Contextual Engineering Leverages Local Knowledge to Guide Water System Design

Ann-Perry Witmer

Key Takeaways

The sustainability and durability of drinking water systems is as dependent on an understanding of place and people as it is on technical design.

The "why" of drinking water system operation (context) must precede the "what" and "how" (content) in design.

The expertise of drinking water professionals is only as effective as the awareness they bring to the design of the end-user experience.

US travelers to Ecuador could be predisposed to see the stripped bamboo home (left) as flimsy, and a nearby masonry home (right) as having relative wealth and power, although in fact the homes are comparable in affluence and status. © 2020 Ann-Perry Witmer. *Background layout imagery by Gil C, Julian Peters Photography/ Shutterstock.com*

In January 2020, a group of young engineers traveled to the coastal Ecuadoran community of El Guarango, a rural farming village of 350 people who buy drinking water by the bottle and cleaning/irrigation water by the tanker because no reliable supply of water has been found. The team's partners—Engineers Without Borders USA and the nongovernmental organization Engineers In Action, which is based in South America—provided a wealth of information about residential conditions, community identity, economic resources, and government oversight. Yet when they arrived, the team members found themselves in a very different reality from what they had expected. All the information they believed they had locked down and fully understood shifted beneath their feet as they moved from home to home, talking with residents and learning the realities of life in the tiny town.

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What changed? The information the team members had received was accurate, but the mental filter through which they processed it was laden with interpretations that had no relevance to life in the coastal plains of Ecuador, a region that barely three years earlier had been devastated by a powerful 7.8 magnitude earthquake. With only news reports, internet searches, and information provided by the partners to establish their understanding, the team members lacked the tools to grasp the context of the community, leading them to presume the solution to El Guarango's water needs was as simple as taking some measurements, installing some infrastructure, and instructing community leaders how to keep the supply flowing. Nothing could have been further from the truth.

"I don't think we were prepared for the kinds of questions people were asking, because we knew it was a small town and everyone knows each other, so we assumed everyone gets along, everyone thinks the same way," said Helena Beikircher, one of the team's project leads. "You really have to be open-minded that some people might say things you weren't expecting, and you can't assume that one person can represent everyone's opinion."

The team's co-lead, Ryan Lake, noted that while the residents appeared to live an isolated life in a rural area, they were well versed on the happenings of the world.

"They were talking about the wildfires in Australia and about President Trump in the United States," Lake recalled. "Before going there, I never would have expected having conversations like that." On top of that, Lake was surprised by the sophistication of understanding that community members exhibited about how to manage a water utility. "I expected some questions like, how are we going to get our water, how soon will it be available. But I don't think I expected so many people asking questions like, how are we going to make it an equitable system, or how it was going to work long term, not just whether," given the region's politics, "it would happen at all."

What flummoxed this team were the societal conditions that govern infrastructure use, not the infrastructure design itself. This is not an uncommon challenge for western water professionals working in nonindustrialized societies, leading to the emergence of contextual engineering, a new discipline that was developed specifically to address the shortcomings in technical professionals' understanding of nontechnical influences on their projects in the field.

The Basis for Contextual Engineering

Contextual engineering employs an investigatory process drawn from the social sciences to inform the technical designer, manager, and operator about place-based characteristics that often determine whether a technology will function as intended, satisfy user needs, and endure. It's an uneasy discipline for many technical professionals because it affirms that decisions regarding appropriate technology don't depend solely on the scientific knowledge of the practitioner; they must also consider the history, place, and people associated with the infrastructure.

While there's an academic definition for contextual engineering, the gist of applying context to technical infrastructure is expressed in the following imperative:

> Recognize that effective infrastructure design must consider community needs and conditions more than the designer's own experience and knowledge, and must acknowledge that the ultimate determinant of success is as much related to a designer's adaptation to local conditions as to the technology and technical knowledge itself.

This may be easier said than done, research has found, because technical professionals have training and experience that guide them toward rejecting an inexact, wide-ranging exploration in favor of the rigorous engineering problem-solving (EPS) approach. EPS is a convention taught by technical educators that advocates a straight-line design process that begins with a problem statement and ends with a solution while disregarding "distracting" conditions that might steer the designer toward a different approach. Contextual engineering, alternatively, follows an iterative, broad-thinking strategy that challenges the technical professional to overlay end-user predispositions with process design and operation.

The origins of contextual engineering lie within the study of water projects implemented by western practitioners in communities outside the industrialized world. One need not look far to find data on the frequency of water design failures in Central America, sub-Saharan Africa, or South Asia. Yet the technical analysis of why those designs fail typically lays blame on the technology user rather than the designer, using comments such as "The beneficiaries didn't maintain the system as they were instructed," "Components of the system were stolen and later replaced with ineffective equipment," or "The community wasn't organized enough to manage the finances associated with running a modern technology." It's interesting to step outside the engineering literature and explore sociological analyses of failed development efforts, many of which place blame on the engineering practitioner instead of the end user, with statements to the effect

Contextual Engineering Model Showing Considerations Associated With Effective Infrastructure Engineering

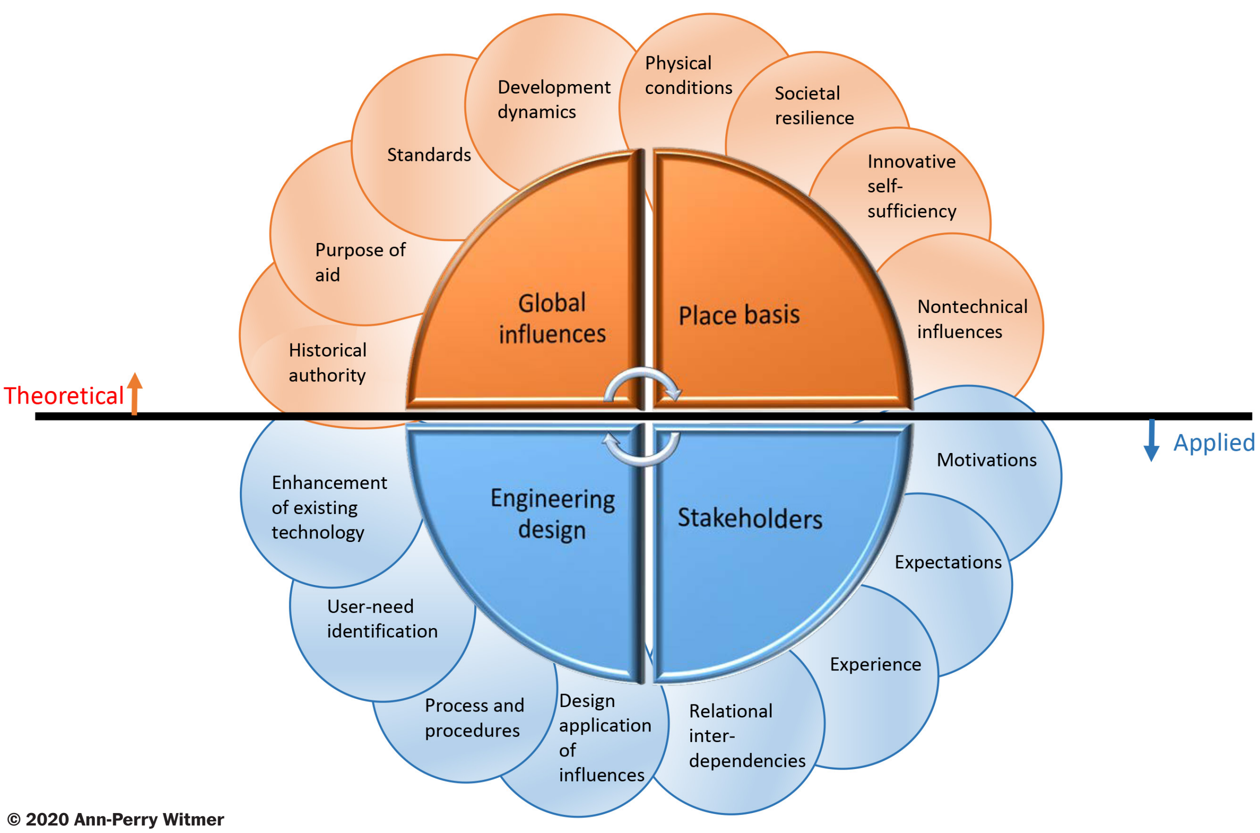

Figure 1

Simplified Contextual Engineering Model With Quadrants of Consideration

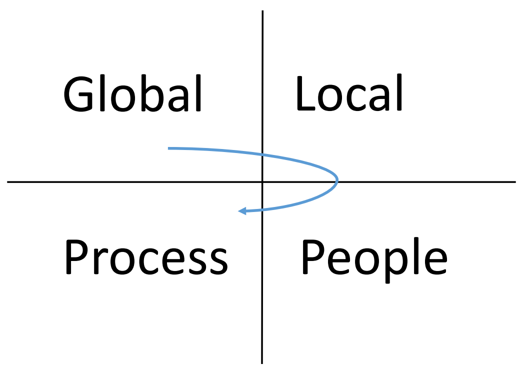

Figure 2

of "The program failed to recognize the hierarchical dynamic between men and women when assigning responsibility to the women of the community," "Imposition of democratic principles upon a society that perceives itself as fully functional without government representation can equate to colonialist control," or "An effort to encourage economic productivity may fail to recognize that the beneficiary society is not monetarily based."

To recognize the need for no-fault user assessments when working with technological applications, contextual engineering created a model that examines not just the technology (technical-based design and processes) nor the end users (human-centered design in light of stakeholder needs), but the impact of place (local geographic, cultural, and other conditions) and global drivers (socioeconomic, political, and institutional influences) that affect that design functionality as well. Figure 1 shows the contextual engineering model, with petals of the flower representing various areas of inquiry that contribute to an understanding of technical applicability. A simplified diagram of the model, shown in Figure 2, more clearly lays out the considerations as global influences, local conditions, people, and—finally—technical processes. This isn't a one-pass EPS approach but an iterative process that refines the solution with each pass around the cycle. Following this process forces the technical professional to consider not only what the infrastructure is intended to do but why it is designed for that purpose and how its users ultimately will adapt it to their own needs.

But do technical professionals think that way? Data from project research in the nonindustrialized world indicate the answer is no, primarily because technical professionals rely on their EPS training and disregard as irrelevant those conditions that are unfamiliar and often unfathomable. And this thinking plays out as much for design, operation, and modification of drinking water systems in our own backyards as it does for projects around the globe. So how do we build an understanding that allows us to use contextual engineering when preparing to design a technical solution for a client, near or far?

The Levels of Contextual Perception

The template that contextual engineering uses derives from studying a variety of engineering practitioners, from young volunteers to seasoned veterans, who have worked

Levels of Perception That Determine a Technology Designer's Understanding of the Infrastructure User

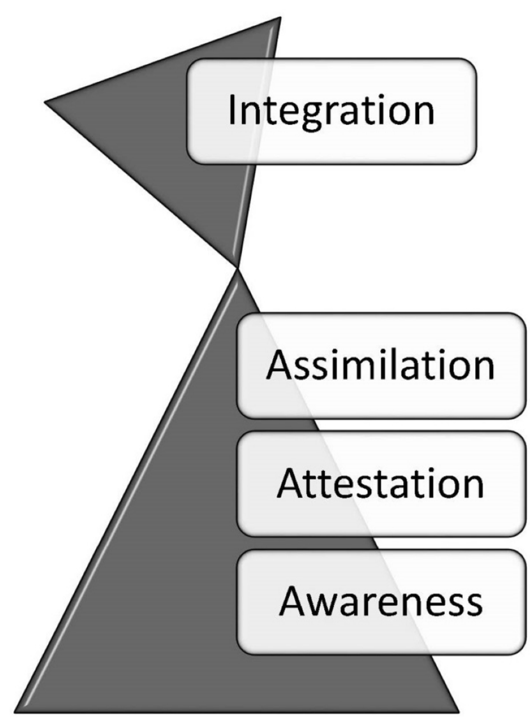

Figure 3

on service projects around the world. A depiction of relevant levels of perception, shown in Figure 3, illustrates the process of advancing awareness that is associated with understanding the particular context of a client or user.

As the figure demonstrates, one cannot create a technical design without awareness of need. This first level of perception is crucial but sometimes can be superficial, like the equivalent of saying, "I must turn off my faucet while brushing my teeth because children in Africa don't have running water." The second level of awareness requires a great deal more effort to achieve. Attestation occurs when technical professionals have in some way witnessed the need they seek to address, whether by visiting the client community or conducting sufficient research to believe they can describe conditions that may govern technology decision-making. For example, technical professionals who seek to incorporate ultraviolet disinfection into a treatment process but learn that direct power is not available at the treatment plant can attest to the unique conditions that influence design.

Five Critical Considerations That Influence Adoption and Sustainable Use of Infrastructure Design

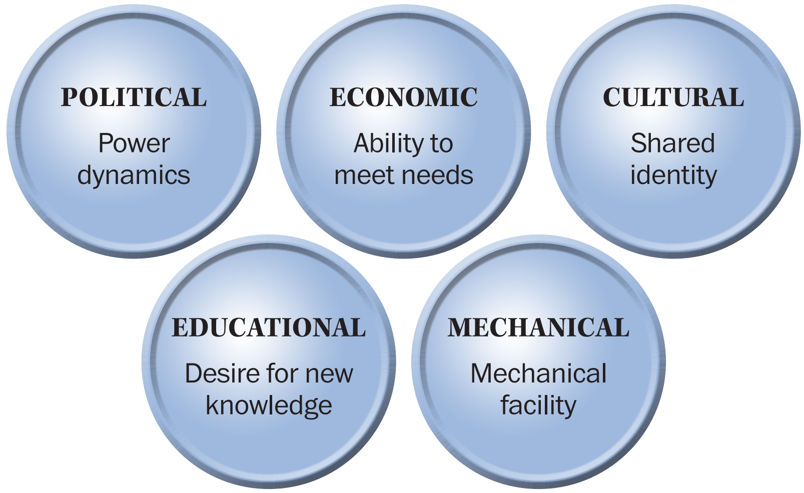

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Figure 4

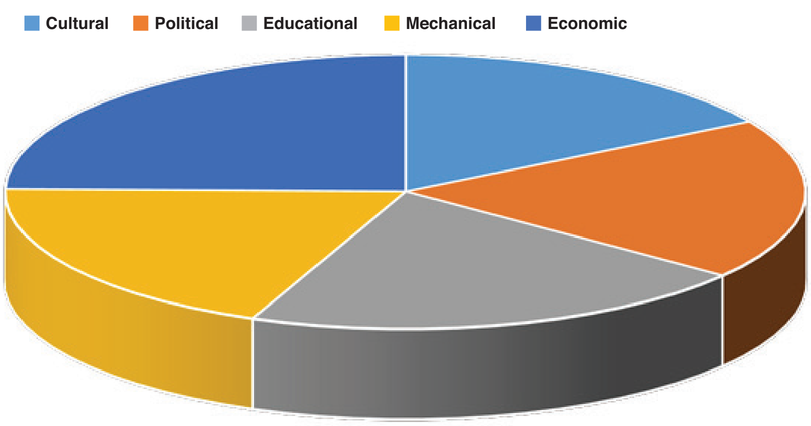
But with contextual engineering, attestation is considered perhaps the most dangerous level of perception in which technical professionals can reside, because it instills a sophomoric confidence of full understanding about conditions, even as those conditions are still being interpreted through the veil of personal experience. Photographs of two homes in El Guarango (pages 42–43), taken in January 2020 by the travel team, offer an example of how attestation can lead to misinterpretation of fact because of personal predisposition. Many of the homes in the community are built of stripped bamboo, which does not insulate the interior from outdoors and may appear flimsy. Nearby masonry homes, meanwhile, conveyed to the team from the US Midwest a sense of wealth and power, with brightly painted walls, grilled windows, and protection from wind and dust. The two houses shown in these photographs lie very near to each other. Both contain refrigerators, gas stoves, flat-screen televisions, and large sound systems. The residents of each home are comparable in wealth and power.

What the midwestern US team was unable to guess before talking with the homeowners, though, was that the masonry home was recently constructed to replace a structure that had collapsed in the earthquake, also destroying the belongings it housed. The bamboo home, much older and sturdier, had withstood the tremors and protected the residents with relatively little loss or damage. The residents of the masonry home lived under a tarp for more than a year while awaiting reconstruction of their house by the government. And the comfort level in the bamboo house far exceeds the masonry home, which becomes hot and stuffy in the equatorial heat of day. In fact, one who can confidently attest to the conditions of the community but fail to question their meaning could completely misunderstand the value of the bamboo house.

It is only through assimilation, or the ability to discard personal experiences, beliefs, and understandings, that technical professionals can fully understand the context of the client for whom they are working. And undeniably, assimilation can be a difficult and sometimes uncomfortable state of perception because it ignores personal values, beliefs, and understandings in favor of the client's operating system. Of note, the inverted pyramid at the top of the template in Figure 3 resulted from research that indicated technical professionals can sometimes immerse themselves in the client's societal system so completely that they integrate with a particular segment of that society, obscuring their understanding of the system in its entirety.

Example of Relative-Influence Mapping for El Guarango, Ecuador

Predictive Tool Results			
Influence	*Community Score*	*Country Weight*	**Weighted Score**
Cultural	16%	23%	16.5%
Political	19%	8%	19.0%
Educational	21%	32%	20.7%
Mechanical	20%	19%	19.1%
Economic	25%	18%	24.7%



Results from a predictive tool are based on project team's January 2020 site visit.

Figure 5

Assessing Technical Influences

One may say that perceptions and beliefs are all well and good, but how do they relate to technical design? Contextual engineering draws on the social sciences to identify five key influences associated with those perceptions and value systems that influence adoption, maintenance, and adaptation of technical infrastructure:

- Political
- Cultural
- Economic
- Educational
- Mechanical

Figure 4 illustrates the interpretations of these influences, which do not correlate directly with popular understanding of each term. For example, economic influence does not refer to the presence or absence of money but indicates how difficult it is for client-society inhabitants to meet what they consider basic needs. For many international locations, then, currency is not a marker of wealth, and the western notion of economic prosperity being related to acquisition of goods and services becomes irrelevant.

Using one of several predictive tools that have been devised to assist technical professionals in looking deeper at client conditions and predispositions, contextual engineering offers a methodology that calculates the relative significance of each influence to create a rough-scale societal blueprint. The blueprint for each client society assessed is unique to that society and provides guidance for decision-making on design criteria, including treatment process and materials selection, operational strategies, and financial constraints when developing and maintaining the system.

Figure 5 shows a calculated relative-influence outcome for El Guarango, based on results from international predictive-tool software, that was completed collectively by all six project team engineers after travel to the site. Results indicate that El Guarango is particularly influenced by a perceived lack of resources to meet basic needs, and cultural identity associated with the community is comparatively insignificant. Lake and Beikircher said they would have been surprised by that result before they traveled to Ecuador, because they had initially envisioned the community as a traditional Andean indigenous society with an ingrained identity and belief system dating back to the Inca Empire. But after spending a week exploring and interacting with the community, both project leads agreed that identity-driven considerations were far less important than affordability and equity to the residents of the town.

The Rocafuerte surface water treatment plant is fully staffed by trained operators and an on-site environmental engineer who monitor plant performance daily.
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Rocafuerte, the municipal water supply nearest to El Guarango, Ecuador, features a new surface water treatment plant with polymer coagulation, filtration, and chlorination.
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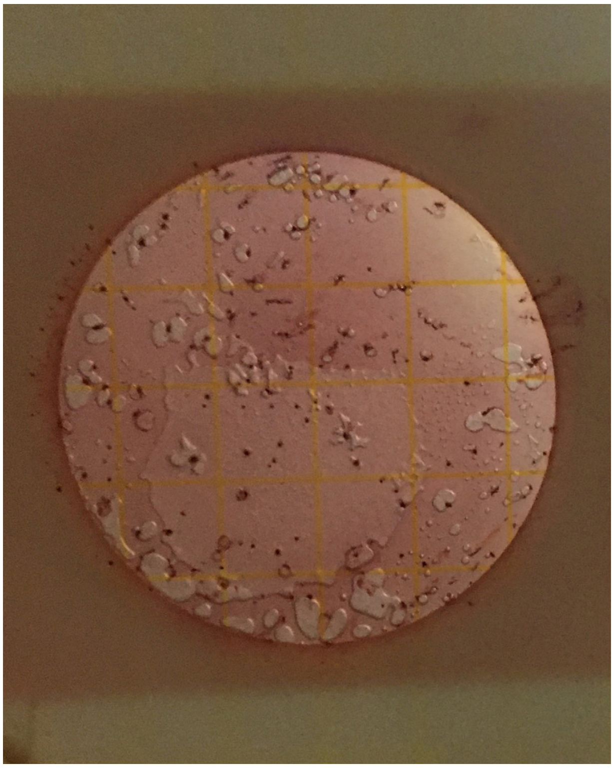
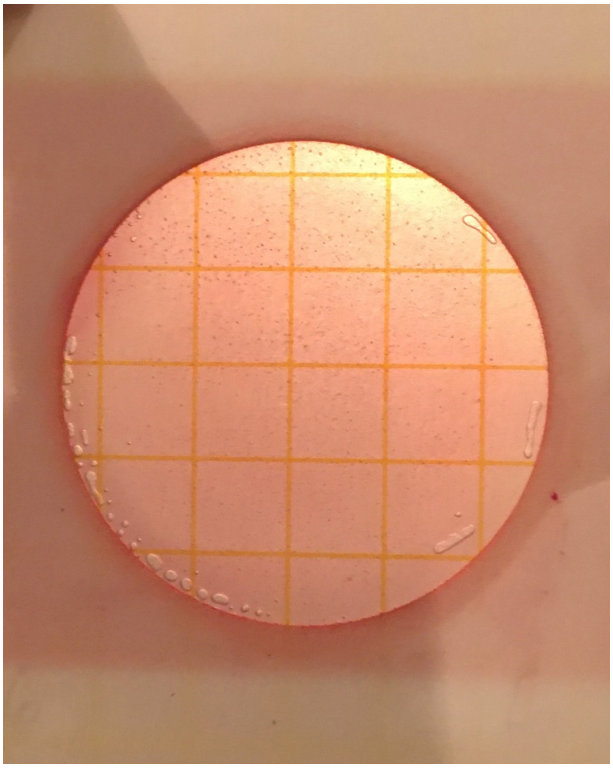
The Relevance of Standards in Context Perspective

While it's easy for technical professionals in industrialized countries to assume that technical design is prescriptive and driven by regulatory requirements rather than user identity, contextual engineering provides evidence that, even within technical standards, sufficient variability exists to determine the success or failure of a water system. We assume, for example, that water treatment facilities constructed in compliance with USEPA's Safe Drinking Water Act standards will produce a disinfected water supply free of harmful bacteria. Ecuadoran government agencies subscribe to this belief as well, and the municipal water supply nearest to El Guarango boasts a brand-new surface water treatment plant complete with alum–polymer coagulation, sedimentation, filtration, and chlorine disinfection. The plant (see the photographs above), which began operation only two months earlier, was fully staffed by trained operators and an on-site environmental engineer who monitors plant performance daily.

The plant's treated water is piped to a distribution tank on a nearby hill, where it is rechlorinated before release into the city's distribution system, serving both residents and industrial users. One of those industrial users is the bottling plant that sells 5-gallon carboys of drinking water to El Guarango, and village residents for the most part indicated to team members that they had sufficient confidence in the safety of their bottled water supply to drink it without additional treatment. So village residents were stunned when coliform testing of their drinking water using 3M Petrifilm plates consistently indicated that their bottled drinking water from the modern treatment plant was as badly contaminated with coliform bacteria as was the untreated water for washing and plant watering that they purchased for far less money from the tanker truck. In the photographs on page 50, compare the plate at the top with water from the same bottle, at bottom, that had been boiled for testing. The plates were used by the team as an educational tool to encourage community understanding of the importance of boiling water before consuming.

The Rocafuerte plant is modern and based on AWWA standards for drinking water treatment plant construction and operation, so what went wrong by the time the water reached the community? A contextual investigation indicated that the bottling plant did not maintain the same level of diligence in preparing its carboys for filling, which could account for the bacterial contaminants. The Rocafuerte community's age and the very recent emergence of the country as a westernized society suggest production standards precede hygienic bottling standards, so the most rigorous disinfection scheme instituted at the treatment plant may be undercut by the unhygienic practices in the bottling plant or lack of care in handling downstream. For the community of El Guarango, then, the US$30–$40 per month that most residents pay for their drinking water might easily be saved if they instead boil their unsanitized tanker supply, a lower-tech treatment process that will achieve a safer product.





Coliform plates indicate contamination of bottled water purchased by El Guarango from Rocafuerte water-plant supply before (top) and after boiling (bottom). *© 2020 Ann-Perry Witmer*

Place-Based Design Instead of Standards

The contextual engineering solution, then, is to resist placing confidence in a technical process simply because it works for a particular population in a particular place at a particular time. Rather, contextual research indicates that the nontechnical influences are the most critical determinant of whether a technology is appropriate, effective, and sustainable for a particular user. This is the point at which the El Guarango team members currently find themselves, and they're taking a different tack in assessing their options for delivering a safer, more affordable, more convenient water supply to their client.

"Our biggest issue going forward isn't the technology itself," said Lake, reflecting on his team's thought process as it dives into technical design. "We're going to have to deal with the varying level of trust in the water, because our assumption—that everyone trusts any water supply we can find—was wrong. We had heard there was no water near El Guarango, but there actually is a lot of water. We just have to deal with how to get access to that water, how we can make sure everyone has trust in their water, and that it's distributed fairly."

About the Author

Ann-Perry Witmer is a research scientist with the Applied Research Institute at the University of Illinois, Urbana-Champaign, Ill. She is also a lecturer in the College of Engineering; College of Agricultural, Consumer & Environmental Sciences; and Carle Illinois College of Medicine; awitmer@illinois.edu.

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AWWA Resources

- Water Shortage Challenges and a Way Forward in India. Chakraborti RK, Kaur J, Kaur H. 2019. *Journal AWWA.* 111:5:42. https://doi.org/10.1002/awwa.1289
- Solar Energy Powers Remote Water Systems. Patterson C, Maldonado C, Sinha R, et al. 2018. *Opflow.* 44:6:24. https://doi.org/10.1002/opfl.1022
- North American Delegation Benefits From Water Education Mission to Israel. Martin B. 2019. *Journal AWWA.* 111:8:83. https://doi.org/10.1002/awwa.1348
- Cut Drinking Water Arsenic Levels Using Best Removal Strategies. Odell LH. 2016. *Opflow.* 42:6:26. https://doi.org/10.5991/OPF.2016.42.0035

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