Hydraulic Gradient – Fundamentals and Wandering Groundwater in a Tidally Impacted Aquifer
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ABSTRACT
Hydraulic gradient is a vector quantity having both magnitude and direction. Fundamentally, magnitude and direction of a gradient vector can be determined by using a set of three wells with concurrent water level measurements. Average gradient, over a specific time scale, can be obtained from a series of gradient vectors calculated over shorter time scales using vector algebra. In practice, this simple analysis is underutilized. The concept becomes even more powerful analytical tool when applied to correlation with pressure transducer readings. This study demonstrates an application of this fundamental concept for flow and transport analysis in a tidally influenced aquifer.

Multiple pressure transducers were installed in an aquifer influenced by a tidal river. Surprisingly complex groundwater flow patterns arose from plotting the hydraulic gradient series for each well triplet. Dynamics occurred at short time scales and spatial scales important to groundwater flow and transport, which are often entirely ignored when analysis methods require the assumption of average uniform steady groundwater flow. Plots of the gradient vectors from this study show that different flow paths result depending on location and distance from the tidal body. Plotted vectors describe groundwater flow paths that are wandering as compared to the average path. These wanderings occur at shorter time scales than that of the average gradient. Importantly, these wanderings contain gradient angles perpendicular to and opposite to the average gradient direction.

Development of Theory
The complexity of the flow system does not diminish our desire for simplified solutions to the transport equations in these systems. The “average” concentration is still a meaningful quantity with respect to exposure and transport to receptors. The equations below illustrate the potential use of the measured changing directions of flow applied to the two-dimensional transport equation.

Conservative solute transport in two dimensions can be written as Equation 1:

\[ \nabla \cdot \mathbf{D} \nabla c = 0 \]

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The dispersion tensors in Equation 1 are defined as follows:

\[ D_{ij} = \frac{1}{2} \left( \frac{\partial^2 c}{\partial x_i \partial x_j} + \frac{\partial^2 c}{\partial x_j \partial x_i} \right) \]

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Our measurement technique suggests a method of incorporating the impact of changes in direction. Assuming constant hydraulic conductivity \( K \), and effective porosity \( n \), and using the hydraulic data from the transducers allows us to write:

\[ D_{ij} = \frac{1}{2} \left( \frac{\partial^2 c}{\partial x_i \partial x_j} + \frac{\partial^2 c}{\partial x_j \partial x_i} \right) \]

CONCLUSION
Groundwater/surface water interaction can result in complex flow patterns that present a challenge to modeling the groundwater hydrology and contaminant transport. Our calculation of gradient changes in gradient over time illustrates the complexity of the system, and may provide a technique to predict both the average direction of flow and average concentrations in these inherently dynamic environments. In tidally impacted aquifers, or in areas with suspended changes in flow direction, extra care should be taken to evaluate the hydrogeological characteristics, such as hydraulic gradient and hydraulic dispersion. Continuous logging devices are suggested as a method to better understand the hydrology and interactions at time and space scales of interest.

REFERENCE
Heath R. C., Basic Groundwater Hydrology, WSP 2220, USGS, 1983