

DRILLER'S TRAINING, EDUCATIONAL EXCHANGE, AND VISION FOR BENIN: A Summary of Results for the August, 2000, Field Efforts in Benin



The Crew Trained in Water Drilling in Houmbo, Benin, Posing in Front of the Completed Well. Included in the Picture are the Local Crew Trained (with the Lifewater Hats in the Rear), Three Students from the Universite Nationale du Benin, Two Representatives from Lifewater-Togo, Two Representatives from Central Afrika Obota (Benin), Dr. Silliman (at left), and Dr. Tidwell (at right).

Executive Summary

Dr. Stephen E. Silliman of the University of Notre Dame (UND) travelled to Benin, Africa, during August, 2000, to pursue a series of projects involving development of both water supply and educational opportunities within Benin. Dr. Silliman was in country for 21 days, during which time he worked with the Universite Nationale du Benin (UNB - the national university within Benin), Central Afrika Obota (CAO - an NGO dedicated to development, education and outreach), the Direction L'Hydraulique (a government agency charged with overseeing development of groundwater resources in country), and village leaders in the village of Houmbo (where the drillers' training occurred).

While the funds from the West Foundation provided direct supported solely for the drillers' training portion of this effort, these funds indirectly impacted all phases of this effort. These phases can be divided into:

- **Drillers' training:** Eight villagers, three students, two members of our Lifewater team in Togo, and two members of CAO were trained in the use of the LS-100 drill rig that was purchased with the funds provided by the West Foundation. The training included all aspects of drilling, including working with the village in selection of a drill site, support of the food and housing requirements of the men being trained, discussion of all aspects of the drilling operation, and experience working with the LS-100. In completing the training, the drill team completed one water well for the village of Houmbo.
- **Higher Education:** Dr. Moussa Boukari of the Universite Nationale du Benin (UNB) worked in close collaboration with Dr. Silliman in all aspects of these projects. This has allowed development of new educational initiatives including: (i) allowing three students from UNB to accompany Drs. Boukari and Silliman in all field work, including the drillers' training, (ii) plans to initiate interaction between students at UNB and students at UND during the current

academic year, (iii) plans to seek funding for further interaction between UND and UNB, and (iv) an aggressive effort at UND to provide used educational resources to UNB through donations from students.

- Water Supply for Cotonou, Benin: Cotonou is the largest city in Benin. At present, the city boasts a high quality water supply based on groundwater wells. UNB and the government in Benin wish to be proactive in the management of this water supply, but lack the necessary computer modeling capabilities for proper assessment of current groundwater flow characteristics. This inability to manage leads to a significant threat from both the intrusion of salt water into the groundwater system and the introduction of contaminants from changing land-use practices in the vicinity of the wells. UNB and UND are currently preparing a proposal to the U.S. National Science Foundation for the purpose of studying this complex aquifer system and identifying best management strategies.
- Water Supply for central Benin: Central Benin is underlain by fractured, crystalline rock. Groundwater, within this setting, is typically derived from networks of fractures (or cracks) in the rock. As such, development of water supply is reliant upon locating these fracture networks and then developing the fracture network so as to produce water at a sufficient rate to be useful as a water resource. The government agency responsible for groundwater wells has extensive experience in locating these wells, but is just initiating work in delineating which wells are likely candidates for development through a technique known as “hydrofracing”. UND and UNB have suggested a series of geophysical and geochemical techniques for identifying candidate wells.
- Water Development Strategy, Western Africa: Lifewater International has pursued projects in Togo, Benin, Niger, Burkino Faso, Ghana and Nigeria. The goal of this initiative is to coordinate these efforts so as to provide greater benefit per dollar of investment.
- Water Education: Dr. Silliman and Mr. Flavian Glidja, the representative of CAO, had extensive discussions during this trip regarding educational initiatives that might be directed towards providing both students (primary and secondary) and adults (post secondary) with information regarding hygiene and the value of clean water in reducing disease. Among the initiatives discussed would be generation of hygiene / water coloring books for distribution to primary school teachers and establishing internet links between primary and secondary school classrooms in Benin and UND.

We anticipate substantial overlap among these initiatives. It is noted that the funds provided by the West Foundation, in addition to funds from private donors, were crucial to the development of all phases of this project as they provided the LS-100 (drill rig) which, in turn, provided the impetus for much of this effort. It is anticipated that this initial \$5000 donation will lead to projects that include provision of clean water to villages in Benin, development of education collaboration between UND and UNB, provision of a model for development of educational exchanges at other universities (based on recent presentations by Dr. Silliman at the University of Nevada, Reno, and Taylor University, Indiana, combined with interest expressed by a colleague at the University of New Mexico), and development of educational materials on hygiene and water-use practices. Links to other agencies are being investigated.

Should the West Foundation be interested in continuing support of this project, Dr. Silliman would suggest that the projects on water education, providing educational resources from UND to UNB, developing collaboration among the various LW projects, and continued training in Benin might be of interest to the West Foundation.

Introduction

This report covers efforts of Dr. Stephen Silliman, the University of Notre Dame (UND), during travel to Benin August 4-26, 2000. This included a drillers' training session that was partially supported by the West Foundation. The trip also included initiatives in water resource management in southern Benin, water development in central Benin, and educational opportunities both in Benin and at UND. The support of the West Foundation was instrumental in making this trip a success and provided the opportunity for development of a number of the educational and water resource initiatives. A full color copy of this report may be found in pdf format at:

<http://www.nd.edu/~silliman/Thirdworld/benin>

As an introduction to the efforts completed by Dr. Silliman, the following is a list of the important players in these projects:

- Lifewater International (LW): Represented by Dr. Silliman and Dr. Vince Tidwell, Lifewater was the U.S. lead on the drillers' training project. As such, Lifewater was responsible for purchase / shipment of the LS-100 drill rig, and all training in country. Funding for the training was developed by Lifewater through both private donations and support from the West Foundation.
- University of Notre Dame (UND): Represented by Dr. Silliman of the Department of Civil Engineering and Geological Sciences, UND received funding from the National Science Foundation to pursue a "planning visit" in collaboration with the Universite Nationale du Benin (UNB). The purpose of the planning visit was development of a research relationship between UND and UNB.
- Universite Nationale du Benin (UNB): Dr. Moussa Boukari was the primary contact representing the Universite Nationale du Benin. Dr. Boukari teaches within the Earth Sciences program. Additional faculty from his program and the program in Aquatic Chemistry were actively involved in this effort. Three students from UNB were actively involved in all facets of this effort.
- Central Afrika Obota (CAO): CAO is an NGO consisting of business men, civic leaders, and teachers from Western Africa who are interested in providing the people of western Africa with the education and skills necessary to develop their own economy without reliance on foreign assistance. CAO actively supports educational programs, programs in sustainable development, and collaboration with expertise from the United States and Europe. Resources available to CAO within Benin include radio and television broadcasting, and a number of outreach programs.
- Direction L'Hydraulique (DH): DH is a division of the national government of Benin. They have primary responsibility for development and management of groundwater resources. They are staffed with well-educated, motivated people intent on sustainable development of high quality water resources for domestic, agricultural, and industrial use. There appears to be an excellent working relationship among DH, UNB, CAO and, now, UND.
- Houmbo, Benin: The village of Houmbo, Benin, is central to the drillers' training portion of this effort as it hosted the training and was the recipient of the first well drilled with the LS-100. The village leaders also played a very active role in both the management and completion of this project.
- Lifewater Togo: Lifewater maintains a very successful pump installation / repair project in Togo, Africa. Two representatives of Lifewater Togo joined the drillers' training.

Project Overview and History

LW and UND became involved in development work in Benin in 1997 through contact from Dr. Christophe Kougniazonde (a citizen of Benin) who was, at that time, studying at the Peace Institute at the University of Notre Dame. Through this initial contact, Drs. Kougniazonde and Silliman established plans for an initial visit by Dr. Silliman to the village of Kpassagon, Benin. The intent of this visit was to identify the potential for use of the LS-100 in the region around Kpassagon. Being a founding member of CAO, Dr. Kougniazonde arranged for communication between Dr. Silliman and CAO for the purpose of planning this visit.

Dr. Silliman initially travelled to Benin in March of 1998. During that 10-day visit, Dr. Silliman and representatives of CAO visited Kpassagon and a number of other villages. It quickly became apparent that the hydrologic problems at Kpassagon and for all regions further north were beyond the capability of the LS-100 (which is limited to a depth of approximately 120 feet and has difficulty penetrating through hard rock and / or sediments containing large cobbles). It also became apparent, however, that the LS-100 would be appropriate for use in the southern portion of the country, including the region around Houmbo. Initial plans were made to pursue funding for a full Lifewater training project in Houmbo. Lifewater (through Dr. Silliman) was to be responsible for raising the required funding, purchasing and shipping the LS-100, and providing the personnel to complete the training. CAO was to be responsible for discussions with the citizens of Houmbo, identification of possible drill locations, and arrangements for housing and food for the Lifewater volunteers and men to be trained. Communication between CAO and UND was to occur by email.

This initial trip also provided for initial discussion among Dr. Boukari, his colleagues, and Dr. Silliman. Interest in development of collaborative research and teaching initiatives was apparent in all parties. Initial plans for a proposal to US AID were outlined. These plans later led to a proposal to US AID which, unfortunately, was not funded. These plans also led to an NSF proposal for a “planning grant”. This proposal was funded and the resulting support provided the air fare and some of the travel costs for the trip discussed in the present report.

Based on the results of the first trip and discussion with colleagues in Benin, two goals were set for the trip discussed herein. The first was to train a drilling crew in Houmbo. The primary players for this effort were anticipated to be CAO and LW. The second was to initiate a research collaboration between UND and UNB with definitive project hypotheses and objectives identified during Dr. Silliman’s visit. Secondary goals included initiation of educational collaboration between UND and UNB, and exploration of other development opportunities with CAO.

The following sections discuss accomplishments in six areas:

- Drillers’ Training - Detailed description provided
- Water Supply in Cotonou, Benin - Outline of results provided
- Water Supply in central Benin - Outline of results provided
- Water Development Strategy for Western Africa - Outline of results provided
- Higher Education - Outline of results provided
- Water Education - Outline of results provided

Drill Training in Houmbo

Preliminary Discussion

Drill training was performed in Houmbo, Benin, a village in southeastern Benin for which water is a scarce commodity. Preparation for this drilling included preliminary discussion between CAO and LW (via email), purchase and shipment of the LS-100 drill rig, initial training in Benin, release of the drill rig from customs in Benin, agreement among CAO, LW, and DH on the roles and responsibilities for this drilling, on-site training and drilling, and completion of a well in Houmbo.

Preliminary discussion between CAO and LW were necessary to establish the common philosophy that this project was a project of the people of Benin with LW acting as a technical training consultant. Discussion centered around two significant questions. The first was whether the drill rig should belong to the village of Houmbo, CAO, or UNB (the last option having been raised during Dr. Silliman's initial visit). The second was the role to be played by the villagers in Houmbo.

It was decided that CAO had best access for using the drill rig to train men in drilling techniques and for installing wells in needy villages. While UNB could provide certain advantages in terms of maintenance and reduced custom/duty fees, it was decided that providing the rig to a governmental organization might lead to significant practical difficulties in utilizing the rig for training on a regular basis and in remote villages. Therefore, ownership of the rig rests with CAO.

The LW philosophy regarding the contribution of the local village is that the village is central to the project with village leaders well represented in any decision process. The philosophy of CAO is similar, with the relatively minor difference that CAO wished, in this case, to maintain control over the drill rig and a significant portion of the decision process. In preparation for this trip, there was significant discussion regarding the roles and responsibilities of the various parties. It was agreed that CAO would maintain ownership of the rig. It was also agreed that the village would have a substantial say in the use of the rig. Finally, it was agreed that the village would provide both housing and food for the LW volunteers (Drs. Silliman and Tidwell) and for the men to be trained.

With these general agreements in place, the drill rig was shipped to Benin in early June with an expected receipt date in Benin of the first week in July, 2000. Dr. Silliman was to arrive on August 5 for initial training and pursuit of the other components of this trip. Dr. Tidwell was to arrive on August 15 to allow field training to start on August 16.

The LS-100

The LS-100 drill rig is a portable, rotary drilling machine (commonly called a "drill rig") designed, in large part, to the specifications of LW for our work in developing countries. The LS-100 used for the present project was purchased through the funds provided by the West Foundation. The drill rig was equipped with 100 feet of drill stem, multiple drill bits (the component that actually cuts through the rock and sediments), the necessary motors, tools and necessary accessories. When shipped, the entire assembly weighs under 1000 pounds and is contained in a crate

approximately the size and shape of a coffin (the figures below show the drill rig in its crate during transport in Benin and during drilling at the site in Houmbo).



(Upper) The LS-100 in its crate being transported from Cotonou to Houmbo. The white pick-up truck was provided by CAO. A second vehicle (not shown) was provided by DH.



(Lower) The LS-100 assembled on site. Dr. Tidwell is leading the training at the base of the rig, while a group of trainees runs the rig and listens to explanations.

When fully assembled, the LS-100 allows drilling of water wells to maximum depths of approximately 120 feet. The design of the LS-100 is such that it is a useful training rig, allowing locals to learn the concepts of drilling on a machine that is relatively safe and easy to maintain.

Shipping and Customs

Due to delays, the drill rig did not arrive in the port at Cotonou, Benin, until approximately August 2. Dr. Silliman and Mr. Glidja (CAO) then expended significant effort in obtaining the timely release of the rig from customs. After multiple discussions / arrangements made with various government agencies within Benin, the rig was finally released on August 17.

Initial Training

Initial training took place on August 5 at the headquarters of CAO (figure, next page). While Dr. Silliman had initially anticipated a training crew of approximately 4 men from Houmbo, CAO made significant efforts to advertise this training session and to link this training session to students at UNB working under the direction of Dr. Moussa Boukari. As a result, the training session involved approximately 15 people, including 4 men from Houmbo, 4 men from other villages, 3 students from UNB, Dr. Boukari, Dr. Kougniazonde (currently a government employee in Benin), Mr. Glidja and Dr. Silliman. The group of students and men to be trained is shown below.

This mixture of people provided for two unique aspects to this training. First, the men from the various villages spoke at least two different dialects. Hence, the students became the teachers as they translated both the words and the concepts expressed by Dr. Silliman to the men who would later run the drill rig. This substantially reinforced the concept that this was a project of the Benin people for which Dr. Silliman was simply an outside consultant providing expertise. Second, the combination of men from the villages, faculty, students, a government official, an outside consultant, and an official from an NGO provided an opportunity for interaction among people from different socio-economic classes towards a common goal. It is such cooperation and collaboration that is key to the long-term success of such development projects.



Initial training at CAO headquarters. Dr. Silliman is at right, Dr. Boukari is on the edge of the photograph at right, and Dr. Kougniazonde is in the foreground at left.



Photograph of the majority of the trainees included in the training session.

Materials covered during the initial training included the need for clean water supplies in rural Benin, the problems faced in using surface water supplies, the reasons for using groundwater, the basics of the hydrologic cycle, hand-pump design and initial examples of hand-pump repairs (on cylinders). Each member at the meeting also had the opportunity to introduce herself / himself and to state what they hoped to gain from the training. The meeting was quite interactive and was considered a major success by all involved. The meeting was arranged such that Mr. Glidja ran the entire meeting with advice / input from Drs. Silliman and Boukari. The meeting lasted approximately 6 hours and, at the end of the meeting, the men were asked to return to Houmbo and identify 3 potential drilling sites consistent with our discussions of groundwater hydrology.

Government Involvement

Drilling wells in Benin is controlled by DH. Planning for the field training and drilling operation was complicated somewhat by a new project run by DH with international financial support. This project was just recently initiated and was unknown to CAO prior to our discussion with DH. Within this project, local villages desiring a new groundwater well must pay a portion of the cost of the hand-pump and the pad for the hand-pump. The remainder of the costs is borne by the project funds. This results in a total cost to the community of approximately \$150 - \$250 U.S. This government project had three immediate impacts upon our drillers' training.

First, the philosophy underlying the government project (require contribution to a new well from the users of the well) is quite consistent with the philosophy followed by LW, even if the process by which that contribution is sought differs from our approach. As a result, the director of DH appeared quite enthusiastic and cooperative when the training project was presented. Specifically, he indicated that our approach (requiring local contribution in terms of men to be trained, provision of food, provision of housing, and provision of water during the drilling process) appeared to be even more rigorous than the DH approach in terms of developing local ownership of the project. It is hoped that this common philosophy will assist the new LW crew in their future efforts (see points 2 and 3, below).

Second, there was a point of conflict in terms of who would provide what materials to this project. The original plan was for LW to purchase an India Mark II hand-pump from a local vendor that had been identified during the initial visit. The estimated cost for that pump had been on the order of \$400 U.S. With the new government project, the Afridev hand-pump is provided to villages for the village cost share (approximately \$100 U.S.) plus the cost of the pump pad (\$50 - \$150 U.S. cost share). Very few India Mark pumps remain in Benin and the cost is now on the order of \$700 U.S. As a result, there was substantial incentive to purchase the Afridev pump. Two difficulties were faced, however. The first was that the Afridev was available only through the government project using government drillers. Fortunately, the director of DH agreed to provide CAO with the pump at the same cost based on our description of local cooperation in the project. The second was that the government project required construction of an enormous pump pad. With cement and rebar, it was estimated that the pad would cost approximately \$600 - \$1000 U.S. As we were the drillers for this well, this pad was our responsibility. Through discussion with the pump installation group and due to the presence of the men from Lifewater Togo, it was agreed that the smaller, LW design for the pump pad was acceptable for this well. It remains to be seen whether similar cooperation with the government project will be forthcoming on future wells drilled by the new LW crew.

Third, through the interest of DH in this drilling project, DH provided (at cost) the use of one of their field vehicles and one of their drivers. Provision of these two resources was absolutely essential to the success of the training (as well as the additional field work).

Field Training

Field training was conducted in Houmbo, a small village in southeastern Benin. The two images on the next page provide an indication of the population density in the region. The upper image is the home of the village chief, while the lower image (with Dr. Tidwell) shows the approximate location chosen for the new well.

Field training was scheduled to commence on August 16. Due to difficulties at customs, the training was delayed until Friday, August 18. Training commenced in Cotonou with a discussion of all the components accompanying the drill rig and the need to keep very careful records of the components. Further, there was substantial discussion regarding keeping all components and tools in the appropriate storage area to avoid the necessity of replacing lost components. The drill rig was then transported to Houmbo. Once in Houmbo, the rig was again unloaded and the trainees were asked to identify all parts and components. This provided both an opportunity for the men to become more familiar with the rig and for chief of the village to see that the rig had arrived and that the men were being trained.

A meeting was held on Saturday morning with the major representatives of the village. At this time, we visited the drill sites preferred by the village as well as a couple of hand-dug wells currently in place in the village. Unfortunately, the primary and secondary sites selected by the villagers were at the top of a local hill. Measurement of the depth to water at an existing hand-dug well indicated that the water level was greater than 200 feet below ground surface. Drs. Tidwell and Silliman attempted to explain to the villagers that the LS-100 would almost certainly fail in these areas as it is incapable of drilling to these depths. This was an extremely difficult concept



House of village chief in Houmbo. The initial field training occurred here and then moved to the field site.



Dr. Vince Tidwell looking into the valley below the area chosen as the site for drilling of the well.

for the villagers to grasp and, at one point, the villagers indicated that they would rather not complete the drilling at all rather than drill a well at the alternative sites we were suggesting (located substantially downslope from the hilltop). It was later explained that the difficulty in the sites we were suggesting was that the sites were located on land owned by the man who was politically second in command in Houmbo. Our understanding is that the chief and this man were concerned that the village would consider locating the well on this property as a form of nepotism. After substantial discussion, and intervention by the regional Sous Prefet (a regional political leader), agreement was reached to base the training in the region shown in the lower image, above.

Due to the late hour at which the final drill site was chosen on Saturday, and the fact that Sunday is maintained for worship, training at the field site was initiated early on Monday morning (August 21). Dr. Tidwell led a thorough discussion of siting wells (to maximize the chance to find water and minimize the chance for contamination). We then unpacked all of the equipment (image on next page) and led the men through the basics of drilling with Dr. Tidwell discussing the construction and maintenance of the mud pits with one half of the group and Dr. Silliman discussing the assembly and use of the drill rig with the other half of the group. The trainees then dug the mud pits and women from the village carried water to fill the large barrels we used to store water at the site (image on next page).

The men then initiated the drilling process by starting to mix the drill mud (purchased from a vendor in country) and assembling the drill rig on the hole. They received their first lesson in the frustrations and challenges of drilling soon after starting the mud pump as, within 5 minutes of starting the pump for the first time, the pump threw its rod through the side of the pump housing (pieces of rod, piston and pump wall shown on next page). Fortunately (miraculously), we were able to locate another mud pump on Tuesday in Cotonou. This pump was rented from a local vendor in the marketplace in Cotonou (image on next page).



Trainees with the components of the drill rig out for display and discussion.



The women of Houmbo were invaluable in providing the water needed for the drilling process. The water was derived from a spring below the site.



Components of pump piston, rod and pump housing after failure of rod.



"Miraculous" location of pump shop in Cotonou

Drill training was continued on Wednesday (August 23) morning with active drilling to approximately 50 feet. During this training, the men were rotated through the various jobs on the drill site, including running the rig, maintaining the mud pumps, carrying pipe, preparing the well screen (by cutting slots in pvc pipe - image below), and keeping a drillers' log (record of the types of rock observed during the drill operation, the total depth of the hole, etc.). The men were able to drill to approximately 45 feet without major incident, and then hit a very hard siltstone and were able to advance the well only another ~3 feet in 2-3 hours. We therefore decided that this siltstone would make an excellent base layer for a shallow aquifer and terminated the hole at that depth.



Combination of local trainee, volunteer from Lifewater-Togo, and a student from UNB work on cutting slots into pvc pipe.

On Thursday (August 24), we returned to the site and showed the men how to “ream”, or clean the inner walls, of a well. Following reaming, we installed approximately 48 feet of casing (images below), allowing 2 feet of blank casing at the base, then 10 feet of slotted casing (slots allow water to enter the well), and then blank casing to the surface. The villagers had located and transported a large amount of gravel to the site and we used this gravel to create a “gravel pack” around the screened portion of the well (we actually added approximately 20 feet of gravel to the area between the outside of the casing and the wall of the drilled hole). This gravel pack helps to filter out fines from the water and ensure long-term flow into the well. Above the gravel, we filled the space between the casing and the wall of the well with cement mixed with some bentonite clay. This cement / clay mixture helps to ensure that surface contamination will not flow along the drilled hole to the well screen (and thereby into the well water).



Placing well casing in drilled hole.



Bailing the well to remove drilling mud and fines produced during drilling. Bailing also helps to recirculate chlorine in the well to reduce risk of drilling related microbial contamination.

Following placement of the cement, we began the bailing process (figure above). This process allows the remove of the drill mud and clays used in the drilling process. It also allows a final opportunity to chlorinate the well in order to kill microbial contaminants that may have been introduced to the well during the drilling process. Following our initial efforts at bailing, the well had a standing water level of approximately 12 feet above the base with a water level that did not drop substantially during the bailing process. These are indications of a good well.

The village responded positively to completion of the training and the bailing process.



Village leaders gather around the trainees and the new well following completion of the training program.

Well Completion

Due to prearranged travel, Drs. Tidwell and Silliman were required to leave the site on the evening of August 24. However, the men from Lifewater-Togo have extensive experience in completion of pump pads around wells (the pad provides a stable base for use of the well, provides for diversion of excess water away from the well, and protects the well from contamination). As a result, these men remained on site through August 28 to complete the well pad and well development. Due to government regulations, we were not allowed to install the pump on the well. However, Dr. Silliman recently received word from Mr. Glidja that an Afridev pump has been installed on the well.

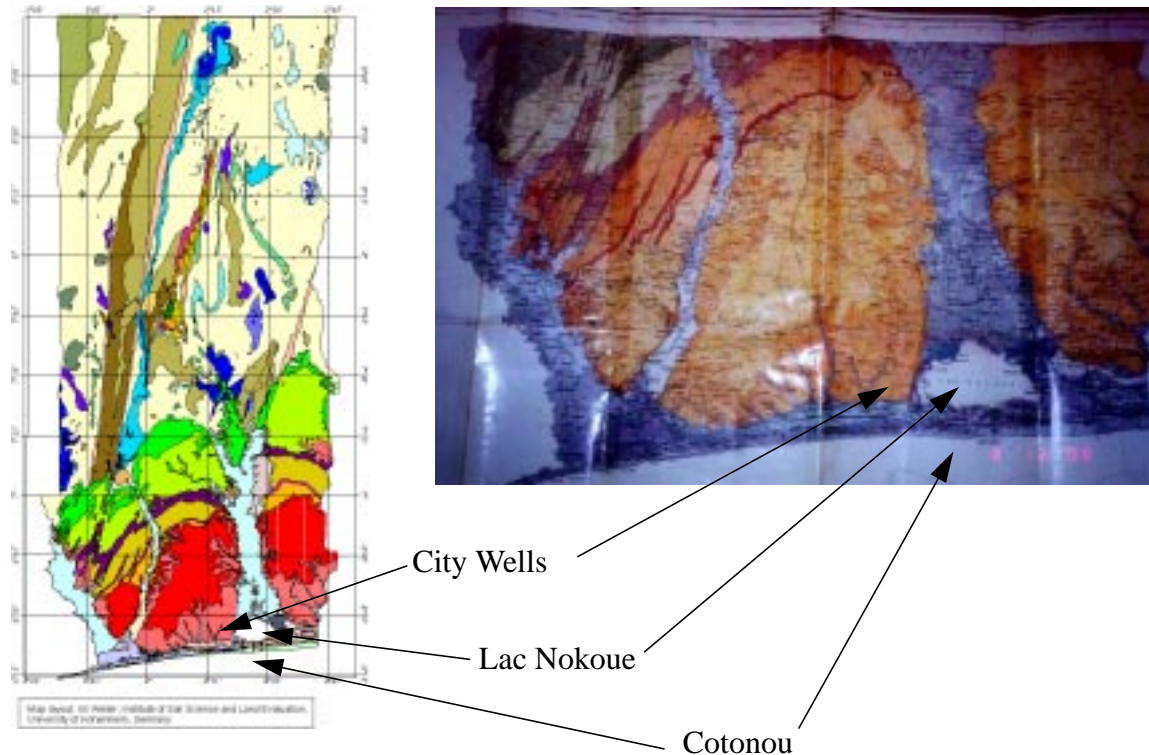
Future Directions of the Drilling Program

CAO and LW have discussed two anticipated extensions of this training. The first involves advanced training of the Houmbo crew to provide them with more insight into well siting, drilling operations, and development of a financial base from which to pursue drilling. The second involves training (either of the existing crews or a new crew) for drilling in the region around Cotonou, Benin, which has relatively high population density, but is not currently served by the city water supply. At present, this population is living on hand-dug wells that have been documented to be highly contaminated. The drilling in this region should be ideal for the LS-100 (primarily sands).

Financial resources required to pursue these two options in Benin are on the order of \$5000 in travel and material supply funds. A number of options are being pursued for securing these funds.

Water Supply in Cotonou, Benin

Cotonou, Benin, is the largest city in Benin and is the economic center for the country. The inner portion of the city currently enjoys a relatively high quality water supply based on production of groundwater from a series of large wells northwest of Cotonou (see maps).



Geologic maps of southern Benin. Left, generalized geological map showing much of southern Benin and the transition from crystalline rock (the yellows and browns on the color image) in the central region to the sediments and sedimentary rocks in the south (reds, blues and greens in the color image). Right, enlarged geologic map of the coastal region showing the relationship of the coastline, Lac Nokoue and the well fields for Cotonou.

At present, the water supply in Cotonou is considered of high quality. It is pumped from relatively deep regions of the coastal aquifer system and is treated prior to distribution into the city water system. Two challenges, however, threaten the long-term sustainability of this supply. The first is termed “salt-water intrusion” and is a process whereby salt water from Lac Nokoue (the large lake on these maps - it is a salt water lake) and from the coast, penetrates the groundwater system in response to pumping from the wells. The result is that wells become contaminated with salt water and must be closed. The second is contamination from human (anthropogenic) sources. In the regions surrounding Cotonou, the population is increasing, but without adequate infrastructure in the form of centralized water supply or garbage / sewage removal. The result is that shallow wells (typically hand-dug wells installed by the local population) are already highly contaminated, and the overall quality of water in the deeper, city wells is threatened. As an indication of the degree of this threat, refer to the figure, below, showing encroachment of a house on a city well. In the United States, the minimum distance from a well to the closest residential or commercial building is typically 150 feet or greater. As shown in this figure, such “set back” distances are not being respected in Benin as the local population encroaches on the individual wells.



City water supply well (foreground) with encroachment by private and commercial buildings. The set back distance here was less than 30 feet in three directions.

The potential threats to water supply along coastal Benin are common not only to this country, but throughout the coastline of sub-Saharan Africa. Further, similar problems are faced elsewhere in the world including locations in industrialized nations such as the United States and locations for which water is becoming a precious commodity such as in Israel. As a result, study of the engineering, scientific, cultural, and political requirements for managing the sustainable development of groundwater supplies under the conditions currently present in southern Benin are of interest worldwide. For this reason, Drs. Boukari and Silliman are actively pursuing research funds for the study of modeling and uncertainty in the management of groundwater resources under threat of salt-water intrusion and anthropogenic contamination. Such a study will utilize the strengths of both UNB and UND, and will provide opportunity for collaborative study not only by Drs. Boukari and Silliman, but also their graduate students. Interest in this project has also been expressed by Dr. Boukari's colleagues at UNB and by government agencies in Benin. At present, a proposal is in preparation for submittal to the U.S. National Science Foundation through their international program.

While West Foundation funds were not used to directly support this initiative, the interest of LW and UND in development of water resources in Benin, in part represented by the drillers' training in Houmbo, led to substantial interest in collaborative studies between UND and UNB. This collaboration would likely not have occurred without the initiative in drillers' training.

Water Supply in Central Benin

As noted in the geologic map above, the geology of Benin changes dramatically approximately 80 km north of Cotonou. Instead of drawing water from the sediments and sedimentary rocks, water must be withdrawn from the fractures, or cracks, in the crystalline rock. This hydrogeologic setting (hydrogeology is the combined study of geology and hydrology) poses a number of challenges to the development of sustainable water resources. The two primary challenges are the identification of fractures that are likely to carry water and the improvement of drilled wells that, upon initial completion, had provided inadequate quantity of water.

DH has been utilizing relatively advanced scientific methods for a number of years in an effort to identify drilling locations that are likely to produce high quality wells. Among the primary methods used in this effort is the analysis of satellite images that show, through visual clues observable from space, linear features on the Earth's surface that can be related to subsurface fracturing. Mr. Felix Azonsi of the DH reports that initial field efforts using satellite imagery produced successful wells nearly 75% of the time that drilling was attempted.

As the “easy” sites were drilled, however, identification of quality drill locations from satellite images has become increasingly difficult. As a result, DH has initiated a project in which they will attempt to improve on the quantity of water that can be derived from wells of low to medium yield (“yield” being the term used to indicate the quantity of water that can be pumped from a well with standard pumping techniques). DH has used innovative well design in some cases to improve yield. The figure below, for example, is a case in which DH constructed a large reservoir next to a well that had low yield. The reservoir is directly connected to the well such that during periods in which the well is not actively being utilized by the local residents (e.g., at night), water in the well will “leak” into the reservoir. As such, the people can withdraw water during the morning hours from both the well and the reservoir, thus effectively doubling the yield of the well.



The drilled well is the small diameter “cap” near the feet of the two men (Dr. Boukari on the right and Mr. Azonsi on the left). The large diameter “well” in the center is actually a large reservoir (approximately 6 feet in diameter and 50 feet deep) that collects water from the drilled well on a continuous basis, thus increasing the yield of the drilled well.

While such innovations can substantially improve marginal wells, development that includes domestic, agricultural, and industrial uses of water requires development of high yield, reliable water supplies. In order to improve yield from marginal wells, DH has recently initiated a project based on a technology termed “hydrofracing” in which high-pressure water is injected into a marginal well in an effort to develop water producing fractures, or cracks, in the rock.

Unfortunately, hydrofracing is quite expensive. As a result, there is substantial motivation to try to optimize the hydrofracing effort. DH has requested assistance from UNB and UND in identifying field techniques that will allow optimization of the hydrofracing effort. At present, it is anticipated that geophysical techniques (studying the propagation of acoustic waves, electrical properties of rocks, and radioactivity within the rock mass) and geochemical techniques (study of the chemistry of the water and rocks) will be applied to this problem. Towards this end, Drs. Siliman and Boukari collected water samples from twenty wells distributed throughout central Benin to provide an initial geochemical data base for Benin. These samples are being analyzed in the laboratories at UND for a variety of elements.

Funding for this project will be sought from the U.S. AID and/or the National Science Foundation. In the short term, it is anticipated that private donations will be used to support the initial sample collection as the DH project moves forward and the first wells are hydrofraced.

Water Development in Western Africa

LW currently has projects in Burkino Faso, Niger, Benin, Togo, and Ghana. UND has initiated the projects discussed herein in Benin. Colleagues of Dr. Silliman at the University of Nevada-Reno have vast experience in water development in Ghana. CAO is active in each of these countries. World Bank and the World Health Organization are active in these countries. A number of other NGOs have substantial presence in these countries. One of the critical components missing from the standpoint of sustainable development is coordination of efforts across organizations.

While there is no illusion that LW, UND, UNB and CAO can develop the magic bullet that leads to perfect coordination among all organizations working in western Africa, they recognize the need to coordinate, at a minimum, the water development efforts of LW. Such coordination might lead, for example, to pooling of funds, thus allowing purchase of larger drill rigs with greater capability to penetrate the crystalline rock that underlies the middle latitudes of several of these countries. Perhaps as importantly, coordination will aid in developing training techniques that allow us to establish sustainable drilling and well-repair operations. These efforts will also provide opportunities to reach into the educational institutions, from primary school through schools of higher education, so as to pass along experience, knowledge, and vision to the next generation of western African students.

An initial effort at this coordination resulted directly from the funds provided by the West Foundation as these funds, through purchase of the LS-100, allowed the opportunity for the men from LW-Togo to meet with the new trainees in Benin. As noted above, the men from Togo led a significant portion of the training through instruction in construction of the pump pad at the Houmbo site. At the same time, this training was the initial exposure of the men from Togo to the LS-100. At present, discussions are underway among members of the LW organization (including Dr. Silliman), Dr. Silliman at UND, Mr. Glidja at CAO, and Dr. Boukari at UNB seeking ways in which to develop collaboration and cooperation among efforts in these various countries in western Africa. It is certain that, while this idea of collaboration and extension into education is a critical next stage in this effort, such development will require a longer-term vision and more stable money supply.

Higher Education

One of the exciting “collateral” benefits of this project has been the development of a strong working relationship between Dr. Silliman at UND and the faculty at UNB (led by Dr. Boukari). As noted above, a proposal is being prepared for the National Science Foundation to establish collaborative research on management of the southern Benin groundwater system. In addition, Dr. Silliman has been invited to submit a preproposal to the Carnegie Scholars Program. This preproposal is focused on development of educational cooperation between UND and UNB.

One immediate concern being addressed by Drs. Boukari and Silliman is the lack of text books and library resources available at UNB. Dr. Boukari, for example, finds it extremely difficult to obtain recent textbooks and supplies. The library system at UNB is woefully under

endowed in terms of funding to purchase books. The computer system at UNB represents a dramatic limitation to the educational resources available to the students.

Drs. Silliman and Boukari hope to address the issue of text books and other related resources quite directly through development of an educational resource drive at UND. Within this drive, students at UND will be asked to donate used textbooks and school supplies to UNB. Dr. Silliman will organize this drive and ship the resulting resources to UNB. At UNB, the resources will be shared among the faculty, students, and library to build a resource base for learning. It is hoped that the U.S. State Department will aid in this effort through free shipping of these resources to Benin (as they had done 5 years ago in a similar effort to provide supplies to primary and secondary schools in Benin). ***It is anticipated that a minimal amount of funding (e.g., \$2000 per year for 3-5 years) from the West Foundation, or similar foundation, when combined with the resource base represented by the student population at Notre Dame and the potential for cooperation from the U.S. State Department could have dramatic impact on the educational opportunities for an entire generation of college students in Benin.***

A second project being developed by Drs. Boukari and Silliman is the collaboration of students from UND and UNB on joint projects. Efforts will be made in the spring semester, 2001, to develop a water resource project in Benin through collaboration of students completing a course in Third-world Water Supply at UNB and students completing a course in Hydrogeology at UNB. The students will use the internet for exchange of information and ideas. It is anticipated that Drs. Boukari and Silliman will attempt to further develop this idea through a proposal to the U.S. Department of Education. In the long-term, this type of educational exchange could be extended back into the primary schools, thus allowing students in Benin and students in Indiana to begin exchanging ideas at ages as young as 7-8 years old.

Water Education

One of the most frustrating experiences to be realized in working with water supply in Benin (and other developing countries) is the observation that the social custom in Benin is one of disregard for personal impact on the environment. Garbage is routinely disposed off through dumping in the streets and storm channels. Personal hygiene in the villages often does not include the use of latrine systems, careful cleansing prior to meals, care in the choice of water to be drunk, or care in the washing of dishes between uses. While one does not have the right to impose a western philosophy of "appropriate" hygiene practices, there is a clear lack of understanding among the people of Benin of the impact of these practices.

Discussions between Dr. Silliman and Mr. Glidja (CAO) have focused on development of educational materials that might be exchanged at minimal cost between primary school students in the United States and primary school students in Benin. One concept would be to develop coloring books that would use pictures to communicate the purpose and need for careful hygiene practices to young children (coloring books avoid language barriers). These coloring books could be produced on a home computer (e.g., by Dr. Silliman) and might be no more than 4-8 pages in length. They would come with support material for the classroom teachers in both the U.S. and Benin. Exchange of these coloring books between classrooms in the United States and classrooms in Benin (Dr. Silliman would organize distribution in the United States and CAO would organize

distribution in Benin) would have the potential to have several impacts on the students. First, the students will become aware of counterparts in another part of the world (Benin for the students in the U.S. and the U.S. for the students in Benin). Second, students in the U.S. will be introduced to the concept that our standards of hygiene are not universally shared by others. They will be encouraged to discuss this idea with their parents. Third, students in Benin will be challenged to discuss with their parents the concepts of hygiene and the use of clean water supplies that are expressed in the pictures drawn by their counterparts in the United States.

While the details of this project are clearly not complete, the concept underlying it - the exchange of ideas between students in the U.S. and students in Benin through pictures (and, where appropriate, words) - is exciting both to CAO and Dr. Silliman at UND. It is anticipated that this project could be initiated for less than \$4000 in the first year and \$2000 in succeeding years. Should the West Foundation be interested in more details, Dr. Silliman would be more than willing to provide them.

An Invitation to Collaboration

Lifewater International and Dr. Silliman are extremely grateful to the West Foundation for the funds that helped get these projects moving. We hope that the West Foundation is pleased with the progress that has been achieved with the initial funds. Dr. Silliman, representing both Lifewater International and the University of Notre Dame, would like to invite the West Foundation to consider continuing their relationship with these projects. Areas that could benefit substantially from funds from the West Foundation include:

- Further develop Lifewater International's presence in Africa through continuing support of this drilling project and/or through support of other Lifewater initiatives in Africa. Funding levels might range from \$5000 for continuation of the project in Benin to \$50,000 for wider initiatives in Africa.
- Providing support for provision of used educational resources from UND to students, faculty and the library system at UNB. Again, funding levels are uncertain, but are likely to be on the order of \$2000/year of this exchange.
- Providing support for the development and exchange of educational materials on water and hygiene for primary schools. These materials are to be exchanged between schools in the United States (primarily Indiana and Illinois) and primary schools in Benin. Funding levels are less certain here, but are likely on the order of \$4000 for the first year and \$2000 in subsequent years.

Should the West Foundation be interested in further details on any of these projects, or should you have comments or suggestions regarding this report, you are encouraged to contact Dr. Stephen Silliman at the University of Notre Dame:

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