The ENIGMA Subsurface Observatory: A high resolution approach to studying a shallow contaminated groundwater system

A.D. Putt[1]*, (aputt@vols.utk.edu), E.R. Kelly[1], K.F. Walker[1], M. Newcomer[2], M.W. Fields[3], J.L. Goff[4], E.G. Szink[4], M.P. Thorgersen[4], F.L. Poole II[4], Y. Fan[5], J.P. Michael[5], P.J. Walian,[2] D. Ning[5], J.D. Van Nostrand[5], K.A. Lowe[6], M. Rodriguez Jr[6], D.C. Joyner[1], T. C. Hazen[1,6], M.W.W. Adams,[4] J. Zhou[5] A.P. Arkin[2,7] and **P.D. Adams[2,7]**

[1]University of Tennessee, Knoxville; **[2]Lawrence Berkeley National Lab, Berkeley**; [3]Montana State University, Bozeman; [4]University of Georgia, Athens; [5]University of Oklahoma, Norman; [6]Oak Ridge National Lab, Oak Ridge; **[7]University of California at Berkeley**.

http://enigma.lbl.gov

Project Goals: ENIGMA -Ecosystems and Networks Integrated with Genes and Molecular Assemblies uses a systems biology approach to understand the interaction between microbial communities and the ecosystems that they inhabit. The field to laboratory efforts of ENIGMA rely on high resolution field data to link genetic, ecological, and environmental factors to the structure and function of microbial communities. The ENIGMA SSO is a critical infrastructure under design to provide unprecedented spatiotemporal resolution for groundwater time series analyses. The SSO is a major component of ENIGMAs three-aim approach for integrating and developing laboratory, field, and computational methods.

The ENIGMA (*http://enigma.lbl.gov*) subsurface observatory (SSO) is a shallow subsurface study site being designed to investigate the spatiotemporal effects of subsurface perturbations. Once established, the SSO will feature a total of 9 boreholes in a 3 x 3 borehole configuration. Each of the nine boreholes will contain four separate wells screened to different depths. The deepest of wells will be in the saturated zone, two wells will divide the shallow saturated and variably saturated zones, and a single well in the unsaturated vadose zone. The multi-level design enables observations of parallel, hydrologically coupled wells oriented along a flow path. Tracking dynamics across the coupled locations will provide a more reliable estimation of differential dispersal forces and improved detection of the persistent and active subpopulations acting under the different local conditions. Once the physical infrastructure is established, the subsurface observatory will provide a spatiotemporal time series of unprecedented resolution.

The SSO multi-level design provides a physical infrastructure for investigations of depth-dependent changes in the biogeochemistry with a focus on the zone of variable saturation. The SSO will be established in a zone with strong stratification of taxonomic and geochemical composition and a strong impact of hydrogeological forces on vertical mixing and recharge within the variably saturated zone.

A three-dimensional model of the shallow subsurface was constructed from a grid of over 100 cone penetrometer pushes which has been used to identify zones of low and high permeability. The identification of high permeability zones has been used to guide the placement of the SSO wells as a part of the development of a high resolution subsurface observatory. A network of continuous monitoring water levels and a multiparameter sonde has indicated precipitation events as a major source of natural subsurface perturbation. Rain events not only increase the water level, but also increase the specific conductivity, dissolved oxygen, and pH. While local infiltration occurs over the course of hours, continuous monitoring indicates that over half of the recharge may come from regional infiltration transported in the underlying bedrock and fractured transition zone. This regional recharge may be a major mechanism of material transfer into the site and is supported by increased concentrations of contaminants and low pH measured in sediment samples collected above the bedrock transition zone. Flow rates from pump tests, slug tests, soil tests, and permeability estimates from the volumetric three dimensional model all share a high level of agreement that the average flow rates in the unconsolidated material are likely between 10^{-5} and 10^{-7} m/s. In total, this program aims to further select an ideal site with high similarity in sediment type composition, where well to well connectivity is highly probable, and where differential dispersal forces can be modeled.

This material by ENIGMA- Ecosystems and Networks Integrated with Genes and Molecular Assemblies a Science Focus Area Program at Lawrence Berkeley National Laboratory is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Biological & Environmental Research under contract number DE-AC02-05CH11231