CHARACTERIZING THE PLATTEVILLE AQUITARD AS A "HYBRID" HYDROGEOLOGIC UNIT

STEENBERG, Julia, RUNKEL, Anthony, TIPPING, Robert, Minnesota Geological Survey, St. Paul, MN 55114, BARR, Kelton, Braun Intertec Corporation, Minneapolis, MN, 55438, ALEXANDER, E. Calvin Jr., University of Minnesota, Minneapolis, MN 55455, JANSEN, Stephen, Peer Engineering, Eden Prairie, MN 55344

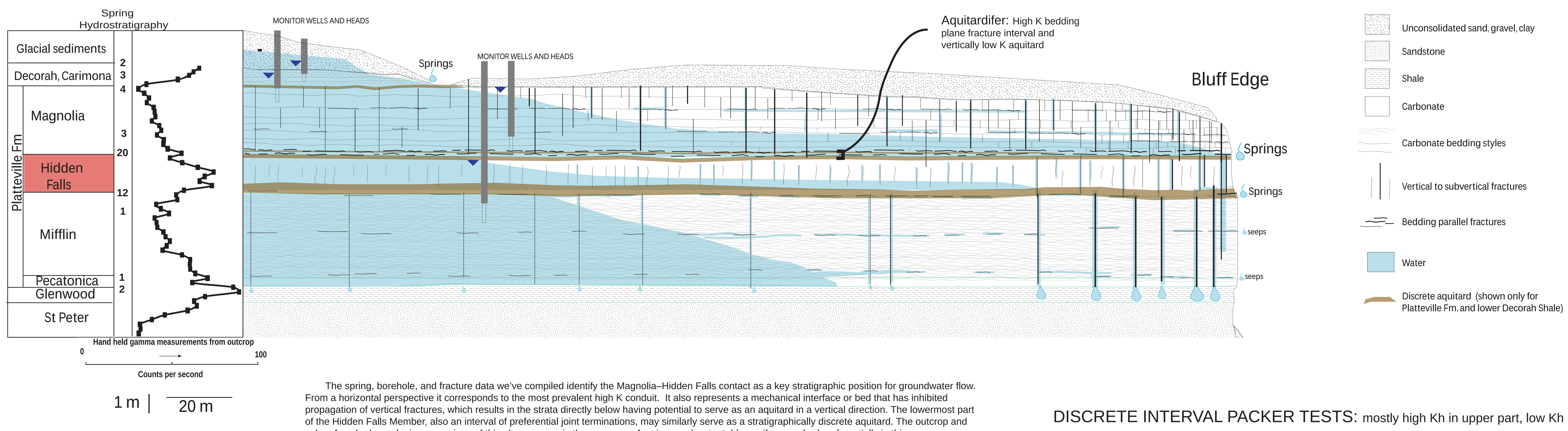
Metropolitan Council
University of Minnesota

ABSTRACT

The Ordovician Platteville aquitard in the Twin Cities Metropolitan area of Minnesota is a shallowly buried, extensively fractured carbonate rock in an urban setting, and therefore vulnerable to contaminants. A large number and wide variety of geomechanical and hydrogeologic studies over the past few decades have yielded a wealth of data that combined with our own borehole geophysics and outcrop observations, has led to a more comprehensive understanding of the Platteville. Key information acquired includes borehole flowmeter logs in ambient and stressed conditions, spring hydrostratigraphy, discrete interval packer tests, multiple head measurements from individual boreholes, long duration "aquifer" tests, vertical fracture characterization based on mechanical stratigraphic analysis of outcrops, and observations of subsurface fractures in underground excavations. These data are brought together within detailed stratigraphic context using natural gamma logs collected from both outcrops and boreholes.

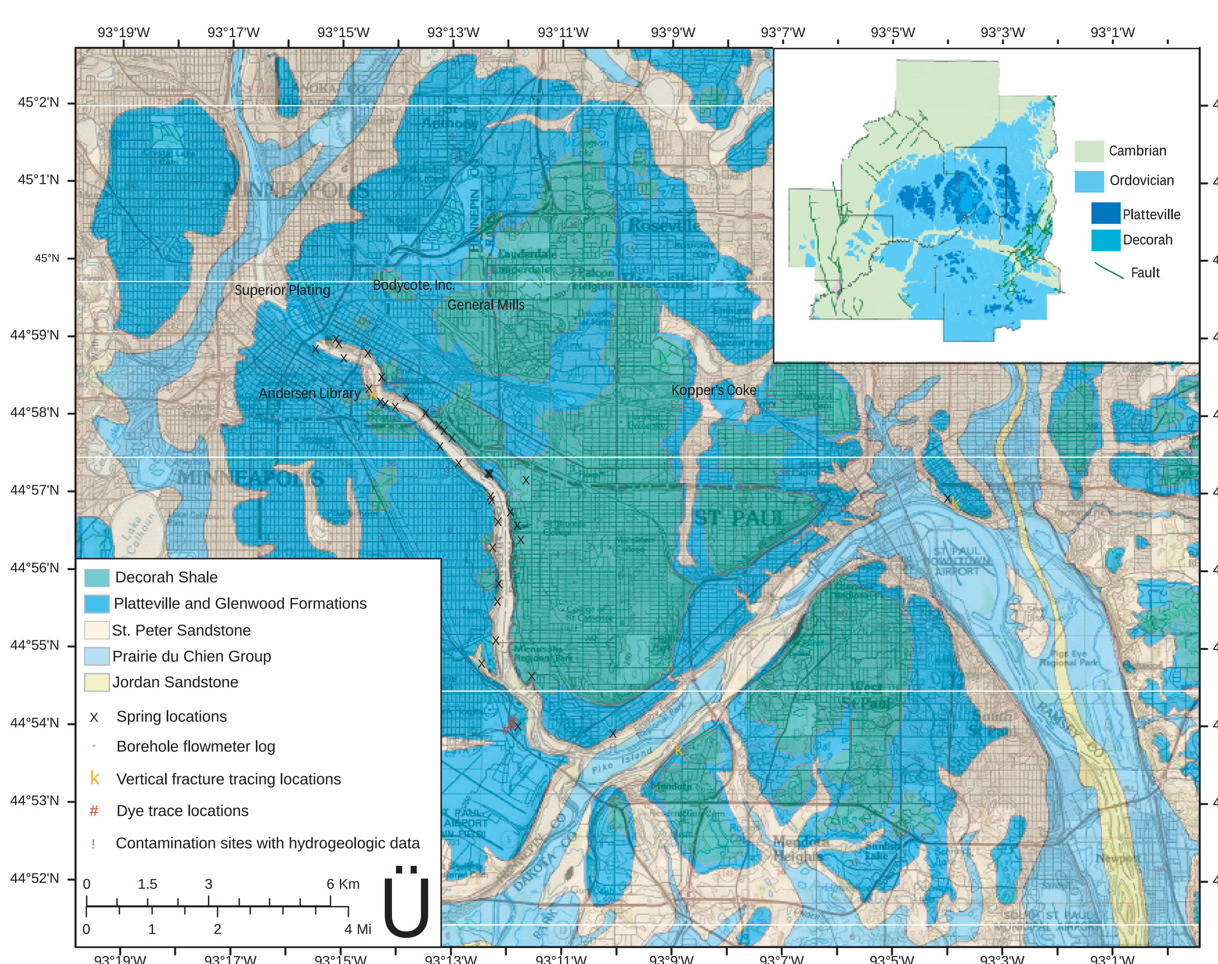
The combination of data from all of these efforts collectively leads to a characterization of the Platteville as a complex, "hybrid" hydrogeologic unit. From one perspective it can serve as an important aquitard that limits vertical flow, while from another perspective, it is best considered a karstic aquifer with well-developed bedding-plane parallel conduit systems of very high hydraulic conductivity that permit rapid flow of large volumes of water. Further, thin stratigraphic intervals of a few feet or less appear to contain both the highest hydraulically conductive bedding-plane parallel conduits as well as the key aquitards. Despite this complexity there is strong stratigraphic control in the vertical and bedding-plane parallel fracture patterns, and thus the potential for a strong degree of predictability in flow path geometries.

HYDROSTRATIGRAPHIC CONCEPTUAL MODEL OF THE PLATTEVILLE FORMATION: defining a "hybrid" hydrogeologic unit

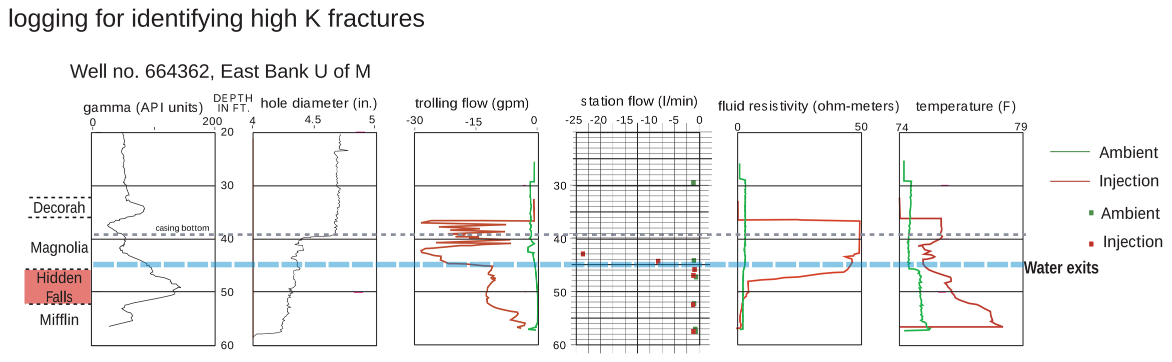


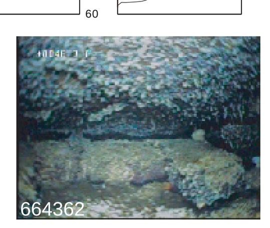
The spring, borehole, and fracture data we've compiled identify the Magnolia–Hidden Falls contact as a key stratigraphic position for groundwater flow. From a horizontal perspective it corresponds to the most prevalent high K conduit. It also represents a mechanical interface or bed that has inhibited propagation of vertical fractures, which results in the strata directly below having potential to serve as an aquitard in a vertical direction. The lowermost part of the Hidden Falls Member, also an interval of preferential joint terminations, may similarly serve as a stratigraphically discrete aquitard. The outcrop and subsurface hydrogeologic expressions of this phenomenon is the presence of springs and water table aquifers perched preferentially in this relatively thin part of the Platteville Formation.

BEDROCK GEOLOGY OF THE TWIN CITIES METROPOLITAN AREA



GEOPHYSICAL AND HYDRAULIC DATA COLLECTION: Injection while EM flowmeter logging for identifying high K fractures



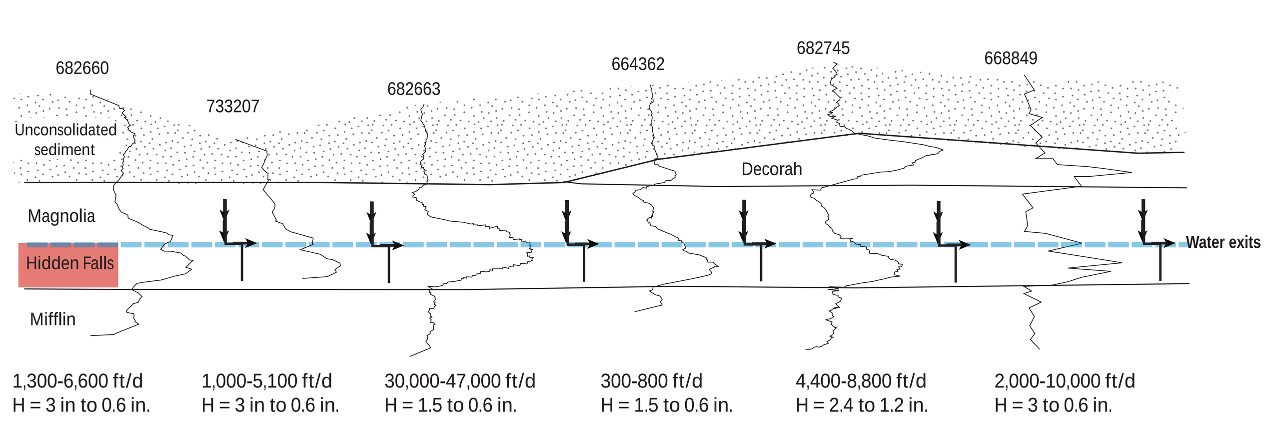


Still shot from the video log of the fracture that accepted water.

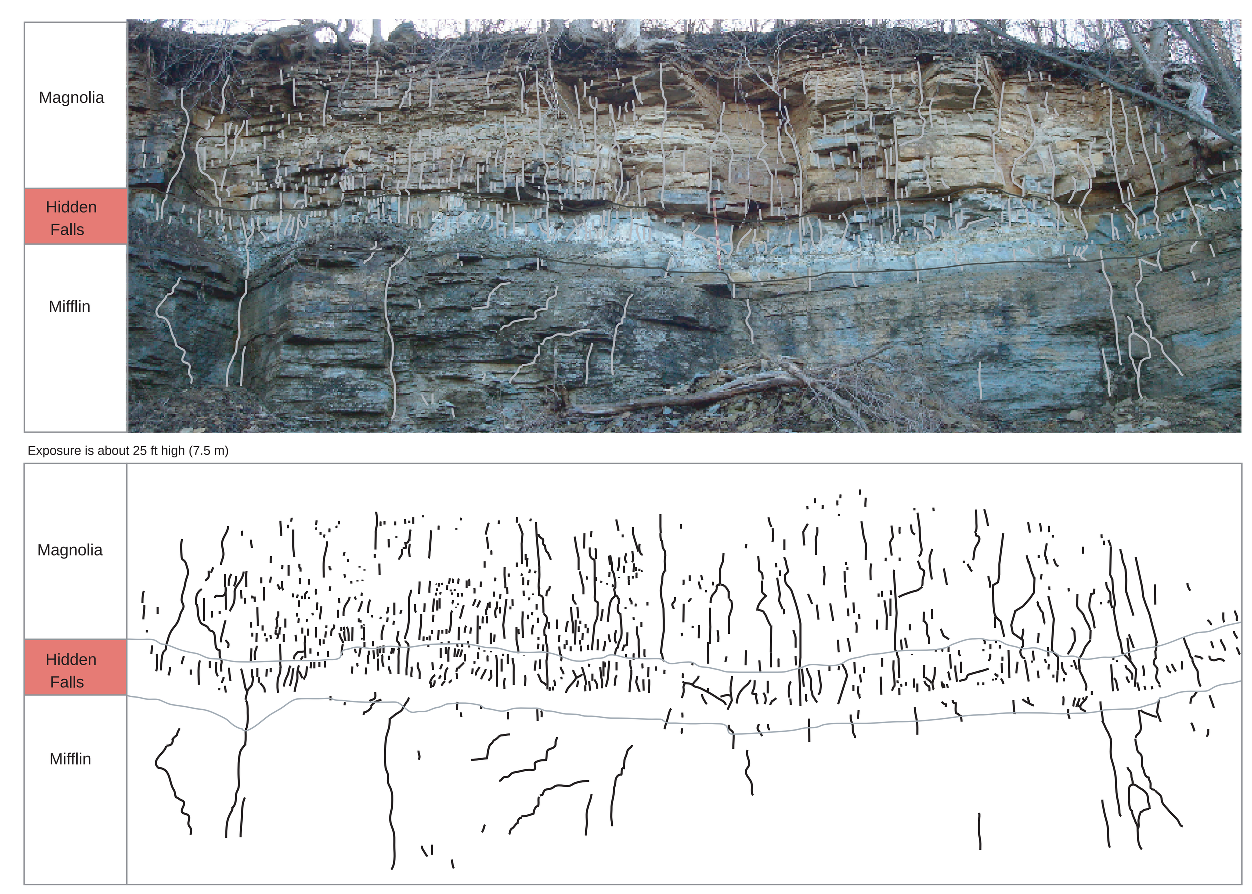
In this borehole there was no measurable ambient flow. Water was injected during logging at a rate of 10 gpm, traveled down the borehole and exited at a depth corresponding to a minor caliper deflection and bedding plane fracture in the video log at about 14 m (46 ft, blue dashed line). This interval is stratigraphically at the Hidden Falls and Magnolia contact.

CORRELATED INJECTION LOGS: High K bedding plane fracture consistently at the top of the Hidden Falls

Results from six of the eight monitoring wells have a bedding plane fracture that dominates hydraulics in the well, at the Hidden Falls and Magnolia contact. Two of the eight tested wells had very different results. One of these wells is open only to the middle of the Hidden Falls and the upper part of the Mifflin Members. Hydraulic conductivity is so low in this borehole that we were unable to achieve a static head during injection. The other well is open to the Hidden Falls and Magnolia boundary, but there does not appear to be a bedding plane conduit at that horizon, and injected water exited the borehole directly at the base of the casing, stratigraphically within the middle of the Magnolia Member.



VERTICAL FRACTURE CHARACTERIZATION: Individual members have characteristic fracture patterns, and preferential termination corresponds to member contacts



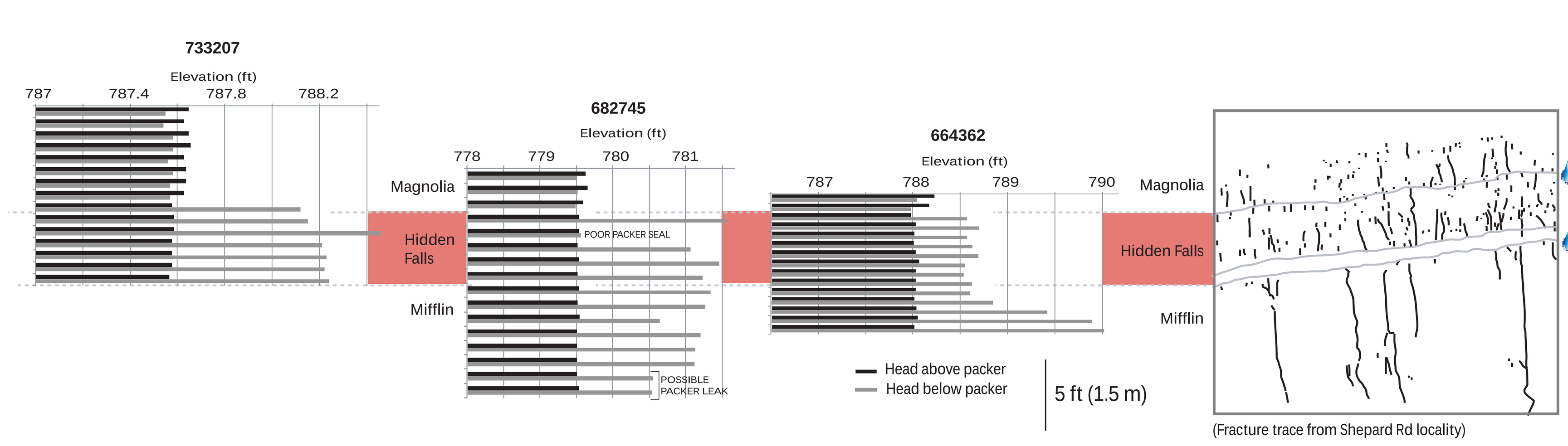
Mapping vertical fractures on exposure surfaces is a technique used in mechanical stratigraphy to characterize fracture density and termination horizons, which can provide insight into fracture network development and improved predication of fluid flow pathways. Results from our analysis at three separate localities show that the members of the Platteville Formation each have a distinct style of vertical fracture density and spacing. Individual vertical fractures extending through the entire formation are rarely present at some highly weathered outcrops. Vertical fractures preferentially terminate at the Hidden Falls and Magnolia contact as well as within the Hidden Falls.

The Hidden Falls Member has a number of material properties differing from members above and below that may account for preferential termination of vertical fractures. Internally it is massive, without individual centimeter-scale beds characteristic of the Magnolia and Mifflin, as indicated by the conchoidal fracture pattern. It contains a higher percentage of siliciclastic material, largely clay and silt, and on weathered exposures the densely fractured, small, blocky texture of the Hidden Falls is more similar to outcrops of relatively ductile shale, such as the Glenwood, than to brittle carbonate rock. Tensile- and compressive-strength values for the Hidden Falls, based on samples from a number of sites in the Twin Cities area, average ~12,000 psi, ~40% lower than values for the Mifflin and Magnolia (CSC Joint Venture, 1985).

The coincidence of preferential termination of vertical fractures with preferential development of bedding plane conduit at the top of the Hidden Falls Member may also be indicative of a cause and effect relationship whereby bedding plane conduits at this position served as a weak mechanical interface where vertical fractures terminated.

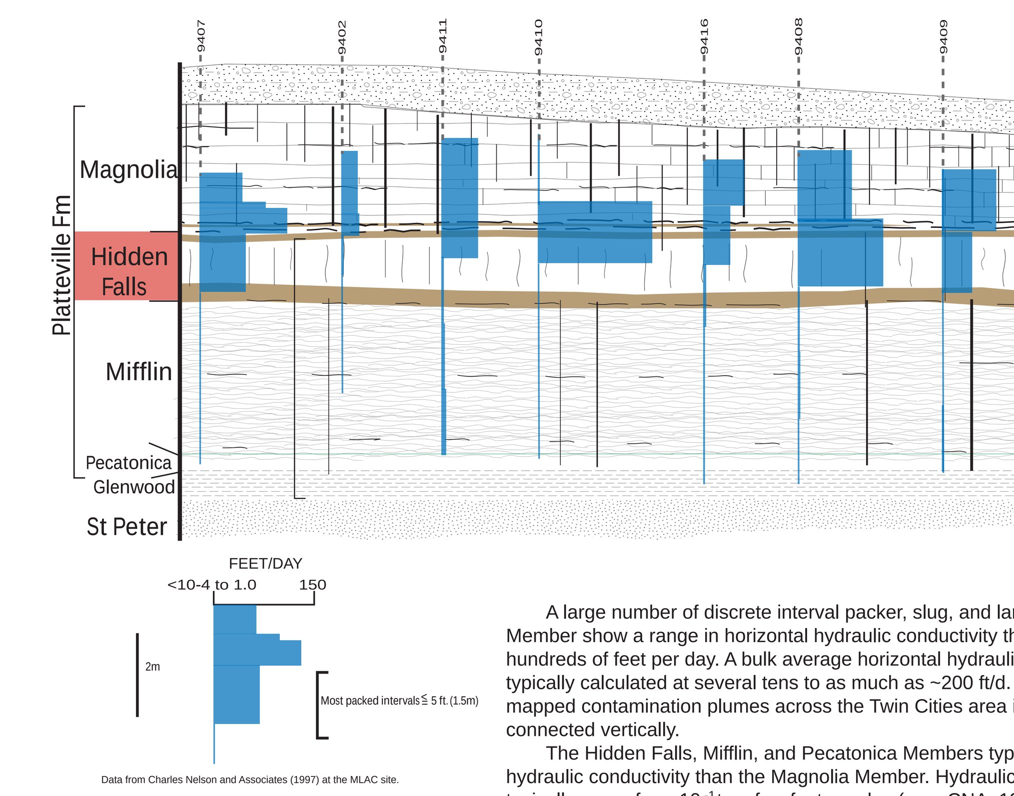
HEAD MEASUREMENTS USING PACKER: Significant change in head where vertical fractures preferentially terminate

We have recently started collection of head data from three Platteville wells on the campus of the U of M, and preliminary results suggest poor vertical hydraulic connectivity between the Magnolia Member and underlying members, indicated by the abrupt change in head differences above and below the packer across the Magnolia–Hidden Falls contact strata. Nested monitor wells at other sites in the Twin Cities area similarly reflect vertical resistance to flow across the Hidden Falls, with heads above and below known to differ by as much as ~3 m (Braun Intertec Corporation, 2011).



(Fracture trace from Shepard Rd locality)

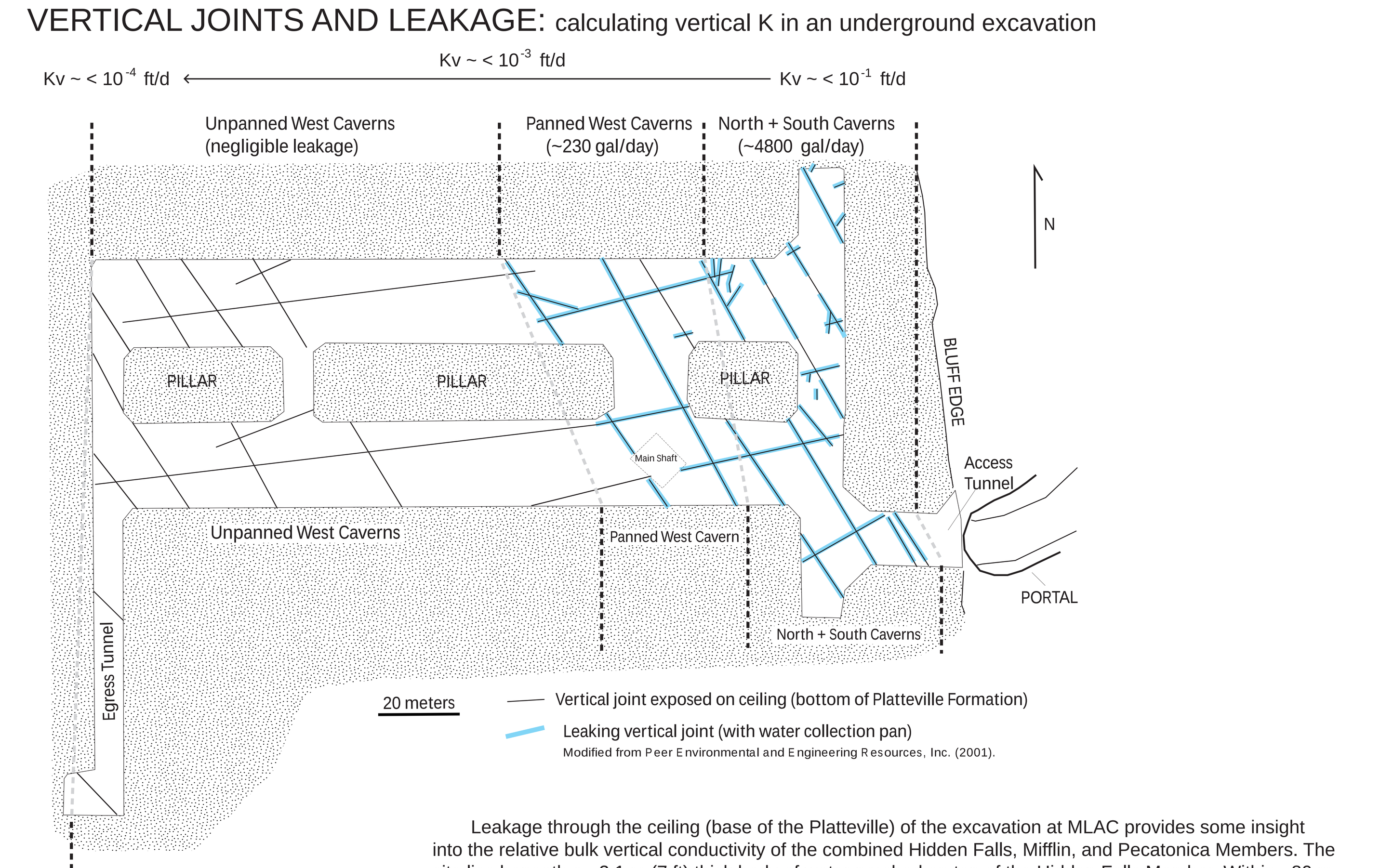
DISCRETE INTERVAL PACKER TESTS: mostly high Kh in upper part, low Kh in lower part



A large number of discrete interval packer, slug, and larger scale aquifer tests of the Magnolia Member show a range in horizontal hydraulic conductivity that varies from a few feet per day to hundreds of feet per day. A bulk average horizontal hydraulic conductivity for individual sites is typically calculated at several tens to as much as ~200 ft/d. Multi-well aquifer tests, dye traces, and mapped contamination plumes across the Twin Cities area indicate that fractures are typically well connected vertically.

The Hidden Falls, Mifflin, and Pecatonica Members typically have markedly lower horizontal hydraulic conductivity than the Magnolia Member. Hydraulic conductivity values from packer tests typically range from 10^{-1} to a few feet per day (e.g., CNA, 1997). Packed intervals commonly are unable to produce water at a sustained rate above a minimum pumping threshold. Values as high as a few tens of feet per day are relatively uncommon and likely indicate intersection or proximity to bedding plane fractures or vertical joints (e.g., Barr Engineering, 1987).

VERTICAL JOINTS AND LEAKAGE: calculating vertical K in an underground excavation



Modified from Peer Environmental and Engineering Resources, Inc. (2001).

Leakage through the ceiling (base of the Platteville) of the excavation at MLAC provides some insight into the relative bulk vertical conductivity of the combined Hidden Falls, Mifflin, and Pecatonica Members. The site lies beneath a ~2.1 m (7 ft) thick body of water perched on top of the Hidden Falls Member. Within ~80 m of the bluff edge, relatively high leakage rates (total of ~5000 gpd; Peer Environmental and Engineering Resources, Inc., 2001, 2003) into the panning system indicate a vertical hydraulic conductivity varying from 10^{-1} to 10^{-3} ft/d across individual parts of the ceiling. Beyond ~80 m from the bluff edge the ceiling is not panned, because leakage is negligible. Using a total leakage for the unpanned area of <10 gpd, vertical hydraulic conductivity is $<10^{-4}$ ft/d. The decreasing hydraulic conductivity deeper into the excavation reflects diminishing aperture width, and likely connectivity and trace length of vertical fractures with increasing distance from the bluff edge and subcrop surface.

Vertical hydraulic conductivity for the Magnolia Member at MLAC was calculated to be as high as 4 ft/d, although lower values were obtained with the same aquifer test data using other methods of analysis (Peer Environmental and Engineering Resources, Inc., 1999).

ACKNOWLEDGMENTS

Our work in the Twin Cities Metropolitan area has been supported by the Metropolitan Council. Special thanks to Chris Gonzalez for his help in the field, and Greg Brick for sharing his years of experience on Platteville springs in the area. We also thank Janet Dalgleish with the University of Minnesota Department of Environmental Health and Safety for helping us access water wells and Pat Mosites with the Metropolitan Airports Commission.

REFERENCES

Barr Engineering, 1987, Remedial Investigation/Feasibility Study: Superior Plating, Inc., August, 1987: On file at the Minnesota Pollution Control Agency.

Braun Intertec Corporation, 2011, Groundwater Assessment Report—Phase 3, Former Metallurgical, Inc., Facility: 900 and 936 East Hennepin Avenue, Minneapolis, Minnesota, MPCA VIC Project Number VP18181: On file at the Minnesota Pollution Control Agency, 23 p.

Consulting Engineers, C.N.A., (CNA), 1997, Geotechnical Data Report, University of Minnesota Library Access Center, UM Project No. 297–91–2023, 22 p.

CSC Joint Venture, 1985, Geotechnical Report, Project No. 87–54, Minneapolis East Interceptor, Phase 2, Volume 4A: Produced for the Metropolitan Waste Control Commission, 66 p.

Peer Environmental and Engineering Resources, Inc., 2003, Performance Monitoring Report Interim Response Action Implementation, Minnesota Library Access Center, University of Minnesota: On file at the Minnesota Pollution Control Agency, January 17, 2003, 12 p.

Peer Environmental and Engineering Resources, Inc., 2001, Interim Response Action Implementation Activities Update, Minnesota Library Access Center: On file at the Minnesota Pollution Control Agency, October 1, 2001, 6 p.

Peer Environmental and Engineering Resources, Inc., 1999, Additional Project Area Characterization: Minnesota Library Access Center, University of Minnesota, 2 vols., November 1999.