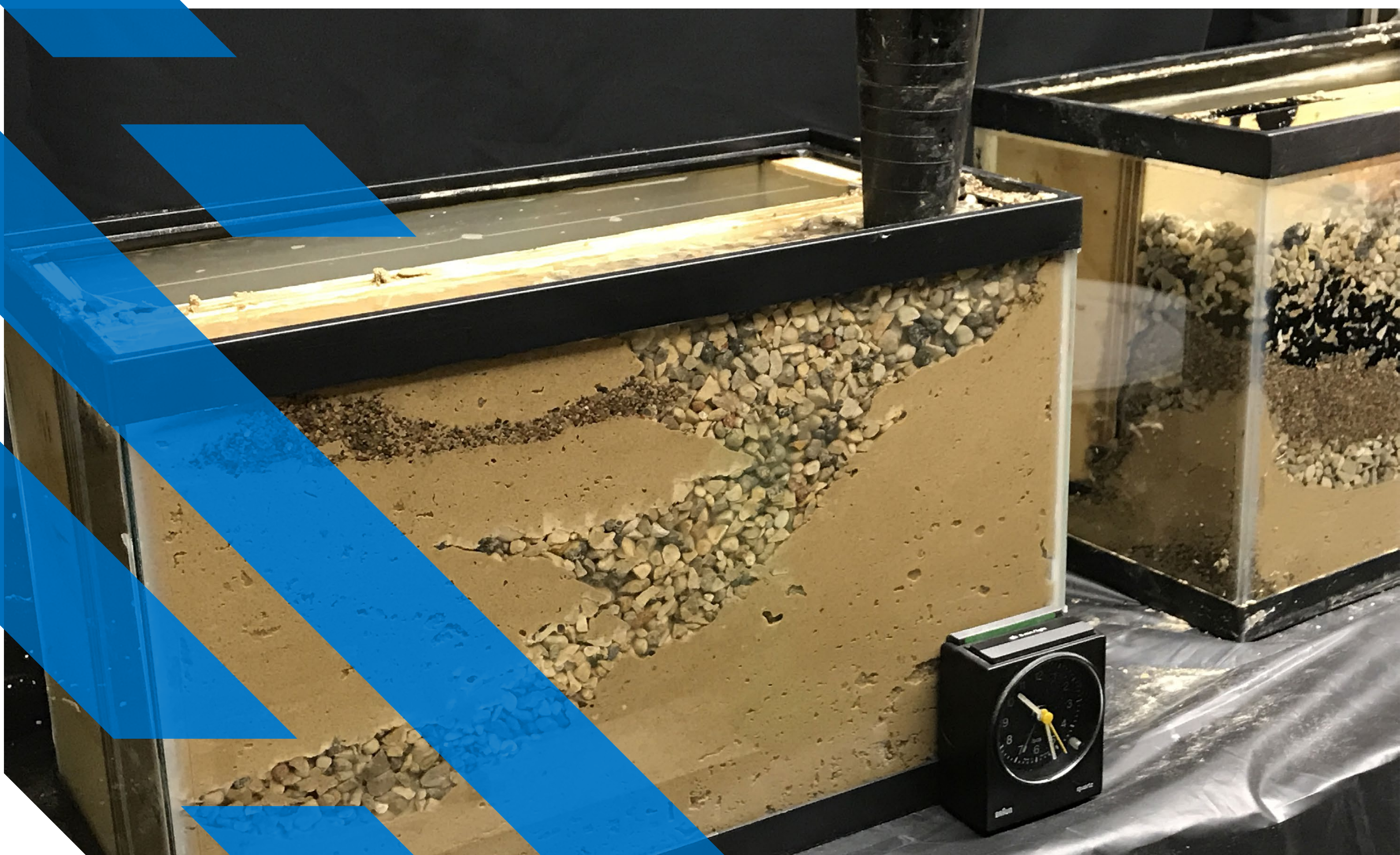
BURNS & McDONNELL

WHITE PAPER / **UNDERSTANDING 'SUBSURFACE PLUMBING'**

A BETTER PATHWAY TO CLOSURE

BY Colin Plank, CPG, AND **Gene McLinn,** PG

Many towns operated manufactured gas plants to generate gas used for lighting, heating and cooking. More than 3,000 shuttered sites remain, many with underground tanks that have leaked dense coal tar. As communities remediate sites, the biggest challenge has been figuring out where contamination has spread. Until now.



Between the mid-1800s and early 1900s, thousands of communities constructed manufactured gas plants (MGPs) to bring residents the then-new modern conveniences of heating and lighting. A century later, utility operators are struggling to achieve closure of these sites, where coal tar residuals have leaked from aging underground storage tanks into ground and surface waters.

Digging up and removing the old tanks is the easy part. The bigger challenge is understanding where the contaminants have gone. It has historically been difficult to predict where if they have migrated. As a result, many utilities and regulators face considerable uncertainty in remediating these subsurface contaminants.

To set and achieve remediation goals, they must first define the extent of contamination, estimate the volume of subsurface tar present, and evaluate potential Non-Aqueous Phase Liquid (NAPL) plume migration pathways and/or potential groundwater impacts, both on and off the MGP site. Understanding and conceptualizing the architecture of site porosity and permeability are key to making effective interpretations of subsurface conditions. Traditionally, that has required costly and often inadequate soil boring and water testing.

TAKING A PREDICTIVE APPROACH USING BENCH-SCALE DEMONSTRATIONS

But there is a faster, more economical alternative. By studying site geology and applying what is already known about how sedimentary processes have acted in similar geomorphic settings, we can draw a powerful predictive picture of subsurface conditions.

Although each site has unique characteristics, MGP owners can greatly reduce remediation uncertainty by understanding the stratigraphic characteristics of common depositional settings. Many former MGPs, for example, are located near rivers, estuaries and coastlines on sites chosen for the ready supply of water needed for the coal gas manufacturing process and transportation of raw materials. The sedimentary deposits in these environments are well understood in terms of typical dimensions, geometry, lateral and vertical grain size trends and stratigraphic connectivity.

HOW WE DID IT

Burns & McDonnell conducted the bench-scale experiments in six-gallon, glass-panel tanks that had been modified to include a wetting reservoir behind the model stratigraphy. Common stratigraphic scenarios were built using sediment in three grain sizes:

- **silt (~0.02 mm to 0.062 mm)**
- **coarse to very coarse sands (0.5 mm to 2.0 mm)**
- **fine to coarse gravel (2.5 mm to 4.0 mm)**

Once constructed, the wetting reservoir was filled with water, saturating the stratigraphy from the bottom up. While some of the stratigraphy was displaced during the wetting process, upward migration of silts was minimal.

After a brief period of equilibration, the water table was held static, and laboratory-grade coal tar with a kinematic viscosity of 500 cSk at 70°F and density of ~1.2 g/cm^3 was inserted into the top inch of the site stratigraphy. A volume of NAPL was allowed to flow downward into the saturated stratigraphy.

Time-lapse photography shot over a 16-hour period documented the results.

To guide the remediation of MGP sites, we took a nod from the petroleum industry, which has studied and conceptualized multiphase fluid behavior for decades. In this case, environmental scientists conducted a series of bench-scale experiments to identify the impact of fluvial stratigraphic characteristics on plume geometry and subsurface migration.

Contaminants variably migrate through and around fine- and coarse-grained layers that define a site's "subsurface plumbing." Through these experiments, our environmental scientists demonstrated that it is not only possible to predict what this plumbing looks like with very little new exploration but also how contamination will migrate and accumulate in those conditions.

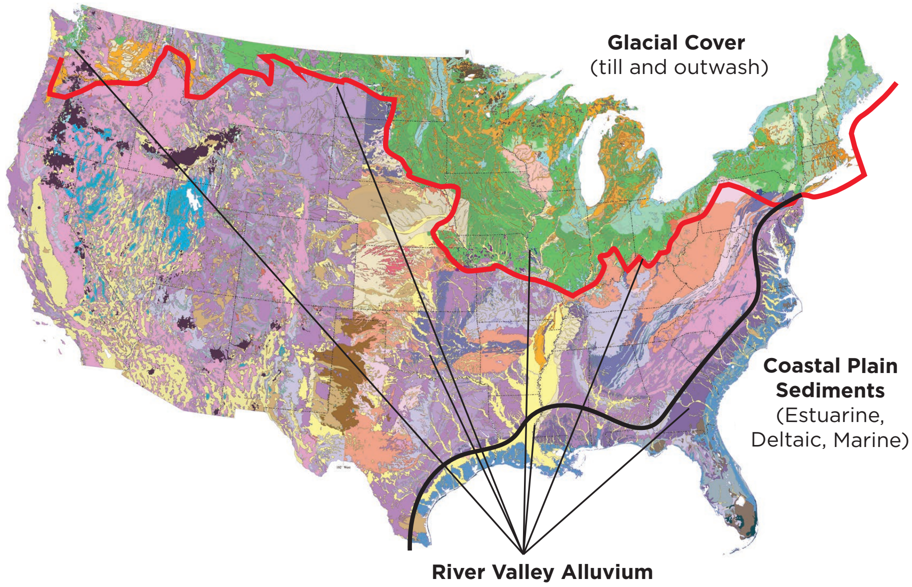


FIGURE 1: *Because the competent bedrock in more than half of the U.S. landmass is covered with fluvial, glacial or coastal/estuarine sediments of various ages, the results of these experiments have widespread applications.*
Source: Soller, D.R. and M.C. Reheis, 2004, Surficial Materials In the Conterminous United States. U.S. Geological Survey Open File Report OFR-03-275.

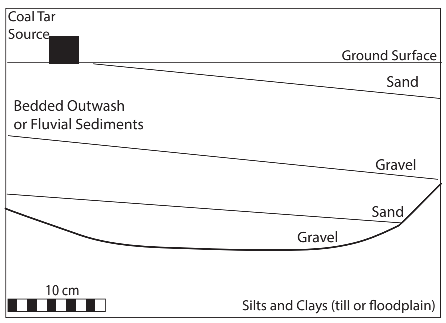
Using physical models, our environmental scientists assessed NAPL migration through a saturated subsurface in three common stratigraphic scenarios:

1. Sands over clay — which is comparable to glaciofluvial outwash over till;
2. Cross-bedded sands — which is comparable to point-bar deposits in rivers; and
3. Sand lenses encapsulated within clays — which is comparable to the "cut-and-fill" stratigraphy common in river valley sediments.

These scenarios were selected because they represent commonly encountered stratigraphy in fluvial, glacial and coastal/estuarine settings.

In fact, the competent bedrock in more than half of the U.S. landmass is covered with fluvial, glacial or coastal/estuarine sediments of various ages.

After using time-lapse photography to record the behavior and migration of the NAPL into the porous "aquifer" media, the scientists developed a summary plot illustrating the migration. By comparing the resulting plume geometries, scientists ascertained the relative impact of geology on NAPL migration.



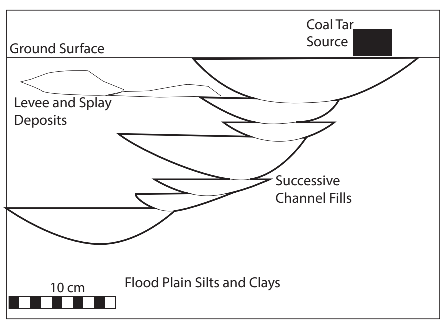


FIGURE 2: *Two stratigraphic scenarios were investigated: Dipping sedimentary beds (top) and overlapping coarse lenses of sediment encapsulated in finer materials (bottom).*

LESSONS LEARNED

These bench-scale experiments demonstrate that the arrangement of fine-and coarse-grained layers of sediment that comprise the stratigraphy does indeed define the "subsurface plumbing" through which contaminants move. They show that trends in grain size directly influence both the NAPL migration pathways and movement rates. They also suggest that, under relatively stable groundwater conditions, an NAPL plume head selects the largest available pore-neck as its preferred pathway. As a result, medium to coarse sand, despite being very porous, may still act as a barrier to NAPL migration if it is overlaid with medium to coarse gravel. This finding has important implications for vertical plume migration, given the cyclical nature of vertical grain-size trends in the majority of depositional systems.

The lessons learned from the bench-scale experiments can be used to create better Conceptual Site Models (CSMs). Leveraging these basic lessons, however, depends on a remediation team's ability to use the stratigraphic clues in their data to recognize the position of a given MGP site relative to the overall stratigraphy. A technique such as Environmental Sequence Stratigraphy,

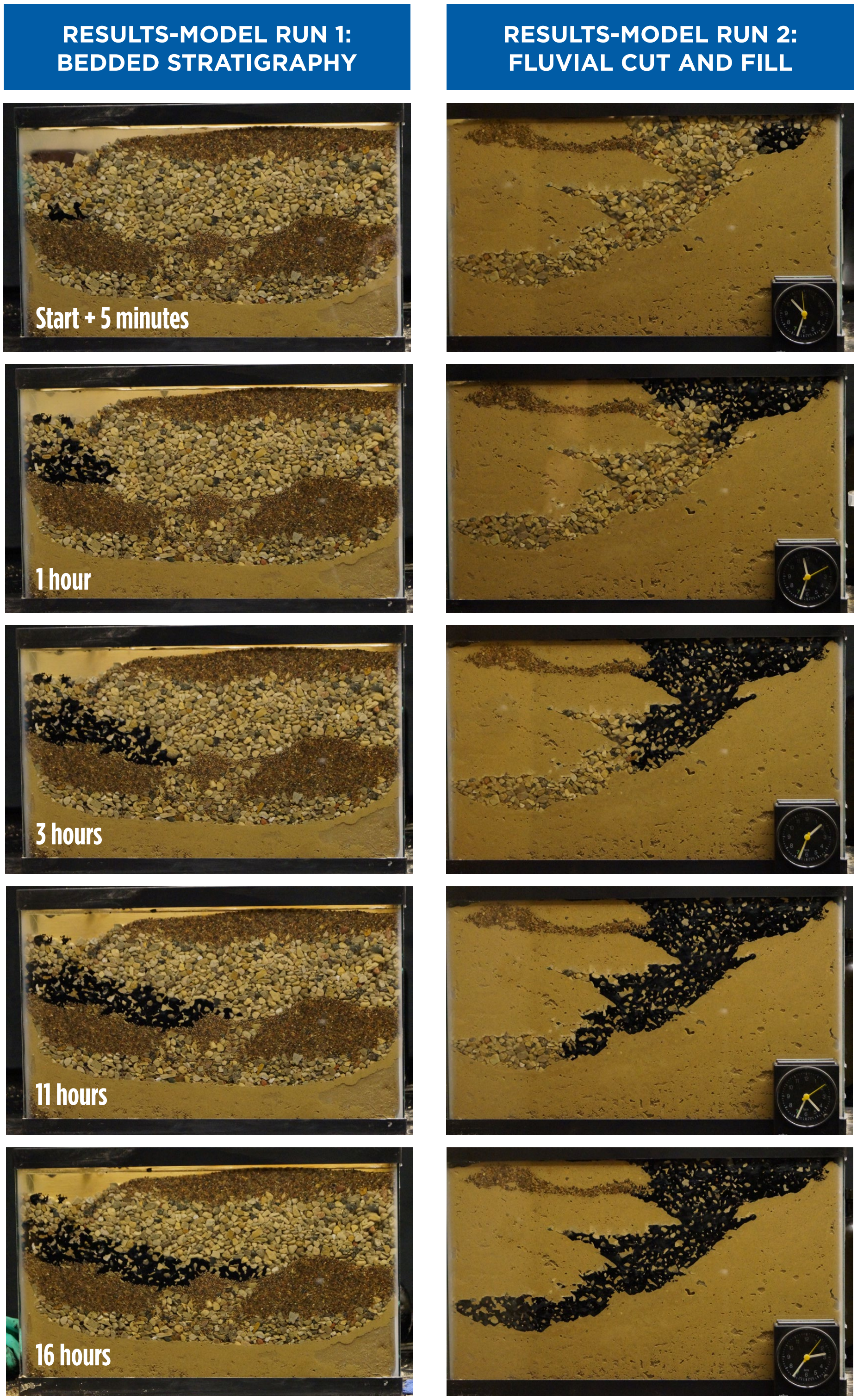


FIGURE 3: *Environmental scientists used time-lapse photography to plot the path coal tar residuals take through the fine- and coarse-grained layers of "subsurface plumbing."*

for example, is ideally suited for this task because it uses vertical grain-size trends, knowledge of depositional settings and reasonable modern equivalents to establish a CSM that is predictive in nature with testable hypotheses of grain-size distributions (or lithofacies) between and beyond data points. What's more, NAPL behavior, migration and plume geometry can also be predicted within this geologic context.

All are key to reduced uncertainty and improved understanding of project costs, risks and the pathways to closure.

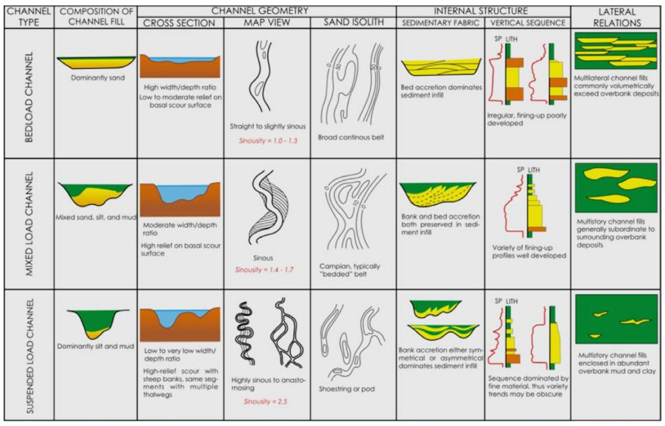


FIGURE 4: *By studying fluvial geomorphology and its relationship to the subsurface architecture and vertical grain-size trends, environmental scientists are able to compile and tabulate the large datasets needed to determine sediment body width-to-thickness ratios, typical depositional dips and other empirical and fundamental geometric relationships.*

BIOGRAPHIES

COLIN PLANK, CPG, has more than 20 years of experience studying geomorphology, stratigraphy, sedimentology and physical processes in both professional and academic settings. He has applied his experience as a stratigrapher and geomorphologist to conceptual site model (CSM) development, sediment remediation and contaminant transport modeling projects. Colin has been instrumental in developing and applying Environmental Sequence Stratigraphy (ESS), a geology-focused practice that defines the "subsurface plumbing" to maximize the use of site data to create CSMs that successfully guide groundwater remediation strategies.

GENE McLINN, PG, has three decades of experience in environmental consulting. He has directed or managed environmental investigations, site remediation and regulatory negotiations at over 100 sites in 25 states. His project management portfolio includes a broad range of industrial sites with VOCs and persistent organic compounds, pesticides, inorganic contaminants, and metals, as well as radiological and biological hazards. Affected media include soil, pore gas, groundwater, sediment and surface water. His experience includes developing and applying innovative methods to answer questions regarding contaminant fate and transport, risk, remediation, and site closure. Gene has extensive experience with evaluation of natural attenuation for organic and inorganic constituents, groundwater-surface water interactions, and contaminant source attribution. He has served as an expert witness in legal proceedings and has given invited presentations to industry groups and multiple state and federal agencies. For more than 15 years, he has focused on developing and testing remediation techniques to address sediment contaminated with non-aqueous phase liquids (NAPLs), such as MGP tar and petroleum products.

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