The G360 Fractured Rock Observatory for Collaborative Groundwater Research & Borehole Technology Development

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Characterization of groundwater flow in fractured rock can be difficult with multiple forms of permeability and highly complex anisotropic controls. The detailed information needed to understand localized groundwater flow (e.g. that which would control a remediation system), scaling issues, as well as the development of new technologies or effective testing / refinement of existing techniques requires a detailed 3 dimensional understanding of the rock mass, fractures and groundwater flow. Generally, this is not the case at most field sites which usually have a limited number of boreholes, that are available for a short period and are not conducive to repeat testing.

To achieve a higher-level understanding of complex bedrock flow systems, as well as foster industry-academic collaborations in the development of technologies and characterization techniques best suited for bedrock aquifers and aquitard flow systems, the G360 Institute, with funding from Canada Foundation for Innovation (CFI) and the Southern Ontario Water Consortium (SOWC), has constructed a field laboratory on the University of Guelph campus. We herein present the details of the facility that provides an accessible local site, with relatively shallow bedrock which is reasonably isolated from external hydraulic influences, that is thoroughly characterized to develop new technologies as well as test existing and emerging hydrogeologic concepts as these pertain to flow in fractured sedimentary rock.

The Fractured Rock Observatory (FRO) consists of six vertical core holes (five 123mm diameter, one 96mm diameter) surrounded by three inclined core holes (96mm diameter) so as to allow the bedrock mass to be understood from a three-dimensional perspective. All boreholes extend to approximately 73 mbgs, through the Silurian carbonate aquifer into the upper portion of the Cabot Head shale aquitard. The spacing, configuration and orientation of the boreholes were iteratively refined to optimize the orientation relative to local fracturing and provide flexibility for future testing. The bedrock borehole network is complemented by a 13m deep overburden multilevel monitoring system. The boreholes remain sealed with temporary flexible liners, to be selectively opened as needed for given research activities. With a footprint of ~4700 m2, in its current configuration the field laboratory samples almost 283,000 m3 of rock. The configuration of boreholes is designed such that the groundwater flow regime can be controlled and assessed with temporary sensor deployments using self-contained pressure sensors and fibre optic cables as examples (Pehme and Parker 2014; Munn et al. 2017, Maldaner et al. 2019 and Munn et al. 2020) while other boreholes can be used for hydraulic testing. The vertical boreholes have PVC casings and asymmetric spacing to allow for a broad range of both hydrogeologic, hydro-physical, and geophysical cross-hole testing.

To our knowledge none of the half dozen or so shallow sites in North America and Europe that are designed for understanding groundwater flow (most with relatively broadly spaced boreholes and in crystalline rock with comparatively few fractures) include angled boreholes or have the density of boreholes over the length achieved at the FRO laboratory. The existing background data includes continuous core with numerous measurements of selected physical properties (e.g. porosity, thermal conductivity), a broad suite of geophysical and extensive hydro-geophysical data sets (collected as part of two MSc and two PhD investigations) and has been featured in multiple publications. The FRO is on the flank of a deep paleo-channel incised into bedrock filled with glacial deposits and complements regional bedrock flow system monitoring and research including quaternary processes (e.g. Steelman et al. 2017).

The FRO has and continues to provide opportunities for industry, governmental and academic collaborations including to date Aardvark drilling, Silixa (DTS, iDAS), ALT, Mount Sopris, Vista Clara, NMRSA, the Geological Survey of Canada, University of Kansas and the University of Waterloo among others. Current investigations include hydro-physical testing using NMR (e.g. Pehme et al. 2022), thermal, flow meter and cross-hole pressure techniques to assess hydraulic properties and interconnection (to be followed by high resolution packer testing), as well as detailed core CT scanning and regional seismic reflection surveys. The field laboratory provides a unique infrastructure opportunity that promises a broad range of fundamental testing, welcomes both industry and research collaborations, where the potential for technical developments is only limited by the imaginations of the hydrogeologic community.