

# How a City Gets its Drinking Water A Case Study - Capital City of Monrovia, Liberia

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The expansion of urban centers in Asia and Africa over the past few decades is unprecedented in human history, and many hundreds of millions of people are not served by conventional water supply infrastructure. This population that is not served a basic human need is the fastest growing population component. The growth of developing nations' urban areas has far exceeded the ability of public and private utilities to provide potable water supply to people within older service areas as well as within the rapidly expanding peri-urban areas. Since the 1970s, the governmental, NGO and International donor community has focused mostly on village water supply provision, and that continues to be the case today, with a recent shift to an urban focus by the World Bank and other donors.

The Greater Monrovia area derives its water supply from an array of sources including:

- Hand-dug wells that are protected or unprotected (open), some fitted with hand pumps.
- Drilled wells fitted with hand pumps.
- Kiosks (neighborhood tanks that receive water from tanker trucks). The kiosk water sources include unprotected hand-dug wells, drilled wells and surface water.
- Public water utility system standpipes (city water taps) that receive water from the Liberian Water & Sewer Corporation (LWSC) surface-water source.

As in many expanding cities in the developing world, an older established water utility serves a limited area, while most of the new urban and peri-urban areas are supplied by informal delivery systems. These include trucked water to kiosks (tanks) in the more densely populated areas, and protected or unprotected (open) hand-dug wells and drilled wells throughout the City.

In the fall of 2011, the World Bank Water and Sanitation Program (WSP) initiated a project to sample a subset of the water points in the Capital City of Monrovia. The World Bank WSP mapped 1000 water points in Greater Monrovia in a 2010-2011 countrywide survey, and 204 of these points were sampled in the fall of 2011 for bacteriological and chemical content. UHL & Associates was the Principal Investigator for the water supply sampling component, and retained The University of the Free State, Bloemfontein, South Africa (UFS) to develop and implement the microbiological and chemical analysis. UHL was also aided by Eden Preferred Water Services, Liberia, and by World Bank personnel from the Liberia Office. This project represented the first systematic sampling of water points and study of water quality in the Capital City of Monrovia.

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**Sampling and Testing Methodology:** The Field Sampling Program was implemented from September 5 to September 14, 2011. The water point samples were analyzed for field parameters at the sample collection point. The microbiological samplers wore dedicated disposable gloves for each water point, and washed their hands with liquid gel disinfectant between points. Care was taken to maintain a sterile environment for sample collection, handling, and storage, prior to delivery in daily batches to the microbiological Project Field Lab set up in Monrovia. The samples were tested on a continuous basis using standard operating procedures and quality control protocols.

For wells equipped with pumps, the well was pumped for a few minutes before collecting the sample, unless the well had been in use at the time of sampling. The pump discharge point was examined, and decontaminated by flaring with a cigarette lighter, before sample collection.

For hand-dug wells without pumps, clear Teflon bailers were used for collecting the sample. The bailer was carefully lowered to the water surface in the well and filled. Care was taken to avoid touching the walls of the well with the bailer during sample collection.

The samples for inorganic and organic chemical analysis were collected after the microbiological samples, as above, with either the well pump or a bailer. The coolers holding the appropriately preserved project samples were stored in a secure place until they were sent in one shipment via Morgan Air to The University of the Free State's home laboratory. In-house standard operating procedures and quality control protocols were utilized.

The following specific parameters were tested for each sampled location:

- Field Parameters (at each Water Point): Electrical conductivity (EC), Oxidation-Reduction Potential (ORP); pH; Temperature (T); and Dissolved Oxygen (DO).
- Microbiological Parameters (in the UFS Project Field Lab): Heterotrophic plate count (HPC), total coliform, and *E. coli*.
- Inorganic and Organic Chemical Parameters (by the UFS home laboratory in South Africa):
  - Anions: Cl, SO<sub>4</sub>, NO<sub>3</sub>, F, Br, PO<sub>4</sub>
  - Cations: Ca, Mg, Na, K
  - Metals: Al, Ba, As, Cr, Cu, Fe, Mn, Pb, Si, Sr, Zn
  - Carbon: TOC, COD.

**Microbiological Results:** Overall, 57% of the samples tested showed the presence of *E. coli*, which is an indicator of widespread fecal contamination. The health standard for *E. coli* is none present/detected.

- 100% of the unprotected hand-dug wells sampled showed the presence of *E. coli*.
- 75% of the kiosks sampled showed the presence of *E. coli*.
- 67% of the LWSC city water taps sampled showed the presence of *E. coli*.
- 52% of the protected hand-dug open wells fitted with hand pumps showed the presence of *E. coli*.
- 44% of the drilled wells fitted with hand pumps showed the presence of *E. coli*.

**Summary Table for Microbiological Sample Results:  
Monrovia Water Point Sampling - September 2011**

<b>Water Point Category</b>	<b>No. of Points Sampled</b>	<b>No. with Coliform Detected</b>	<b>No. with Coliform Absent</b>	<b>No. with <i>E. coli</i> Detected</b>	<b>No. with <i>E. coli</i> Absent</b>
<b>Hand-Dug Well with Hand Pump</b>	147	125	22	76	71
<b>Drilled Well with Hand Pump</b>	18	12	6	8	10
<b>Unprotected Hand-Dug Well - No Pump</b>	18	18	0	18	0
<b>Kiosk</b>	12	12	0	9	3
<b>City Water Tap (Including 4 below ground vaults)</b>	6	5	1	4	2
<b>Source Water for Kiosks - Trucked Water</b>	3	3	0	2	1
<b>Total Points Sampled</b>	<b>204</b>	<b>175</b>	<b>29</b>	<b>117</b>	<b>87</b>

The various types of water points are discussed individually below.

### **Unprotected Hand-Dug Wells**

Eighteen (18) unprotected (open) hand-dug wells were sampled. These wells were not mapped on the original water point inventory, but given their widespread usage for water supply provision in the City, were considered as an important element to add to the sampling program. They are a common feature in the dense low-lying neighborhoods like West Point, Clara Town, and in the older parts of Monrovia.

All of the open wells sampled showed the presence of *E. coli*, indicating unacceptable water quality, and the locations of these wells range from very densely populated areas to semi-rural areas to the north and east of downtown Monrovia. *E. coli* levels were detected in the range from 15 to >200 colony forming units per 100 milliliter (ml), most probable number (MPN/100 ml). Many of these wells showed a very high level of contamination that was above the upper reporting limit of 200 MPN/100 ml.

Possible mitigation measures to improve water quality include:

- Replacement of these wells with protected and deeper drilled wells in the low-to-medium density population areas.
- Replacement with piped water or regulated kiosks in the high density population areas like West Point and Clara Town, where drilled wells might not be practicable.

## **Kiosks and Kiosk Water-Supply Sources**

The kiosks are an important source of water supply in the City, particularly in the very dense urban areas. Twelve (12) kiosks were sampled. As an add-on to the sampling program, three kiosk water-supply sources (two wells and one piped water source from LWSC) were also sampled. Seventy-five (75) percent of the kiosk samples showed the presence of *E. coli*, as did the two kiosk source-water wells.

*E. coli* in the two kiosk source-water wells were reported at 1 MPN, while *E. coli* levels reported in the kiosk samples ranged from 0 to as much as 53 MPN. The introduction of *E. coli* between the source-water wells and the kiosk tanks is a variable that was not quantified during this study. Possible entry points include:

- (a) unsealed kiosk tanks;
- (b) water transport tankers; and
- (c) poor loading/unloading practices, e.g., piping that is laid down on the ground and road surfaces; etc.

Possible mitigation measures to improve water quality include:

- Installing new deep wells for kiosk water supply in protected areas, with overhead sealed tanks and source chlorination.
- Routine kiosk tank and water transport tanker chlorination, and cleaning programs with periodic sampling.
- Assessment of other unknown kiosk source-water sources.
- Regulation and management of the kiosk water-supply chain including kiosk suppliers and transporters.

## **LWSC Standpipes (City Water Taps)**

It was initially planned to sample over twenty (20) LWSC standpipes, but many had no water at the time of the site visits. As such, six (6) samples were taken from piped city water sources and of these, four (4) showed unacceptable water-quality, with *E. coli* present at levels ranging from 1 to >200 MPN.

## **Drilled Wells with Hand Pumps**

Eighteen (18) drilled wells were sampled. Eight (8) drilled wells showed the presence of *E. coli* at levels from 2 to >200 MPN. Most of these drilled wells are located in residential areas with medium to low population density, and there is a mix of acceptable (no *E. coli* detected) and unacceptable water-quality results for these wells in both types of neighborhoods.

Construction details for these wells were not available. In discussions with a few drilling organizations (private sector and NGO), it is our understanding that protective grouting of the well casing to prevent entrance of contaminants from ground surface is not a common practice.

Causation of the presence of *E. coli* in these drilled wells points to:

- (a) Construction issues such as a lack of significant length of well casing (minimum of 50 feet recommended) and/or no protective cement grout sanitary seal between the borehole-well casing annulus, thus allowing surface/shallow contamination and microbes to enter the well system.
- (b) Lack of safe separation distance between the wellhead and latrines/septic systems.

Potential mitigation measures include:

- Replacement of impacted wells with new wells that are properly sited and with well construction that includes a protective grout seal.

### **Hand-Dug Wells Fitted with Hand Pumps**

Hand-dug wells fitted with hand pumps represent the largest category of water supply wells in Monrovia and 147 of these wells were sampled. Of these, 76 wells or slightly over half showed the presence of *E. coli* at levels from 1 to >200 MPN.

As with the drilled wells, there was a mix of acceptable (no *E. coli* detected) and unacceptable results for the hand-dug wells with hand pumps; in low, medium, and high-density residential city neighborhoods.

Causation of the presence of *E. coli* in these shallow hand-dug wells includes:

- (a) Very shallow water levels overall;
- (b) Poor sanitary construction of some wells allowing pathways for contaminant migration into the wells from the ground surface; and
- (c) Proximity to latrines, septic systems, and contaminated surface drainage.

Potential mitigation approaches to improve water quality include:

- Repair and chlorination of impacted wells with follow-up microbiological sampling.
- Replacing impacted shallow hand-dug wells with deeper (and properly sited and constructed) drilled wells, where practicable.

**Chemical Results:** Certain inorganic constituents, including nitrate, fluoride and arsenic, have been shown to cause widespread health effects in humans as a consequence of exposure through drinking water. Serious human health effects associated with lead and chromium

(hexavalent) in drinking water have also been demonstrated. Iron and manganese are of widespread significance because of their secondary effects on the aesthetic quality of water, but do not generally have direct impacts on the health and well-being of consumers.

The results for nitrate, fluoride, arsenic, lead and chromium in the sampled water points in Monrovia are summarized below. In general, except for nitrate, which was detected in 20 percent of the samples above acceptable levels, and lead with widespread minimal exceedances, these constituents of primary concern with respect to drinking water were detected only occasionally above the Liberian water-quality standards and/or guidance values established by the World Health Organization (WHO) in isolated wells.

**Nitrate (NO<sub>3</sub>):** Nitrate is known to produce a short-term exposure health effect of methemoglobinemia (“blue baby syndrome”), a condition that prevents red blood cells from releasing oxygen to bodily tissues. The Liberian Class 1 water-quality standard (for potable water) for nitrate is 9 mg/l and the WHO guideline value is 11 mg/l. Approximately 20 percent of the water point samples had nitrate levels above the Liberian Class 1 water-quality standard. The water points with elevated nitrate concentrations showed a reasonable correlation with the water points that showed elevated levels of coliform and *E. coli*. The presence of latrines and septic tanks in undesirable proximity to the water points appears to contribute both microbiological contaminants and nitrates.

**Fluoride (F):** Studies of the adverse effects of the long-term ingestion of fluoride via drinking water have clearly established that high fluoride intakes produce deleterious effects on skeletal tissues (bones and teeth), whereas low concentrations provide protection against dental cavities. The Liberian Class 1 water-quality standard (for potable water) for fluoride is 1.5 mg/l, and the WHO guideline for drinking water is equivalent. Fluoride was detected in 23 percent of the water point samples, generally at very low levels of 0.01 to 0.2 mg/l. No water point was above the standard/guideline.

**Arsenic (As):** Arsenic is classified by the WHO International Agency for Research on Cancer (IARC) as a human carcinogen (Group 1). Effects of long-term exposure to arsenic include dermal lesions, peripheral neuropathy, skin cancer, bladder, kidney and lung cancers, and peripheral vascular disease. The Liberian Class 1 water-quality standard for arsenic is 0.05 mg/l. A new provisional guideline of 0.01 mg/l for arsenic was put forward by WHO in 2011, based on treatment performance and analytical achievability. Arsenic was detected in 14 percent of the water point samples, generally at low concentrations from 0.006 to 0.009 mg/l. All of the arsenic results were below the Liberian Class 1 water-quality standard (for potable water) of 0.050 mg/l. Three water points exhibited arsenic above the WHO guideline value of 0.010 mg/l.

**Lead (Pb):** Lead is a general toxicant that accumulates in the skeleton, and interferes with calcium and vitamin D metabolism. Lead is also toxic to the central and peripheral nervous systems. Since they absorb 4 to 5 times as much lead, young children are more at risk than adults for neurotoxic effects. The WHO IARC has classified lead and inorganic lead compounds as possible human carcinogens (Group 2B). The Liberian Class 1 water-quality standard for lead is 0.1 mg/l. However, the current WHO provisional guideline value has been lowered to 0.01 mg/l, based on treatment performance and analytical achievability. Lead was detected in 93 percent of the water point samples tested, all of which were below the Liberian Class 1 water-quality standard. About 69 percent of the water point samples had lead concentrations above the 0.01 mg/l WHO provisional guideline value. However, these lead concentrations

were for the most part just slightly above the WHO guideline, and in the range from 0.011 to 0.020 mg/l. The highest value of 0.054 mg/l was reported in sample B-084.

**Chromium (Cr):** The hexavalent form of chromium is classified as a human carcinogen (Group 1) by WHO IARC and is active in genotoxicity testing. The Liberian Class 1 water-quality standard for chromium (total) is 0.05 mg/l, and the current provisional WHO guideline for drinking-water quality is equivalent. Chromium was only detected in one of the water point samples. Sample B-007 showed a very low chromium level of 0.009 mg/l, which is below the standard/guideline.



**Sample Collection from a Shallow Protected Hand-Dug Well with a Hand Pump**

### **Conclusions:**

The detection of *E. coli* in 57 percent of the collected drinking-water source samples in the Capital City of Monrovia calls for an immediate action-oriented program. This program would include immediate steps to protect public health; short-term steps to improve the water-supply infrastructure and regulation; and planning for a long-term program to modify the system configuration for better treatability and control.

#### **1. Immediate Steps to improve Public Health** should include:

**Public Health Surveys:** Although it was outside the scope of this project, a comprehensive public health study is needed to correlate public health problems with the water quality of specific sources. This would serve as a basis for treating or shutting down particularly harmful sources, noting the presence of cholera “hot-spots” in the City at the time of this study.

**Marking of Well Points:** All of the water-supply sources (wells, kiosks, city taps) that have shown the presence of *E. coli* should be marked with a warning designated by the Ministry of Health officials.

**Chlorination of Impacted Wells and Routine Sampling:** *E. coli* impacted wells (hand dug and drilled) should be chlorinated on a routinely scheduled basis with follow-up *E. coli* sampling.

**Establishment of a Contact System (Hotline) to Report Problems:** A system should be established so that the public can report (to the Ministry of Health or its designated representative) poor wellhead and tank conditions, and evident water-quality problems.



**Sample Collection from an Unprotected Hand-Dug Well With Hand Pump Out-of-Service**

**2. Short-Term Steps for Water-Supply Source Improvement** should include:

**Physical improvements to the kiosk and source-well infrastructure:** The scope would include replacement of the kiosk water-supply hand-dug wells with deeper drilled wells that are properly constructed (sealed) and within a source (wellhead) protection zone. These same wells should be equipped with submersible pumps; chlorination treatment, and elevated sealed tank storage for distribution to water tanker trucks.

**Formulation of a “Regulation and Management Plan” for Kiosk Suppliers and Transporters:** The elements of such a program might include: a) Routine kiosk and water tanker chlorination; b) Cleaning procedures with periodic sampling; and c) Best practices for loading/unloading, and d) Provisions for inspections and enforcement.

**Replacing Hand-Dug Wells With Drilled Wells Where Feasible:** Drilled wells can be a solution in the areas of the City that are not densely populated. They are not considered to be a solution for densely populated areas, where even the deeper groundwater might be impacted by *E. coli*. For the densely populated areas where access to potable groundwater is not a solution,

kiosks will need to serve as the source of supply until a safe regional water supply source is secured.

**3. Long Term Solutions:** The water supply system configuration of Monrovia is typical of many other urban areas that rely on groundwater in developing countries, which are fundamentally different from water supply systems in the modernized world in ways that exacerbate the difficulty of implementing mitigation measures that are effective and lasting. Whereas in American cities, for example, the water-supply sources are primarily centralized (i.e., one or more well field sources run by a limited set of regulated public or private utilities), in Monrovia, there are many sources interspersed throughout the city. In addition, in American cities, there are numerous points-of-use each belonging to individual customers, whereas in Monrovia, many fewer points-of-use are shared by many consumers. These characteristics make treatment, quality control, and regulation of both the water-supply sources and at points-of-use more chaotic, complicated, and difficult. In the long-term, projects should aim at moving toward centralizing the water-supply sources and decentralizing the points of use of the system in order to improve control of water quality both at the supply sources and points of use.

