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June 12, 2015

Our File: 112-3155

TOWN OF GIBSONS
474 South Fletcher Road
Gibsons, BC V0N 1V0

Attn: Dave Newman

Re: Proposed "The George" Mixed Use Development
377, 385 & 407 Gower Point Road, 397 & 689 Winn Road, and Winn Road Right-of-Way, Gibsons, BC
Memorandum Regarding Hydrogeological Review Report

1.0 INTRODUCTION

Horizon Engineering published a Geotechnical Investigation Report (Revised) for the aforementioned development on April 7, 2015. Subsequently, this report was reviewed by Levelton Consultants Ltd. and Waterline Resources Inc. on behalf of the Town of Gibsons. The resulting review reports are referenced as follows:

- "Gibsons Aquifer Review of Geotechnical Investigation Report (Revised) for the Proposed "The George" Mixed Use Development at 377m 385 & 407 Gower Point Road, 397 & 689 Winn Road, and Winn Road Right-of-Way, Gibsons, BC", by Waterline Resources Inc., dated May 4, 2015
- "Geotechnical Review - Horizon Engineering Inc. Geotechnical Investigation Report - 07 April 2015 - Proposed "The George" Mixed Use Development, Gibsons, BC", by Levelton Consultants Ltd., dated May 7, 2015.

Our comments regarding the aforementioned Levelton review report have been prepared under separate cover. The following sections contain our comments and brief discussions in response to the aforementioned Waterline review report. It is recommended that our responses to the Levelton and Waterline reports be distributed to both companies because some discussions are relevant to both reviews. The referenced section numbers pertain to the aforementioned Horizon report dated April 7, 2015.

It should be emphasized that the role of the reviewing parties was "to provide a level of professional due diligence" rather than endorse the technical recommendations provided in our report. As such, and under the existing contractual arrangements, we do not expect that Waterline (nor Levelton) are expected nor required to claim responsibility for the hydrogeological and geotechnical aspects of this project.

2.0 WATERLINE'S REVIEW REPORT

Section 2.1 - Review Comments on Part A and Appendix B of Horizon's Report

"Collar Elevation" is the elevation of the grade (i.e., ground or seabed) adjacent to a borehole.

As observed by the peer reviewers and recorded in the December 2014 to January 2015 transducer measurements, the water levels in the monitoring wells at the subject site are influenced by tidal fluctuations, and a single measurement does not necessarily indicate average water levels at a location. The water levels shown on the cross-sections are for illustrative purposes. As discussed below in this response letter and attached appendix, the measured water levels were adjusted upward in wells that did not have a one month period of pressure measurements. It should be noted that even with this upward adjustment in water level, all of the seepage analyses overestimate head at BH14-3; the degree of over-prediction in head is higher for the deformation model used to evaluate safe excavation elevation than for the seepage analyses presented below.

Section 2.2 - Review Comments on Part B of Horizon's Report

As discussed later in this letter, the seepage analysis upon which the deformation analysis is used is highly conservative. Additional 'seepage only' simulations and a seepage sensitivity analysis have been completed and are discussed below.

Section 2.2 - Review Comments on Sections 8.2 and 8.3, Bullet #1

The two-dimensional deformation analysis presented in Horizon's report was designed using conservative assumptions for soil hydraulic properties in order to not underestimate pore pressures and potential ground deformation during construction. The parameters discussed in the report were selected to be within accepted ranges for the soil types while ensuring that the pressures predicted for the Gibsons Aquifer were not underestimated. In other words, a combination of high Gibsons Aquifer hydraulic conductivity and low till hydraulic conductivity was selected. In responding to Waterline's review comments, the seepage model created for the deformation analysis has been re-run and re-analyzed in the interest of better understanding the groundwater flow processes in support of their aquifer management program. A description of this additional analysis is presented in Appendix 1 of this document.

The primary conclusion of the additional seepage analysis completed for this project is that the parameters used in the deformation analysis are highly conservative. The most effective way to simulate the observed head reduction in the monitoring wells on the subject site in a manner consistent with the groundwater discharge estimates of Doyle (2013) is to reduce the simulated value of the Gibsons Aquifer hydraulic conductivity. The field investigations completed by Horizon and earlier data obtained by others in this area show that the hydraulic head between Town Well #1 and nearby BH14-4 drops as one approaches Howe Sound. The rate at which the head in the Gibsons Aquifer drops between BH14-4 and the foreshore is greater than would be predicted with a highly permeable Gibsons Aquifer and an intact confining layer above it all the way through the foreshore. The data and seepage modelling point to an aquifer configuration in the foreshore characterized by a less permeable Gibsons Aquifer down-gradient of BH14-4. In addition, recent field investigations completed by Horizon illustrate the discontinuous nature of the lowerpermeability Gibsons Aquitard material in the subject area (see Appendix 2, attached).

The two-dimensional seepage analysis in Appendix 1 concludes that in the site area, a Gibsons Aquifer hydraulic conductivity of less than $5x10^{-5}$ m/s is required to simulate seepage to Howe Sound on the order of that predicted by Doyle (2013).

<u>Section 2.2 - Review Comments on Sections 8.2 and 8.3, Bullet #2</u>

As discussed in Appendix 1, setting the hydraulic conductivity of both the low-permeability Gibsons Aquitard materials (i.e, land-based "Silty Sand to Sandy Silt to Silt" and "Till-Like Silty Sand") to $2x10^{-6}$ m/s from the base case value of $5x10^{-8}$ m/s, as requested by the reviewers, reduces the predicted heads in the project area within the Gibsons Aquifer and slightly reduces the predicted steady state groundwater discharge to the ocean. In other words, between Town Well #1 and the ocean, the hydraulic conductivity of the Gibsons Aquitard plays a minor role in predictions of hydraulic head in the Gibsons Aquifer and groundwater discharge rates to the ocean.

<u>Section 2.2 - Review Comments on Sections 8.2 and 8.3, Bullet #3</u>

The hydraulic conductivity of the units above the bottom two low-permeability Gibsons Aquitard materials do not noticeably change the predicted head within the Gibsons Aquifer, nor the predicted groundwater discharge to the ocean. The materials above the low-permeability Gibsons Aquitard material include the Fill, Sand, and Peat. These materials are, for the most part, "placeholder materials" that are included for the sake of completeness. They function as part of an essentially separate perched aquifer system and do not affect the results within the Gibsons Aquifer. Because it could not be definitively verified that they form part of the Capilano Aquifer of Doyle (2013), the sand and peat have been included in the grouping "Inferred Gibsons Aquitard" in Horizon's report. In the seepage and deformation analyses, on the other hand, they were assigned hydraulic conductivities that are consistent with their material properties. In the remainder of this response letter, the term *Gibsons Low-K Aquitard* comprises the "Till-Like Silty Sand" and the land-based "Silty Sand to Sandy Silt to Silt"; the sand and peat above these two units, both of which are included as part of the Gibsons Aquitard in the report are not considered part of the Low-K Gibsons Aquitard in this response.

The "Till-Like Silty Sand" and the "Silty Sand to Sandy Silt to Silt" are easily distinguishable from each other in boring logs and have different density and strength characteristics. To maximize flexibility in the modelling, these two materials that comprise the Low-K Gibsons Aquitard were assigned different material zones in the seepage analysis. In the end, for the sake of simplicity, they were assigned the same hydraulic conductivity in the seepage analysis (Appendix 1), as there is no field hydrogeologic information with which to calibrate different hydraulic conductivities. In the deformation analysis, the clear difference in strength parameters for these two units required that they be treated separately.

In the seepage analysis and the deformation analysis, the "Silty Sand to Sandy Silt to Silt" was separated into two subgroups: one that was present above the high water mark and the other present under the ocean. These two sub-areas were introduced in order to have the flexibility to assign different parameters to the two groups if required. This decision makes it possible, for instance, to complete the simulation requested by the reviewers in Bullet 2 above without changing the silty sand hydraulic conductivity in the foreshore. The reason this is important is that, while the silty sand on top of the till-like material plays a truly minor role in the predicted heads in the Gibsons Aquifer and groundwater discharge rates to the ocean, the seabed silty sand, located as it is at the groundwater discharge boundary, plays a large role in controlling both head and flux, and therefore can be varied over a much smaller range of hydraulic conductivity values in the two-dimensional seepage analysis than the silty sand above the till-like material.

Finally, field observations support a hypothesis that the loose, structure-less seabed sediments have different hydraulic parameters than the more coherent seabed silty sand beneath it. Therefore, the two seabed materials were treated separately in the seepage analysis and the sensitivity analysis.

Section 2.2 - Review Comments on Sections 8.2 and 8.3, Bullet #4

Appendix 1 presents simulations in which the western constant head boundary at Town Well #1 was raised from 14.9 m to 16 m and 18 m. The probable magnitude of this constant head boundary value is constrained by the observed heads in wells uphill of Town Well #1.

The uncertainty in the boundary condition at BH14-2 was not assessed because the magnitude of tidal fluctuations at this location could not be determined and because the magnitude of the boundary condition is not expected to play a large role in predictions of hydraulic head in the project site.

Section 2.2 - Review Comments on Sections 8.2 and 8.3, Bullet #5

The constant head boundary on the surface of the eastern portion of the model was specified to be 2.2 m, corresponding to the high water mark. At the down-gradient Gibsons Aquifer boundary, a constant head of 3.2 m was applied, as observed in BH14-2 after well installation.

Section 2.2 - Review Comments on Sections 8.2 and 8.3, Bullet #7

The discharge rate of groundwater to the ocean is estimated to be 1,790 m^3/d by the base case seepage model presented in Appendix 1, assuming the seepage section is representative of a 100m wide area along the foreshore. The groundwater model developed for the Gibsons Aquifer estimates groundwater discharges to Howe Sound at a rate of approximately 2,750 m^3/d over an area along the foreshore that is about 13 times longer than the strip of land modeled by the two-dimensional seepage model (see Doyle, 2013). As discussed in Appendix 1, the predicted seepage to the ocean can be reduced to be significantly closer to the groundwater discharge rate calculation of Doyle (2013) if the Gibsons Aquifer hydraulic conductivity is reduced from the value used in the existing three-dimensional groundwater model. Nevertheless, both the deformation analysis and the seepage analysis use conservatively high values of the Gibsons Aquifer hydraulic conductivity so as not to underestimate potential impacts to the water supply of the Town of Gibsons.

Section 2.2 - Review Comments on Sections 8.2 and 8.3, Bullet #8

The shape of the aquitard in three dimensions cannot be accurately resolved in a two-dimensional sectional model. At most, a two-dimensional model can simulate strips of aquitard parallel to the shoreline. As this is likely not the type of aquitard discontinuity of interest to the reviewers, we recommend that further analysis of aquitard shape be carried out with the Town of Gibsons' three-dimensional groundwater flow model.

With respect to the impact of Low-K Gibsons Aquitard properties on seepage predictions, sensitivity analyses on the seepage model show that the hydraulic conductivity of the Low-K Gibsons Aquitard on land does not significantly affect the heads in the Gibsons Aquifer nor the groundwater discharge rate to the ocean (see Appendix 1). For example, the sensitivity analysis discussed in Bullet 2 involved increasing the hydraulic conductivity of the Low-K Gibsons Aquitard by more than an order of magnitude, with limited impact on the predicted heads in the Gibsons Aquifer and the groundwater discharge rate to the ocean.

<u>Section 2.2 - Review Comments on Section 12 (Ground Improvement)</u>

The field investigations, seepage analysis, and review of previous studies of the Gibsons aquifer do not indicate a likelihood of adverse impacts on the Gibsons Aquifer from the project. The project will involve minor excavations of fill materials placed during historical construction activities. There will be *no excavation* of any of the native Low-K Gibsons Aquitard materials. On the foreshore, Appendix 1 presents a calculation of the impact on the hydraulic conductivity of the seabed aquitard if 200 pile-shaped "plugs" of *permeable sand*, rather than solid piles, are to be installed. This calculation anticipates an increase in hydraulic conductivity of the seabed aquitard of approximately 5 percent. Construction monitoring activities will be sufficient to ensure no adverse impact on the Gibsons Aquifer.

<u>Section 2.2 - Review Comments on Section 17.2 (Piles)</u>

Horizon's boring logs and the pressure monitoring of the Gibsons Aquifer both indicate that the aquifer is only partially confined in the project area (see Appendix 2). It is Horizon's opinion that a well-managed and monitored program of *driven* pile installation will not jeopardize the sustainability of the aquifer. The impact of the piles on the integrity of the seabed silty sand portion of the Gibsons Aquitard is predicted to be minimal. As discussed above, the impact on the seabed silty sand hydraulic conductivity of 200 additional piles on the foreshore, if every single pile crumbles to a sandy mass, is negligible.

<u>Section 2.2 - Review Comments on Section 17.3 (Dredging)</u>

For our response to this comment, please refer to other sections of the report and the seepage analysis results.

<u>Section 2.2 - Review Comments on Section 21.2 (Temporary Excavation)</u>

The conclusion made by Waterline that Horizon Engineering will not be present during construction is not correct. Horizon Engineering representatives will be present to supervise excavation procedures and installation of the shoring system. The statement provided in our report is typical and emphasizes the responsibility of the contractor in addition to the supervising body.

We have provided a concept of the excavation strategy in our report. A detailed excavation / shoring strategy and preparedness program will be included in the detailed design drawings, which will be prepared at the building permit stage.

3.0 CLOSURE

At this stage of the project and in order to provide geotechnical engineering recommendations for the proposed development, specifically addressing protection of the aquifer, Horizon Engineering demonstrated a high level of professional due diligence by conducting subsurface investigations, in-situ and laboratory testing, and engineering analyses. The engineers involved in this project were qualified for the type and complexity of the project, and we are confident that the recommendations provided are valid and can safely be implemented for the design and construction of the project. We also acknowledge that more rigorous engineering analysis will be required at the detailed design stage of the project and that revisions to our recommendations may be required depending on the outcome of the detailed design stage. Therefore, we confidently confirm that our field investigations are sufficiently detailed and our computational analyses are sufficiently conservative for this stage of the project. If our recommendations are implemented into the detailed design and construction phases of the project, the project will be safe for the intended use from a geotechnical point of view.

The hydrogeological data obtained during the investigations complement previous studies of the Gibsons Aquifer; both indicate that the confinement of the Gibsons Aquifer by the Gibsons Aquitard occurs primarily in the immediate vicinity of the Town Wells. In the project area, the composition and thickness (and hence integrity) of the aquitard is variable. The artesian heads at the Town Wells appear to be due more to their location near the groundwater discharge zone of a mountain-fed aquifer and the narrowing of the groundwater flow field in the project area than to the strength and integrity of the Gibsons Aquitard downhill of the Town Wells; the mountain recharge process and the narrowing of the flow field are well illustrated in the work of Doyle (2013). Taken together, these observations and computations lead to the conclusion that the project will not adversely impact the potential of the Gibsons Aquifer as a long-term, sustainable source of water supply to the Town of Gibsons.

I, Karim Karimzadegan, P.Eng., as the geotechnical engineer of record for this project, also emphasize that I am confident with the recommendations provided in our report. I have more than twenty-five years of experience in the field of geotechnical engineering and have been involved in the design and construction stage of more than one hundred projects with complexities comparable to the proposed development. Jean Cho, Ph.D., P.Eng., is a hydrogeologist with more than twenty years of experience in the field of hydrogeology and the numerical simulation of groundwater systems. Ms. Cho provided high-level technical assistance for the project to Horizon Engineering and performed as an internal reviewer for the groundwater modelling.

We trust that our comments and recommendations are both helpful and sufficient for your current purposes. If you would like further details or require clarification of the above, please do not hesitate to contact us.

For

HORIZON ENGINEERING INC

PROFESSIONAL PROVINCE OF K. KARIMZADEGAN #27156 BRITISH COLUMBIA ENGINEER

June 12, 2015

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

Principal

For

HORIZON ENGINEERING INC

PROFESSIONAL PROVINCE OF H.J. CHO BRITISH COLUMBIA ENGINEER

Jean Cho, Ph.D., P.Eng.

Hydrogeology Specialist

Appendix 1: Seepage Model and Sensitivity Analysis of Seepage Model

Appendix 2: Gibsons Aquitard

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Appendix 1 – Seepage Model and Sensitivity Analysis of Seepage Model

The hydraulic parameters selected for the deformation analysis consistently overestimate the heads measured in the Gibsons Aquifer at monitoring wells along the section. This is because the deformation analysis was intentionally designed to provide a conservative estimate of potential outcomes during construction, and the hydraulic parameters were selected to yield a suitably conservative result.

In response to the peer review comments, the hydraulic parameters used in the deformation model were re-evaluated:

- to improve the fit of the predicted heads in the two-dimensional model to observed heads in monitoring wells, and
- to compare predicted groundwater discharge rates to the discharge rate obtained in the existing three-dimensional groundwater model of the Gibsons Aquifer (Doyle, 2013).

As in the deformation analysis, conservative values were used in the seepage analysis in order to ensure that potential impacts to the aquifer from the proposed project were overestimated rather than underestimated. It should be noted that the groundwater flow regime in the vicinity of the subject site is three-dimensional, and a two-dimensional seepage model may not be able to fully simulate every aspect of the flow regime. The objective of both the two-dimensional deformation analysis and the two-dimensional groundwater seepage analysis is to simplify the three-dimensional world, while maintaining sufficient conservatism that the results of the analysis are suitable for design purposes.

The table below lists the hydraulic conductivities used in the deformation analysis and those used in the seepage analysis completed to respond to peer review comments.

Soil Type	Deformation Analysis Hydraulic Conductivity (m/s)	Base Case Seepage Analysis Hydraulic Conductivity (m/s)
Fill	$1x10^{-5}$ – $5x10^{-5}$	$5x10^{-5}$
Peat	$1x10^{-6}$	$1x10^{-6}$
Sand	$5x10^{-5}$ – $1x10^{-4}$	$5x10^{-5}$
Silty Sand (on Land)	$1x10^{-6}$ – $1x10^{-5}$	$5x10^{-8}$
Till-Like Material	$1x10^{-8}$ – $5x10^{-7}$	$5x10^{-8}$
Gibsons Aquifer	$2.6x10^{-3}$ – $1x10^{-1}$	$5x10^{-5}$
Seabed Sediments	$1x10^{-2}$	$1x10^{-2}$
Seabed Silty Sand	$1x10^{-4}$	$5x10^{-5}$

It should be noted that for the purposes of evaluating the Gibsons Aquifer-Gibsons Aquitard interaction, the hydraulic conductivity of the fill, peat, and sand overlying the Low-K Gibsons Aquitard are not important parameters. However, they are listed here for completeness. In the seepage analysis, the hydraulic conductivity of the Gibsons Aquifer gravel was reduced to $5x10^{-5}$ m/s from the previous values, which were at least an order of magnitude higher. The primary reason for this reduction in hydraulic conductivity is that the values used in the deformation analysis as well as those obtained from the work of Doyle (2013) result in predicted groundwater discharge rates to Howe Sound through the two-dimensional model that far exceed the recharge estimates of Doyle (2013). Furthermore, the high Gibsons Aquifer hydraulic conductivity used in the deformation analysis results in significant over-predictions in hydraulic head at borehole BH14-3 in the two-dimensional section. The hydraulic conductivity of the seabed silty sand was also reduced in order to better fit the groundwater discharge rates of Doyle (2013). Finally, the hydraulic conductivity of the silty sand component of the Gibsons Aquitard was reduced to equal that of the till-like material, for the sake of simplicity.

For the Base Case Seepage model, the predicted heads at wells within the two-dimensional section and the predicted flow to the ocean are presented in the table below. The head at BH14-4 is under-predicted by approximately 2 m. By contrast, the head at BH14-3 is over-predicted by 1 m. As noted above, the head value reported for BH14-3 was measured at the end of drilling. The transducers measurements from BH14-5 in December 2014 and January 2015 indicate a tidal head fluctuation of +/-0.5 m around the average head. Therefore, 0.5 m was added to the head at BH14-3 — or the maximum expected discrepancy between measured and average head, if the well was completed during low tide — in order not to underestimate Gibsons Aquifer heads. The predicted discharge to Howe Sound along the 100m width of the two-dimensional section model is 1,790 m^3/d. This value is eight times higher than the prorated flux from the basin-wide analysis of Doyle (2013).

Item	Base Case Seepage Analysis Result
Predicted Head at BH14-4 (target 12.6 m)	10.6 m
Predicted Head at BH14-3 (target 5.1 m)	6.1 m
Predicted Groundwater Discharge to Howe Sound (target 2750/13 = 220 m^3/d)	1,790 m^3/d

Although the predicted groundwater discharge to Howe Sound is unrealistically large compared to the accepted value, a further lowering of the hydraulic conductivity of the Gibsons Aquifer, which would be require to reduce the flux to reasonable values, was not considered conservative. Therefore, the parameters listed in the table above are used for the base case seepage analysis discussed in this appendix. To better understand the impact of the individual parameters, a sensitivity analysis was completed on the two-dimensional seepage model.

In the first sensitivity analysis, the hydraulic conductivity of the two Low-K Gibsons Aquifer materials (i.e., the silty sand and the till) were raised to $2x10^{-6}$ m/s, as requested by the reviewers. The results of this analysis are shown in the table below. Increasing the hydraulic conductivity of both components of the Low-K Gibsons Aquitard led to a reduction in heads throughout the Gibsons Aquifer and a slight reduction in predicted groundwater discharge rate to Howe Sound. Raising the hydraulic conductivity did not improve the goodness-of-fit, as the heads at the two wells increased together. An improvement in fit would require the rate of change of head at BH14-4 to differ from that at BH14-3.

Parameter	Base Case Seepage Analysis	Sensitivity Run 1: Gibsons Aquitard K
Silty Sand (on Land) K (m/s)	$5x10^{-8}$	$2x10^{-6}$
Till-Like Silty Sand K (m/s)	$5x10^{-8}$	$2x10^{-6}$
Head at BH14-4 (m) – target 12.6	10.6	10.0
Head at BH14-3 (m) – target 5.1	6.1	5.5
Discharge to Howe Sound (m^3/d) – target 220	1,790	1,560

The second set of sensitivity analyses was also requested by the reviewers. In these runs, the magnitude of the boundary head at Town Well #1 was increased from 14.9 m to 16 m and then to 18 m. Higher values were not tested because, as discussed in Appendix 2, the static water table elevations at WL10-2, the Strata Well, and MW06-1, located 600 m or more uphill of Town Well #1, is approximately 23 m. Therefore, a piezometric head elevation halfway between the heads measured at these three uphill wells and the accepted piezometric elevation for Town Well #1 — in other words, approximately 18 m — is considered sufficiently conservative. As shown in the table below, increasing the boundary head raises the predicted water table elevation at both monitoring wells. The simulated head at BH14-3 for an up-gradient constant head condition of 18 m is 3.5 m higher than the calibration target, and the predicted head at BH14-4 is 0.7 m higher than the calibration target. Again, as for the Low-K Gibsons Aquitard hydraulic conductivity, this parameter results in a coincident increase in head at both well points in tandem, and therefore does not improve the generalized goodness of fit of the model to head measurements. The predicted groundwater discharge to Howe Sound increases by a modest 3 percent to 10 percent.

Parameter	Base Case Seepage Analysis	Sensitivity Run 2: Boundary Head	Sensitivity Run 3: Boundary Head
Assumed Town Well #1 Boundary Head	14.9	16	18
Head at BH14-4 (m) – target 12.6	10.6	11.9	13.3
Head at BH14-3 (m) – target 5.1	6.1	7.4	8.1
Discharge to Howe Sound (m^3/d) – target 220	1,790	1,850	1,970

The importance of the loose seabed sediments was evaluated by lowering the hydraulic conductivity of this material two orders of magnitude from $1x10^{-2}$ m/s to $1x10^{-4}$ m/s. The results are shown in the table below. Lowering the hydraulic conductivity of this material increases the hydraulic head in the Gibsons Aquifer near the foreshore above the target value and reduces the predicted discharge to Howe Sound by 11 percent. As for the other parameters, the hydraulic conductivity of the seabed sediments does not improve the simulated hydraulic gradient between BH14-4 and BH14-3.

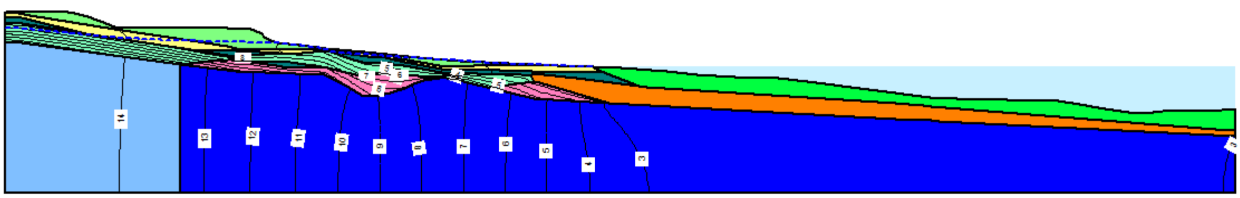
Parameter	Base Case Seepage Analysis	Sensitivity Run 4: Seabed Sediment K
Seabed Loose Sediment K (m/s)	$1x10^{-4}$	$1x10^{-2}$
Head at BH14-4 (m) – target 12.6	10.6	11.2
Head at BH14-3 (m) – target 5.1	6.1	7.0
Discharge to Howe Sound (m^3/d) – target 220	1,790	1,590

The importance of the Gibsons Aquifer sand-and-gravel hydraulic conductivity was evaluated by increasing the hydraulic conductivity by a factor of 10 and decreasing it by a factor of five. The model results are highly sensitive to the hydraulic conductivity of the Gibsons Aquifer. Raising the hydraulic conductivity of this unit increases head throughout the aquifer and greatly increases the predicted groundwater discharge to Howe Sound. As for the other parameters tested above, increasing the Gibsons Aquifer hydraulic conductivity raises heads at both monitoring well locations. Furthermore, the predicted seepage rate for this sensitivity analysis is more than fifty times higher than the accepted discharge rate.

Parameter	Base Case Seepage Analysis	Sensitivity Run 5: Gibsons Aquifer K Times 10	Sensitivity Run 6: Gibsons Aquifer K Divide by 5
Gibsons Aquifer K (m/s)	$5x10^{-5}$	$5x10^{-4}$	$1x10^{-5}$
Head at BH14-4 (m) – target 12.6	10.6	11.7	10.7
Head at BH14-3 (m) – target 5.6	6.1	8.1	6.4
Discharge to Howe Sound (m^3/d) – target 220	1,790	11,200	670

Lowering the hydraulic conductivity of the Gibsons sand-and-gravel aquifer reduces the discharge to Howe Sound to a factor of three higher than estimated by Doyle (2013) without significantly changing the predicted heads in the Gibsons Aquifer.

Based on the seepage analyses presented above, a final sensitivity simulation was completed on the Gibsons Aquifer hydraulic conductivity. In this simulation, the Gibsons Aquifer was divided into two zones, as shown in the figure below. The hydraulic conductivity of the Gibsons Aquifer at Town Well #1 was kept at the base case value of 5x10^{-5} m/s. However, starting approximately 10 m up-gradient of BH14-4, the hydraulic conductivity was lowered to 1x10^{-5} m/s, the value used in Run 6 above. As noted above, Run 6 yielded the best fit to the accepted groundwater discharge rate to Howe Sound from the Gibsons Aquifer. The predicted head and groundwater discharge for Sensitivity Run 7 is shown in the table below. This simulation has the best overall fit to the calibration statistics: the predicted head at BH14-4 is within 0.2 m of the target value. The groundwater discharge rate is improved over the Base Case run and also over Run 6, but the predicted discharge is still 2.6 times greater than the value computed by Doyle (2013). The degree of over-prediction of hydraulic head at BH14-3 in Run 7 exceeds the discrepancy in the Base Case and Run 6. The discrepancy between the target and modelled groundwater discharge rate and the head at BH14-3 indicates that, although Run 7 fits the calibration data better than the previous models, even Run 7 has extra conservatism built into it. Therefore, Run 7 was used as the basis of the final sensitivity run.



Parameter	Base Case Seepage Analysis	Sensitivity Run 7: Gibsons Aquifer with 2 K Zones
Gibsons Aquifer West K (m/s)	5x10^{-5}	5x10^{-5}
Gibsons Aquifer East K (m/s)	5x10^{-5}	1x10^{-5}
Head at BH14-4 (m) – target 12.6	10.6	12.4
Head at BH14-3 (m) – target 5.6	6.1	7.4
Discharge to Howe Sound (m^3/d) – target 220	1,790	560

A final sensitivity analysis was completed on the seabed silty sand. This parameter was increased in order to simulate a possible increase in effective hydraulic conductivity due to the installation of the proposed piles in the marina. The expected increase in hydraulic conductivity was calculated assuming the installation of 200 piles, each with a diameter of 0.46 m. It was further assumed that each pile footprint will result in an effective hydraulic conductivity of 1x10^{-3} m/s; in other words, it was assumed that the pile itself is a porous sand rather than a solid material, in order to account for potential leakage around the pile. With these assumptions, and the further assumption that the flow direction of interest is upward from the Gibsons Aquifer through the Gibsons Aquitard to the ocean, the proposed marina development will result in an increase in the effective vertical hydraulic conductivity of the seabed silty sand from 5x10^{-5} m/s to 5.26x10^{-5} m/s, an increase of 5.2 percent. Note that this calculation assumes that in fact no piles will be present but instead a collection of 200 holes filled with sand. To add conservatism, the simulated hydraulic conductivity of the seabed silty sand was increased to 5.5x10^{-5} m/s in the simulation; this value corresponds to an increase in hydraulic conductivity of ten percent. The results of this simulation are presented in the table below. The predicted change in head and groundwater discharge is negligible.

Parameter	Sensitivity Run 7: Gibsons Aquifer with 2 K Zones	Sensitivity Run 8: Run 7 with Increased Seabed Sediment K
Seabed Loose Sediment K (m/s)	$5x10^{-5}$	$5.5x10^{-5}$
Head at BH14-4 (m) – target 12.6	12.4	12.4
Head at BH14-3 (m) – target 5.6	7.38	7.37
Discharge to Howe Sound (m^3/d) – target 220	564	563

Appendix 2 – Gibsons Aquitard

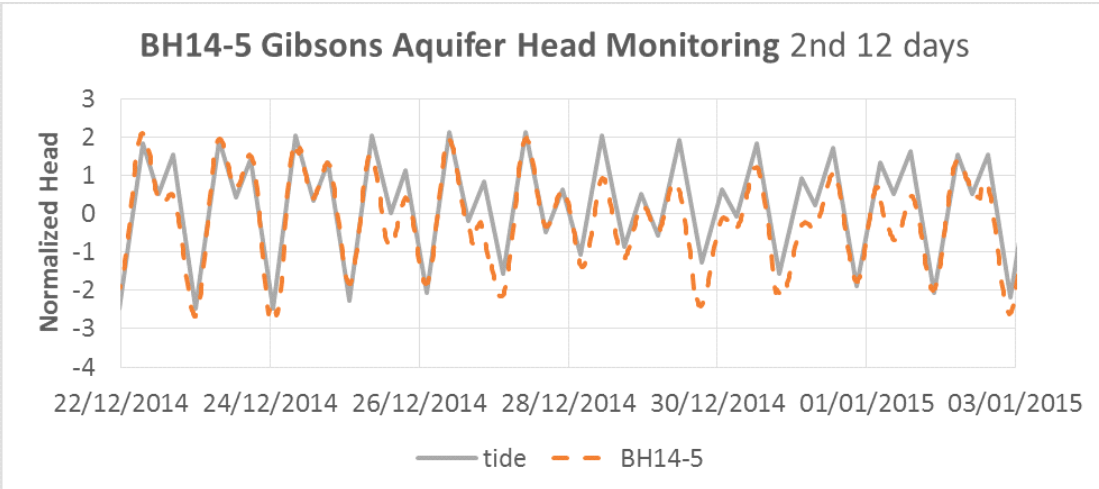
The importance and extent of the Low-K Gibsons Aquitard is clearly outlined in the UBC Master's Thesis completed by Doyle (2013). The Doyle (2013) study of the Gibsons Aquifer found that the Low-K Gibsons Aquitard acted as a confining layer only in the down-gradient region of the aquifer. At the Town Wells, the Low-K Gibsons Aquitard was present and accompanied by artesian pressures in the aquifer. Uphill of the Town Wells, all of the monitoring wells used in the study indicated water levels below the bottom of the Low-K Gibsons Aquitard. At all wells uphill of the Town Wells, unconfined aquifer conditions were encountered.

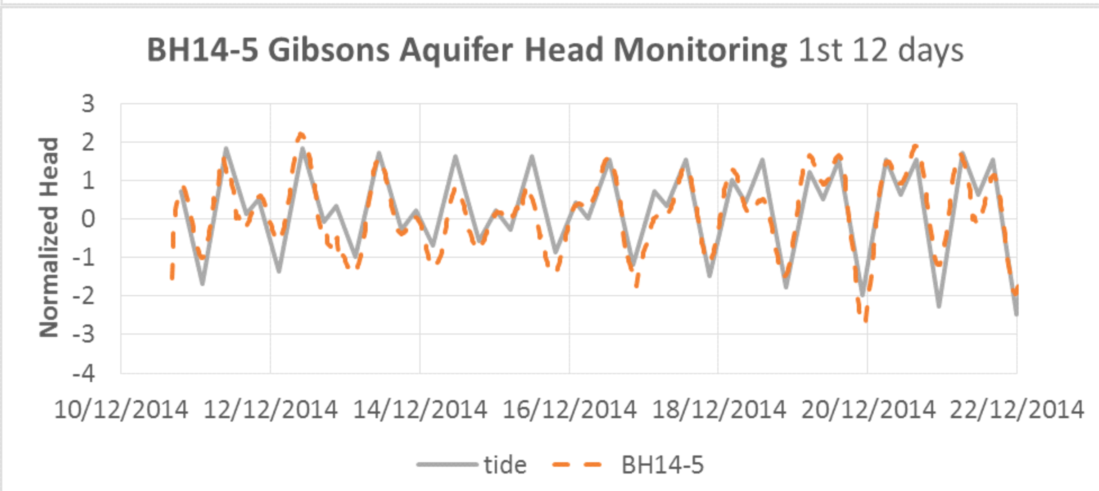
At the northern-most monitoring well, the School Board well, the estimated static water level was 50 m above mean sea level. At WL10-01, near Seamount Way, the static water level was estimated to be 33 m above sea level. At the Strata well, the static water level was estimated to be 23 m above mean sea level. This gradual and persistent decline in piezometric head is consistent with the groundwater flow direction from Mount Elphinstone to Howe Sound. At Town Well #1, the static water level has been estimated to be 15 m above sea level.

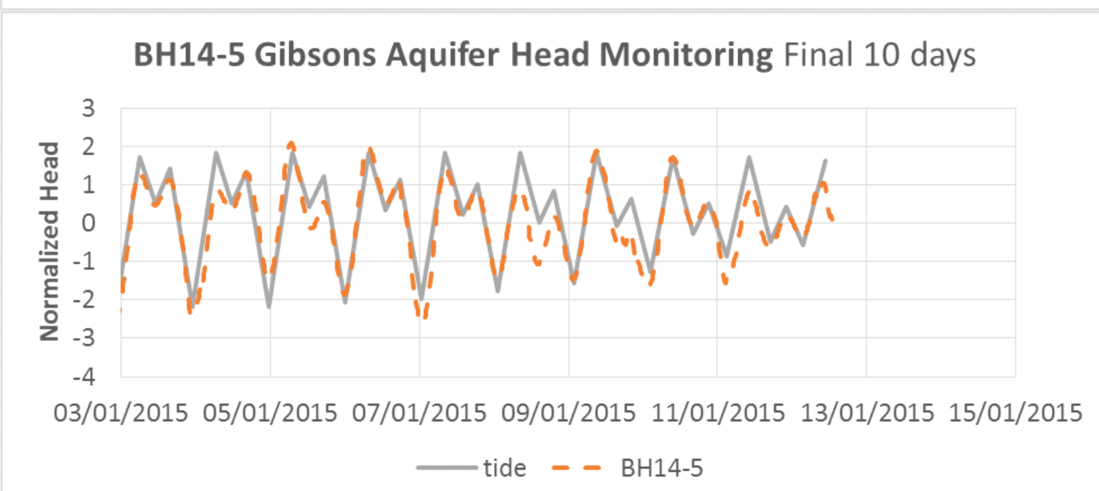
The field investigations completed by Horizon in 2014 and early 2015 in the proposed project area add new data to the conceptual model outlined in Doyle (2013). Doyle (2013) found that the Low-K Gibsons Aquitard confines the Gibsons Aquifer in the area of the Town wells and hypothesized that the Low-K Gibsons Aquitard could become thinner in the foreshore. Horizon's field investigations provide data to support the hypothesis of a thinning of the Gibsons Aquitard in the foreshore. The three Horizon wells outfitted with transducers in December 2014 and January 2015 are informative in this regard. BH14-4, located across the street from Town Well #1 shows an average water level elevation of 12.6 m above mean sea level for the period of December 10, 2014 to January 13, 2015. When the water level depressions associated with pumping of Town Well #1 are excluded from the calculation, the average water level elevation is 12.8 m above mean sea level. This is approximately 2 m lower than the water level at Town Well #1 used in the seepage analysis. At BH14-6, located on Gower Point Road near the southeastern corner of the proposed development, the average water level elevation over the monitoring period was 8.2 m above mean sea level. At BH14-5, located approximately midway between BH14-6 and the shoreline, the average water level elevation was 6.6 m above mean sea level.

An estimate of the hydraulic diffusivity, or the ratio between the transmissivity and storativity of the Gibsons Aquifer, can be derived from the water level fluctuations recorded at these three wells. In this analysis, following the method of Erskine (1991), the lag time and peak attenuation between high and low tides recorded for Howe Sound at Gibsons and the head observed in the monitoring wells is computed and used to estimate the hydraulic diffusivity. At this site, the analysis is informative for determining the degree to which the Gibsons Aquifer is confined.

The figures below show the normalized heads at BH14-5 and Howe Sound for the period of monitoring. The heads at BH14-5 were normalized by the calibrated time lag and tidal efficiency for this data set, making use of only the semi-diurnal component of the tidal cycle. The time lag for pressure propagation between Howe Sound and BH14-5 is approximately 30 minutes, and the tidal efficiency (dimensionless) is 0.21. In this analysis, the hydraulic conductivity of the Gibsons Aquifer is assumed to be 2.2×10^{-4} m/s, the value calibrated by Doyle (2013) to the groundwater model, and the aquifer thickness is assumed to be 70 m, based on the hydrostratigraphic section in Figure 9 of Doyle (2013). With these assumptions, the storativity of the Gibsons Aquifer between BH14-5 and Howe Sound is computed to be 0.069 using the tidal efficiency. The tidal efficiency is a more reliable parameter than the time lag to use in this analysis, because the only the high and low elevations of Howe Sound ocean tide were used in the calculation of time lag. A storativity of 0.069 indicates an unconfined component of the head perturbation response at this well. In other words, we can see that the tidal pressure perturbation travels rapidly within the Gibsons Aquifer in the southern portion of the property and that the reduction in the amplitude of the tidal signature is consistent with that of a partially or fully unconfined aquifer. Assuming that the aquifer is confined results in an estimate of the (confined) specific storage of $3x10^{-3}$ m^{-1}, which is approximately two orders of magnitude higher than a typical value for a sand and gravel aquifer. An unconfined or partially confined aquifer condition between BH14-5 and Howe Sound is consistent with the boring logs in this area, which confirm an absence of a dense confining till in several locations along the foreshore and a thinning of the Low-K Gibsons Aquitard.



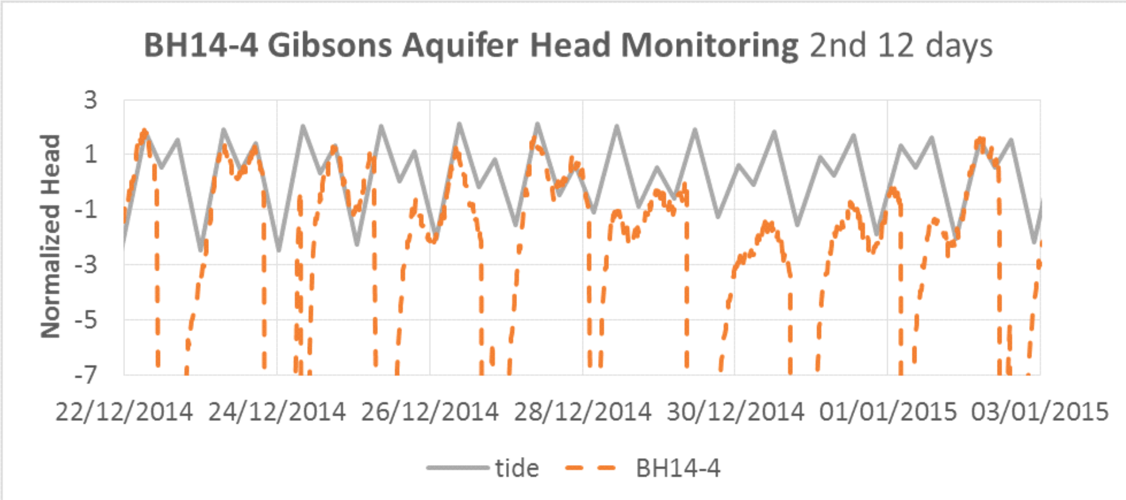


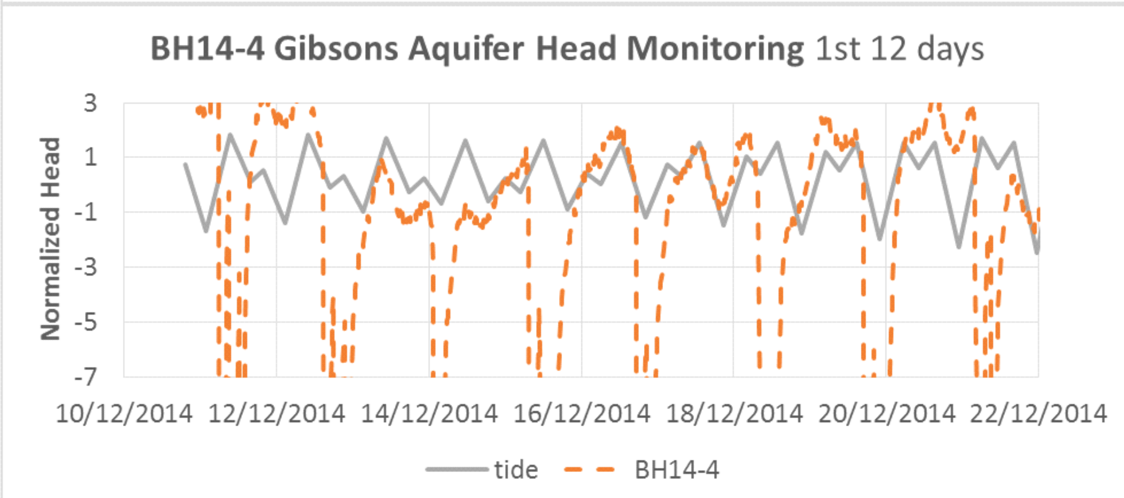


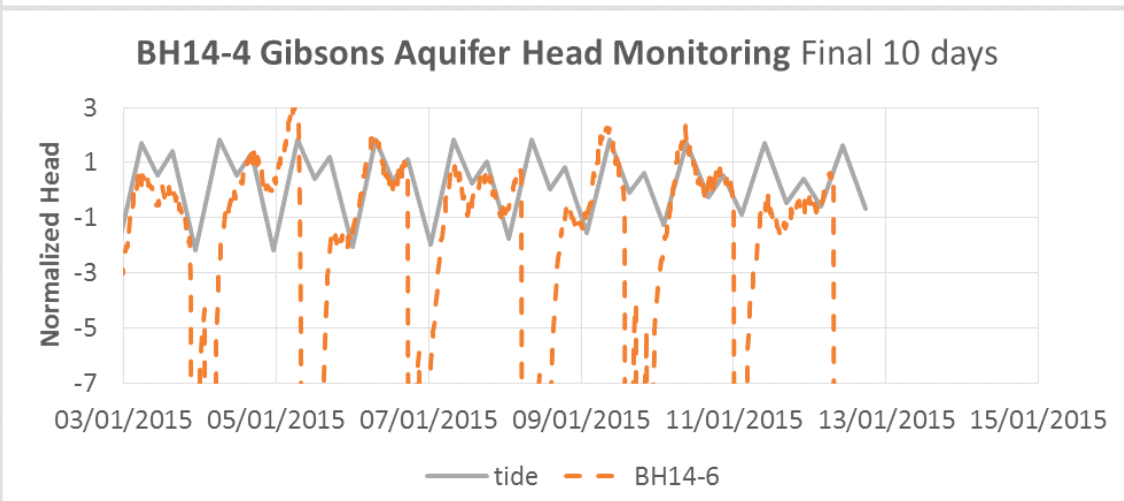
Increasing the hydraulic conductivity used in the storativity calculation to the geometric mean value of $6x10^{-4}$ m/s (Doyle, 2013) yields higher computed storativity values, which are even more consistent with unconfined conditions. Reducing the hydraulic conductivity to the value of $5x10^{-5}$ m/s used in the base case sensitivity analysis reduces the computed storage coefficient, but the resulting specific storage is still high for a sand-and-gravel aquifer.

A similar analysis completed for BH14-6 yields similar results, again indicating only partial confinement of the aquifer in this area.

Although the water table fluctuations at BH14-4 are dominated by the pumping of Town Well #1, a weak tidal signature is evident at this location. The hydraulic diffusivity analysis of Erskine (1991) was applied to this well, and the results are illustrated in the figure below. Even at this location, where the Gibsons Aquitard is clearly present in the boring log, the tidal signature indicates only partial confinement between the well and the ocean. At this well, the storativity computed from the tidal efficiency is 0.26, or an estimated specific storage of $3.7x10^{-3}$ m^{-1}. These values also indicate an unconfined aquifer condition between the ocean and well. The figure below shows that not all of the factors controlling the piezometric head at BH14-4 are captured by the simple tidal analysis using only the semi-diurnal oscillations. Nevertheless, the data points indicates that partially unconfined conditions occur between BH14-4 and Howe Sound.


BH14-4 Gibsons Aquifer Head Monitoring 2nd 12 days
Normalized Head
3
1
-1
-3
-5
-7
22/12/2014 24/12/2014 26/12/2014 28/12/2014 30/12/2014 01/01/2015 03/01/2015
tide
BH14-4


BH14-4 Gibsons Aquifer Head Monitoring 1st 12 days
Normalized Head
3
1
-1
-3
-5
-7
10/12/2014 12/12/2014 14/12/2014 16/12/2014 18/12/2014 20/12/2014 22/12/2014
tide
BH14-4


BH14-4 Gibsons Aquifer Head Monitoring Final 10 days
Normalized Head
3
1
-1
-3
-5
-7
03/01/2015 05/01/2015 07/01/2015 09/01/2015 11/01/2015 13/01/2015 15/01/2015
tide
BH14-6

References:

Doyle, Jessica, 2013. Integrating Environmental Tracers and Groundwater Flow Modeling to Investigate Groundwater Sustainability, Gibsons, BC, Master of Science Thesis, University of British Columbia.

Erskine, A. D., 1991. "The Effect of Tidal Fluctuations on a Coastal Aquifer in the UK," *Ground Water*, vol. 29(4), pp. 556-562.