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Assessing the Hydrogeologic Conditions of Flowing Artesian Bedrock Wells in the Okanagan Basin, British Columbia

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Motivation

Flowing artesian wells can have important socio-economic and environmental consequences. Drilling into an aquifer that exists under flowing artesian conditions can unexpectedly add additional costs to drilling, in the range of thousands to millions of dollars (Lee, 2016) because of regulatory requirements to stop and control artesian flow. This is an issue for water well drillers and their clients, as well as geotechnical, environmental and geoexchange drillers. Additionally, wells that are allowed to flow uncontrollably have the potential to deplete the water supply in the aquifer, and thus need to be considered in measures surrounding water security. Unfortunately, landowners (and some drillers) are generally unaware of the risks of flowing artesian wells, and apart from a few well known areas, the risk of drilling an artesian well in different regions of British Columbia (BC) is largely unknown. This study aims to improve a broader understanding of factors that control the occurrence of flowing wells. The focus of this presentation is flowing bedrock wells.

Background

There are two widely accepted models of hydrogeologic systems that result in flowing artesian conditions. Geologically controlled systems are the most well-known and are widely acknowledged as representing the typical conditions needed for flowing wells. Geologically controlled models depict a sloping confined aquifer extending from high to low elevation, which creates flowing artesian conditions in the down-dip region of the aquifer because the hydraulic head in the recharge area is higher than the ground surface in the down-dip region. Topographically controlled systems have flowing artesian conditions because the variable topography creates upwards gradients in discharge areas. A well drilled in a discharge zone would have a hydraulic head above ground surface. Topography controlled systems are often neglected in the literature, and indeed often are not depicted in standard hydrogeology textbooks, likely because a confining unit is present in most scenarios of flowing wells. While these two models are distinct from each other, both could be important in some areas.

Flowing wells are also found in locations that normally would not be considered favourable for flowing artesian conditions. Flowing wells in fractured bedrock represent one such condition. Although these conditions have been acknowledged in the literature as early as 1908 (Fuller, 1908), they are frequently omitted from discussions about flowing wells. Fractured bedrock aquifers under flowing artesian conditions are common in mountainous regions such as the Okanagan Basin.

Herein, we focus on the relationship between the occurrence of flowing bedrock wells and lineament density in the Okanagan Basin. The Okanagan has a high number of wells, particularly in urban areas, and a high occurrence of flowing wells.

Methods

An initial geostatistical analysis was conducted using BC's GWELLS database. GWELLS includes well records containing basic information on the well's location, construction, yield and lithology. Well data from the Okanagan Basin were extracted from GWELLS and imported into ArcMap (GIS software) to map the spatial distribution of wells and conduct a simple geostatistical analysis. The GWELLS database has three categories for aquifer lithology 1) Unconsolidated 2) Bedrock, and 3) Unknown. Before any analyses were conducted, the well logs of flowing wells were examined, and bedrock wells that had been mislabeled as 'Unknown' were corrected to 'Bedrock'.

Flowing bedrock and non-flowing bedrock wells were subsequently examined with respect to their relationship to lineament density. Regional scale lineament data, used in previous research by Voeckler & Allen (2012), were provided by Natural Resources Canada. The lineaments were mapped using both detailed aerial orthophotos and satellite (LANDSAT TM) images from the near-infrared band 4 (Figure 1 (left)). Kernel density maps were produced in ArcMap (Figure 1 (right)) and density values extracted at the location of each flowing well, flowing and non-flowing. Wells that fell outside the mapped lineament density area were excluded from analyses (39 wells excluded). The Wilcoxon Rank-Sum test (for non-parametric and independent data), also known as the Mann-Whitney U-test, was used to determine if the flowing and non-flowing bedrock wells are equally related to lineament density.

The Naramata region in the Okanagan Basin has a relatively high occurrence of flowing bedrock wells. This region was used to develop a vertical 2D conceptual model of the hydrogeologic conditions that result in flowing bedrock wells. The GWELLS database was used to examine well records for lithology, flow rates, and water levels for both flowing and non-flowing wells. ArcMap was used to examine spatial characteristics of the wells in the region.

Results

The initial geostatistical analysis determined that the Okanagan Basin has over 8000 reported wells, 533 of which were reported to be flowing at the time of drilling. Flow rates ranged up to 600 USgpm, but the majority of the flowing wells had unreported flow rates. Approximately 23% of the wells are completed in bedrock and of these bedrock wells 9% are flowing.

The lineament kernel density map (Figure 1) suggests that flowing bedrock and non-flowing bedrock wells are distributed throughout Okanagan Basin, clustering in regions with medium and high lineament density. Figure 2 shows percent frequency plots of flowing bedrock and non-flowing bedrock wells for different lineament densities. Flowing bedrock wells occur across the range of lineament densities, but are more common in areas of moderate to high lineament density, whereas non-flowing bedrock wells have a similar distribution, but are occur more frequently in lower lineament densities. The Wilcoxon Rank-Sum test compared the kernel density distributions of flowing and non-flowing bedrock well locations and determined that they do not have the same distribution at the 0.01 confidence level. This infers that higher lineament density is a factor that results in flowing bedrock wells.

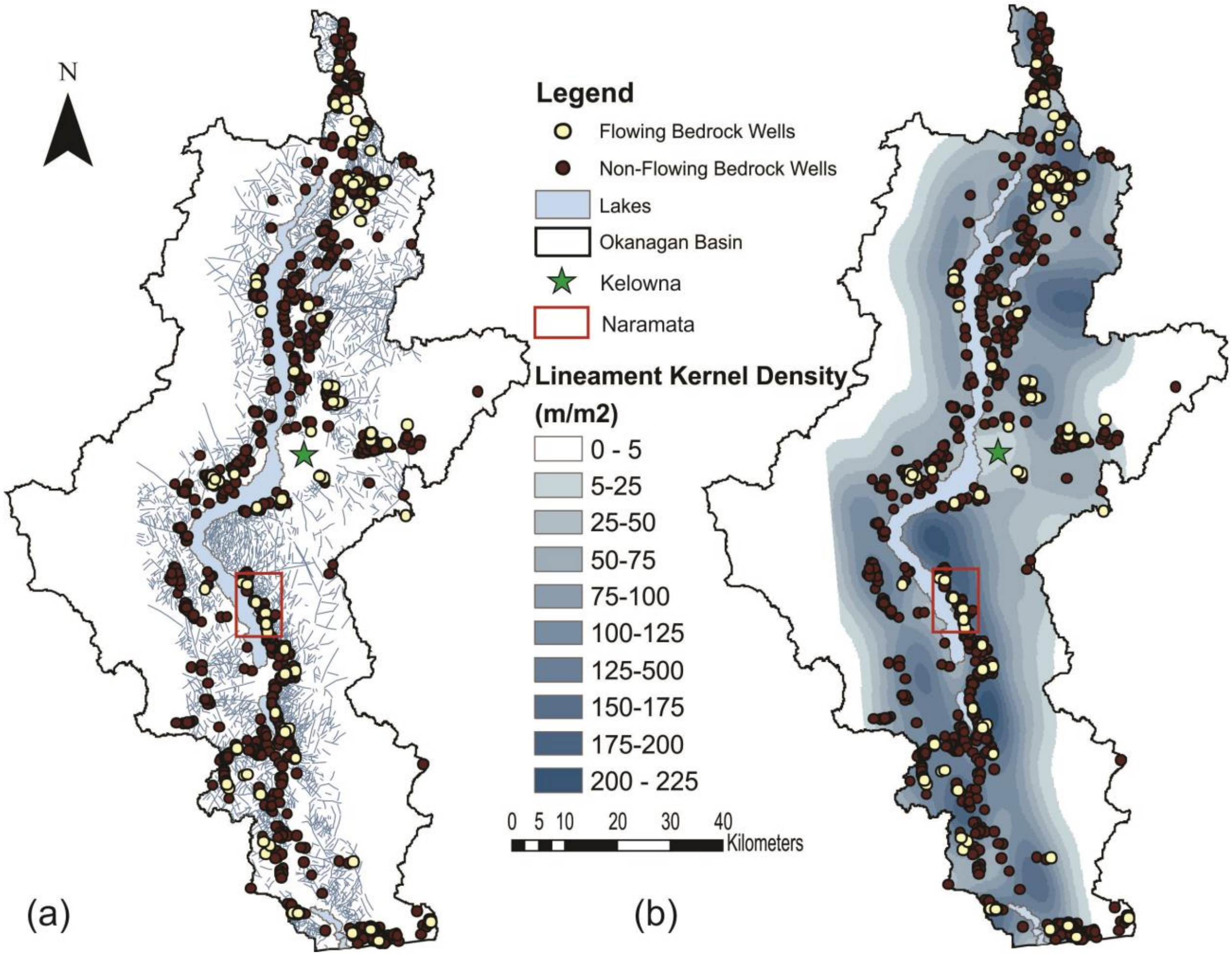

Figure 1: (a) Lineaments in the Okanagan Basin. (b) Kernel density of lineaments in the Okanagan Basin. Flowing bedrock wells are shown in pale yellow and non-flowing bedrock wells are shown in dark red. The Naramata region is outlined in red

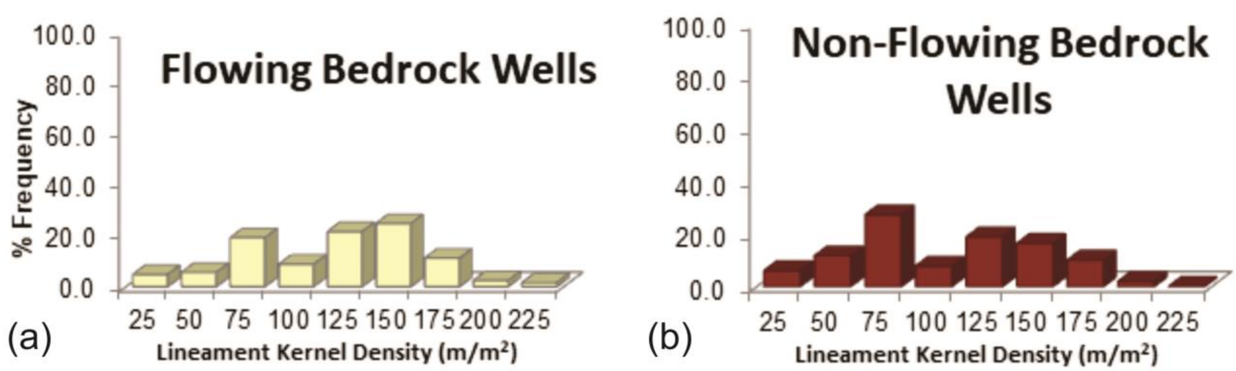

Figure 2: (a) Frequency plot of the lineament kernel density of flowing bedrock well locations. (b) Frequency plot of the lineament kernel density of non-flowing bedrock well locations. The X-axis represents the upper value of the binned data.

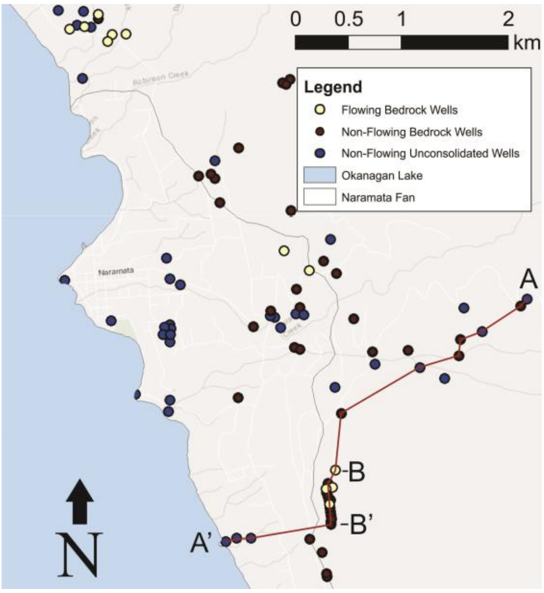

Figure 3: Flowing bedrock and non-flowing bedrock wells with non-flowing unconsolidated wells in Naramata, BC and the location of the conceptual model cross sectional model (A-A') shown in Figure 4

The community of Naramata is a good case study for determining why flowing wells occur where they do and how this may be related to fracturing. The Naramata region is underlain by a low productivity fractured bedrock aquifer that contains a number of flowing wells. The community of Naramata predominately resides on an alluvial fan deposit and a terrace bench. All of the flowing wells in the region are classified as bedrock wells and tend to cluster around the outer perimeter of the fan (Figure 3). Interestingly, there are several non-flowing bedrock wells located immediately adjacent to flowing bedrock wells in Naramata, which suggests there may be distinctly different piezometric levels encountered by wells in proximity to each other.

The conceptual model, is presented in Figure 4, suggests there are at least two distinct potentiometric levels in the area between B and B' - one above or close to ground surface that results in flowing wells, and one at greater depth, approximately 20 m below ground surface, that does not result in flowing wells. At this location, there are only minor differences in lithology, well depth, and the depth of water bearing fractures between these wells. This suggests a possible fracture control, whereby wells with a higher potentiometric surface are simply intersecting a fracture(s) that originate at higher elevation. However, the limited extent of artesian conditions along B-B' indicates that fracture networks and lineament density are not the sole determining factor of flowing well occurrence.

The records for wells between B and B', which were drilled between 1904 and 2002, were examined to see if the potentiometric surface had declined over time at this site. Unfortunately, the results were inconclusive. However, looking at how flowing conditions have changed over time is one aspect of the broader project.

Conclusions and Future Research

Flowing wells could be better understood by broadening the understanding of why and where flowing wells occur in both typical and atypical locations. Examining factors, such as lineament density, and their relationship to the occurrence of flowing wells is needed to develop a comprehensive understanding of flowing wells. This research is part of a larger project aimed at mapping the likelihood of flowing artesian conditions throughout the Okanagan Basin and the Lower Fraser Valley of BC. This larger project aims to disseminate this information to professionals and practitioners in the hopes of reducing the adverse effects associated with encountering of flowing conditions during drilling.

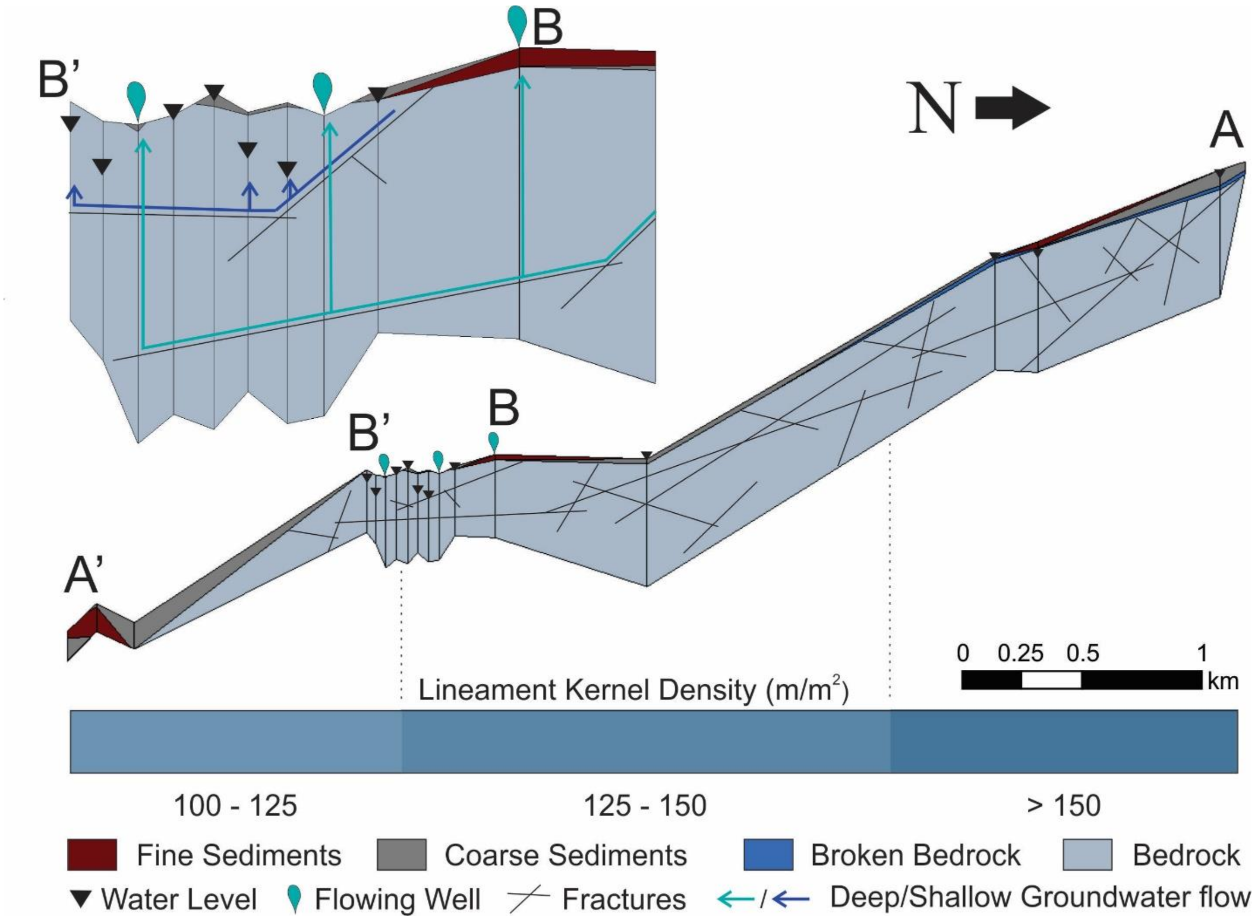

Figure 4: 2D conceptual model of flowing bedrock wells in Naramata. Lineament kernel density values determined in Figure 3 are shown along the bottom of the figure. The inset shows conceptual groundwater flow paths in the fractures which would lead to flowing and non-flowing wells. (2x vertical exaggeration)

Acknowledgements

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