DEVELOPMENT PERMIT

No. <u>DP-2022-18</u>
(Drilling)

TO: **1359742 BC Ltd.**
c/o Tunnel Rah Construction Ltd./ Alireza Meibodi

ADDRESS: [redacted]
(Permittee)

1) This Development Permit is issued subject to compliance with all of the Bylaws of the Town of Gibsons applicable thereto, except those specifically varied or supplemented by this Permit.

2) The Development Permit applies to land within the Town of Gibsons described below:

Parcel Identifier: **017-206-502**

Legal Description: **LOT R BLOCK 2 DISTRICT LOT 1328 PLAN VAP23218**

Civic Address: **835 Gibsons Way**

(the "Lands")

3) This permit applies to the boring of test holes on the lands, which are subject to Development Permit Area No. 9 of the Town of Gibsons Official Community Plan (Bylaw 985, 2005).

4) The work shall be conducted only in strict accordance with the terms and conditions and provisions of this Permit, including without limitation to the specifications in the following reports, which are attached to and form part of this Permit:

- Proposal report titled: *Proposed Drilling Program for 835 Gibsons Way, Gibsons, BC*, dated August 11, 2022, and signed by Nima Tafazzi, Ph.D., P.Eng., and Karim Karimzadagan, M.A.Sc., P.Eng.

- Schedule "F", Table 1 and Site Map dated August 11, 2022

5) All recommendations of the report(s) are to be followed.

6) On site monitoring by the Geotechnical Engineer is required.

7) Minor changes to the aforesaid plans that do not affect the intent of this Development Permit are permitted only with the approval of the Director of Planning and Director of Infrastructure Services.

8) Upon completion of the works, a letter from a qualified professional is required to provide all drill well logs and to ensure all conditions of this permit were met.

9) Monitoring wells, boreholes, test pits, or other excavations shall not extend into the Gibsons Aquifer. If the Aquifer is encountered, the driller is to notify the Director of Infrastructure Services before proceeding further. Additional requirements may be imposed.

10) If the Permittee does not commence the development permitted by this Permit within twenty-four months of the date of this Permit, this Permit shall lapse.

11) This Permit is <u>NOT</u> a Building Permit.

ISSUED THIS 8th DAY OF SEPTEMBER, 2022.

Lesley-Anne Staats, MCIP, RPP
Director of Planning

Emanuel Machado,
Acting Director of Infrastructure Services

Copy of permit to the Geotechnical Engineer

5. The above process is repeated until effective refusal is encountered. This is expected to be encountered within the Vashon Drift Deposits of the Gibsons aquitard underlying the site.

4.3.3 Sonic Drilling

The proposed boreholes will be drilled vertically to the depths summarized in Table 1. The actual termination depths of these boreholes will be finalized in the field based on the subsurface conditions encountered. The boreholes will generally be advanced using the following procedure which is also illustrated in the attached "Sonic Drilling System" brochure:

1. A core barrel will be advanced below ground surface from the ground in approximately 1.5 metre long segments using sonic frequencies. Water may be used to advance the core barrel, depending on the subsurface conditions encountered.

2. The core barrel will be sonically overridden with a larger diameter casing which will prevent the borehole sides from sloughing.

3. The core barrel will be returned to the surface for sample extraction and logging by the Field Engineer.

4. The above process will be repeated to the target investigation depth.

5. The Field Engineer will complete geotechnical logging at each test hole location.

6. A Town of Gibson's field Hydrogeologist (if required to be on site) will observe the process and assist wherever possible, as previously described.

7. If the aquifer stratum (which is understood to comprise coarse grained sand and/or gravel) and/or artesian pressures are encountered, the test hole will be terminated immediately and sealed as described in Section 4.3.6 below.

4.3.4 Piezometer Installation Details

A standpipe piezometer will be installed within the designated boreholes as follows:

1. After the borehole has been advanced to the final depth, the core barrel will be withdrawn from the borehole. The borehole will remain encased to facilitate the installation of the piezometer.

2. The piezometer will be installed by lowering a 50 millimetres diameter PVC standpipe into the cased borehole. The bottom 1.5 to 3.0 metres of the PVC pipe will be slotted/screened which will serve as the intake zone for groundwater to enter the piezometer and allow for groundwater levels to be measured. The intake zone is typically developed at depths below the groundwater level which will be estimated during drilling. If the bottom of the intake zone is to be situated above the termination depth of the borehole, then the bottom of the borehole will be backfilled with bentonite chips and soil cuttings to restore grades within the borehole up to the bottom of the piezometer. This would also suitably seal the bottom of the borehole. The portion of the piezometer above the intake zone will be constructed with solid PVC in order to extend the piezometer to the existing ground surface.

3. The annulus between the screened portion of the piezometer and the outer casing will be backfilled with silica sand which will serve as a filter medium. The sand backfill will extend up to approximately 30 centimeters above the top of the screened section of the PVC. The annular space of the borehole situated above the filter media will be backfilled with bentonite chips in order to isolate the intake zone of the piezometer. As bentonite swells overtime and expands

in volume, the bentonite seal will typically extend up to approximately 1 metre below existing grades at paved surfaces in order to reduce risks of this future 'swell' damaging the adjacent pavement. The balance of the borehole will be backfilled with either drill cuttings or filter sand.

4. Upon completion of piezometer installation, the top of the piezometer will be capped with a "J-Plug". The piezometer will be covered with a flush mount cover which will be embedded in concrete placed between the flush mount and adjacent pavement surface of the parking lot.

4.3.5 Borehole Abandonment Procedure (Non-Flowing / Non-Artesian Hole, if Piezometer Not Installed)

The bore holes will be backfilled with conventional methods and materials comprising soil cuttings, filter sand and bentonite chips in general accordance with British Columbia Groundwater Protection regulations. The surfaces of these boreholes will be restored with cold-mix asphalt patching, compacted with a hand tamper.

4.3.6 Borehole Abandonment Program (Flowing Artesian Hole, Piezometer Not Installed)

1. If the aquifer were to be breached, it is envisaged that the artesian groundwater would flow out the top of the casing. The artesian pressure could be contained by extending the above-grade portion casing using shorter casing segments. A cap should be placed with a pressure gauge onto the top of the casing to determine the artesian pressure before adding supplementary casing lengths.

2. A heavy cementitious grout will be prepared by mixing Portland Cement with bentonite grout. The mix-design of this grout, which will be provided by Blue Max Drilling) will be calculated based on artesian flow conditions. The grout mix will be introduced into the bottom of the borehole with a tremie tube to seal the artesian flow and suitably develop a grout column which will extend to the underside of the asphalt patch to be placed at the surface of the borehole. The grout column will serve to resist the upward forces induced by the artesian groundwater pressure.

3. The 'Mud Balance' of the heavy cementitious grout should be such that pressure of grout plug that is placed to resist the artesian pressures is known.

4. No casing would be removed prior to confirming control of any artesian flow.

5. Allow grout backfill to set and confirm suitable seal has been developed before removing drill casing, patching hole surface, and moving to the next test hole location.

6. A sufficient volume of fresh water would be on site for the mixing of the cementitious grout.

7. Sufficient storage capacity would be available on site for the collection of any drill fluid returned to the surface.

5. FIELD PACKAGE

The following documents are attached:

1. Schedule F – Gibsons Aquifer Development Permit Area No. 9
2. Figure 1: Proposed test hole location plan
3. BC MoE Flowing Artesian Well document
4. Blue Max Drilling sonic drill rig specifications sheet
5. Horizon Engineering Certificate of Insurance
6. Blue Max Drilling Certificate of Insurance
7. Horizon Engineering WorkSafe BC letter
8. Blue Max Drilling WorkSafe BC letter

For:
HORIZON ENGINEERING INC.

PROFESSIONAL ENGINEER PROVINCE OF BRITISH COLUMBIA Dr. N. TAFAZZOLI # 45761

N. Taf. Apr 1, 2022

Nima Tafazzoli, Ph.D., P.Eng.
Geotechnical Engineer

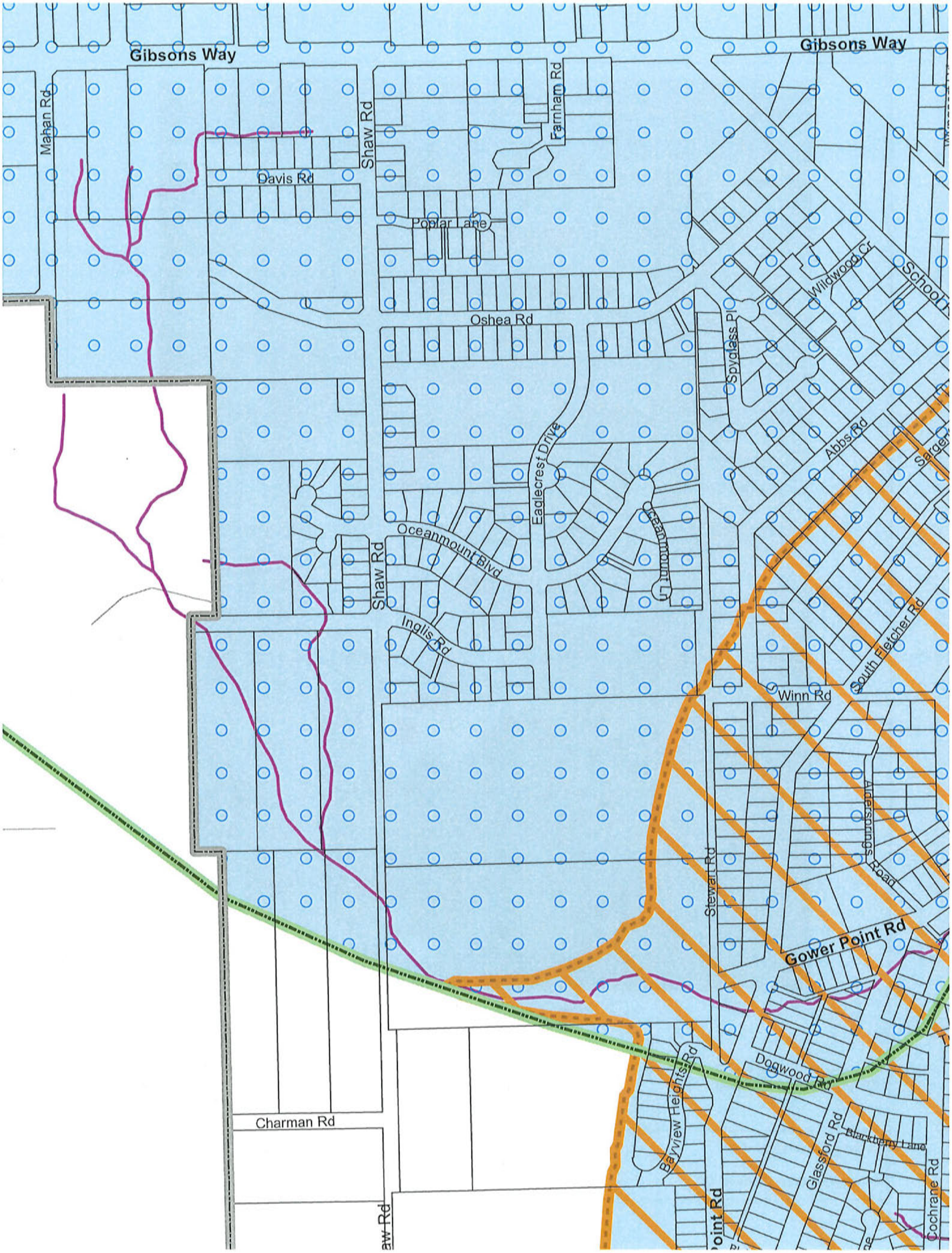
For:
HORIZON ENGINEERING INC.

PROFESSIONAL ENGINEER PROVINCE OF BRITISH COLUMBIA K. KARIMZADEGAN #27158

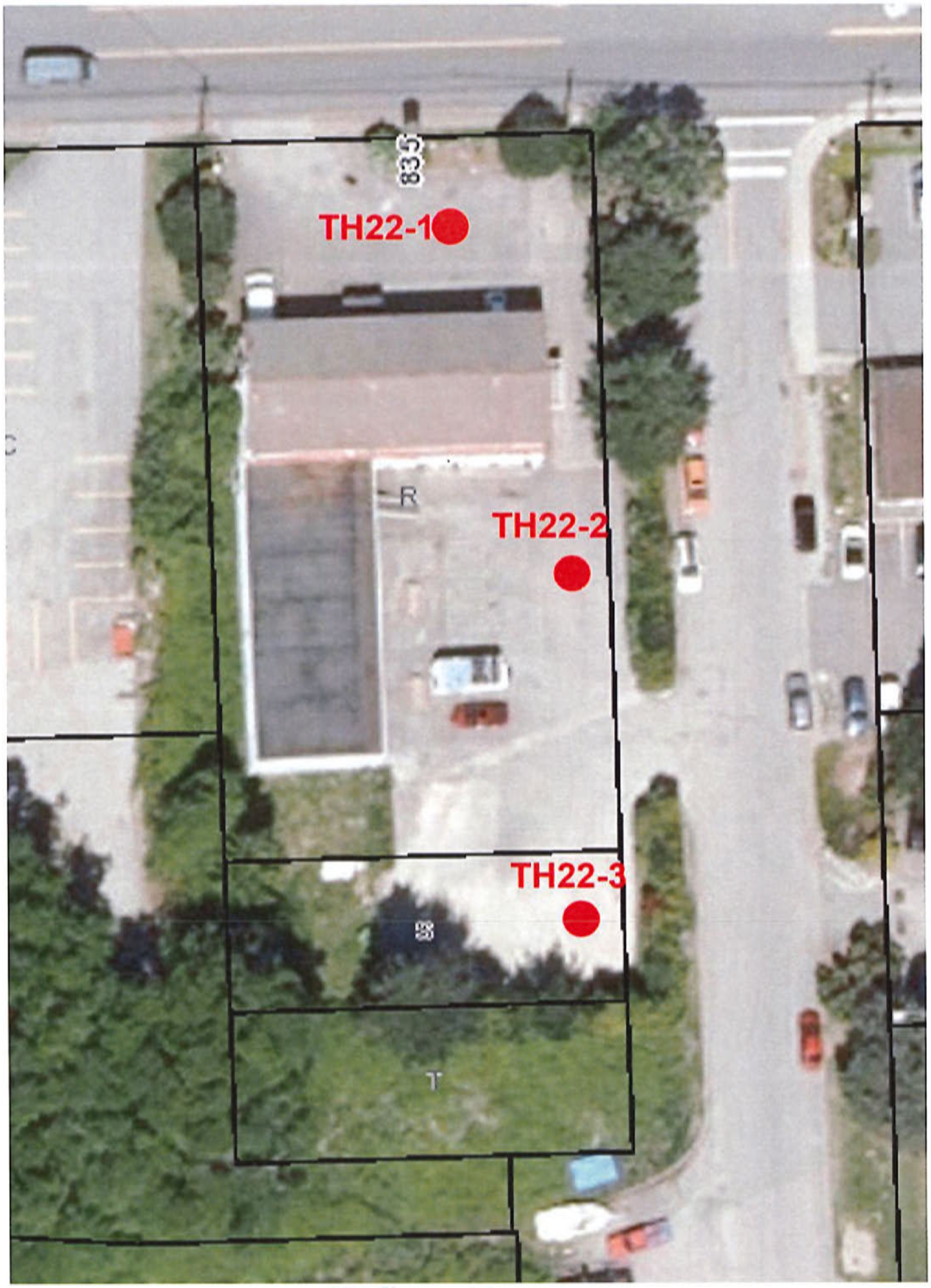
Karim Sept 1, 2022

Karim Karimzadegan, M.A.Sc., P.Eng.
Principal

HORIZON ENGINEERING INC
PERMIT TO PRACTICE No.1001550
ENGINEERS AND GEOSCIENTISTS BRITISH COLUMBIA



Gibsons Way
Gibsons Way
Mahan Rd
Shaw Rd
Farnham Rd
Davis Rd
Poplar Lane
Wildwood Cr
School
Oshea Rd
Spyglass Pl
Abbs Rd
Eaglecrest Drive
Oceanmount Blvd
Oceanmount Ln
Shaw Rd
Inglis Rd
South Fletcher Rd
Winn Rd
Aldersprings Road
Stewart Rd
Gower Point Rd
Dogwood Rd
Bayview Heights Rd
Glassford Rd
Blackberry Lane
Cochrane Rd
Charman Rd
Point Rd



● Approximate location of test hole

TRC Construction Managers	Proposed Test Hole Location Plan	HORIZON ENGINEERING INC						
Proposed Development at 835 Gibsons Way, Gibsons, BC		Scale: NTS	Job No: ---		Date: 10-Aug-22		Figure: 1	
		Des: NT	Dwn: NT	Chk: KK	Rev: 0			

Flowing Artesian Wells

Water Stewardship Information Series

BRITISH COLUMBIA
The Best Place on Earth

Table of Contents

This booklet contains general information on flowing artesian wells for well drillers, groundwater consultants and well owners in British Columbia. The booklet provides general guidelines on flowing artesian wells and does not replace professional knowledge or experience.

What's the difference between a flowing artesian well and an artesian well?

An **artesian well** is a well that taps into a confined aquifer (see Figure 1). Under artesian pressure, water in the well rises above the top of the aquifer, but does not necessarily reach the land surface. A **flowing artesian well** is one that has been drilled into an aquifer where the pressure within the aquifer forces the groundwater to rise above the land surface naturally without using a pump. Flowing artesian wells can flow on an intermittent or continuous basis and originate from aquifers occurring in either unconsolidated materials such as sand and gravels or bedrock, at depths ranging from a few meters to several thousand meters. All flowing wells are artesian, but not all artesian wells are flowing wells.

Why do wells flow?

Flowing artesian wells can be found in two types of situations:

- the aquifer is confined by impermeable materials (i.e., confined beds where the static water level is above the top of the aquifer and land surface); or
- the aquifer is not confined, but the static water level is above the land surface.

Static water level is the level to which water will naturally rise in a well without pumping. For flowing artesian wells, the groundwater level or static water level can be expressed as a head (e.g., artesian head) and reported as a length (feet or meters above ground level) or pressure (pounds per square inch or psi).

Artesian conditions can be generated by geological and topographical controls (see Figure 1) or by topographical controls alone (Figure 2). In the former, water in an artesian well rises upward due to the pressure confined in the aquifer. Artesian wells are found in inclined confined aquifers sandwiched between layers of rock or overburden that are impervious or have low permeability. Water enters the exposed portion of the aquifer at a high elevation and percolates down through interconnected pore spaces. The water held in these spaces is under pressure (confining pressure or hydrostatic head) due to the high elevation from which it originally came. If a well is drilled from the land surface through the overlying impervious layer, the pressure inside the aquifer will cause the water to rise in the well. In areas where the pressure of the aquifer is great enough, the water rises above ground level resulting in a flowing artesian well.

Hydrostatic head (or confining pressure) is the vertical distance between the water level in the well and the top of the aquifer and is expressed in feet or meters of water or pressure (psi).

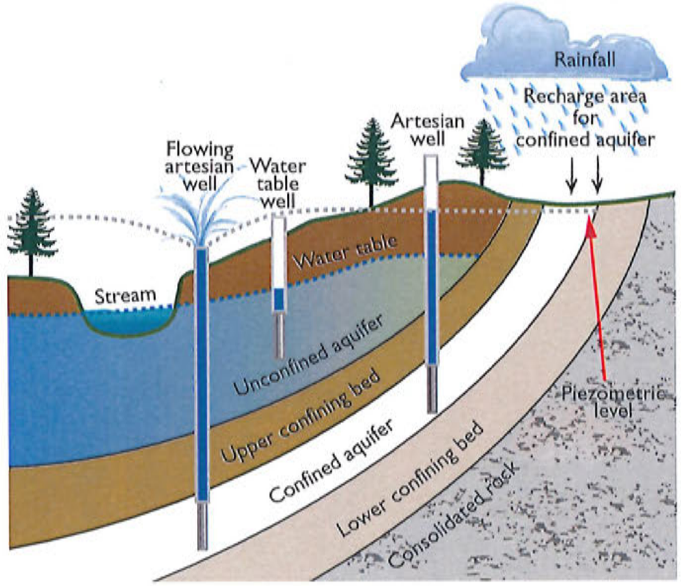


Figure 1. Geological and topographical controls affecting artesian and flowing artesian wells.

Topographical control situations can be found in unconfined aquifers where the well intake is deep enough to intercept a zone where the hydraulic head is higher than the land surface (see Figure 2). This situation typically occurs in groundwater discharge areas at lower elevations near rivers and lakes in valleys surrounded by steep slopes. The pressure of the groundwater typically increases with depth in the discharge areas where the slope of the water's

Hydraulic head is a measurement of the water level or total energy per unit weight above a datum such as sea level. It is commonly measured as water surface elevation in feet or meters.

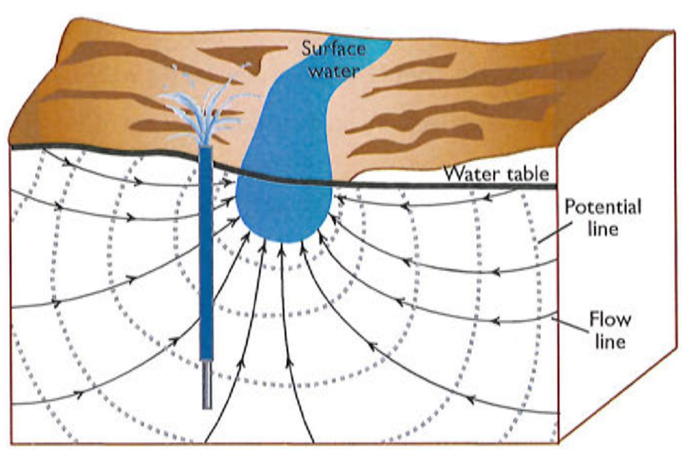


Figure 2. Topographically controlled flowing artesian well.

flow path and its pressure are controlled by the topography. As the groundwater moves along the flow path, it can migrate deep below ground where it can lie beneath shallow non-artesian groundwater. When a well is drilled into a deeper zone of higher hydraulic head, the groundwater can move upwards inside the well casing to a level that is higher than the levels of the land surface, resulting in a flowing artesian well.

Why is stopping or controlling artesian flow important?

Flow from artesian wells should be controlled to prevent wasting groundwater. For instance, an uncontrolled artesian well flowing at 10 USgpm (55 m^3/day) wastes 14,400 USgallons (55 m^3) every day and 5.25 million USgallons (2.0 x 10^4 m^3) per year. An uncontrolled flow of 1 USgpm wastes enough water to supply four homes. Wasting water may lower the confining pressure in the aquifer so that the well no longer flows or flows at a reduced rate and affects the yield of neighbouring wells and springs.

Figure 3. Erosion caused by flowing artesian well.

When groundwater breaks out on the outside of the well casing, flooding, damage and/or subsidence and sinkhole formation can occur. Another reason to control flow is to prevent groundwater flowing from an aquifer under artesian pressure into an overlying aquifer(s). If the flowing well breakout is not promptly contained, silt, clay, gravel, sand, and drilling fluids can be carried along with the artesian groundwater to the ground surface and eventually reach surface water. The quality of the surface water and the habitat of aquatic organisms can be impacted.

Flowing artesian wells can also cause erosion (see Figure 3). Flowing water that accumulates into ponds can also contribute to mosquito problems.

How can flowing artesian conditions be determined before drilling?

Before a well is drilled, it is important for the person responsible for drilling the well (qualified well driller or qualified professional[1]) to do a pre-drilling assessment to determine the range of pressures and flows that might be found during drilling, i.e., whether flowing artesian conditions are likely to be encountered.

[1] Qualified professionals who are registered with the Association of Professional Engineers and Geoscientists of British Columbia with competency in hydrogeology or geotechnical engineering.

The pre-drilling assessment should include gathering information about geological conditions, static water levels and any history of flowing artesian wells in the area. This information can be obtained from:

- reviewing available local well construction reports;
- reviewing hydrogeologic information (e.g., maps on the Water Resource Atlas http://www.env.gov.bc.ca/wsd/data_searches/wrbc/index.html showing flowing artesian well coverage (see Figure 4) or reports on Ecocat http://www.env.gov.bc.ca/ecocat/);
- consulting with the Ministry of Environment regional hydrogeologists; and
- consulting with well drillers and professional hydrogeologists or geotechnical engineers with knowledge of the local area.

If this information is not available, the person responsible for drilling the well should consider the proposed well depth in relation to relevant topographic and geologic information about the site (i.e., whether the proposed well is going to be deep in a valley-bottom location). Geophysical logs or an electric survey can also be used to better understand subsurface conditions. When knowledge is limited, a precautionary approach should be taken and planning should assume that flowing artesian conditions will be present.

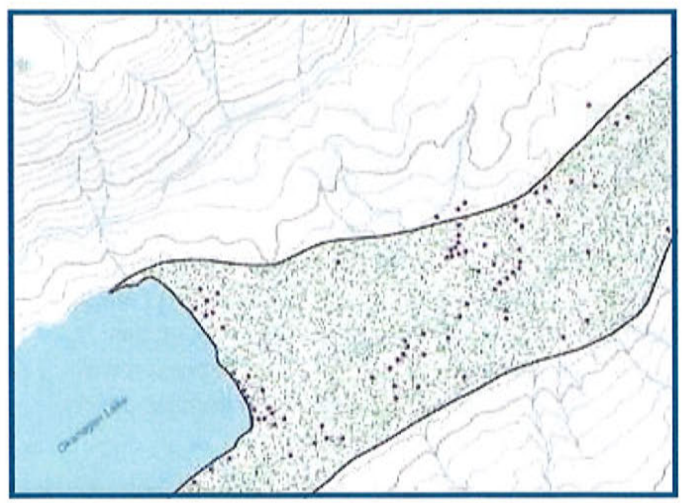


Figure 4. Map from the BC Water Resource Atlas showing provincial mapped and classified aquifers, contoured elevations and wells (purple dots) that were flowing artesian wells at the time drilling.

What are the provincial regulatory requirements for controlling or stopping artesian flow?

The provincial regulatory requirements for controlling flowing artesian wells are outlined in section 77 of the *Water Act*. If artesian conditions are encountered when constructing or supervising construction of a well, the qualified well driller or qualified professional must ensure the artesian flow is or will be stopped or controlled and advise the well owner (and the land owner, if applicable) of the steps taken to do so. It is also good practice to advise of any potential hazards associated with uncontrolled flow not being controlled (e.g., erosion, flooding, subsidence) and any associated costs. Agreement on these issues, prior to drilling can help prevent or minimize misunderstandings. For example, some issues can be addressed in a contract. If the qualified well driller or qualified professional fails to stop or control the flow, it is the well owner's responsibility to hire another qualified professional or qualified well driller to ensure that the flow is stopped or controlled. If the ownership of the well is not known, the land owner is responsible to have this done. If the flow cannot be controlled, the person responsible for drilling the well should advise the Ministry of Environment's regional hydrogeologist and must comply with any direction given.

A flowing artesian well must have a securely attached cap to provide access to the well, prevent entry of vermin and contaminants, and to prevent flow escaping from the well.

What does it mean to "control" artesian flow from a well?

A flowing artesian well is considered "under control" when the entire flow is through the production casing to the wellhead and the flow can be stopped indefinitely without leaking on the surface of the ground and with no leakage into any other aquifer penetrated by the well.

Will a flowing artesian well dry up if the flow is stopped or controlled?

Controlling the flow from a flowing artesian well should not stop the flow or dry up the well if the well has been properly constructed. In fact, the opposite is true as waste of artesian water will often eventually cause a decrease in artesian pressure. Controlling the flow from a flowing artesian well prevents unnecessary loss of groundwater from the aquifer upon which other wells rely.

Are there any water quality concerns with flowing artesian wells?

In general, the water quality of flowing artesian wells is excellent. However, some artesian waters may be very poor quality and cause serious damage on the surface or contaminate an overlaying aquifer. In general, water quality can be affected by the depth of the well, i.e., a deeper flowing artesian well may have poorer water quality than a shallower flowing well. Water from bedrock formations, such as deep sandstone formations, may contain concentrations of arsenic that could pose a health concern. Artesian wells with poor quality water should be permanently closed (see page 8).

Are there any other concerns with flowing artesian wells?

Most of the problems associated with flowing artesian wells result from improper discharge controls or improper well construction.

Casing corrosion (see Figure 5) and leakage can occur due to the constant flow of water, particularly if the water is corrosive

Figure 5. Corroded well casing.

or contains fine sand. Where artesian water is known to be corrosive, a smaller diameter flow pipe may be installed in the well. The pipe may be made of corrosion-resistant material or may be periodically replaced when it becomes corroded. Where the casing has been damaged, a slightly smaller diameter casing can be installed inside the old casing using packers if there is an existing surface seal and sealed in place with a cement grout. It is recommended to have the flowing artesian well checked periodically by a qualified well driller to verify the integrity of the well casing and to inspect the well screen, as the well can be difficult to repair once the casing has been corroded or breached. Thin-wall casing should not be used in flowing artesian wells.

Failure of the casing/surface seal during construction or decades after well completion can be costly and may result in the eruption of large volumes of silt, sand, clay or gravel, causing unstable conditions and potential flooding, damage to nearby structures through erosion and subsidence and harm to the habitat of aquatic organisms.

Well screens for flowing artesian wells can yield water with sand or become plugged with sand if the well is not properly developed. This is an issue when a flowing artesian well in a fine-grained aquifer is shut off and the sand settles and clogs the area in and around the bottom of the casing. The screen size should be coarse enough to prevent pressure build-up in the aquifer and the well should be properly developed. Perforated casings for flowing artesian wells are not recommended. In some areas an unpleasant rotten egg smell (hydrogen sulphide gas) may be present and by reducing or stopping the artesian flow the smell can be brought under control.

What can be done with an existing flowing well?

Trying to stop or control the flow from older flowing wells may result in an uncontrolled discharge of water outside the well casing or at a distance from the well due to the lack of an adequate seal, a defective surface seal or corroded casings. If water does not appear to be flowing outside of the outer casing, then it may be advisable to leave the well alone and not restrict the flow. However, if water appears to be flowing outside the casing and/or the well is causing property or environmental damage, then the well should likely be closed. Alternatively, it may be possible to lower the water levels using a pump but care must be taken to keep the water flowing from the well relatively continuously to avoid additional uncontrolled discharge from occurring.

There are numerous special measures that may be applicable to controlling the flow of an existing flowing artesian well such as using well packers or a bridge to restrict the flow in the confining layer, adding polymers or plasticizers to keep the grout together during placement, using barite to reduce the confining pressure of the water, etc.

Any alteration to an existing flowing well to control the flow needs to be done in compliance with the *Water Act* and Ground Water Protection Regulation and any directions of a Ministry of Environment hydrogeologist. A qualified well driller or qualified professional must be hired. Before any work is done, the well owner should be made aware of the costs and complexities of the work involved with controlling the flowing artesian well, as well as the chances of successfully controlling the flow.

What if the flow is needed, for example, to increase the baseflow of a creek or stream?

In some instances, artesian flow is used to maintain water levels in ponds used for irrigation, fire protection, fish rearing, recreation or wetland enhancement. For existing wells, flow is permissible as long as property is not damaged and streams or aquatic habitats are not negatively impacted. If damage does or may occur, contact the local Ministry of Environment office (see back cover of this booklet).

Are there some general guidelines for constructing a flowing artesian well?

In constructing a well under flowing artesian conditions the potential pressure and flow and the permeability of the formation need to be taken into consideration. A pre-drilling assessment of local conditions may provide this information. If these conditions are known, the following provides general guidance for the design and construction of the well. If this information is not known the well should be designed conservatively for worse case conditions. Flowing artesian wells should not be constructed if the formation conditions are not favourable, i.e., in shallower situations where there is no suitable formation to seal into.

Green Zone (<5 psi)

If the pressure is or will be less than 5 psi (pounds per square inch), flow can usually be controlled by adding additional casing, except where permeability of the formation is extremely high, e.g., medium to coarse gravel. To determine the artesian head use the following conversion factors: 2.31 feet equals 1 psi, and one foot equals 0.3048 meters. For example, for a flowing well with 5 psi, there will be 11.6 ft or 3.5 meters of artesian head, therefore the casing would need to be extended more than 3.5 meters above the ground surface to contain all the artesian head. In general, a 30 per cent bentonite grout can be used for flowing well construction or repair.

Artesian head is the hydraulic pressure created within the confined aquifer that drives the water upward in a well to the piezometric level. The distance from the ground surface to the piezometric level, converted into equivalent pressure (expressed as pounds per square inch, or PSI), is the artesian head.

Yellow Zone (5 to 10 psi)

If the pressure is or will be between 5 and 10 psi, extending the well casing may reduce flow, but extreme care must be taken in highly permeable formations that produce significant volumes of water. Flows of 20 USgpm can potentially occur in this zone and the upward annular velocity resulting from this flow is high enough to begin separating grout mixtures as they are being pumped down. When the pressure is high and the formation highly permeable, it is recommended that an outer surface casing be installed before the permanent casing. The outer casing should end in the confining layer and should not penetrate the underlying artesian aquifer. Cement-type grout should be used.

Red Zone (>10 psi)

If the pressure is or will be greater than 10 psi, static head control or extending the well casing is not usually possible, especially in highly permeable, high-yielding formations. In this category the flow is great enough to make the grout placement very difficult. An outer casing or multiple casings should be installed before the production casing and set to the confining layer so the production casing can be cemented within the outer casing. Cement or cement plus barite (or other weighting additives) should be used as grouting materials.

What are the key issues to be aware of when drilling a flowing artesian well?

Flowing artesian wells under high pressure and with high flow rates (yellow and red zones) are challenging to construct. Flowing wells that are drilled deep (≥200 feet or ≥60 meters) in unconsolidated deposits or drilled into bedrock are less prone to flow problems and are generally easier to deal with. In bedrock environments (see page 7 for more information on bedrock wells), the competent rock allows for easier installation of the seal (i.e., no casing to wash out or concerns about an eroded annulus).

Drilling a well into a confined aquifer disturbs the overlying geologic confining layer and provides a potential pathway for the upward movement of the pressurized artesian water. Well construction must include restoring any damage to the confining layer. In general, the closer the top of the artesian formation is to the ground surface and the higher the pressure, the more difficult it is to control the flow.

In certain conditions (e.g., soft clay/silt formations), the formation will squeeze back in and set up around the well casing over a period of time. If this condition is likely to occur, it is advisable to let the well flow for a week or two to give the formation a chance to settle in before stopping or controlling the flow. This will result in a seal around the casing at deeper depths than the surface seal.

It is good practice for the qualified well driller to observe the condition of the flowing artesian well head for one or two weeks after construction and check for leakages outside the surface casing or between casings.

Materials and Equipment

One of the key factors to successfully controlling the flow is being prepared with the right tools and materials at the job site. Suggested materials and equipment include:

- drilling mud and additives of sufficient weight to deal with the pressures in the aquifer,
- surface and production casing appropriate to the water quality and geological conditions,
- grouting and sealing materials appropriate to the artesian pressure and anticipated flow,
- tremmie pipes,
- pumps suitable for delivering the grouting and sealing materials,
- well screens with adequate transmitting capacity,
- valves,
- inflatable packers,
- surge block, and
- shale traps.

Drilling Muds

To determine the extra weight of drilling mud needed to counteract the pressures of the artesian aquifer during rotary drilling, the estimated artesian head and the depth to the top of the aquifer is needed. The following formula can be used to estimate the additional weight of drilling mud needed to control the flow during the drilling process:

$$\text{Additional mud weight} = \left(\frac{8.34\ \text{lbs/USgal} \times \text{height of water above ground level (ft)}}{\text{Depth to top of aquifer (ft)}}\right) + 0.4\ \text{lbs/USgal}$$

Where:
One USgallon of water weighs 8.34 pounds
0.4 lbs/USgallon is a safety factor

Example

If the depth to the top of the aquifer is 75 feet and the height of water above ground is estimated to be 10 feet, the additional weight of drilling mud needed would be (8.34 x 10/75) + 0.4 = 1.5 lbs/USgal.

Properly mixed, fresh drilling mud will normally weigh about 9 pounds per US gallon. Drilling mud can be made heavier by adding drilling clay, drilling gel and special solids such as barite. However, some drilling gels are treated with polymers to build viscosity and become difficult to pump before their weight significantly increases. Therefore, some drilling gels have limited ability for control of flows. Mud weights of up to 15 pounds per gallon can be achieved using weighting materials such as powdered barite.

Well Casings

Generally, in areas where flowing artesian conditions are known or suspected, at least one outer surface casing should be installed before installing the permanent/production casing or liner to allow for better control. It is not advisable to pull the surface casing within 20 feet (6 meters) of ground surface. Doing so may disturb the seals and cause water to flow around the surface casing as it is pulled, especially if bentonite is used. There should be at least a 4-inch (10 cm) gap or annulus between the outer surface casing and the production casing to allow for the insertion of a tremmie pipe to pump adequate grout volumes For example, if a 6-inch production casing is needed, a 14-inch outer surface casing would have to be installed to provide a 4-inch annulus.

In areas where the pressure is > 5 psi and the formation is highly permeable, a 4 to 6-inch (10 to 15 cm) annulus between the surface and permanent casing is recommended. Ensuring there is an adequate annulus is especially important where formations are highly permeable and high-density grout mixtures are required to adequately control the artesian flow.

Grouting Mixtures

Use of appropriate grouting material is key to constructing a flowing artesian well. Table 1 is useful for finding the hydrostatic head pressure (in psi) and for understanding the relationship between drilling fluid or grout density and their ability to successfully control the flow during drilling, plugging, or repair. Table 1 shows that heavy grouts, such as neat cement/bentonite slurry or cement slurry with additives, have a distinct advantage for flowing well work. Mixing neat cement with bentonite is recommended to avoid cracks from occurring.

It is important to allow for sufficient time for the cement or cement grout mixture to set before proceeding with drilling. Use of the appropriate drilling method to minimize impacting the integrity of the seal is also important. In addition, the flowing artesian well should be gradually sealed or shut-in to prevent rupturing the seal(s).

TABLE 1
TOTAL PRESSURE ABOVE TOP OF CONFINED AQUIFER (HYDROSTATIC PRESSURE) FOR FLOWING ARTESIAN WELLS

Depth to Top of Flowing Aquifer (feet)	Artesian Head Above Ground Surface (feet)					
	5	10	15	20	25	30
10	6.5	8.7	10.8	13.0	15.2	17.3
20	10.8	13.0	15.2	17.3	19.5	21.7
30	15.2	17.3	19.5	21.7	23.8	26.0
40	19.5	21.6	23.8	26.0	28.1	30.3
50	23.8	26.0	28.1	30.3	32.5	34.6
75	34.6	36.8	39.0	41.1	43.3	45.5
100	45.5	47.6	50.0	52.0	54.1	56.3
125	56.3	58.4	60.6	62.8	65.0	67.1
150	67.1	69.3	71.4	73.6	75.8	78.0
175	78.0	80.1	82.3	84.4	86.6	88.7
200	88.7	91.0	93.1	95.2	97.4	99.6
225	99.6	101.7	104.0	106.0	108.2	110.4
250	110.4	112.5	115.7	117.0	119.0	121.2

Adapted from the Michigan Department of Environmental Quality, Water Bureau, Lansing, Michigan

Material	Weight	Hydrostatic Pressure
Barite Slurry:	18 - 22 lb/USgal	.96 - 1.1 psi/ft
Neat Cement and Bentonite @ 6 gal water/sack:	15.0 lb/USgal	.78 psi/ft
Bentonite Slurry Grout:	10.4 lb/USgal	.54 psi/ft
Bentonite Slurry Grout:	9.5 lb/USgal	.49 psi/ft

GROUTING MATERIAL SUITABILITY

	Heavy Enough To Overcome Hydrostatic Pressure	Not Heavy Enough To Overcome Hydrostatic Pressure
(dark shading)	Neat Cement @ 15 lb/USgal	All Bentonite Grouts
(light shading)	Neat Cement @ 15 lb/USgal or Bentonite Grout @ 10.4 lb/USgal	Bentonite Grouts lighter than 10.4 lb/USgal
(no shading)	All standard grouts have enough weight to overcome hydrostatic pressure of the flow.	

The values in Table 1 correspond to the downhole head pressure (in psi) for different scenarios, e.g., if the depth to the top of the aquifer was 10 feet and the artesian head was 5 feet, the downhole head pressure will be 15 feet or 6.5 psi. To overcome the flow, the downhole grout pressure must be greater than the downhole head pressure.

The following example illustrates how Table 1 can be used to select drilling fluids or grout that are heavy enough to control the flow during drilling.

Example of how to use Table 1

Q. *The top of an artesian aquifer is found at 50 feet and wells in the area have about 15 feet of artesian head. What minimum weight drilling fluid would be needed to overcome the hydrostatic pressure during drilling?*

A. The following steps are used to solve the problem:

Step A: To determine the downhole hydrostatic head pressure look at **Table 1** and find the cell corresponding to depth of top of aquifer (50 ft) and artesian head (15 ft) which is 28.1 psi. This pressure represents the total head above the top of the confined aquifer (e.g., 15 + 50 = 65 ft or 28.1 psi).

Step B: Divide the downhole hydrostatic pressure (28.1 psi) by the depth to the top of the aquifer (50 ft) to determine the downhole grout pressure needed to equalize the flow (28.1 psi/50 ft = 0.56 psi/ft).

Step C: To determine the grout weight divide the downward pressure of the grout (0.56 psi/ft) by 0.052 (a factor to convert lb/USgal to psi/ft of depth). The minimum grout weight needed to control the flow is 10.8 lb/USgal.

Are there specific actions to avoid when flowing artesian conditions are present?

When a large volume, high pressure flow breaks out, the immediate situation can be serious and there is usually a concern to quickly move the drilling rig away from the borehole. Hastily made decisions can get in the way of successful future corrective actions. As up-flowing artesian water typically will erode fine sediments around a solid object that has been placed loosely below ground, the following actions should be avoided:

- dumping field stone or gravel into the annulus around the well casing as this can prevent the installation of grout pipes or a larger casing into the borehole and can collapse PVC well casing;
- pouring ready-mix concrete or bentonite chips into the annulus as it is likely that the concrete or bentonite will solidify above the depth where the flow is originating and

result in a plug that causes the flow to wash out around its perimeter; or

- jamming unopened bags of cement, bentonite chips, lumber, cardboard or other debris into the washed out annulus as these materials are ineffective and complicate further corrective action.

How can flowing artesian wells be constructed in bedrock aquifers?

When constructing an artesian well that is likely to flow in a **bedrock aquifer**, the final or outer well casing should be sealed at least 10 feet (0.3 meters) into competent bedrock. Figure 6 shows one possible method of completing a flowing artesian well in bedrock. Construction techniques and choice of sealant materials need to be determined by the qualified well driller based on site specific conditions, e.g., pressure and flow.

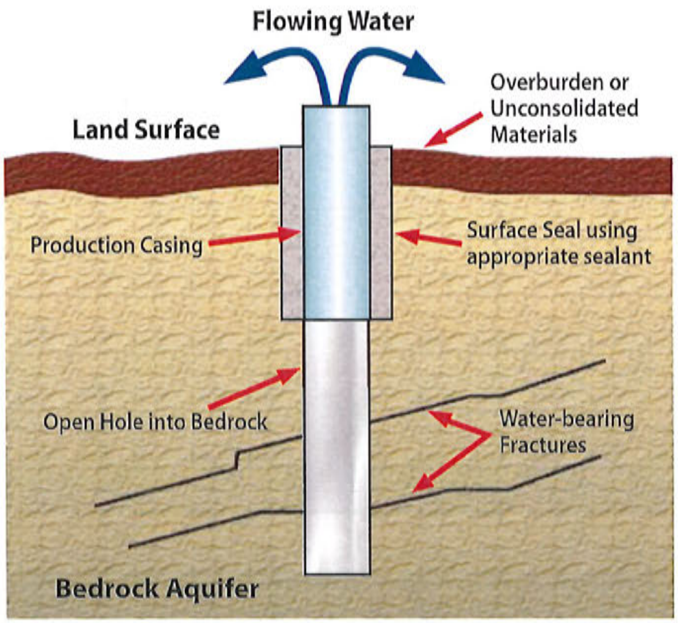


Figure 6. One possible method of completing a flowing artesian well in a bedrock aquifer.

How can flowing artesian wells be constructed in unconsolidated aquifers?

For **confined, unconsolidated aquifers** where flowing artesian conditions are likely, a cased oversized hole should be drilled into the confining layer, to allow a cement, or high solids bentonite seal to be placed between the final production casing and the outer casing (see Figure 7). This can be very complicated and expensive if the pre-drilling assessment indicates the confining layers are more than 100 ft (30 metres) deep. The size of the hole or casings and the depth of the seal must be determined on a site-by-site basis since choices are influenced by local geology and the specific artesian conditions encountered. A careful, conservative approach is recommended.

Figure 7. Bentonite cement grout seal between casings.

When constructing a well into a confined, unconsolidated flowing artesian aquifer, the appropriate sealant material between the outermost well casing and the confining layer must be of a sufficient depth and thickness to contain the flow.

Artesian conditions in **unconfined, unconsolidated aquifers** require special construction techniques such as using heavier drilling mud to counteract the pressure of the aquifer and a temporary surface casing to prevent hole collapse.

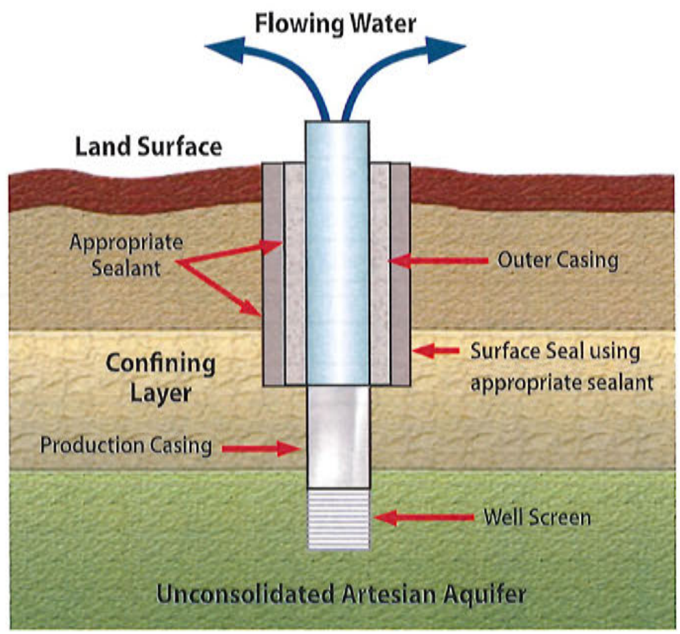


Figure 8. One possible method of completing a flowing artesian well in unconsolidated materials, e.g., sand and gravels.

What should be done if flowing artesian conditions are suddenly encountered?

When unexpected flowing artesian conditions are encountered (i.e., instant flow occurs), a qualified professional, or qualified well driller, should take control of the site and equipment should not be removed from the site until the artesian flow is under control. Contact the owner of the well and the land owner immediately to report the situation and provide plans to control the flow (see below). Steps to take include:

- control the flow,
- secure the casing or borehole, and
- protect the drill rig.

The flow may be brought under control by:

- increasing the weight of the drilling mud,
- using plugs,
- using a surge-blocking to restrict flow, or
- installing a drillable packer.

The drill pipes can be left in place in cases where the uncontrolled flow occurs in an uncased drill hole, to indicate the exact location of the hole.

If the flowing artesian well is discharging water into a wetland or surface water body, contact the local Ministry of Environment office.

It is important for the well owner (and land owner if applicable) to develop a clear understanding, potentially in the form of a contract, with the drilling contractor on how the well will be repaired and/or the flow stopped or controlled before any work on the well commences to avoid or minimize potential misunderstandings when artesian flow is encountered.

What are the key factors in completing and equipping a flowing artesian well?

Flowing artesian wells, when properly constructed, should be equipped with a device to completely stop or control the artesian flow from the well (see Figure 9). After flow is stopped, there should be no leakage up the annulus between the outermost casing and the borehole. If water does escape, the annulus should be sealed.

Figure 9. Completed high pressure flowing artesian well.

Flowing artesian wells, like all wells, need to be vented. Well caps should be equipped with a two-way vent that allows the well to inhale and exhale air as the water level changes during pumping cycles. The vent will seal the well when the pump is not in use.

Determine the shut-in pressure (see below) and record the measurement on the well construction report. The wellhead should also be designed and equipped to prevent any backflow into the well.

Where freezing conditions may occur, the wellhead of the new flowing artesian well should be covered, insulated and heated, where necessary, to prevent damage of the flow control device leading to an uncontrolled flow situation.

How is the pressure or static water level for a flowing artesian well measured?

It is important to determine and record the hydrostatic pressure of the flowing artesian well for future pre-drilling assessments. There are several ways to measure the hydrostatic pressure or static water level of a flowing artesian well:

1. Extend the well casing, or a smaller diameter pipe through a well seal on the top of the casing, high enough above the ground surface until water no longer flows out the top (without pumping). The water level in the casing extension can then be measured using a water-level sounder. The distance from the piezometric water level in the casing to the ground surface is the artesian head of the aquifer – this can be converted to pressure.

   2.31 feet equals 1 psi or
   0.433 psi equals 1 foot

Example

A static water level of 30 feet is converted to pressure by dividing 30 feet by 2.31 feet/psi = 13 psi.

2. A pressure gauge installed on a well seal at the top of the casing will provide the pressure reading which can be multiplied by 2.31 to find the artesian head at the gauge elevation.

How should flowing artesian wells be closed?

A qualified well driller and/or qualified professional should be hired to close a flowing artesian well and ensure that the well is closed in such a manner that there is no leakage at the surface of the ground (see Figure 10). The driller must be prepared to handle the flow from the well and the discharge of any plugging materials immediately on removal of the flow control device(s). The work site can be dangerous if the flow is not properly diverted. Closing a flowing artesian well is simplified if the flow can be overcome by extending the well casing above the artesian head. Alternatively, insert an inflatable packer or expandable rubber plug at the bottom of the casing. Physically stopping the flow may make things worse, however, which is why the rapid loading of drilling gel is often a better approach.

Another effective approach is lowering the water level by pumping from adjacent wells. A leaking annulus should be sealed (if possible) before proceeding with grouting the production casing.

Pump a high density grout such as neat cement or concrete grout with bentonite through a PVC pipe or drill rod which is lowered to the bottom of the well. The cement mixture is pumped until it reaches the land surface. Pressure grouting with a packer may be required. It may also be good to pull or perforate some of the casing to allow the grout to flow from the casing into the annulus, although this is not critical if the casing is already perforated or corroded.

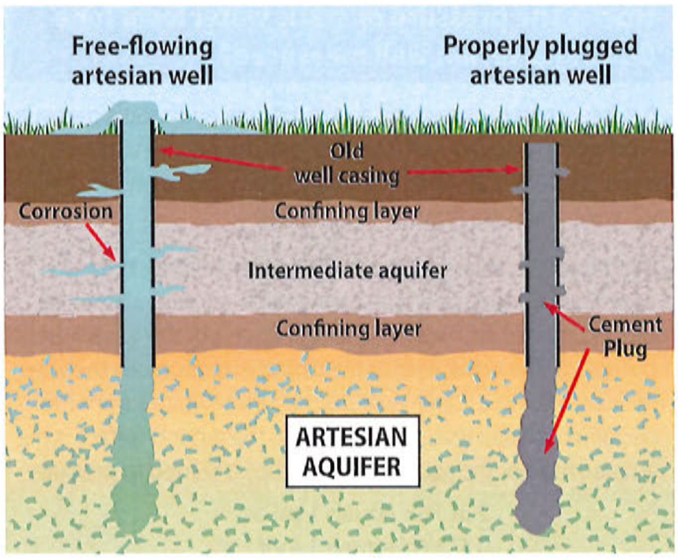


Figure 10. Example of a properly closed flowing artesian well.

How is a flowing artesian well disinfected?

Because of the protected nature of the confined artesian aquifer, flowing wells are generally less prone to bacterial contamination. Furthermore, the positive artesian pressure can minimize entry of surface contaminants into the well. Contamination introduced during the drilling process may be flushed out by the continuous discharge of water.

To disinfect a flowing well using chlorine, a temporary casing extension above the piezometric level or a tight well cap or seal can stop the flow and increase the chlorine contact time. A chlorine solution can also be pumped into the well via the secure well cap and hose connections. Once the casing extension or cap is removed, the well discharge will flush residual chlorine and inactivated bacteria from the well.

If the chlorinated water has a potential to harm the environment (e.g., fish), use an effective neutralizing agent, such as Vitamin C, to inactivate the chlorine. A solution of at least 1 per cent (by weight) of ascorbic acid is the most cost-effective form of Vitamin C. Added to the sump or a stream of chlorinated water, reaction time is nearly instantaneous.

Further Information

A registry of qualified well drillers can be found at: http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/wells/applications/well_drillers_reg.pdf.

A listing of groundwater consultants (qualified professionals) can be found at: http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/library/consultants.html.

Michigan Department of Environmental Quality, 2005. Flowing well handbook: http://www.michigan.gov/documents/deq/deq-wb-dwehs-wcu-flowwellhandbook_221323_7.pdf.

For further information on whether approvals are needed for discharging flowing artesian well water to surface water bodies, contact the local Ministry of Environment office:

Vancouver Island Region	Nanaimo	250-751-3100
Lower Mainland Region	Surrey	604-582-5200
Thompson and Cariboo Regions	Kamloops	250-371-6200
Kootenay and Okanagan Regions	Nelson	250-354-6333
	Penticton	250-490-8200
Omineca Peace and Skeena Regions	Prince George	250-565-6135

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Photos by Jim Fyfe, David Martin, Mike Simpson, Peter Epp & Thierry Carriou.
ISBN 978-0-7726-7034-2

Mini Sonic Drill Rig

Environmental | Geotechnical | Exploration

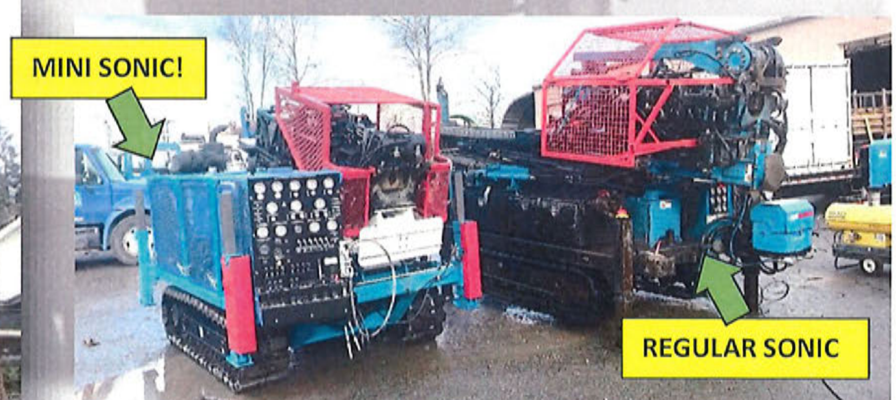
BLUE MAX DRILLING

This is a full service sonic drill rig in a small package. This drill is equipped with a Boart Longyear 33K drill head on a compact frame. The most distinguishable feature of this drill rig is its 12.5ft high mast height. This drill rig can access areas no other sonic drill rig can. Don't let the mast height fool you since this drill rig still has the capabilities to drill over 200ft (60m) in tough conditions. With a safety cage, SPT hammer and automatic rod loader, this drill is built for any environmental, geotechnical or exploration investigation program.

TRACK Rig Specs	Imperial	Metric
Height, Mast Up	12.5'	3.81m
Height, Mast Down	9'	2.7m
Length, Mast Up	15'	4.6m
Length, Mast Down	15'	4.6m
Width	8'	2.4m
Weight	18,000 lbs	7,700 kg

TRACK Drill Depths	Imperial	Metric
Sonic, (Overburden)	200'	60m
Coring, HQ (Rock)	300'+	100m+

TRACK Additional Features
Automatic Rod Loader
Engineered Safety Drill Cage
Remote controlled
Rock coring head attachment (NQ, HQ)
Angle drilling capable
SPT Auto Hammer
CPT capable
Aggressive rubber track design
Compact unit with full sonic capabilities



Locations

Surrey, BC (Head Office)
Chilliwack, BC
Vancouver Island, BC
Terrace, BC

www.bluemaxdrilling.com
(778) 237-BLUE (2583)

BLUE MAX DRILLING INC.

Schedule "F" – Subsurface Exploration

Table 1

Subsurface Investigation Summary

Project: Proposed Development at 835 Gibsons Way **DATE:** August 11, 2022 **Completed by:** Horizon Engineering

A	*Number (Test Pit, Well, borehole, etc...)*	TH22-1	TH22-2	TH22-3
B	*Subsurface Disturbance Type (from Table 2)*	Borehole/Piezometer	Borehole	Borehole/Piezometer
C	*Method of exploration (from Table 3)*	Other-Sonic with Casing	Other-Sonic with Casing	Other-Sonic with Casing
D	*Northing (m)*	See attached plan for approximate location	See attached plan for approximate location	See attached plan for approximate location
E	*Easting (m)*			
F	*Ground Elevation (m amsl)*	~ 121.5	~ 119.5	~ 119
G	*Proposed testing depth below ground (m)*	~ 9	~ 9	~ 9
H	*Previously Encountered Depth to top of Gibsons Aquitard (ie: Till-Like Soil (m))*	Not available	Not available	Not available
I	*Previously Encountered Depth to top of Gibsons Aquifer (ie: Sand and gravel with Artesian flow (m))*	Not available (expected to be greater than 50 m based on the information from the Town of Gibsons)	Not available (expected to be greater than 50 m based on the information from the Town of Gibsons)	Not available (expected to be greater than 50 m based on the information from the Town of Gibsons)
J	*Distance of existing subsurface information to proposed new intrusive work (m)*	Not available	Not available	Not available
K	*Report Reference for previous work to support new proposed work (Copies of original logs/records should be attached)*	Not available	Not available	Not available
L	*Estimated depth offset to top of Gibson Aquitard Row H minus Row I (m, + if above and - if below)*	Not available	Not available	Not available
M	*Estimated depth offset to top of Gibson Aquifer Row L minus Row G (m, + if above and - if below)*	Expected to be greater than 41 m based on the information from the Town of Gibsons	Expected to be greater than 41 m based on the information from the Town of Gibsons	Expected to be greater than 41 m based on the information from the Town of Gibsons
N	*Comment on uncertainty and potential risk to aquifer*	Aquifer is expected to be at depths of greater than 50 m below the site grades, based on the information from the Town of Gibsons. Therefore, low risk.	Aquifer is expected to be at depths of greater than 50 m below the site grades, based on the information from the Town of Gibsons. Therefore, low risk.	Aquifer is expected to be at depths of greater than 50 m below the site grades, based on the information from the Town of Gibsons. Therefore, low risk.
O	*Describe Aquifer Protection measures to be implemented*	Section 4.3.6 of our Proposed Driling Program (Attached)	Section 4.3.6 of our Proposed Driling Program (Attached)	Section 4.3.6 of our Proposed Driling Program (Attached)

Approximate location of test hole

TRC Construction Managers	Proposed Test Hole Location Plan	HORIZON ENGINEERING INC				
Proposed Development at 835 Gibsons Way, Gibsons, BC		Scale: NTS	Job No: ---		Date: 10-Aug-22	Figure: 1
		Des: NT	Dwn: NT	Chk: KK	Rev: 0	