Identify and Inform: The Process of Bridging Information Gaps Utilizing Technology

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ABSTRACT

Globally the amount of water is finite. Tensions over water have increased as more gain awareness of the issues. The innate value of water is increasing as security of access for individuals is becoming more vulnerable with urbanization, industrialization, and increase of use. Acknowledging this truth in the private and public sector is the first step in working towards consistent and reliable water infrastructure, even in the most undeveloped.

In the municipality of Verón, near the east cost of the Dominican Republic, perceptions associated with water quantity and quality issues are commonly held. The way the water in Verón is accessed is primarily through mechanized wells, or *pozos*, which draw water up from an aquifer reserve. Although water quality is a concern, this research project took a bottom-up approach that established a comprehensive database of *pozos* within Verón. The objective was to better understand spatial distribution of points of access and their characteristics, such as: if the well was open for community usage, the age of wells, how many homes had direct access to each individual well, and how many days a week is the well accessible. With a team of local youth, this research inventoried household level water points in 19 out of the 24 sectors of the Verón municipality and captured GPS points, photos, general characteristics associated with each water point.

In pairing the collected information with technology as a tool for assessment, a comprehensive understanding of the water narrative was gained. Using spatial models, GIS maps were created to then disseminate the data to decision-makers in the region, which included local community leaders within the sectors; the mayor of the municipality; and private-sector interests in the region.

The intention of this study is to assemble a base layer of information for water-related infrastructure in the region, to conduct appropriate spatial analysis on the data, and to communicate this analysis in written and spatial formats to the key decision-makers in the region, so that decisions working towards fruition of SDG 6 are be based in the realities of the existing conditions.

Introduction

Within developing countries, issues of water quality and access are a common discussion. The simple answer is to modernize the infrastructure and management of these developing systems to ease tension in the natural process, but it is often a mistake to create a solution that is disconnected from realities on the ground. Westernization is not always the best response, especially when a situation is not fully understood. In our tendency to fix perceived problems as quickly as possible, the lives of those impacted might not actually improve. In the face of failure in planning and sustainability, most often, ignorance is staring back. In order to competently answer the questions of water quality and access, the current state of the issue in relation to each specific region has to be understood. Historically, the white response has been identified as the right response, with complete disregard for cultural context or the priorities of local stakeholders. In hopes of encouraging stable development with a more positive cultural concern, the United Nations formulated the Sustainable Development Goals (SDGs). These 17 goals balance all three pillars of sustainability: economic, environment, and social in "areas of critical importance for humanity and the planet" (SDGs: Sustainable Development Platform).

Put into effect in January of 2016, the SDGs have been a guiding force for global development and guide policy, nationally and internationally. The sixth SDG, "ensure availability and sustainable management of water and sanitation for all," has been key to the formulation of this research project (United Nations). This SDG's influence has grown as defining the current state of water, sanitation, and hygiene (WASH) and initiatives moving forward. Decades before the SDGs were created, the Joint Monitoring Program (JMP) between WHO and UNICEF has been researching and collecting WASH data since 1990 (United Nations, Water). As an organization, JMP provides data on WASH globally, broken down to a global,

regional, or national scale. An interactive online database through JMP provides the most recent WASH data, as well as capabilities to look back in time at previous year's data on drinking water and sanitation. All of the monitoring data collected by JMP and its affiliates can be found at WashData.org, but despite the availability of the data, it is not exceptionally accessible. The interface is challenging to navigate, especially to one with a lower educational level or technological literacy. The spatial component of this database does very little to enhance understanding, particularly in a specific area of concern; data is broken down by country but not providences, which creates issues in accurate data on smaller scales due to generalization. Rural and urban areas are identified, but inequalities within only rural or only urban areas are overlooked because of the averages created.

Filling the gaps in JMP's data, the Rural Water Supply Network (RWSN) compiles reports based on findings through JMP that goes further into what this information means for rural water services. Although the study site of Verón, Dominican Republic, right outside of Punta Cana, is rapidly developing, it is still a rural area and the RWSN's report can give some simple insight on what water services and outcomes look like in this municipality. Based on JMP and RWSN, we know that the Dominican Republic is part of the "89% of the global population that uses at least a basic water service" (Rural Water Supply Network, 2017). A basic water service is defined by one's proximity to a source, under 30 minutes away, but to qualify as basic the water can be intermittently accessible or even contaminated with fecal or priority contamination (JMP). Most of the Dominican Republic, 94.48%, has access to basic drinking water but that doesn't mean that those 9,946,916 people are drinking water that is of a safe quality and the specific, location-based data does not exist to isolate problem areas of contamination (JMP).

Despite the pervasive collective body of work from both organizations, JMP and RWSN, there is no information from La Altagracia, the providence in the DR where Verón is located. Due to the lack of understanding about the water narrative of Verón, informed decisions are impossible. There is no right answer when a spectrum of what is working, or what is not, does not exist. For decision-makers to formulate a plan to provide water to this region, localized data needs to be collected. There is a major gap in the breadth of information that exists and the ability for a local stakeholder to understand their particular regional issues, specifically relating to water. This relationship becomes complex within the region because of the ecotourism industry that is largely contingent on water availability, quality, and its derived natural beauty. In focusing on localities, and including a GPS component of an extensive private and public well research project, a more relevant body of background information on the water services in Verón was complied to help inform decision-makers in working towards fruition of the sixth SDG.

Background

Up until about 50 years ago, the Punta Cana region of La Altagracia providence was mostly uninhabitable jungle. One of the many reasons why there is so little information on the area is because it was practically inaccessible, and most certainly undesirable. There was not even road access to this particular region, but all was changed when 30 square miles of undeveloped land, covering 5 miles of coastline, in La Altagracia was purchased in 1969 by what was to become Grupo Puntacana (GPC). The conglomerate of GPC has grown to establish Punta Cana as the of the most visited destination in the Caribbean and now oversees the Punta Cana Resort and Club (PCRC), Punta Cana International Airport (PUJ), an international school, tourism services, and a range of permanent and temporary accommodations for all kinds of tourists (Grupo Puntacana History). A trademark of GPC and all affiliated branches is it's dedication to sustainable tourism and through the Grupo Puntacana Foundation; an extra step is taken in establishing corporate social responsibility programs. The connection between GPC and Verón is established in proximity, but a relationship between the two entities has been fostered by initiatives spearheaded by the Foundation. As the people of Verón are shuttled into resorts, such as PCRC, funds are allocated by the Foundation to create programs and facilities benefiting those who live in Verón, such as free pediatric clinics, basketball courts, and school supplies. This symbiotic relationship benefits both parties and is one of the many reasons why GPC is a benchmark in sustainable tourism and development internationally.

Within this relationship are many shared natural resources that need to be stewarded responsibly by both members of the ecotourism industry and people living in the surrounding communities. The dynamic nature of water resists conforming to any kind of boundaries. When discussing the water systems of Verón, there are two end sources of groundwater that can be

address: water that remains within Verón to be used domestically and water that is piped out of Verón to be used by businesses within the tourism industry. GPC is the only company with a well field within the boundaries of Verón and because of this, the groundwater system diverges on quality and quantity because of the multiple pressures from inside and outside of Verón. Pollutants from Verón can taint the water supply that is pumped to PUJ or overuse from a well that belongs to GPC's well field can lower the water table enough to limit access for people living in Verón. In order to understand the water narrative of this area, not only is a survey of the existing survey necessary, the physical landscape needs to be known as well. Because of the lack of information available through JMP, RWSN, or other research entities on this particular area of the Dominican Republic, it is important to look at management practices and environmental factors of similar landscapes throughout the country and even the entire island of Hispaniola.

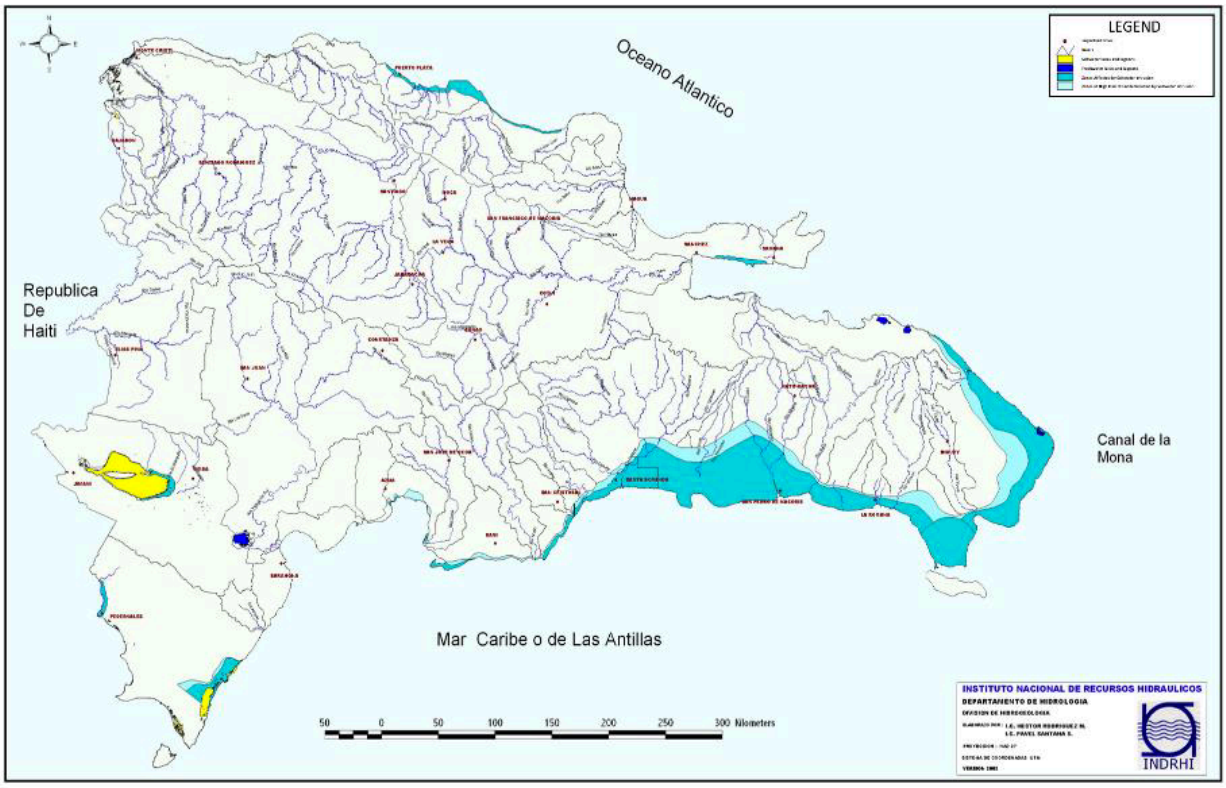
The VisiEAu 2018 water summit in Part-au-Prince, Haiti provided information on the water management within Haiti, as well as across the border, that was used in gaining intel on public perceptions, challenges, and main objectives in moving towards sustainability. Université d'etat d'Haïti (UEH) held the summit in partnership with the University of Florida (UF) and parties throughout the private, public, academic, and non-profit sectors were represented in sharing topics not only specific to the Haitian context, but exploring the importance of "data systems through the integration of technologies can better support integrated water management in Haiti (Widmer, 2018). One of the most important overarching themes of the summit was the fact that there is enough water in Haiti to serve the needs of the population, much like in the Dominican Republic. Water as a renewable resource can be inexhaustible, but is currently being inadequately distributed and poorly managed. If inefficient practices can be identified and

reconfigured based on data-supported information, there is opportunity for tensions in supply versus quality to be eased as both countries work towards seeing the sixth SDG reach fruition.

This discussion in Haiti lead to a higher understanding of the process of drilling into aquifers to collect groundwater and then the subsequent recharge on the island, a foundation of which is necessary to properly manage these water resources. These wells, referred to as *pozos* in the Dominican Republic, are drilled to varying depths, just until water is reached. In tapping into these aquifers, the water table, the level of water underground stored in the aquifer, is lowered in the process of drawing up groundwater for use within the home for cleaning, cooking, or bathing. The aquifer is naturally recharged or refilled as water percolates through surface ground layers. This process is sped up through the porous nature of the limestone ground cover in the Dominican Republic, which can contribute to issues of water quality, especially in low-lying areas. Gravity flow controls surface water bringing it to pool in pits or caves used to discard of trash or human waste. Other pollutants are collected before the water even reaches these areas of low elevation and quickly runs through the rocky surface layers with little opportunity to filtration. The geology of the island, specifically what is seen in Verón threatens the quality of water in the aquifer by introducing a wide array of contaminants in the recharge process.

In the limestone foundation of Verón, the integrity of the aquifer is not only threatened in contamination from anthropogenic pollutants. The coastal location of Verón causes large concern for saltwater intrusion, creating an aquifer reserve that skews towards brackish opposed to the ideal, natural freshwater state. As the water table diverges greatly from the sea level, the gradients due to gravity and varying concentrations of chemical compounds causes the salty ocean water to osmose and penetrate into the aquifer. The fluid nature of water causes a fluid

nature in the aquifer's state. As illuminated in VisiEAu 2018, it is critical to monitor aquifers as the quality and quantity of groundwater can change with urbanization, population, and pollution.



Map depicting coastal zones in the Dominican Republic as being particularly vulnerable to saltwater intrusion (Salwater Intrusion in the Dominican Republic, 2002).

Recognizing the crossover between actions aboveground and water quantity belowground, the private sector, specifically GPC, is necessary for the proactive understand of the vertical as well as the horizontal. Acknowledging the proximity of Verón to their well field, this water management study was necessary to ensure longevity of their shared aquifer. Much like most sustainability financing, an upfront cost sees a lucrative return on investment over time. The vitality of the region relies on the tourism industry, which is maintained by the people living in

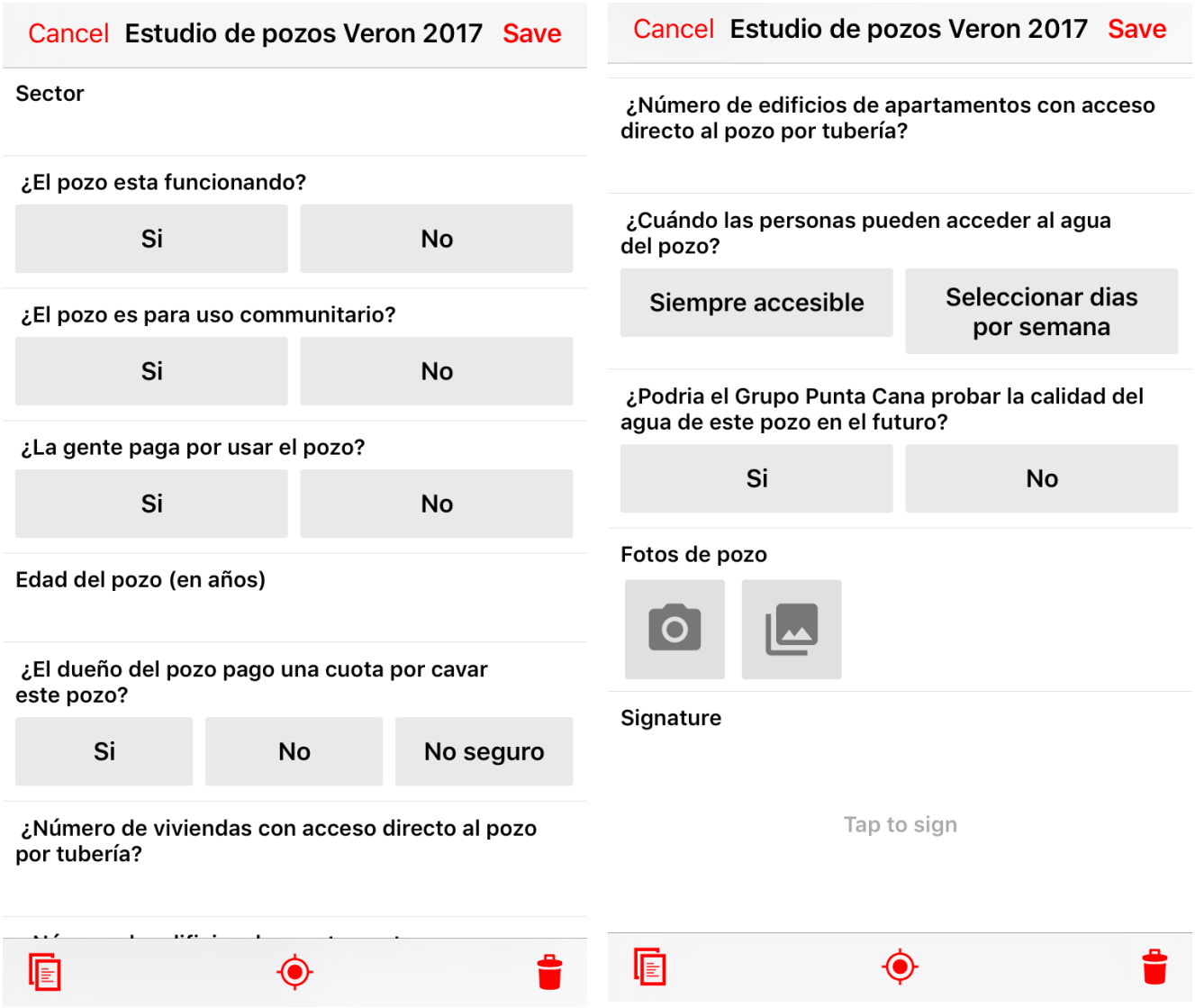
the surrounding Bávaro-Verón communities. This entire industry is only sustained by the availability of water to tourists and people living around them. The well field of Grupo Puntacana is not only the "life blood of PuntaCana Resort and Club," as described by Vice President of the Ecological Foundation, Jake Kheel, but also the lifeblood of the whole ecotourism industry in the region. Every person within Verón, every tourist visiting any of GPC's properties, every traveler coming through PUJ (which in itself accounts for 5.9 million people) is receiving water from this same aquifer (Punta Cana International Airport). And although there might be enough water available to serve all of these people, there are valid concerns about whether or not that would be possible with the current water narrative that occurs within Verón. Technology is proving to be critical in both the data collection and sharing processes. As aptly described during VisiEAu 2018, "decisions informed by data lead to better actions, while also creating a layer of accountability among those who make community-based decisions" (Widmer, 2018). Improved data sharing strengthens public and private partnerships. Technology grants access that has been previously unimaginable and the information spread in this rise of capacity has incited knowledgeable decision-making—one of the many building blocks on the way to sustainability.

The research site of Verón is a rapidly developing, informal municipality outside of Punta Cana, Dominican Republic. Because of the cultural distinctions between different sectors within Verón as well as the speed at which the infrastructure was built, there is huge variation between water systems and management within Verón. The disconnect between the water narrative that exists in Verón and potential improvements stems from a lack of knowledge in what really exists. In order to understand the water crisis regionally, a baseline of knowledge had to be formulated. By utilizing technology, a large scale of data was collected in coordination with all

sectors of Verón. In community partnerships and working in conjunction with a social corporate responsibility foundation on the ground, cultural differences could be bridged between researchers, those working in the tourism industry, and the low-income peoples of Verón. In efforts to identify the current water narrative of the region, researchers utilized technology to compensate for the limitation of other resources on the ground. This information was then used to complete and analysis of sustainability of the water system in relation to the sixth sustainable development goal.

Methods

In partnership with GPC's Foundation, the purpose of this study was to utilize technology in answering the question of what water infrastructure exists and how that information can be made accessible to ensure informed decisions in the future. Within the resource-limited context of Verón, one of the most valuable assets in this study was anecdotal data that came with working on the ground and understanding the undocumented environmental, social, and cultural stressors on water quality and quantity. Understanding the cultural context was integral, especially within the context of this project of directly asking questions to gather information. Utilizing the access to surveys and other work done by Dr. Jocelyn Widmer in previous years, unknowns within Verón's water system were prioritized to create a survey using the mobile surveying app, Fulcrum. A survey was created in English targeting information such as how old wells are, how they are managed, when they are accessed, how many homes or apartments they are connected to, and if they are even functioning at all. In addition to this quantitative data, the GPS position and photo of each well point was recorded within Fulcrum. Once the commissioners of the project from GPC's Foundation added questions to target information specific to the region and approved the survey, the final product was then translated into Spanish and tested within Fulcrum to ensure ease of use.



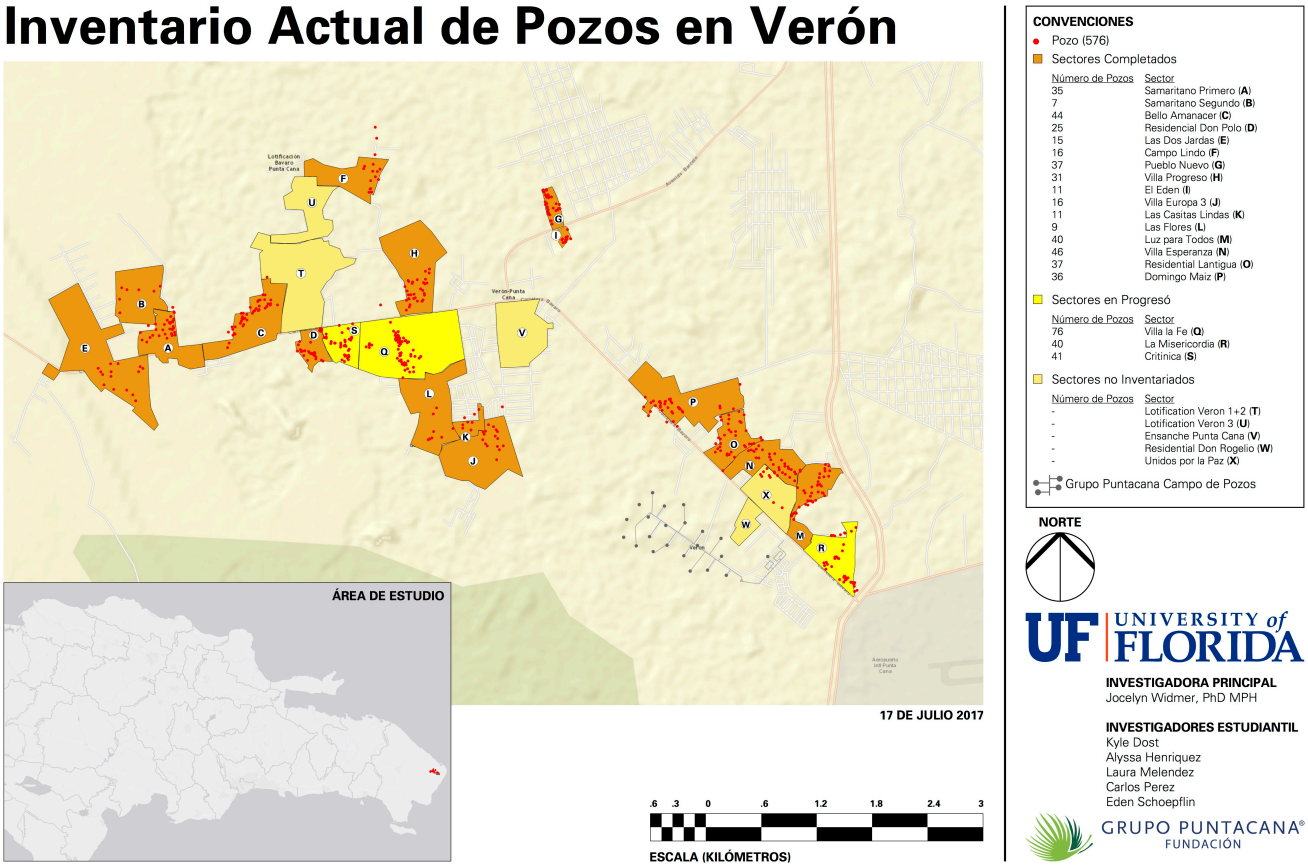
Community Survey in Spanish, Developed on Fulcrum App

Because of the culture differences between researchers and the people of Verón, it was necessary to include locals in data collection. Through a process of connecting with community leaders and then, through them, engaging youth, the survey was administered by adolescents between 13 and 20 years old from the communities of Verón. Without engaging community members, it is likely our survey responses would have been altered by biases and hesitations of full transparency. With a team of 12 youth and 6 tablets equipped with Fulcrum and accurate

GPS locating, over 600 well points were collected across 19 of the 24 sectors in Verón over a one-month period. An estimated 250 well points are left undocumented in the municipality as 70% of wells were captured within Verón in this project. Using a systematic approach of sweeping sectors, based on previously collected boundaries, an accurate representation of existing wells. A huge benefit of using Fulcrum was that we were able to see collected data in real time on a map within the mobile app to guide our progress through sectors but also as an engagement tool when validating our purpose to community members questioning our presence.

Upon completion of surveying, limited by time and willingness of community leaders to partner with us, the collected data was then exported from Fulcrum as a geodatabase to plot the GPS location of each well point recorded. Once the spatial distribution of wells were available visually, the variation in water access and management between sectors, especially because of the variation in population densities, was distinguishable. High-resolution maps were created documenting the borders of each sector and the wells within Verón. From these baseline maps, discussions among stakeholders in local government and the tourism sector about a regional water system have been better informed. By just producing a map of wells, information that was previously estimated was documented with clarity and accuracy.

From the first map created, an understanding of the situation in Verón was gathered that did not exist previously. Before any data analysis was completed, this information caught the attention of President Danilo Medina of the Dominican Republic. Even if some similar data was available, it was not categorized efficiently or accessible. In using GIS, this data was organized by each well point's location first and foremost. Related water management and infrastructure could be gathered from our data, but the mapping created an idea of what is going on within the communities that is vital for decision makers who are disconnected from the region.



First Map Produced for President Danilo Medina, July 2017

Throughout this entire project, technology was the fundamental building block. Precise GPS points were only able to be collected because of the location services provided by the tablets used. WhatsApp allowed constant communication between researchers and the team of youth helping. Without Fulcrum, the quantity of surveys collected would have been impossible and being able to track data collection spatial was invaluable to covering every part of each sector surveyed. Through technology, the dynamic nature of water and water management was captured and prepared to then spread widely and quickly through various interfaces.

Results

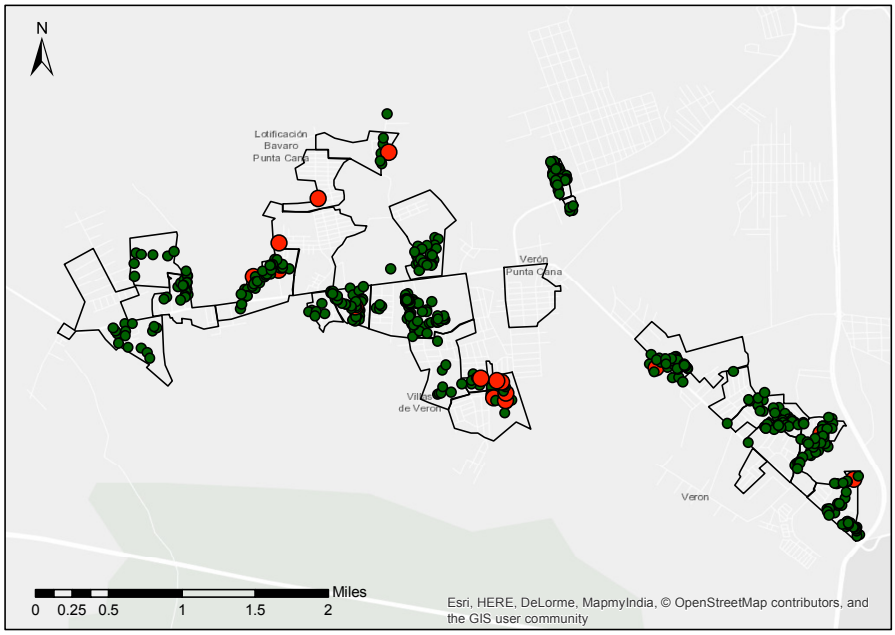
Through this project, a definite number of wells within Verón was established. Not only were GPS coordinates of each water point recorded, but also related details of each well were included in a survey. In walking the communities and talking to leaders during previous visits to Verón, a general estimate of wells was formulated but was only conjecture until this project when hard data was collected. With the wells displayed spatially, the uneven distribution of wells throughout Verón was obvious. Because of different management practices between sectors, Villa la Fe had more wells than anywhere else, but there was also a wide range of distribution within Villa la Fe and all other sectors as well. The wells layers pretty closely with more densely populated areas, but due to the porous limestone foundation of Verón, these wells are slowly creating cones of depressions in these well clusters and threatening the system of aquifer recharge. Density was assessed not only from the wells but also data from previous projects with Dr. Widmer that assessed basic demographics of Verón. By combining the hot spots of wells and population surveyed, the overlap of density shows areas of Verón that are most populated. In these populous areas, more wells are being drilled, which could actually add more tension to the groundwater system.

Visualizations

These results were the basis of further analysis, but in looking at the information available from the similarly situation country of Haiti, large gaps of what information does not exist were exposed. In working with GPC's Foundation, the emphasis on social corporate responsibility spurred on this obligation to not only answer the questions of GPC, but to inform local decision-makers as well. The first objective in the analysis of this data was to create a spatial representation of the data. In utilizing GIS, comprehensive maps were produced of the entire

study area. From there, key characteristics of the wells were identified which reveled that Verón is dominated by younger wells and new development. 97% of the wells that exist in Verón are functioning, but only 22% are for community use. The sweeping majority of these wells serve five or less homes and only one apartment building. In understanding the baseline of what exists, decisions can finally be informed by realities of best management practices in working towards sustainability. This computer software enable visual representations of the area to be changed quickly and having all of this data, hopefully available online, will allow decision-makers to target specific needs of their community in information acquisition.

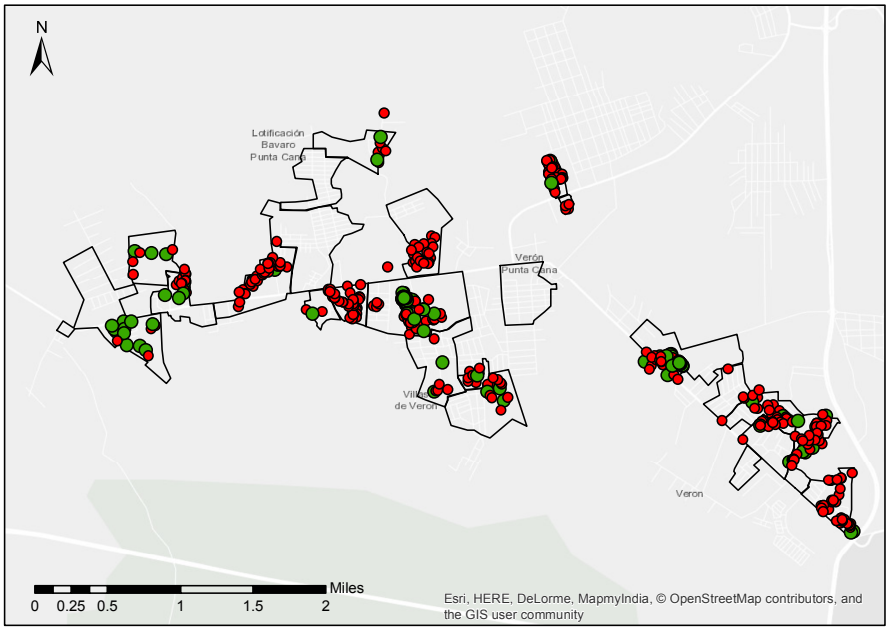
Wells in Veron, Dominican Republic



Is this a functioning well?

- Yes
- No

Wells in Veron, Dominican Republic



Is the well for community use?

- Yes
- No

Map Created By: Eden Schoepflin

Data Collected by Eden Schoepflin in Veron, Dominican Republic

Environmental Concerns

When discussing the sustainability of water management practices, specifically in Verón, the surrounding environment incites many concerns. Without factoring in any other geological features, the physical location of the study site already puts Verón at a disadvantage environmentally because of the high risk for saltwater intrusion. As urbanization and the spread of Verón increases, so will deforestation and the rise of impermeable surfaces. As can be seen below, there are still large concentrations of trees and green space surrounding Verón, but at the rate of growth in Verón, the landscape will be dramatically changed in less than ten years. Because of the economic vulnerability of the Dominican Republic, people are migrating to this area in masses to partake in the job opportunities offered by the tourism industry surrounding Punta Cana. This increase in national and international traffic in La Altagracia will only put more stress on the aquifer. Demand of draw will increase for water with the end source of Verón and GPC properties. Because no information on the groundwater reserves of the aquifer that supplies this region is unavailable, there is no way to determine the true availability of water at this time.

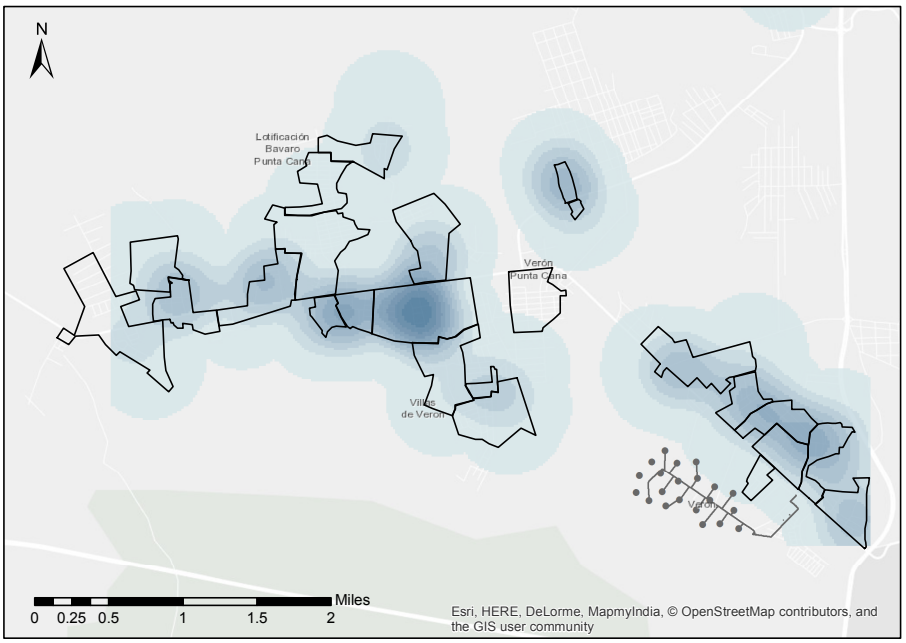
Arial view of Verón
From private collection

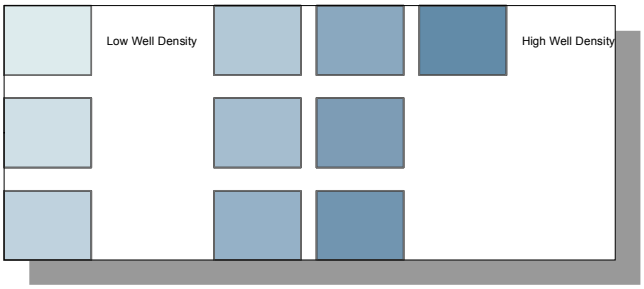
In order to fight against this ignorance, decision makers should err on the side of caution in their unfaltering draw of groundwater. There is danger even in this information being available as it is a one-time only survey. Because of the resource-limited context, no monitoring system was put in place to gain information on the construction of new wells or disuse of older ones. The demand for groundwater is only going to increase and unless there is behavior change in the management of this resource, the quantity and quality will only decrease.

Hot Spots versus Dead Zones

On first look of the maps created through GIS, it was obvious that there were areas of overuse. Specifically in Villa la Fe, there are many privately owned wells in extremely close proximity to each other.

Wells in Veron, Dominican Republic

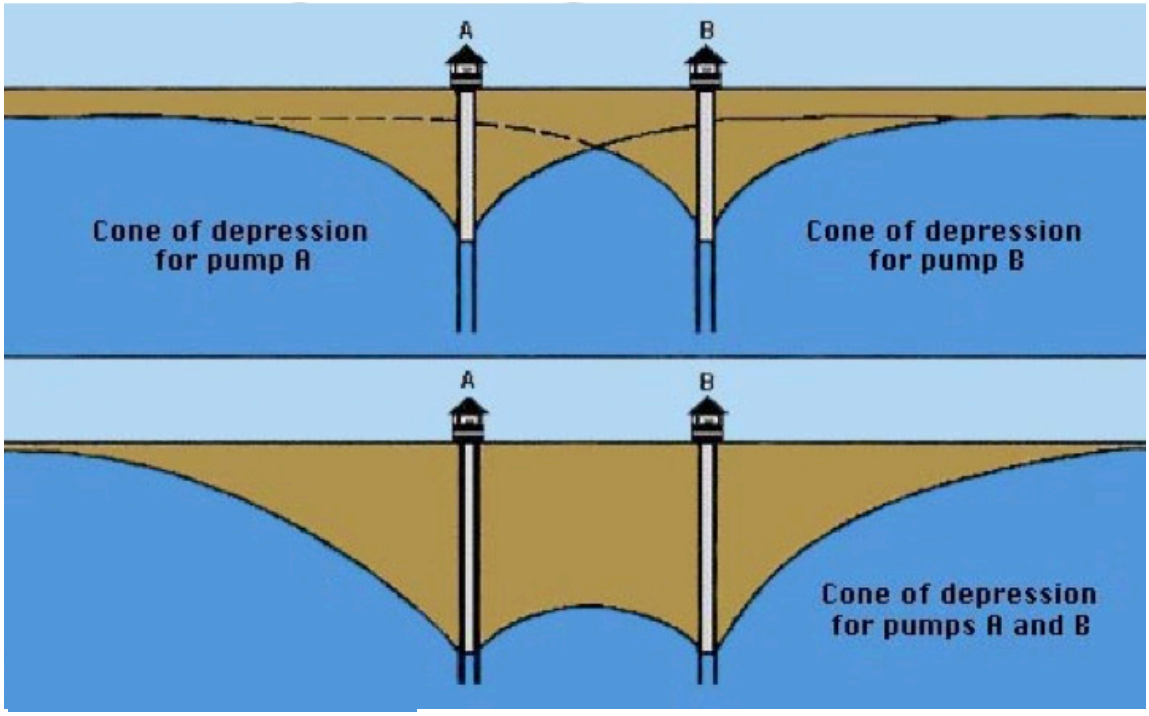




Map Created By: Eden Schoepflin

Data Collected by Eden Schoepflin in Veron, Dominican Republic

This overlapping in *pozos* creates what was referred to as a "hot spot." In a limited area, a high concentration of wells exists, almost to an unnecessary point. If these private wells were shifted to a more community minded focus, such as in Samaritano Segundo, there would be less pressure of the aquifer production in that specific area. These hot spots cause a cone of depression in this area, which is a sink in the porous limestone sedimentation where many wells are drilled in close proximity to each other.

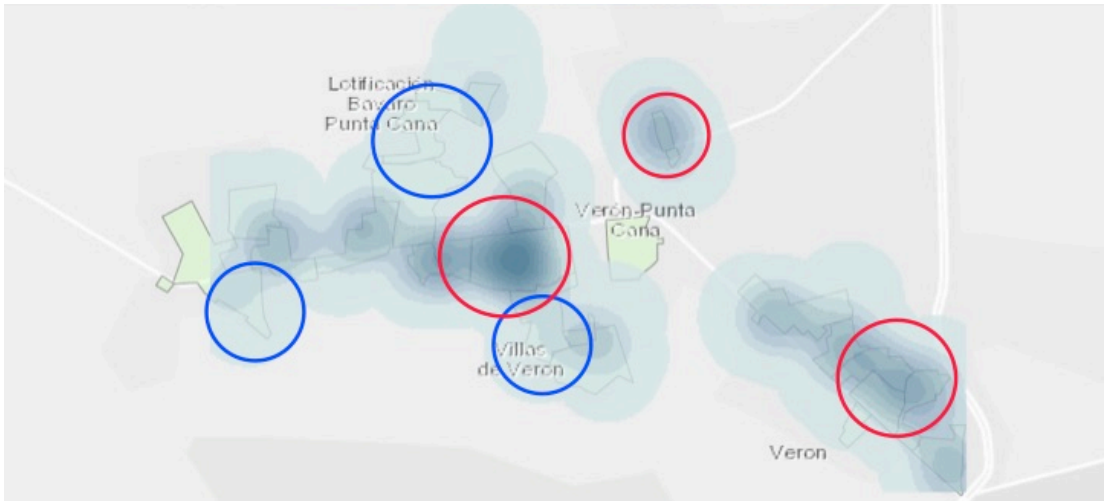


Cone of Depression
Ponce, V. M. (2006, March). Groundwater Utilization and Sustainability. Retrieved April 19, 2018, from http://groundwater.sdsu.edu/

Although it seems like an obvious solution to just prevent the drilling of new wells and legally require a collaborative nature of water, it is necessary to recognize the economic component of the water sector. These wells are expensive and contribute to job creation, directly

and indirectly, in the region. Government intervention in this business of water could have unanticipated ramifications on a small sector of the Dominican Republic's weak economy. It is unwise to expose this vulnerability in the local economy without a plan in place of recreating these skill-oriented jobs that do not demand high education levels, potentially in the process of monitoring and managing these water systems.

On the other side of the issues that are connected to the hot spots, there are dead zones that also need to be considered. Because of the high cost of drilling a well, in more rural or poorer sectors there are very few. These underserved areas are dead zones in their ease of accessing water. The lack of wells in these areas put the entire community at a disadvantage, especially women and children. Because of the patriarchal structure of society, women and men take on their stereotypical roles as homemaker and primary earner of income, respectively. Because home responsibilities fall to women and children, the distance of available water from their home is a direct concern for them. The time taken to collect water, even though it mostly is just filling up buckets and bringing them home, is time that could be spent by women participating in the workforce. Poor areas are further entrenched in the cycle of poverty when women are forced to spend time performing duties within their home instead of contributing directly to the income of a family.



Red Circles—Hot Spots of Use
Blue Circles—Dead Zones of Use

Success of GPC Well Field

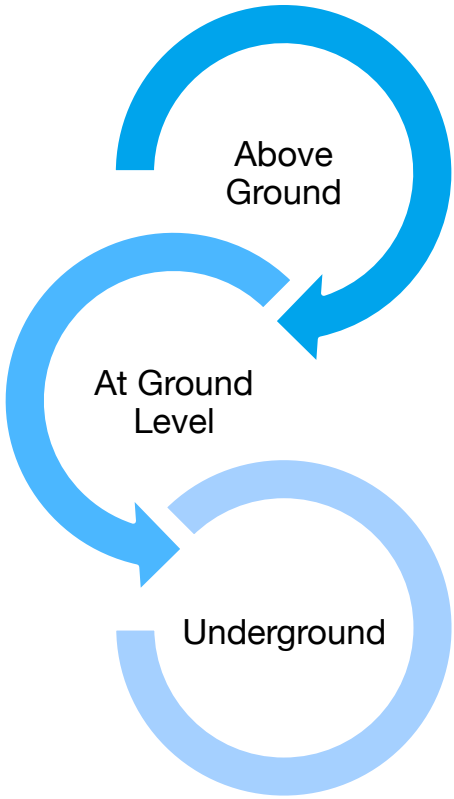
Grupo Puntacana's industrial water system has the same of goal of the *pozos* in Verón, but have a completely different process of achieving this goal. The GIS spatial data model identifies features as points, lines, or polygons. In this project, the points are the individual wells recorded, the lines are the infrastructure that supports the movement of water, usually along road lines, and the polygons represent either the individual sectors or Verón as a whole. In taking this spatial thinking model, it is easy to see the differences between the domestic system serving Verón and GPC's industrial well field. In drilling deeper and wider wells, they were able to pull a greater quantity of water from each individual well which was then transported over a longer line, or a further distance, from its point of draw to its final outflow location. GPC serves a greater polygon area and more people directly than Verón in a more streamlined way. By building up the infrastructure around the wells, instead of double or tripling up on wells drilled, there is less pressure on the ground around these wells—and hopefully more opportunity for recharge around the aquifer. Draw still has to be monitored and further understood, but according to spatial thinking, GPC's well field has more efficient productivity. It is still important to understand that while there is improved pull of water, the actual mechanisms to draw groundwater up and transport this water to PCRC, PUJ, and other GPC holdings, requires a much higher input of energy.

In limiting points and increasing polygons, there are fewer sources of water being used, which enables a greater ability for control in quality and quantity of draw. Management and monitoring becomes more feasible because of the proximity of the wells to each other. There are more resources available to GPC compared to Verón's municipal government, which is why the partnership between these two parties in working towards water sustainability is imperative. The

only way that Verón could handle these costs from an improved system would be if it were shared between the two entities. There is vested interest for both GPC and Verón to streamline their groundwater distribution network to ensure the longevity of their shared aquifer.

Not a Broken System

Despite all of the gaps in service and information realized through this project, it is imperative to note that the water system in Punta Cana is not broken, but simply in need of innovation and problem solving to better serve the needs of the population. There is enough water to maintain the vitality of this region, but only if it is manage and disturbed effectively. In making the information collected in this study available, hopefully decision-makers can be better-informed revisions to what is happening aboveground and below. By becoming responsible stewards of resources, and building a system that encourages this behavior by users, water managers can create sustainable change to this region. The interconnected nature of above and underground processes, influencing the water system, demand spatial thinking to embrace and innovate within this wicked issue. Only equipped with a complete understanding of these processes can decision-makers begin to work towards bettering management practices. Information needs to be complied in order to create a 3D model of the system. Because water is being drawn from underground, what happens below ground needs to be managed, similarly to the water distribution process.



- Disconnect between water and sanitation
- Pollution altering the quality of water
- Thriving business from supplying potable water—water goes through advanced purification processes to be sold as drinking water

- Spread of urbanization
- Increase in impervious surfaces
- Economic stress from purchasing drinking water in addition to groundwater source for cooking, cleaning, and

- Depletion of aquifer
- Saltwater intrusion
- No existing knowledge of realities of groundwater aquifer

Equipped with this information, stakeholders have answers to previous gaps in knowledge. In utilizing technology to bridge those gaps, will hopefully encourage the behavioral change needed to achieve SDG 6. By taking into account the horizontal and vertical elements of groundwater, a 3D understanding is created that is proactive instead of reactive. In comparison with its

predecessor, the Millennium Development Goals (MDG) that focused solely on changing the infrastructure to achieve sustainability, the SDGs focus on behavior change. In behavior change, a change in infrastructure is still important, but the public perceptions of water much also be changed in order to achieve the goal of ensuring access to clean water for all.

Technology creates a platform for this information to be shared and then absorbed by the local population as well as visitors. By focusing on the spatial component of this data, it was hoped that it could be accessible on all levels from government leaders to everyday citizens of Verón. Most of the power for change in management and distributions lies in the hands of groups like GPC's Foundation or governmental agencies, but if the general population is not educated about the importance of embracing these changes, no progress will be made. Education is the keystone of enforcing the acceptance of new behaviors in a community. It is the hope that in engaging youth in data collection, emphasizing the importance of this information while surveying, and in opening access to this data, a culture will be developed within Verón and GPC that supports changing behavior towards a more sustainable reality.

Recommendations

All of this information was collected with the hope that changes would be put into practice, as stakeholders are equipped with this knowledge. All recommendations made have taken into consideration all facets of sustainability—economic, environmental, and social—which are all equally important when addressing the issues of quality and quantity accessible of groundwater. Because of the vulnerable economic status of the Dominican Republic, and especially in Verón with limited opportunities beyond tourism, contributions to the economy from drilling wells, processing water to be potable, and deliver water should be further explored before any definitive change is initiated. There is a sizable burden of cost to each home though, due to the necessity of buying drinking water in addition to water for domestic uses, such as cooking and cleaning. The value of streamlining this system is invaluable to the general population of Verón, but it is important to plan ahead for the disturbance in the economy that will happen due to any change in the current system.

Upon looking at the successes of GPC's well field, they could potentially add more industrial wells to their field and then divert some of that water to Verón using the existing infrastructure. This recommendation would provide more control from GPC in outflow from the aquifer and allows streamlined management, but would only be possible with a close partnership and coordination between GPC and the municipal government. There should still be an economic responsibility for water of people in Verón so it is important to prevent complete privatization of groundwater management to ensure water remains a public good. Another possibility is to centralize the water system within Verón by closing off wells clustered closer together and encouraging a culture of collaboration necessary to share water between homes from a single well point. In all of these recommendations, and others those closer to the issue are able to

contemplate, it is vital to consider all sides of this complicated and interdependent issue of groundwater management. The information gathered in this project is still just a baseline and a further in-depth study should be completed to explore all possible innovations for the evolution of the water narrative in Verón.

Conclusion

In the mass drilling of these wells more water is being available immediately, but the flow of water, recharge of the aquifer, and limestone foundation are threatened. By viewing the overlap of population and well density, areas of high development are identified. The spatial data in GIS provides not only high resolution and easily accessible maps, but also a deeper understanding of the area in present as well as past. The ages of the wells shows the transition of development in the region and the managers of wells can create a path of information back to the water origins. This information and its spatial display have been invaluable in the process of dissemination not only to influential stakeholders, but to the general public of Verón as well.

The spatial and technological component of surveying allowed for a mass collection and then categorizing of data. By using technology to conduct the survey, we were able to collect multiple surveys at the same time but coordinate them within the same interface. Data collection that could be done independently was integrated into in one common system to expedite the process and ensure that all wells in Verón were recorded. Because of the visual nature of spatial data, the information collected could be shown immediately as it was being collected to people on the ground due to the simplicity of the display. Map images were able to overcome educational and cultural barriers that limit the proper relay of information between researchers, decision-makers, and local stakeholders. As Verón continues to develop and modernize, the water narrative is constantly changing and GIS mapping allows that information to not only be easily complied but also revised as it changes at a fast past with the dynamic nature of Verón.

In addition to time being a disadvantage working against data collection, language and cultural differences created challenges in trying to gather accurate information. Because of the innate value of water, especially in a resource-limited area, some people were extremely

hesitation and suspicious of questions that related to their personal well. In the process past data collection, working primarily online created challenges where Wi-Fi was limited or technological issues occurred. The largest limitation in the scope of this project though was the separation between water and sanitation in Verón. WASH is normally all grouped as one system, as seen in SDG 6, but in Verón there are two partially developed water and sanitation systems. Even though water is being addressed and gaps for innovation are being exposed, impact is limited because waste and wastewater is not being addressed at all. Due to the cyclical nature of water, without waste management, water management can only do so much to improve quality. Although water and sanitation have not been merged into one single system, this topic should be high priority in future discussions of water, pollution, or waste in the future.

Beyond mapping, the data produced allowed a holistic understanding of groundwater systems in this area of the Dominican Republic. Uni-directional thinking was cast out of this project and everything was approached with a fluid nature, mimicking the primary characteristic of water. The finite quantity of water in this region was accepted but was not the primary focus of research. Instead, in collecting data, it was discovered that this water sector is independently thriving and simply needs better regulations in guiding toward sustainability. By focusing on changes to the system that alter behavior, it is hopeful that the perceptions of society's interaction with water will shift, as will the outlook for the longevity of the aquifer. Just as Verón is developing, so is the process by which water is obtained and distributed. In working on the ground, the areas that needed further development were illuminated and the most productive way to do so is in isolating the unknowns to create bridges to efficiency and sustainability.

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