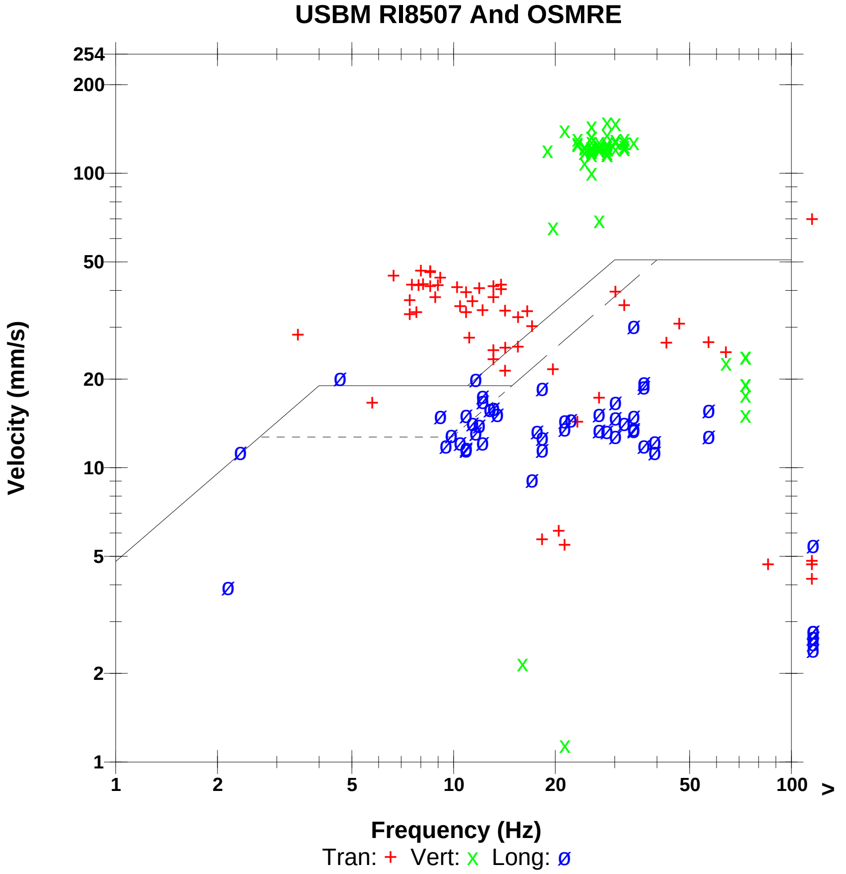
Extended Notes

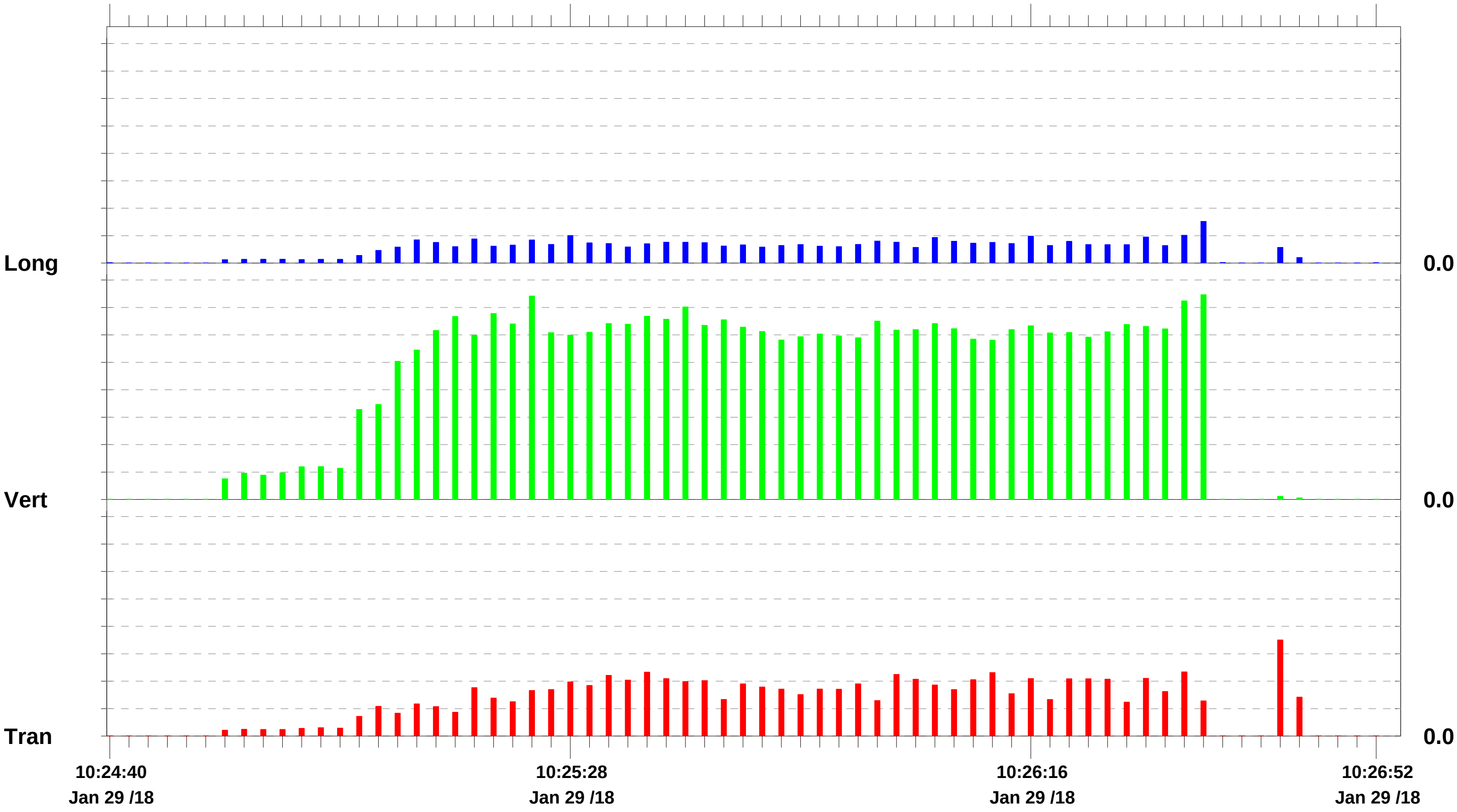
Geophone weighted to same surface as test cylinder.

	Tran	Vert	Long	
PPV	69.98	149.2	30.35	mm/s
ZC Freq	N/A	28	34	Hz
Date	Jan 29 /18	Jan 29 /18	Jan 29 /18	
Time	10:26:42	10:26:34	10:26:34	
Sensor Check	Passed	Passed	Passed	

Peak Vector Sum 151.4 mm/s on January 29, 2018 at 10:26:32

N/A: Not Applicable





Time Scale: 2 seconds /div **Amplitude Scale:** Geo: 20.00 mm/s/div

Printed: January 29, 2018 (V 10.74)

Instantel

Event Report

Sample T41MW/T51MW - Gravel
Horizontal Hammering

Histogram Start Time	10:42:06 January 29, 2018
Histogram Finish Time	10:44:34 January 29, 2018
Number of Intervals	74.00 at 2 seconds
Range	Geo:254.0 mm/s
Sample Rate	1024sps

Serial Number	BE18695 V 10.72-8.17 MiniMate Plus
Battery Level	6.3 Volts
Unit Calibration	February 22, 2017 by Instantel
File Name	T695H9H1.Q60

Notes

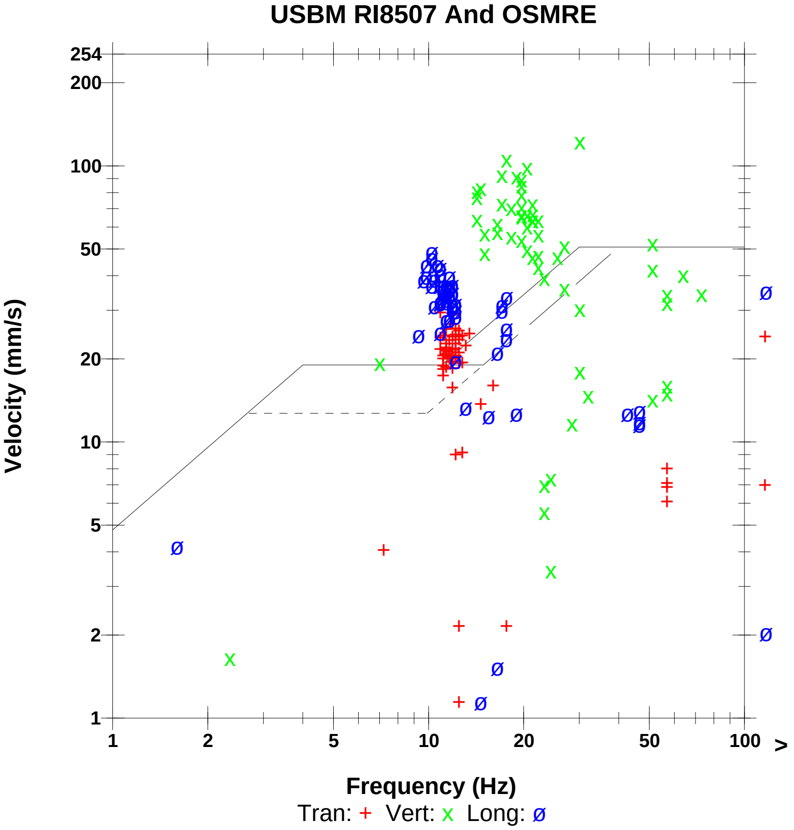
Location: Demonstration 1
Client:
User Name: Golder Associates Ltd.
General:

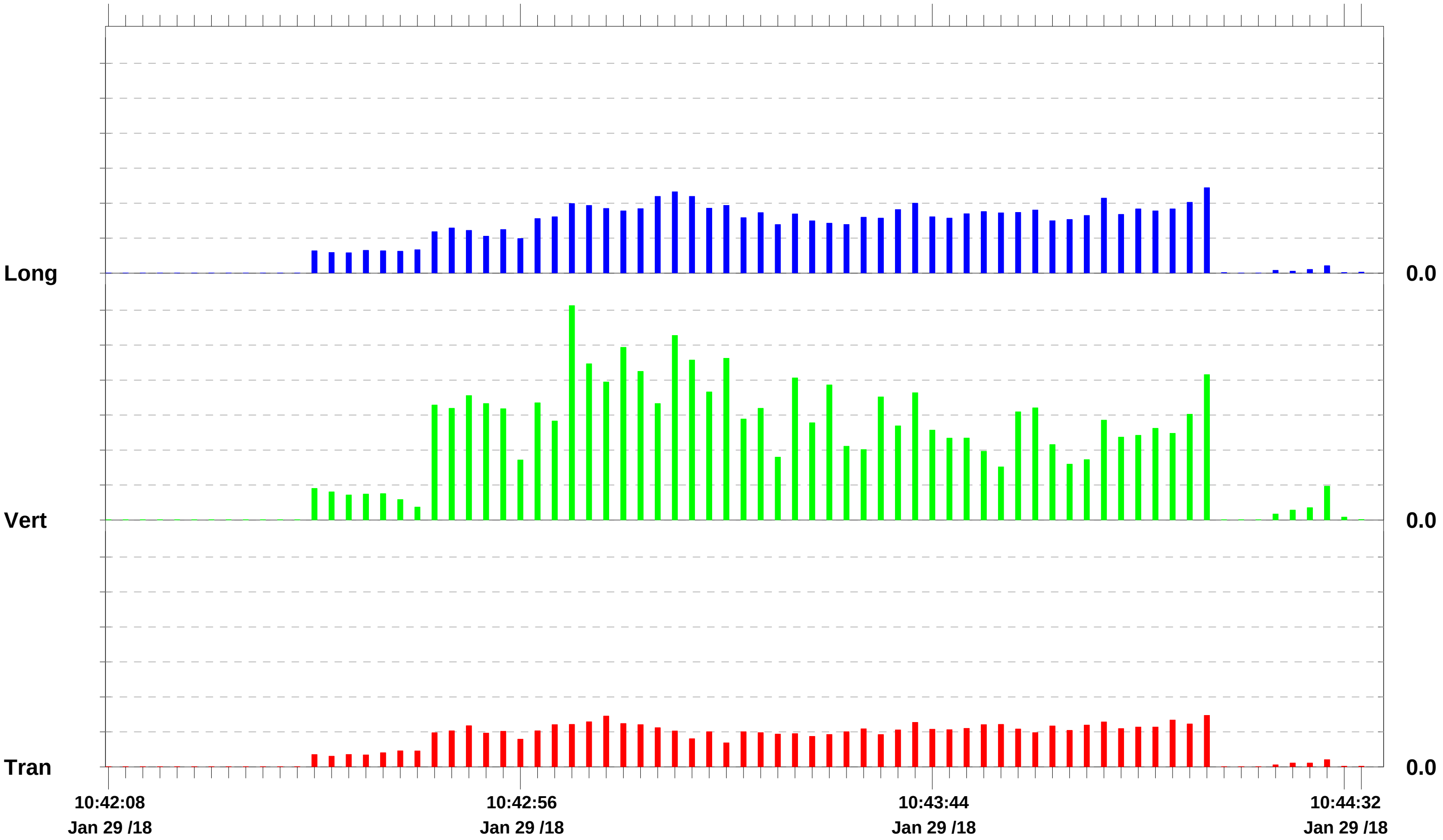
Extended Notes

Geophone weighted to same surface as test cylinder.

	Tran	**Vert**	**Long**	
PPV	29.46	122.6	48.77	mm/s
ZC Freq	11	30	10	Hz
Date	Jan 29 /18	Jan 29 /18	Jan 29 /18	
Time	10:44:16	10:43:02	10:44:16	
Sensor Check	Passed	Passed	Passed	

Peak Vector Sum 126.9 mm/s on January 29, 2018 at 10:43:02





Time Scale: 2 seconds /div **Amplitude Scale:** Geo: 20.00 mm/s/div

Event Report

Sample T41MW/T51MW - Gravel
Vertical Hammering

Histogram Start Time	10:39:20 January 29, 2018
Histogram Finish Time	10:41:40 January 29, 2018
Number of Intervals	69.00 at 2 seconds
Range	Geo:254.0 mm/s
Sample Rate	1024sps

Serial Number	BE18695 V 10.72-8.17 MiniMate Plus
Battery Level	6.2 Volts
Unit Calibration	February 22, 2017 by Instantel
File Name	T695H9H1.LK0

Notes

Location:	Demonstration 1
Client:	
User Name:	Golder Associates Ltd.
General:	

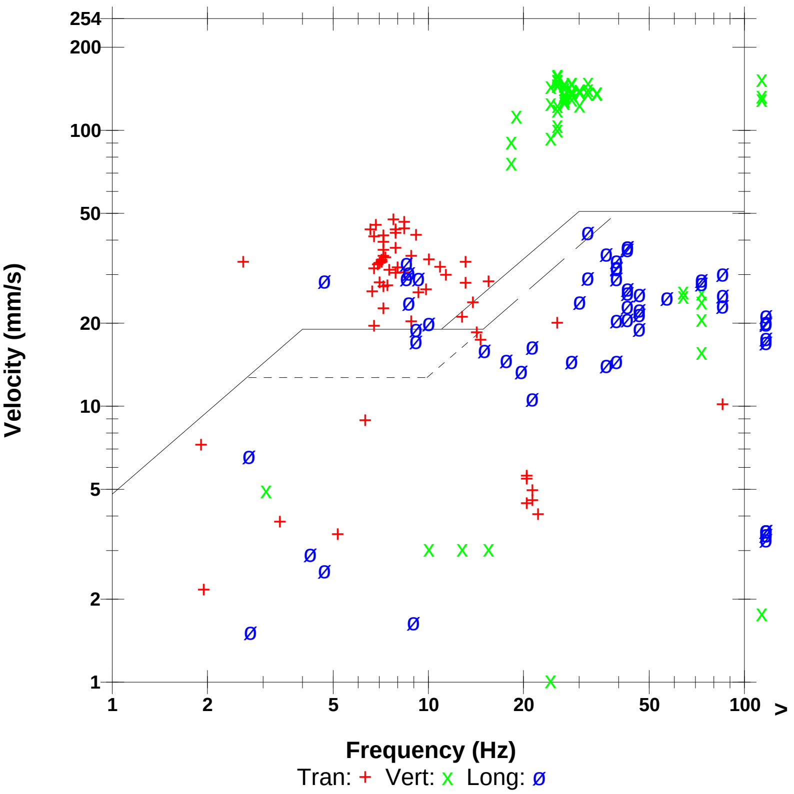
Extended Notes

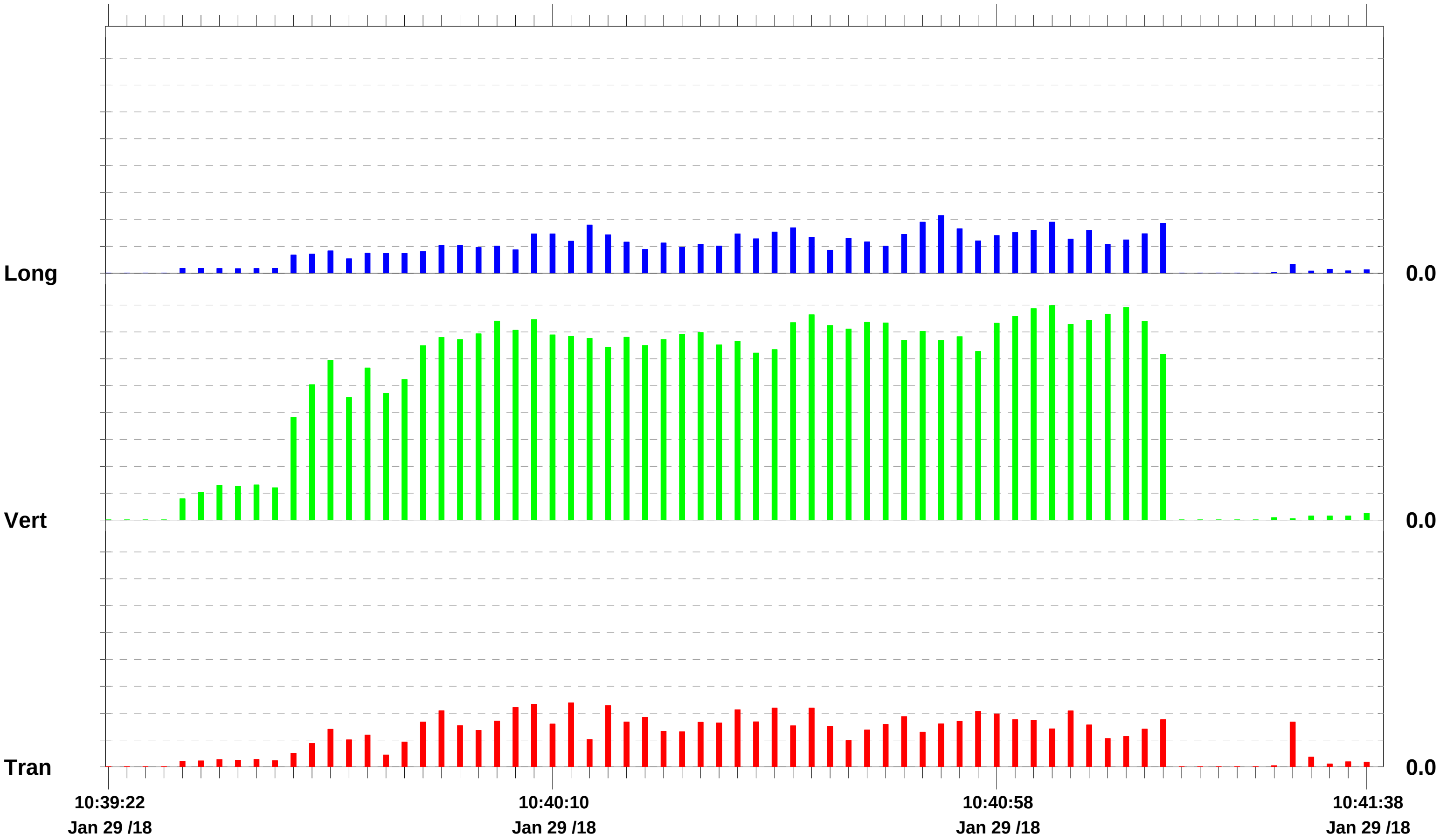
Geophone weighted to same surface as test cylinder.

	Tran	Vert	Long	
PPV	47.62	159.5	42.80	mm/s
ZC Freq	7.8	26	32	Hz
Date	Jan 29 /18	Jan 29 /18	Jan 29 /18	
Time	10:40:12	10:41:04	10:40:52	
Sensor Check	Passed	Passed	Passed	

Peak Vector Sum 161.1 mm/s on January 29, 2018 at 10:41:04

USBM RI8507 And OSMRE





Time Scale: 2 seconds /div **Amplitude Scale:** Geo: 20.00 mm/s/div

Printed: January 29, 2018 (V 10.74)

Event Report

Sample T41MW/T51MW - Gravel
Horizontal Hammering

Histogram Start Time	10:54:34 January 29, 2018
Histogram Finish Time	10:56:22 January 29, 2018
Number of Intervals	54.00 at 2 seconds
Range	Geo:254.0 mm/s
Sample Rate	1024sps

Serial Number	BE18695 V 10.72-8.17 MiniMate Plus
Battery Level	6.3 Volts
Unit Calibration	February 22, 2017 by Instantel
File Name	T695H9H2.AY0

Notes

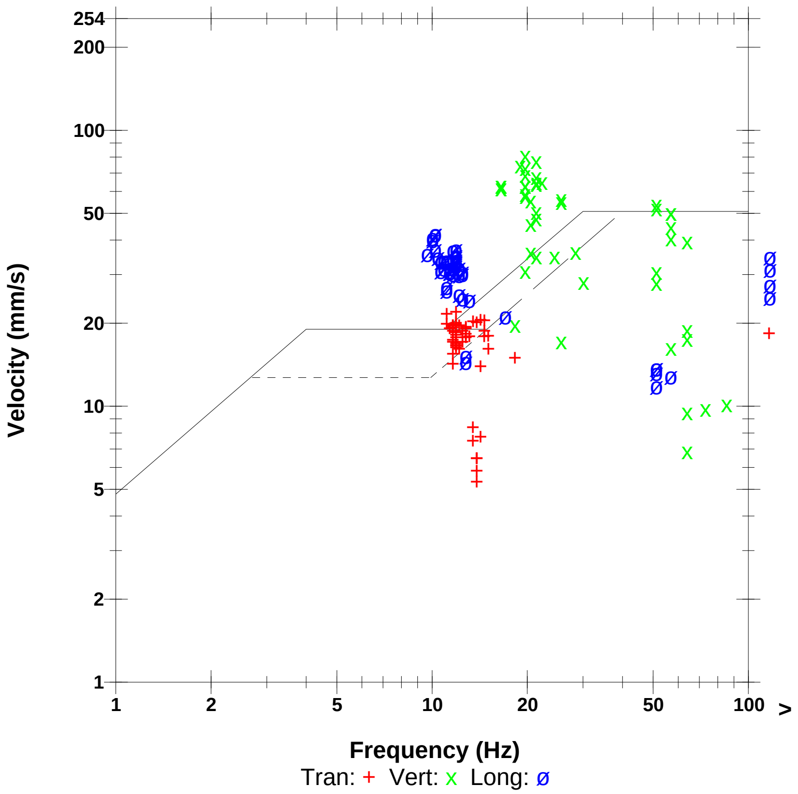
Location:	Demonstration 1
Client:	
User Name:	Golder Associates Ltd.
General:	

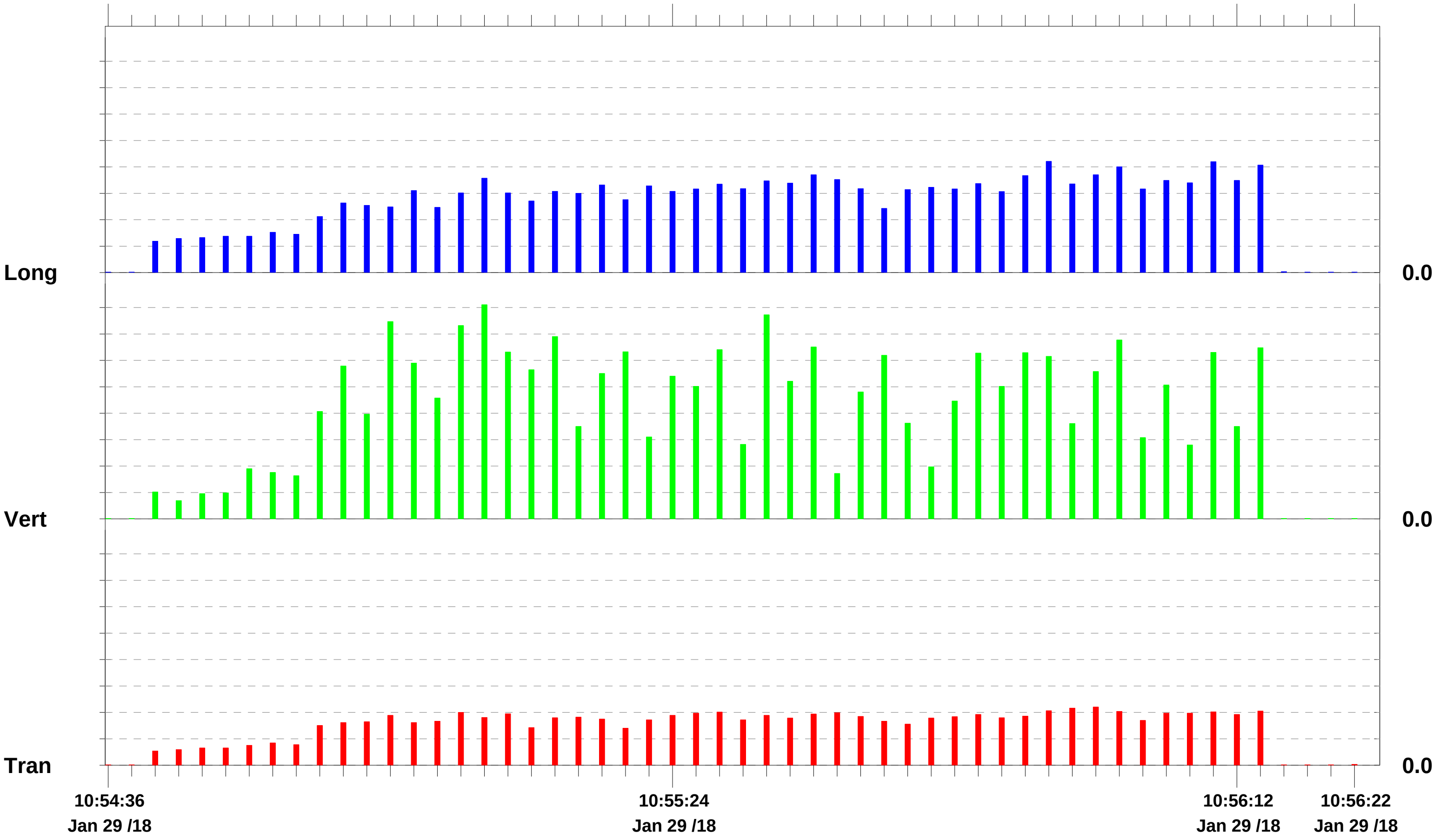
Extended Notes
Geophone weighted to same surface as test cylinder.

	Tran	Vert	Long	
PPV	21.97	81.03	42.04	mm/s
ZC Freq	12	20	10	Hz
Date	Jan 29 /18	Jan 29 /18	Jan 29 /18	
Time	10:56:00	10:55:08	10:55:56	
Sensor Check	Passed	Passed	Passed	

Peak Vector Sum 81.06 mm/s on January 29, 2018 at 10:55:08

USBM RI8507 And OSMRE





Time Scale: 2 seconds /div **Amplitude Scale:** Geo: 10.000 mm/s/div

Instantel

Event Report

Sample T41MW/T51MW - Sand
Vertical Hammering

Histogram Start Time	10:51:38 January 29, 2018
Histogram Finish Time	10:53:52 January 29, 2018
Number of Intervals	67.00 at 2 seconds
Range	Geo:254.0 mm/s
Sample Rate	1024sps

Serial Number	BE18695 V 10.72-8.17 MiniMate Plus
Battery Level	6.2 Volts
Unit Calibration	February 22, 2017 by Instantel
File Name	T695H9H2.620

Notes

Location:	Demonstration 1
Client:	
User Name:	Golder Associates Ltd.
General:	

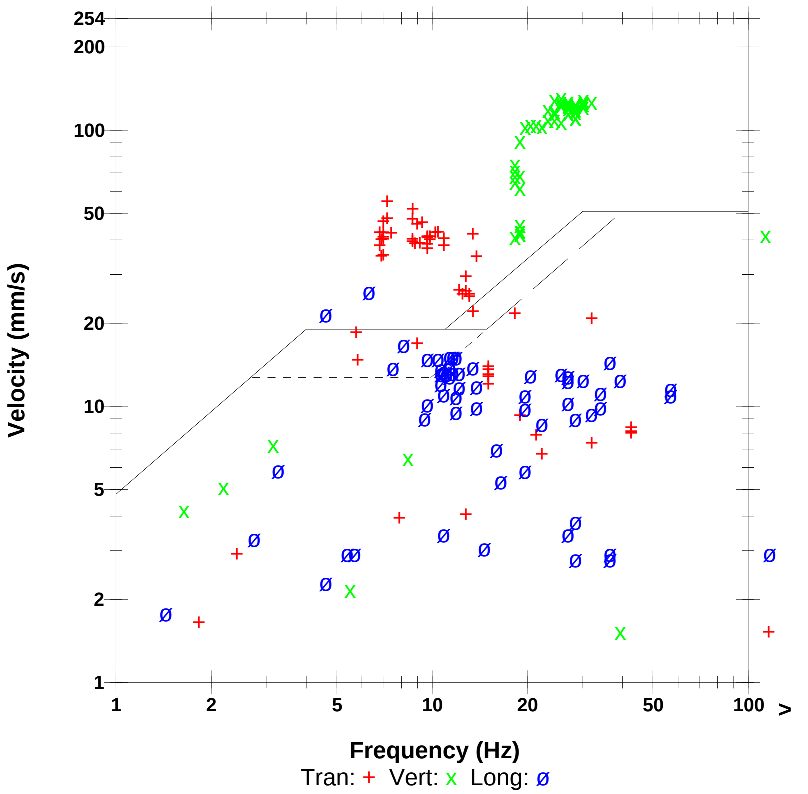
Extended Notes

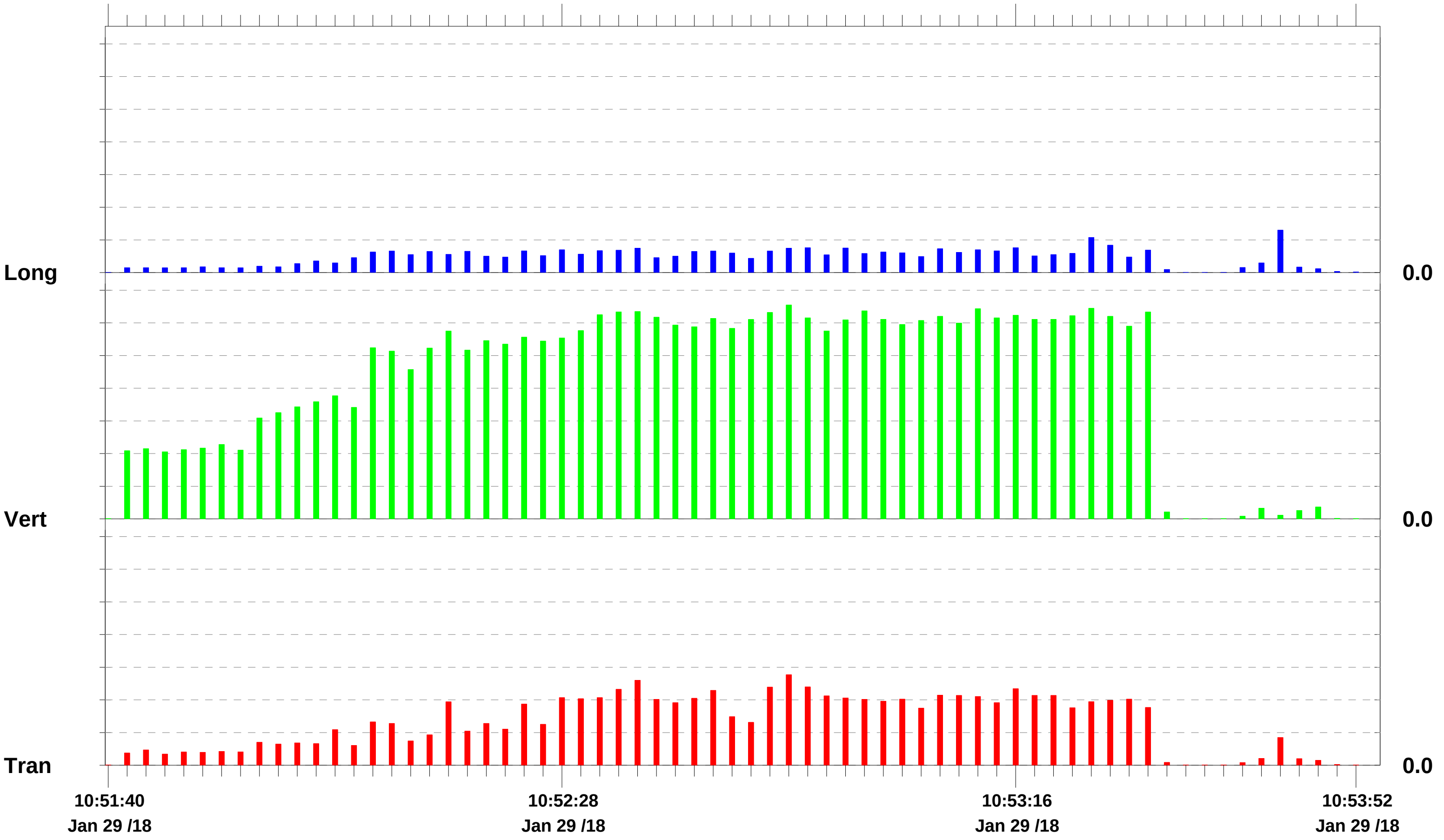
Geophone weighted to same surface as test cylinder.

	Tran	Vert	Long	
PPV	55.37	130.9	25.91	mm/s
ZC Freq	7.2	26	6.3	Hz
Date	Jan 29 /18	Jan 29 /18	Jan 29 /18	
Time	10:52:52	10:52:52	10:53:44	
Sensor Check	Passed	Passed	Passed	

Peak Vector Sum 142.4 mm/s on January 29, 2018 at 10:52:52

USBM RI8507 And OSMRE





Time Scale: 2 seconds /div **Amplitude Scale:** Geo: 20.00 mm/s/div

Printed: January 29, 2018 (V 10.74)

Instantel

Event Report

Sample T41MW/T51MW - Silt & Clay
Horizontal Hammering

Histogram Start Time	11:03:20 January 29, 2018
Histogram Finish Time	11:05:31 January 29, 2018
Number of Intervals	65.00 at 2 seconds
Range	Geo:254.0 mm/s
Sample Rate	1024sps

Serial Number	BE18695 V 10.72-8.17 MiniMate Plus
Battery Level	6.2 Volts
Unit Calibration	February 22, 2017 by Instantel
File Name	T695H9H2.PK0

Notes

Location:	Demonstration 1
Client:	
User Name:	Golder Associates Ltd.
General:	

Extended Notes

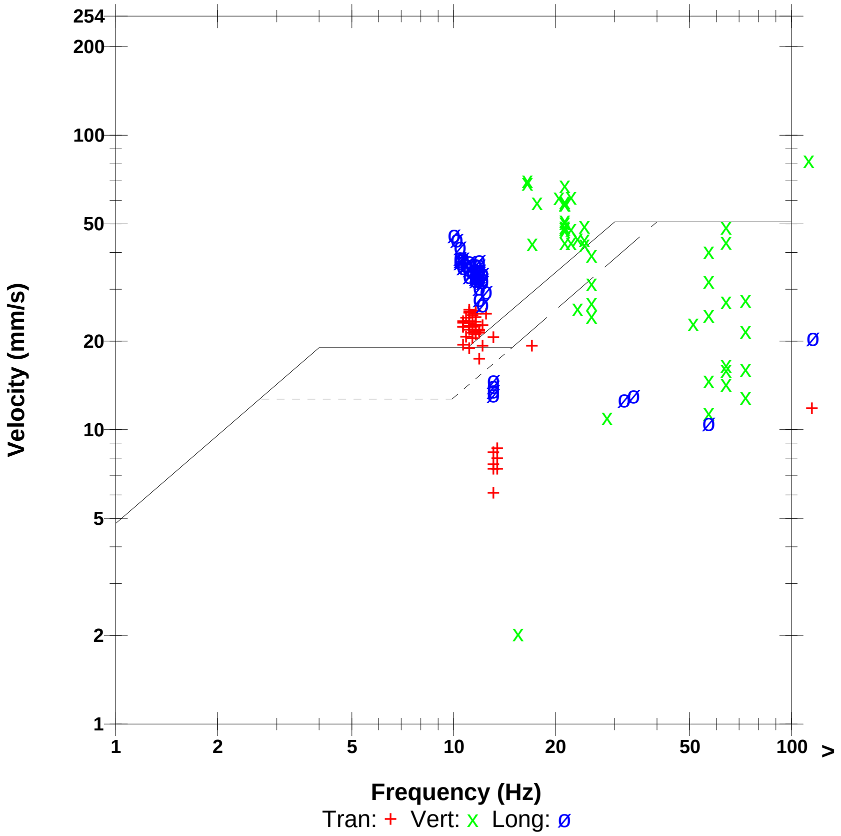
Geophone weighted to same surface as test cylinder.

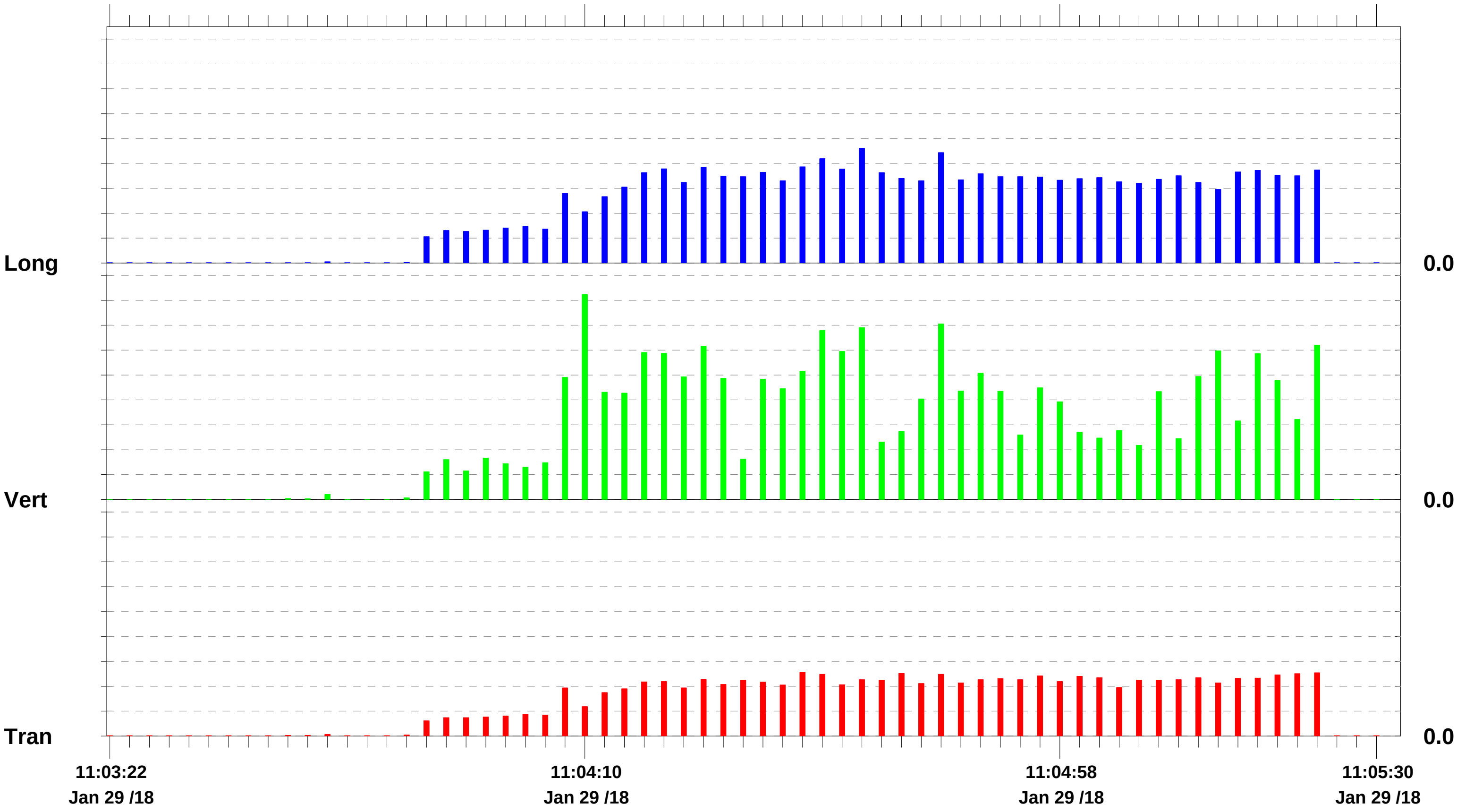
	Tran	Vert	Long	
PPV	25.53	82.30	46.10	mm/s
ZC Freq	11	N/A	10	Hz
Date	Jan 29 /18	Jan 29 /18	Jan 29 /18	
Time	11:04:32	11:04:10	11:04:38	
Sensor Check	Passed	Passed	Passed	

Peak Vector Sum 82.85 mm/s on January 29, 2018 at 11:04:10

N/A: Not Applicable

USBM RI8507 And OSMRE





Time Scale: 2 seconds /div **Amplitude Scale:** Geo: 10.000 mm/s/div

Printed: January 29, 2018 (V 10.74)

Instantel

Event Report

Sample T41MW/T51MW - Silt & Clay
Vertical Hammering

Histogram Start Time	10:59:21 January 29, 2018
Histogram Finish Time	11:01:50 January 29, 2018
Number of Intervals	74.00 at 2 seconds
Range	Geo:254.0 mm/s
Sample Rate	1024sps

Serial Number	BE18695 V 10.72-8.17 MiniMate Plus
Battery Level	6.3 Volts
Unit Calibration	February 22, 2017 by Instantel
File Name	T695H9H2.IX0

Notes

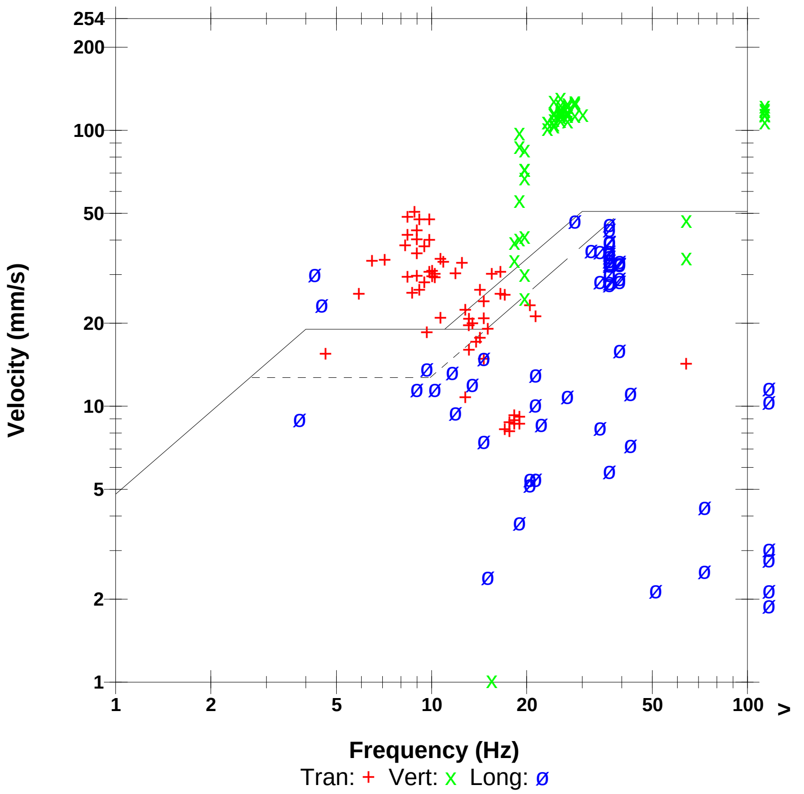
Location:	Demonstration 1
Client:	
User Name:	Golder Associates Ltd.
General:	

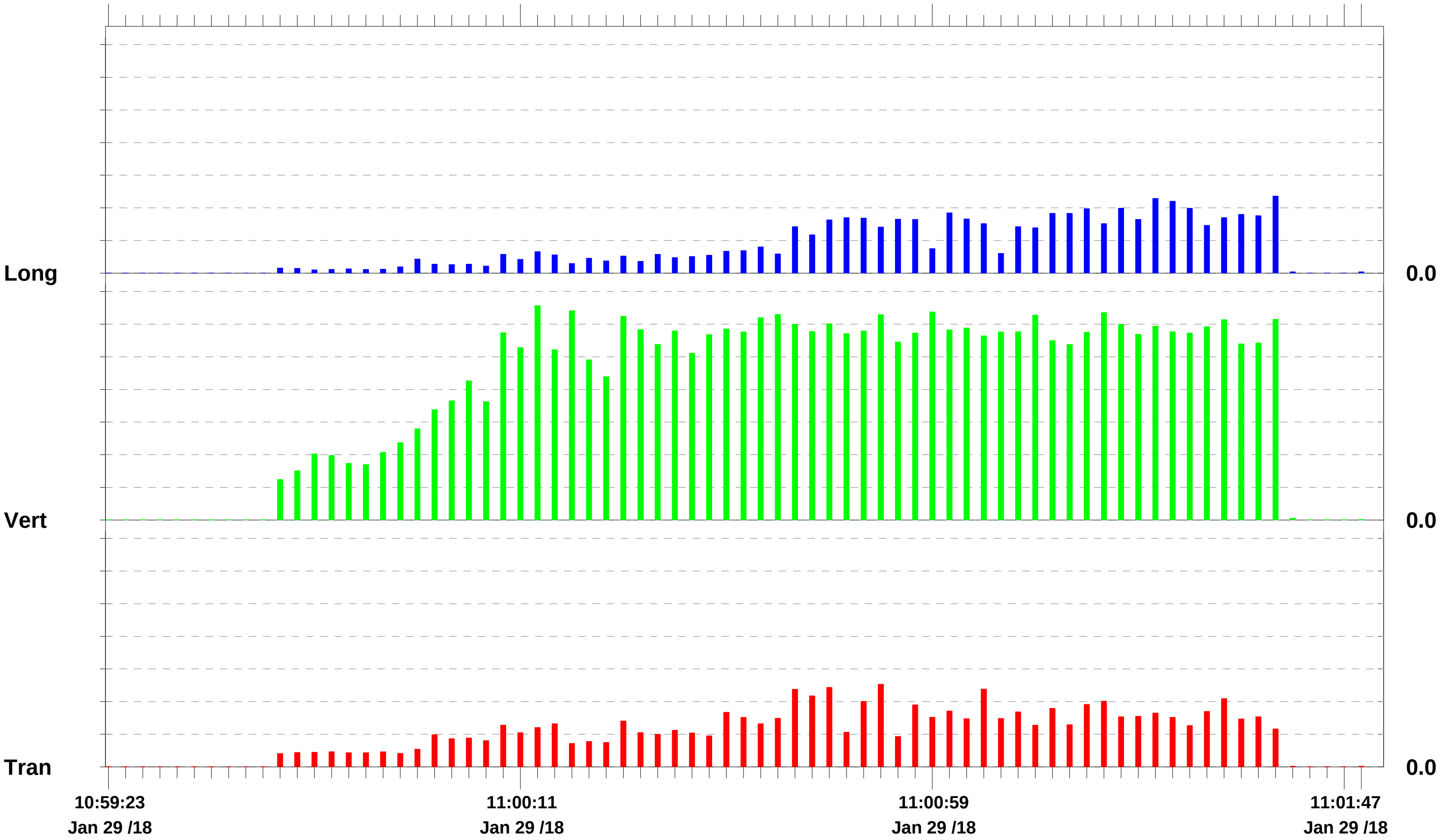
Extended Notes
Geophone weighted to same surface as test cylinder.

	Tran	Vert	Long	
PPV	50.55	131.3	47.12	mm/s
ZC Freq	8.8	26	28	Hz
Date	Jan 29 /18	Jan 29 /18	Jan 29 /18	
Time	11:00:53	11:00:13	11:01:39	
Sensor Check	Passed	Passed	Passed	

Peak Vector Sum 131.6 mm/s on January 29, 2018 at 11:00:13

USBM RI8507 And OSMRE





Time Scale: 2 seconds /div **Amplitude Scale:** Geo: 20.00 mm/s/div

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