Final Report of the

Independent Panel of Experts on the Cholera Outbreak in Haiti

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Executive Summary

Ten months after the devastating earthquake of January 12, 2010, cholera appeared in Haiti for the first time in nearly a century. The outbreak subsequently claimed over 4,500 lives, sickened almost 300,000 people, and continues to cause infections and deaths in Haiti. The source of the cholera has been controversial, with hypotheses that the pathogen that causes cholera (*Vibrio cholerae) arrived* into Haiti from the Gulf of Mexico due to tectonic shifts resulting from the earthquake, *evolved* into disease-causing strains from non-pathogenic strains naturally present in Haiti, or originated from a human host who inadvertently *introduced* the strain into the Haitian environment. A specific form of the third hypothesis, that soldiers deployed from a cholera-endemic country to the Mirebalais MINUSTAH camp were the source of the cholera, is a commonly held belief in Haiti.

In order to determine the source of the outbreak definitively, the Secretary-General of the United Nations formed an Independent Panel of four international experts (the "Independent Panel"), with a mandate to "investigate and seek to determine the source of the 2010 cholera outbreak in Haiti". To fulfill this mandate, concurrent epidemiological, water and sanitation, and molecular analysis investigations were carried out.

On October 22nd, 2010, the first cholera case in Haiti in nearly a century was confirmed at the Haiti National Public Health Laboratory. A review of hospital admission records along the Artibonite River from the mountains of Mirebalais to St. Marc on the coast clearly showed that a normal background rate of non-fatal diarrheal disease in adults and children was abruptly interrupted by the onset of a cholera outbreak. The first hospitalized cholera case in Mirebalais, in the upstream region of the Artibonite River, was on the evening of October 17th, 2010. The first hospitalized cholera cases on the coast, in the Artibonite River Delta in St. Marc and Deschapelle, were on October 20th, 2010. The outbreak was widely established in the coastal areas by October 22nd, 2010. The timeline suggests that the outbreak spread along the Artibonite River.

After establishing that the cases began in the upper reaches of the Artibonite River, potential sources of contamination that could have initiated the outbreak were investigated. MINUSTAH contracts with an outside contractor to handle human fecal waste. The sanitation conditions at the Mirebalais MINUSTAH camp were not sufficient to prevent fecal contamination of the Meye Tributary System of the Artibonite River. Water in the Meye Tributary System reaches the Artibonite River junction in less than 8 hours, and flows downstream in another 1-2 days to a dam and canal system widely used for irrigation throughout the Artibonite River Delta.

Several independent researchers studying genetic material from the bacteria responsible for the outbreak of cholera in Haiti graciously provided their results to us. They used a variety of molecular analysis techniques to examine multiple samples of the bacteria. Their results uniformly indicate that: 1) the outbreak strains in Haiti are genetically identical, indicating a single source for the Haiti outbreak; and, 2) the bacteria is very similar, but not identical, to the South Asian strains of cholera currently circulating in Asia, confirming that the Haitian cholera bacteria did not originate from the native environs of Haiti.

The hydrological data, combined with the epidemiological timeline, and supported by the molecular analysis information verifies that contaminated river water was the likely route of spread of *Vibrio cholerae* from the mountains of Mirebalais to the coastal areas around the Artibonite River Delta.

These research findings indicate that the 2010 Haiti cholera outbreak was caused by bacteria *introduced* into Haiti as a result of human activity; more specifically by the contamination of the Meye Tributary System of the Artibonite River with a pathogenic strain of the current South Asian type *Vibrio cholerae.*

This contamination initiated an explosive cholera outbreak downstream in the Artibonite River Delta, and eventually throughout Haiti. This explosive spread was due to several factors, including the widespread use of river water for washing, bathing, drinking, and recreation; regular exposure of agricultural workers to irrigation water from the Artibonite River; the salinity gradient in the Artibonite River Delta, which provided optimal environmental conditions for rapid proliferation of *Vibrio cholerae;* the lack of immunity of the Haitian population to cholera; the poor water and sanitation conditions in Haiti; the migration of infected individuals to home communities and treatment centers; the fact that the South Asian type *Vibrio cholerae* strain that caused the outbreak causes a more severe diarrhea due to the larger production of the more potent classical type of cholera toxin; and, the conditions in which cholera patients were initially treated in medical facilities did not prevent the spread of the disease to other patients or to the health workers.

The introduction of this cholera strain as a result of environmental contamination with feces could not have been the source of such an outbreak without simultaneous water and sanitation and health care system deficiencies. These deficiencies, coupled with conducive environmental and epidemiological conditions, allowed the spread of the *Vibrio cholerae* organism in the environment, from which a large number of people became infected.

The Independent Panel concludes that the Haiti cholera outbreak was caused by the confluence of circumstances as described above, and was not the fault of, or deliberate action of, a group or individual. The following recommendations to the United Nations, to the Government of Haiti, and to the international community are intended to help in preventing the future introduction and spread of cholera:

1) The Haiti cholera outbreak highlights the risk of transmitting cholera during mobilization of population for emergency response. To prevent introduction of cholera into non-endemic countries, United Nations personnel and emergency responders traveling from cholera endemic areas should either receive a prophylactic dose of appropriate antibiotics before departure or be screened with a sensitive method to confirm absence of asymptomatic carriage of *Vibrio cholerae*, or both.
2) United Nations missions commonly operate in emergencies with concurrent cholera epidemics. All United Nations personnel and emergency responders traveling to emergencies should receive prophylactic antibiotics, be immunized against cholera with currently available oral vaccines, or both, in order to protect their own health and to protect the health of others.
3) To prevent introduction of contamination into the local environment, United Nations installations worldwide should treat fecal waste using on-site systems that inactivate pathogens before disposal. These

systems should be operated and maintained by trained, qualified United Nations staff or by local providers with adequate United Nations oversight.

4) To improve case management and decrease the cholera case fatality rate, United Nations agencies should take stewardship in:
    a) Training health workers, especially at the treatment center level;
    b) Scaling-up the availability and use of oral rehydration salts at the household and community level in order to prevent deaths before arrival at treatment centers; and,
    c) Implementing appropriate measures (including the use of cholera cots) to reduce the risk of intra-facility transmission of cholera to health staff, relatives, and other patients.

5) To prevent the spread of cholera, the United Nations and the Government of Haiti should prioritize investment in piped, treated drinking water supplies and improved sanitation throughout Haiti. Until such time as water supply and sanitation infrastructure is established:
    a) Programs to treat water at the household or community level with chlorine or other effective systems, handwashing with soap, and safe disposal of fecal waste should be developed and/or expanded; and,
    b) Safe drinking water supplies should continue to be delivered and fecal waste should be collected and safely disposed of in areas of high population density, such as the spontaneous settlement camps.

6) The international community should investigate the potential for using vaccines reactively after the onset of an outbreak to reduce cholera caseload and spread of the disease.

7) Recent advances in molecular microbial techniques contributed significantly to the investigative capabilities of this report. Through its agencies, the United Nations should promote the use of molecular microbial techniques to improve surveillance, detection, and tracking of *Vibrio cholerae*, as well as other disease-causing organisms that have the potential to spread internationally.

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Abbreviations

CDC	U.S. Centers for Disease Control and Prevention
CFR	Case Fatality Rate
CT	Cholera Toxin
EDH	Électricité d'Haïti
FCR	Free Chlorine Residual
MINUSTAH	The United Nations Stabilization Mission in Haiti
MLVA	Multiple Locus Variable Number Tandem Repeat Analysis
ODVA	Organization for the Development of the Artibonite Valley
ORS	Oral Rehydration Salts
PCR	Polymerase Chain Reaction
PFGE	Pulse Field Gel Electrophoresis
UN	United Nations

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1 Introduction

Ten months after the devastating earthquake of January 12th, 2010, cholera appeared in Haiti for the first time in nearly a century. The first cases were confirmed on October 22nd, 2010. As of April 17th, 2011, 285,931 cases of cholera had been reported, with 154,041 (54.0%) patients hospitalized, and 4,870 (1.7%) deaths.

Cholera is a severe, acute, dehydrating diarrhea that can kill children and adults in less than 12 hours. Cholera is the result of infection with a pathogenic strain of the bacterium *Vibrio cholerae*, which is capable of producing a potent toxin known as cholera toxin (CT). Depending on the severity of the infection, cholera may be treated with oral rehydration salt (ORS) solutions, intravenous fluids, and/or antibiotics. The case fatality rate (CFR) in a well-managed cholera outbreak should be less than 1%. In this outbreak, the CFR stands at 1.7%. *Vibrio cholerae* infection displays a clinical spectrum that ranges from asymptomatic infection to severe cholera known as *cholera gravis*. The number of asymptomatic cases that play a role in the transmission of cholera varies according to age and the endemic nature of the disease. In countries such as Bangladesh, asymptomatic cases may represent roughly half of all cases (Nelson et al., 2009).

Although cholera has been a localized phenomenon in South Asia for centuries, the pathogen has repeatedly demonstrated the ability to spread both regionally and internationally. The seventh worldwide pandemic of cholera began in 1961 and is ongoing. The control of the disease requires a combination of interventions that range from water supply and sanitation improvements at the community level to the use of currently available oral cholera vaccines at the individual level.

Cholera had not been documented in Haiti in almost 100 years, and the source of the 2010 outbreak is a topic of debate. Three credible hypotheses have been proposed. The first hypothesis holds that an environmental strain of *Vibrio cholerae* that normally inhabits the Gulf of Mexico travelled to Haiti naturally via ocean currents as a consequence of the January 12th, 2010 earthquake and caused the present cholera epidemic. The second hypothesis holds that a local, non-toxigenic *Vibrio cholerae* strain endemic to the Haitian environment naturally mutated into a virulent pathogenic strain, which quickly spread throughout the human population of Haiti. The third hypothesis holds that the source of the outbreak was an infected human who carried a pathogenic strain of *Vibrio cholerae* into Haiti from a cholera endemic region outside the country.

The United Nations Stabilization Mission in Haiti (MINUSTAH) was created in April 2004 by the United Nations Security Council. After the January 12th, 2010 earthquake, the United Nations (UN) Security Council passed additional resolutions increasing the number of MINUSTAH forces in order to support recovery, reconstruction, and stability efforts. A specific form of the third hypothesis for the source of the cholera outbreak, that soldiers at the Mirebalais MINUSTAH camp were the direct source for the cholera outbreak, is a commonly held belief in Haiti. Testimony cited to support this belief includes the following: 1) the Mirebalais MINUSTAH camp is located near the area where the first cholera cases were identified; 2) a new group of soldiers had recently arrived at the time of the first cases; and, 3) witnesses reported sanitation practices at the camp that allowed soldiers' feces to enter the environment.

Until the publication of this report, a definitive determination of the source of the 2010 cholera outbreak in Haiti has been lacking. Two previous investigations that commented on the source of the outbreak came to opposing conclusions: Sack (personal communication) concluded that the outbreak was caused by a local event; whereas Piarroux (2010) concluded that the outbreak was caused by cholera being imported to Haiti by an infected MINUSTAH soldier. Neither report presents sufficient evidence to support its conclusions with reasonable certainty.

In order to definitively determine the source of the outbreak, the Secretary-General of the United Nations convened the Independent Panel of Experts on the Cholera Outbreak in Haiti (the “Independent Panel”), with the mandate to “investigate and seek to determine the source of the 2010 cholera outbreak in Haiti”, and to present the findings of this investigation in a written report submitted to the UN Secretary-General and to the Government of Haiti.

This document is the written report requested by the Secretary-General. In it, the methods, results, conclusions, and recommendations from the investigation are presented.

2 Methodology of Investigation

To complete the mandate to "investigate and seek to determine the source of the 2010 cholera outbreak in Haiti", the Independent Panel completed six activities:

1) Having an initial coordination meeting in Delhi and subsequent conference calls between Independent Panel members;
2) Collecting and collating information and reports;
3) Communicating and/or meeting with experts outside Haiti;
4) Visiting Haiti from February 13th to February 20th, 2011, including a field visit to the Artibonite region;
5) Developing and compiling this report to summarize and analyze the information obtained; and,
6) Visiting United Nations Headquarters in New York City twice, first to advance the writing of this report and second, to present this report to the Secretary General.

2.1 Investigations by the Independent Panel

To determine the source of the 2010 Haiti cholera outbreak, the Independent Panel undertook three concurrent investigations throughout the five activities: 1) epidemiological; 2) water and sanitation; and, 3) molecular analysis. The methodologies for these investigations are briefly described in the following paragraphs. A map of locations visited in the Artibonite River region is shown in Figure 1.

Epidemiological information was obtained from organizations investigating the outbreak and from records of diarrheal illnesses among MINUSTAH personnel, as well as during visits to hospitals along the Artibonite River in order to determine the exact onset dates of the cholera outbreak throughout the watershed. These findings are presented in Section 3: Epidemiological Investigation.

Visits were made to various locations in the Artibonite watershed and discussions were held with local experts to understand the hydrology of the Artibonite River and its tributaries, the water and sanitation situation in the Mirebalais MINUSTAH camp, and water use practices of the population along the river. These findings are presented in Section 4: Water and Sanitation Investigation.

Published and unpublished information was obtained from groups currently working on the evolution of *Vibrio cholerae* in Haiti and worldwide. Information on the basic microbiology and data from advanced molecular typing techniques was used to compare the Haitian strains against other known worldwide strains of *Vibrio cholerae*. These findings are presented in Section 5: Molecular Analysis Investigation.

The report culminates with conclusions and recommendations in Sections 6 and 7. An Annex with supplementary epidemiological data is appended to this document. Source references were provided to the Secretary General in a confidential addendum.

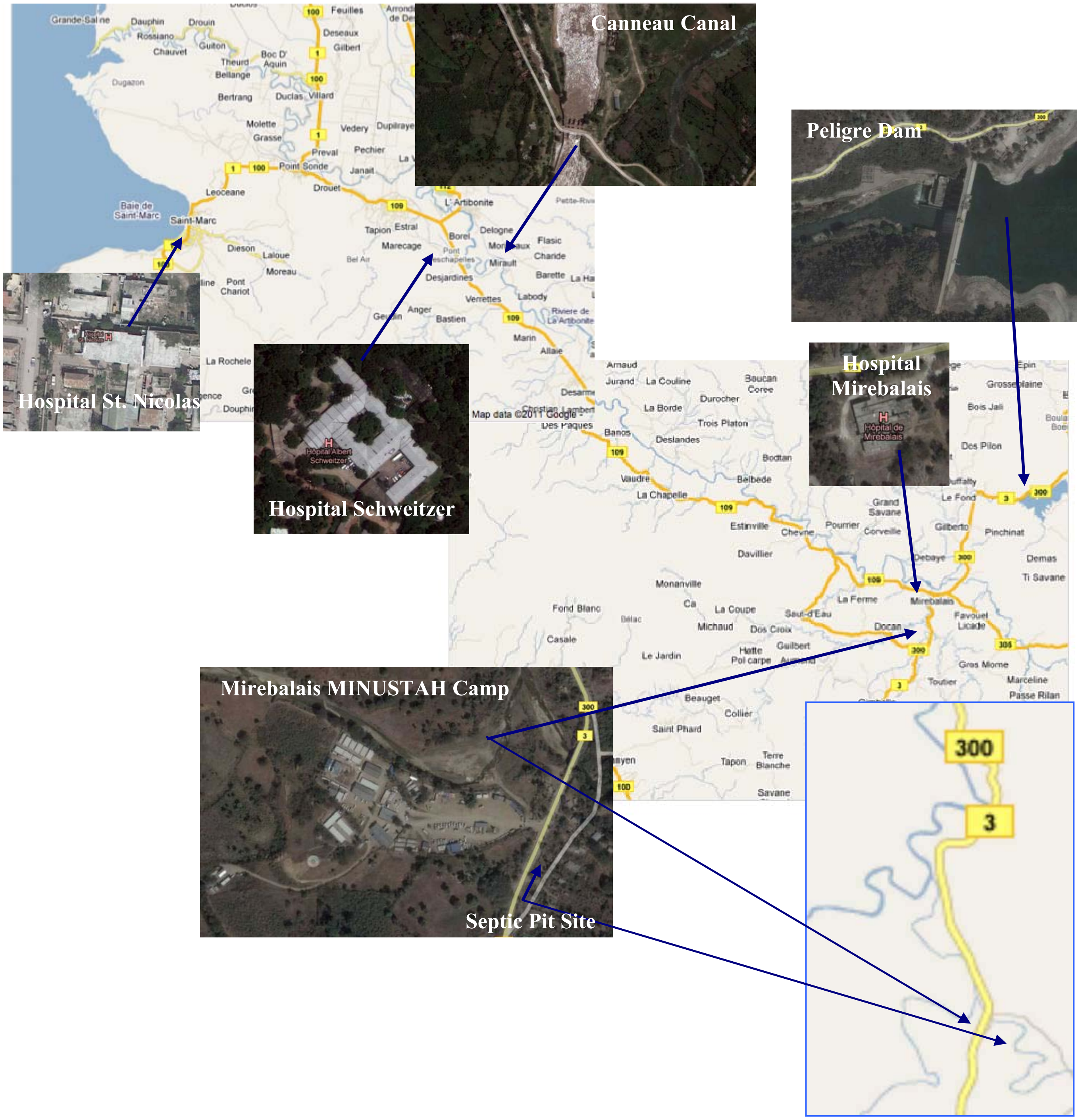

Figure 1: Places Visited in the Artibonite River Region (Not to scale, source: Google Maps)

(note: Terre Rouge MINUSTAH facility not depicted)

3 Epidemiological Investigation

3.1 Introduction

The goal of the epidemiological investigation was to determine where and when the first cases of cholera in Haiti occurred. All reports indicated that the first cholera cases occurred in Centre and Artibonite Departments along the Artibonite River. For this epidemiological part of the investigation, the Independent Panel began by interviewing individuals who might have had knowledge about the early cholera cases in this region. Verbal reports from those interviewed varied significantly with regard to both the perceived start date of the cholera outbreak, as well as other important issues relating to the disease: 1) mentioning initial cholera cases as early as Oct 12th; 2010; 2) reporting an outbreak of typhoid fever, which had prompted an official government warning in early October in Gonaives in the Artibonite River Delta, as misclassified cases as cholera; and, 3) declining to comment about the origin of the outbreak and restricting themselves to endorsing the official start date established by the Haitian Government. None of the individuals interviewed provided data to support these comments. The lack of physical evidence to confirm this anecdotal data led the Independent Panel to search for clinical information in the form of medical records of MINUSTAH personnel and admission records at Centre and Artibonite Department regional hospitals. The Panel conducted site visits to hospitals along the Artibonite River, beginning in the upstream mountains near Mirebalais in the Centre Department, and ending at St. Marc on the coast in the Artibonite Department (Figure 1).

3.2 Health Status of MINUSTAH Personnel in the Artibonite Region

Currently, MINUSTAH uniformed personnel in Haiti originate from 22 countries, and are deployed in contingents based on their country-of-origin to specific geographical areas in Haiti. Some areas, such as Port-au-Prince, have MINUSTAH contingents originating from a number of different countries. In the Centre and Artibonite Departments, there are permanently deployed contingents from Nepal, Argentina, and Peru. Contingents from Bangladesh were deployed in these same Departments on a short-term basis. Contingents from Nepal are stationed in three camps (Hinche, Mirebalais, and Terre Rouge) in the Centre Department (Figure 2). Contingents from Argentina are stationed in the Artibonite Department near the coast and in the Artibonite River Delta. In addition, a small police contingency (60 officers) from Bangladesh was stationed in Hinche and Mirabalais between September and October 2010. Lastly, Peruvian troops that patrol the Haiti/Dominican Republic border sometimes traveled to the Mirabalais MINUSTAH camp to eat and take provisions before returning to their camps and patrol duties.

MINUSTAH contingents are deployed in six month rotations. The replacement Nepal contingent arrived in Centre Department between October 8th and 24th, 2010 after three months of training in Kathmandu, Nepal. A medical examination was completed before they departed Kathmandu. This examination only included microbiological testing of stools when clinically indicated. Once the training and medical examination were completed, soldiers were given a 10-day free period to visit their families, wherever they happened to be located in Nepal, before traveling to Haiti. Within one day of arrival in Haiti, soldiers were transported to their posts at the Mirebalais, Hinche, or Terre Rouge camps.

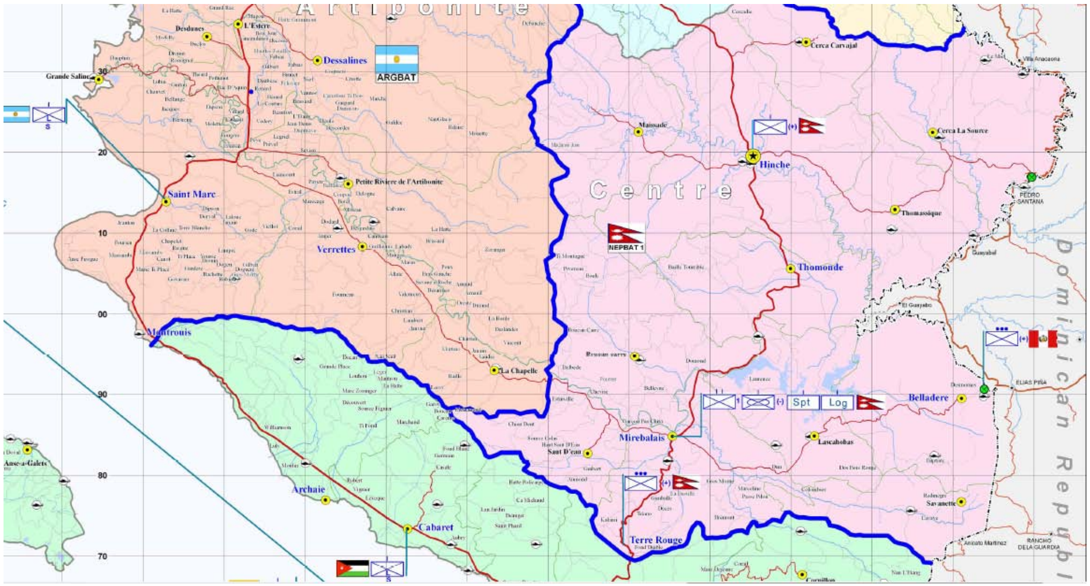

Figure 2: MINUSTAH Contingents in Centre and Artibonite Departments

The medical records of MINUSTAH personnel stationed in Haiti for the time period between September and October 2010 were obtained and reviewed. A review of national level data and dispensary clinic data at the Mirebalais camp showed that no cases of severe diarrhea and dehydration occurred among MINUSTAH personnel during this period. The review of these records indicated that no clinical cases of cholera occurred among MINUSTAH personnel before or during the start of the cholera outbreak in Haiti.

3.3 Initial Cholera Cases in the Artibonite Region

There did not appear to be any national or regional systematic reporting system for diarrheal disease in Haiti before the cholera outbreak. A sentinel surveillance system was implemented by the Ministry of Public Health and Population after the earthquake in January 2010, with the assistance of the U.S. Centers for Disease Control and Prevention (CDC). However, background information on nationwide diarrheal disease incidence was not able to be obtained from this database.

Three hospitals serving patients at the beginning of the epidemic along the Artibonite River region were visited: 1) the Mirabalais Hospital in Mirabalais; 2) the Albert Schweitzer Hospital in Deschapelle; and, 3) the St. Nicholas Hospital in St. Marc (Figure 1). In each hospital, a detailed review of medical records from October 2010 was carried out to identify cases that required hospitalization due to diarrhea and dehydration in order to establish an outbreak onset date. Since detailed medical records did not exist, which would have allowed an epidemiological definition of a cholera case to be created, hospitalizations due to severe diarrhea were used as a proxy for cholera cases. Particularly focus was given to adults in this analysis, as severe diarrhea in adults is rare, and the transition between background baseline cases and outbreak onset is clearer in this group.

3.3.1 Mirabalais Government Hospital in Mirebalais

At Mirebalais Hospital, a team of physicians who were working at the hospital in October 2010 when the outbreak began provided access to the hospital's admission records and provided anecdotal information to the Independent Panel from during that period. Between September 1st and October 17th, 2010, sporadic diarrhea cases without death were seen at a consistent baseline rate in both adults and children. Data from October 8th to October 21st are presented in Figure 3. The first severe diarrhea case that required hospitalization and the first death from dehydration in patients older than 20 years of age occurred during the night of October 17th, 2010 and early morning of October 18th, 2010, respectively. No recorded information on the origin of these cases was identified, but staff mentioned that the first cholera cases came from an area named Meye, located 150 meters downstream from the Mirabalais MINUSTAH camp. As can be seen, the cases increased significantly on October 21st, 2010.

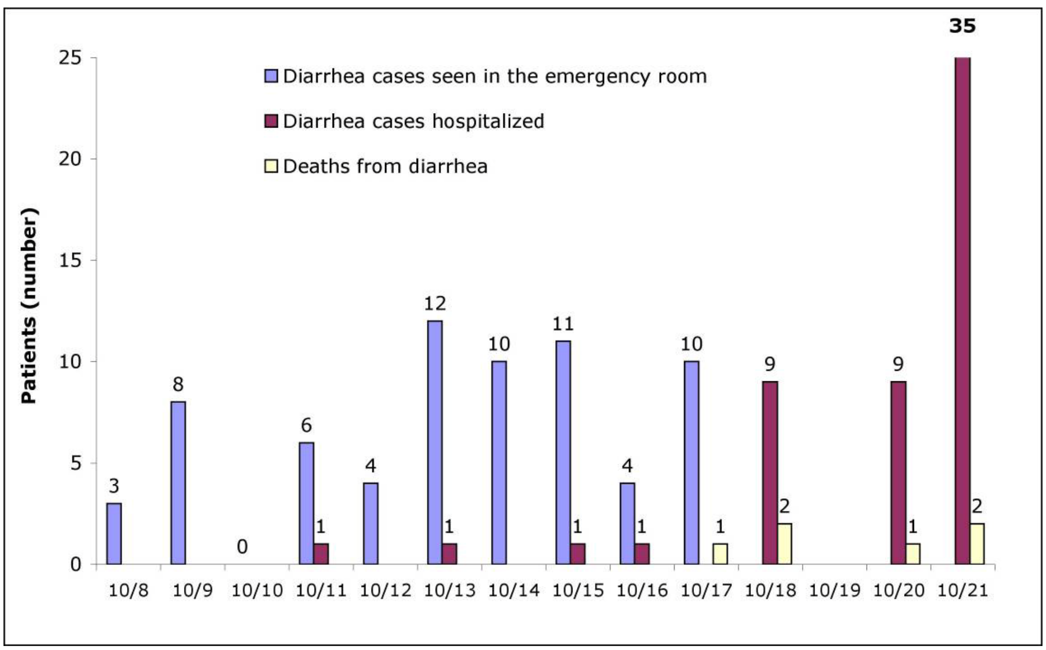

Figure 3: Patients seen for Diarrhea at the Mirebalais Hospital, October 8th-21st, 2010

3.3.2 Mirabalais Market

The Mirebalais Market was visited to determine if fish or shellfish products, which can be a vehicle for the transmission of cholera, are regularly consumed by the population. No fish or shellfish products from the coast were found in the market by the Independent Panel. Market women confirmed that these products are not sold in the market nor consumed by the local population. The only fish sold in the market were river fish sold by a small number of women in one area of the market and stored at ambient temperature in woven baskets. The price of fish was five times that of chicken meat when calculated on a cost by weight basis. It was clear that the population in Mirebalais was not exposed to *Vibrio cholerae* from possibly contaminated seafood.

3.3.3 Albert Schweitzer Hospital in Deschapelle

Opened in 1956, Albert Schweitzer is a private, non-profit facility that serves as the regional referral hospital for over 300,000 people in the Artibonite Valley. The hospital is located approximately two-thirds of the distance from Mirebalais to St. Marc. As the hospital is not located near a major population center, this facility saw fewer cholera cases than other hospitals in the Artibonite River Delta. The hospital's admission records where any patient required to be kept under observation was registered were reviewed. The first cases of severe diarrhea requiring observation and hospitalization were seen on October 20th, 2010, when 24 cases in adults and children compatible with cholera were seen (Figure 4). After October 20th, 2010, the number of cases increased to the point where exact record keeping became difficult.

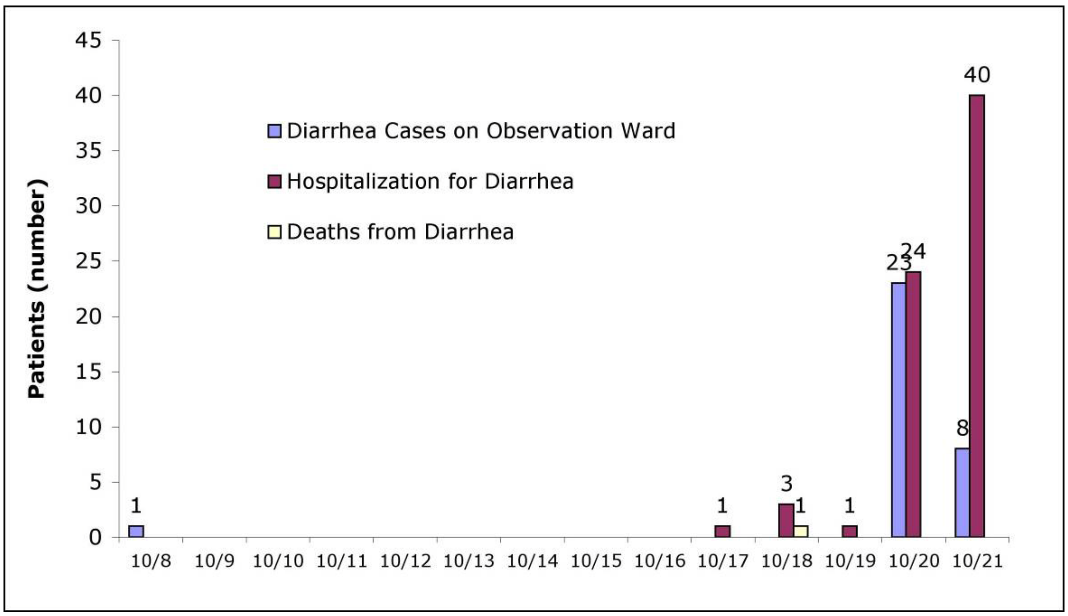

Figure 4: Patients seen for Diarrhea at the Albert Schweitzer Hospital, October 8th-21st, 2010

Discussions were held with the Hospital Administrator and the physician in charge of outpatient and emergency room services. They believed that the first case of cholera seen at the hospital was in a migratory agricultural worker in the Artibonite River Delta rice fields. The individual became sick at his home in the mountains, was transported to the hospital on October 18th, 2010, and arrived to the hospital already deceased.

Hospital medical staff provided a retrospectively compiled short list of 32 potential cholera cases hospitalized between October 17th and October 21st, 2010. Upon review of the available medical records for these cases, it was not possible to retrospectively diagnose any cholera case occurring before October 20th, 2010. The patient who was dead on arrival could also not be confirmed as a cholera case using the available medical records.

3.3.4 St. Nicolas Government Hospital in St. Marc

At the government operated St. Nicolas Hospital in St. Marc, located in the Artibonite River Delta, full access was given to the Medical Records Office, which housed records for children and adults seen in the emergency room, as well as records from several outpatient clinics. A review of the records dating between September and October 2010 clearly showed that the number and severity of diarrhea cases, mostly in children, had a consistent low profile. This low background rate of diarrhea was abruptly interrupted by an explosive outbreak of cholera cases with dehydration and death on October 20th, 2010 (Figure 5). On this date, medical staff recorded 404 hospitalizations (one every 3.6 minutes) and 44 deaths on individual pieces of paper, which record keepers had filed.

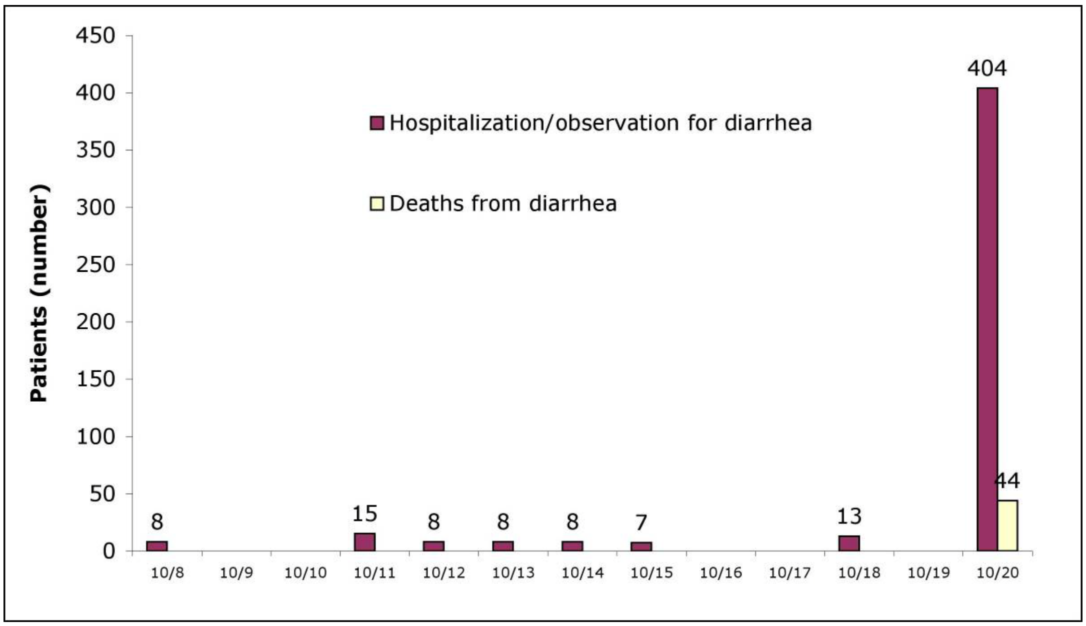

Figure 5: Patients seen for Diarrhea at the St. Nicolas Hospital in St. Marc, October 8th-20st, 2010

These 404 cases came from 50 identified communities throughout the Artibonite River Delta region (see Annex A). An average of eight patients per community came to the hospital on the first day, with a minimum of 1 and a maximum of 87 per community. Only 9 (2.2%) of the 404 patients originated from St. Marc, which indicates how widespread the outbreak was throughout the Delta on this first day. The St. Nicolas hospital received cholera patients from numerous locations because it is easily accessible to communities located throughout the Artibonite River Delta.

The majority (88.6%) of the 404 cases seen on the first day of the cholera epidemic in the St. Nicolas Hospital in St. Marc were 5 years of age and above, with the 20-24 year age group being seen most frequently (14.6%) (Figure 6). Hospital staff attributed this age distribution to the increased risk of cholera transmission in agricultural workers exposed to Artibonite River irrigation water in the rice paddies and fields. Generally, adults are the most commonly affected group in a cholera naïve area because they are ambulatory as compared with infants and children.

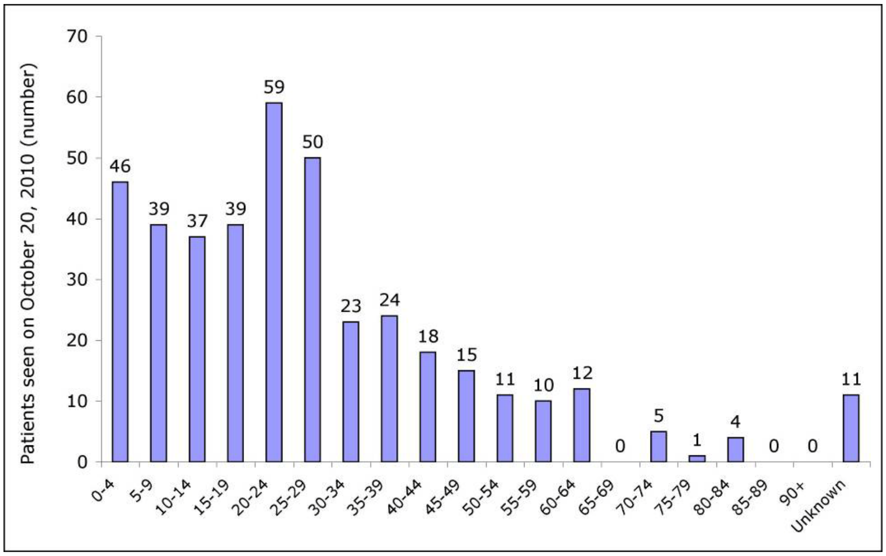

Figure 6: Cases by Age at the St. Nicolas Hospital in St. Marc on October 20th, 2010

3.3.5 Cases in the Artibonite River Delta

Data on the number of cholera cases in health facilities in the Artibonite River Delta between October 20th and 22nd, 2010 was obtained and graphed by the Independent Panel. This data (Figure 7) confirms the widespread nature of the outbreak in the Artibonite River Delta region by October 22nd, 2010.

Figure 7: Cases in Health Facilities in the Artibonite River Delta, October 20th-22nd, 2010

(to scale, large red circle in St. Marc in 780 cases, yellow boxes are road numbers, source: Google Maps)

3.3.6 Case Management

It is important to mention that cholera cots were not seen in any of the three hospitals visited. Cholera cots are designed to minimize fecal contamination in cholera wards and to measure fluid loss easily. All three cholera units visited were equipped with regular or small portable beds only. Cholera patients thus defecated in the bed itself, or were asked to walk to the toilet. Asking cholera patients to walk puts them at risk of orthostatic hypotension, a decrease in blood pressure that can be fatal in cholera patients. Hospital staff reported walking on feces in cholera units. In addition, neither hand washing facilities with running water nor hand cleansing products for patients or relatives in these units were evident. Thus, intra-hospital transmission could have been a source of cholera for families, visitors, other patients, and health staff.

3.4 Summary

Based on the epidemiological information available, the cholera epidemic began in the upstream region of the Artibonite River served by the Mirabalais Hospital on October 17th, 2010. This region has little to no consumption of fish or shellfish products, which are known to be associated with outbreaks of cholera worldwide. Therefore, the most likely cause of the outbreak was the consumption of contaminated water from the river. An explosive cholera outbreak began on October 20th, 2010 in the Artibonite River Delta, indicating that cholera had spread throughout the Artibonite River Delta within two to three days of the first cases being seen in the upstream region.

4 Water and Sanitation Investigation

4.1 Introduction

The Independent Panel visited various locations along the Artibonite River and spoke with local experts to understand the hydrology of the Artibonite River and its tributaries; the water and sanitation situation in the Mirebalais MINUSTAH camp; and, water use practices of the population along the river (Figure 1).

4.2 Hydrology of the Artibonite River

The Artibonite River is the largest river in Haiti, flowing from the mountains of the Dominican Republic to the coast near the town of Grande Saline (Figure 1). The river is controlled at two points: 1) the Peligre Hydroelectric Dam, which is located approximately 10 kilometers upstream from Mirebalais and is operated by Électricité d'Haïti (EDH) to provide electricity to the Port-au-Prince region; and, 2) at the Canneau Canal Site, near the town of Deschapelle downstream from Mirebalais, where the river splits into a series of canals, from which water is used by small farmers to irrigate their fields in the Artibonite Valley.

Discussions were held with staff from the Peligre Dam, the Canneau Canal Dam, and the Organization for the Development of the Artibonite Valley (ODVA) office in St. Marc to learn more about the river system, water quality and quantity monitoring, and river flows (Figure 8).

At the Peligre Dam, EDH engineering staff reported the presence of two meteorological stations upstream from the Dam on the border with the Dominican Republic. A rain gauge at the Peligre Dam broke 11 years ago, and no monitoring of environmental or river conditions is currently performed. EDH staff reported that it takes 1.5 to 2 days for water released from the dam to reach the Canneau Canal Site in both the dry and the wet seasons. The dry season was reported to be from January to August, and the wet season from August to November.

At the Canneau Canal Site, operations and maintenance staff reported that: 1) no water quality or flow readings are routinely collected, although there is both a depth gauge and a non-functioning electronic depth gauge installed on the bank of the Artibonite River; and, 2) that water flows from the Peligre Dam to Canneau in two days. They know this because operators at the Peligre Dam call the Canneau staff on mobile phones when water is released, and water arrives two days after the call.

Figure 8: Artibonite River (at Peligre Dam, and between Mirebalais and Canneau)

At the ODVA office, engineering staff reported that in the dry season the Artibonite River has a flow rate of about 50 m^3/sec, with 40 m^3/sec diverted to the left bank canal system, and 10 m^3/sec diverted to the right bank canal system. In the wet season, this flow rate increases. The staff mentioned that it takes about one day for water to flow from the Peligre Dam to the Canneau Canal Site. This is known because during a time when the motors broke at Peligre Dam, it took one day for water to arrive at Canneau. The staff also estimated it takes one day for water to flow from Canneau through the canal system to the sea in the Artibonite River Delta.

Although there is a lack of verifiable technical information, and there are minor inconsistencies in verbal information obtained from operators, the evidence collected from staff operating and maintaining the Artibonite River control systems indicates that water flows from the Peligre Dam to the Canneau Canal Site in 1-2 days, and to the coast in another day. Given the economic importance of the water flow to farmers in the Artibonite Valley, this anecdotal information is considered to be accurate and valid.

4.2.1 The Meye Tributary System

Two branches of the Meye Tributary of the Artibonite River flow northwards from the mountains that are located to the southwest and southeast of Mirebalais (Figure 1). The branches join together to form the Meye Tributary just north of the Mirebalais MINUSTAH camp, and are joined by another tributary just south of Mirebalais before flowing into the Artibonite River at Mirebalais itself. There is significant human activity along this tributary, with women washing, people bathing, people collecting water for drinking, and children playing (Figure 9). During the month of October 2010, it was reported that the Mirebalais City water supply system was not operating for a few weeks, and recipients relied on alternate water sources until repairs were completed. Information concerning the exact dates on which the Mirebalais water system was non-operational, and thus any relation to the onset of cholera cases, was not available.

Figure 9: Human Activity in the Meye Tributary, Saturday Morning, February 19th, 2011

4.3 The MINUSTAH Camp near Mirebalais

The water source for the Mirebalais MINUSTAH camp is a borehole with a depth of 265 feet (80 meters) that is treated on-site using a high-quality process chain including filtration, reverse osmosis, and chlorination. The system was most recently refurbished on October 26, 2010. Locally-available commercial bleach is used to make a stock chlorine solution for the chlorination step, and treated water is tested for free chlorine residual (FCR) using a Hach ColorWheel (Chestertown, MD, USA) test kit. FCR results are recorded in a logbook. Some errors were noted in the FCR testing procedures as follows: 1) all results were recorded as 0.5 or 1.0 mg/L, which while this is an acceptable FCR range, is odd, as the test kit is capable of an accuracy up to the 0.1 mg/L range; and, 2) the testing tube was stored with the last sample still in the tube, which can stain the tube and affect the reading. At the water treatment facility, two water quality testing results (from laboratories in 2009 and 2010) were made available. They showed positive results for microbiological indicators (total coliform, fecal (or thermotolerant) coliform, and *E. coli)* in the water and zero total chlorine, indicating that previously there had been some potential problems with the water treatment processes. Currently, treated water is transported using a MINUSTAH water truck to other MINUSTAH locations.

There is one main area at the Mirebalais MINUSTAH camp that houses toilet and showering facilities for the contingent. Kitchen water waste is also disposed of in this area. Gray water waste (cooking water, wash water, shower water) flows into on-site soak pits and is allowed to drain into the soil. Black water waste (containing human feces) flows into six 2,500-Liter fiberglass tanks. There are additional soak pits and one concrete tank for black water storage at a separate containment area near the medical facilities. The construction of the water pipes in the main toilet/showering area is haphazard, with significant potential for cross-contamination through leakage from broken pipes and poor pipe connections, especially from pipes that run over an open drainage ditch that runs throughout the camp and flows directly into the Meye Tributary System (Figure 10). It was evident from inspection, as well as reported by local Haitians, that recent (post October 2010) construction work in this area had been undertaken. During the hurricane in 2008, this entire area flooded.

Figure 10: Canal through Camp, Pipes over Canal, Canal Flowing into Meye Tributary

The black water tanks in the main area and medical area of the camp are emptied on demand by a contracting company approved by MINUSTAH headquarters in Port-au-Prince. MINUSTAH staff reported that the contractor empties the tanks twice per week when called. The contracting company dispatches a truck from Port-au-Prince to collect the waste using a pump. The waste is then transported across the street and up a residential dirt road to a location at the top of the hill, where it is deposited in an open septic pit (Figure 11). Black water waste for the two other MINUSTAH facilities – Hinche and Terre Rouge – is also trucked to and deposited in this pit. There is no fence around the site, and children were observed playing and animals roaming in the area around the pit. The southeast branch of Meye Tributary System is located a short walk down the hill from the pit, on the banks of which is located the solid waste disposal site for the MINUSTAH camp. Local residents reported trucks delivering waste to this disposal site and commented that the area is susceptible to flooding and overflow into the Tributary during rainfall.

Figure 11: The Black Water Disposal Pit

The southeast branch of the Meye Tributary System is a small brook that lies downstream from the black water disposal pit, 5 kilometers south of Mirebalais (Figure 12). The velocity of the tributary was measured with results showing a water flow rate between 0.18 and 0.58 meters/second in the calm and rapid waters, respectively. Calculations indicate that it would take 2-8 hours for water to flow from near the septic disposal pit to the junction with the Artibonite River. As the tributary flows towards the Artibonite River, it widens and becomes larger, until the area where the two rivers meet in Mirebalais.

Figure 12: Meye Tributary near Black Water Disposal Pit

4.4 Water Use Practices

There is significant human activity – including washing, bathing, drinking, and recreation – along the Meye Tributary System and Artibonite River. Additionally, in the Delta region, Artibonite River water is extensively used for irrigation and agricultural purposes through the canal system.

4.5 Summary

The sanitation conditions at the Mirebalais MINUSTAH camp were not sufficient to prevent contamination of the Meye Tributary System with human fecal waste. It is clear that: 1) there was potential for feces to enter into and flow from the drainage canal running through the camp directly into the southwestern branch of the Meye Tributary System; and, 2) there was potential for waste from the open septic disposal pit to contaminate the southeastern branch of the Meye Tributary System either by overflow during rainfall or contamination via animal transport. MINUSTAH contracts with an outside contractor to handle human fecal waste. Additionally, although residents report contractor trucks dumping feces into the septic pit, it has been suggested there might have been an unauthorized feces dumping directly into the Meye Tributary System (Piarroux, 2010). This proposition could not be independently confirmed. Although, at the time of the Independent Panel's visit, the battalion stationed at the Mirebalais MINUSTAH facility had made substantial improvements in the sanitary conditions compared with those commented upon during personal interviews and discussions in previous reports, conditions were not optimal and additional work was needed to ensure prevention of environmental contamination.

Given the velocities of the water in the Meye Tributary System, and the flow of water reported by operators along the Artibonite River, contamination in the Meye could have reached Canneau within one to two days, and would have been fully distributed in the canal system in the Artibonite River Delta within a maximum of two to three days. This timeline is consistent with the epidemiological evidence indicating that the outbreak began in Mirebalais and within two to three days cases were being seen throughout the Artibonite River Delta. This timeline verifies that river transport was the likely transmission route for cholera to spread from the mountains of Mirebalais to the Artibonite River Delta. It is unknown how the closure of the Mirebalais municipal water supply system, which would have increased the dependence of the population on river water, impacted the initial spread of cholera. Although water quality information on salinity in the Artibonite River Delta region was not available, it can be assumed that the delta waters are brackish, which is conducive to the rapid proliferation of *Vibrio cholerae*, as discussed in the following section.

Some mention has been made of severe weather events, including a 24 hour flooding event in the Artibonite Valley in July 2010 and Hurricane Thomas in November 2010, and the potential role they might have played in spreading cholera in Haiti. Based on the dates, these events are not related to the source of the cholera outbreak in Haiti, although they highlight the need for adequate waste treatment that prevents environmental contamination during heavy rainfall..

5 Molecular Analysis Investigation

5.1 Introduction

The bacterium *Vibrio cholerae* is classified into more than 200 serogroups based on differences in the outer cell surface of the pathogen. Among these, only two serogroups (O1 and O139) produce a powerful toxin, known as cholera toxin (CT). Toxin-producing *Vibrio cholerae* from these two serogroups have the ability to cause severe acute watery diarrhea (cholera) when ingested by humans in sufficient numbers. *Vibrio cholerae* belonging to the other serogroups are associated with sporadic diarrhea and are mostly found as innocuous residents in aquatic environments. The O1 serogroup is further sub-classified into two biotypes, Classical and El Tor; and each biotype into two serotypes, Ogawa and Inaba. The present classification of *Vibrio cholerae* is shown in Figure 13.

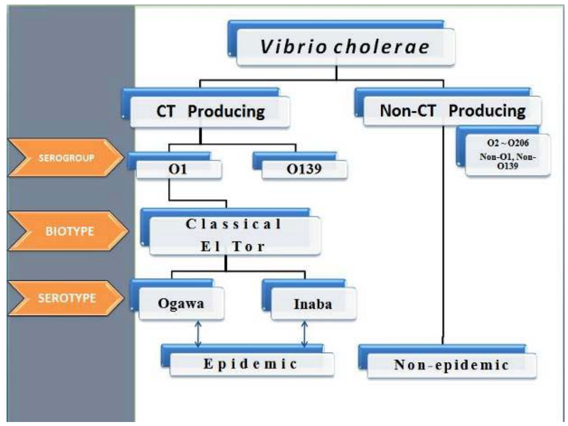

Figure 13: *Vibrio cholerae* Classification

Outbreaks of cholera have occurred in large waves, known as pandemics, which sweep across continents. Seven such pandemics have occurred since 1817. The first six pandemics originated in the Gangetic Delta of the Bay of Bengal in India and Bangladesh. The seventh pandemic, caused by the El Tor biotype, started in 1961 in Sulawesi, Indonesia, and is ongoing (Figure 14). The Classical biotype is believed to be extinct since it has not been isolated since 1992. Over the past fifty years, several variants have emerged from the initial El Tor biotype first isolated in 1961. A hybrid variant of the El Tor biotype first described in Bangladesh (Nair *et al*., 2002; Ansaruzzaman *et al*., 2004) is the most recent of these changes. These hybrid variants are El Tor strains capable of producing classical toxin after acquiring DNA sequences of the classical cholera toxin B subunit (Nair *et al*., 2006). It has also been shown that these hybrid variants produce a more severe diarrhea than the usual El Tor types due to the production of larger amounts of cholera toxin, which reacts specifically with antibodies against the classical cholera toxin only and not against the El Tor type (Ghosh-Banerjee *et al*., 2010, Siddique *et al.,* 2010). One variety of the hybrid variant of the El Tor biotype has spread during the past two decades into much of south Asia and parts of the African continent, particularly sub-Saharan East Africa (Safa *et al*., 2010).

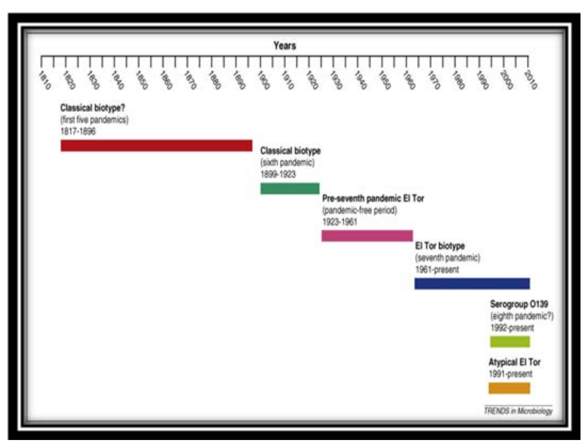

Figure 14: Cholera Pandemics

In the next sections, the bacteriological and molecular genetics of this bacteria are summarized.

5.2 Bacteriological characteristics

The Centers for Disease Control and Prevention (CDC) in Atlanta, Georgia and a research group from Harvard University in Cambridge, Massachusetts have investigated the bacteriological characteristics of *Vibrio cholerae* strains isolated independently from cholera cases in Haiti. Both groups have found that the Haitian isolates were toxigenic *Vibrio cholerae* O1 belonging to serotype Ogawa and biotype El Tor (CDC, 2010; Chin et al., 2011). Using a genetic technique known as polymerase chain reaction (PCR), the Haitian outbreak isolates were shown to have two specific genes (*ompW* and *rpoB*) that are used to confirm the identity of *Vibrio cholerae* globally. Furthermore, the strains have the following traits: 1) presence of VSP-1 gene cluster, which is a marker for the seventh pandemic strains; 2) typical El Tor *tcpA,* which is a marker for the El Tor biotype; and, 3) a *ctxB* gene of classical type further subclassified as *ctxB* subtype 6 (Kumar *et al*., 2009; Choi *et a*l., 2010). All of these characteristics indicate that the Haitian strains of *Vibrio cholerae* belong to the hybrid variant.

Overall, this basic bacteriological information indicates the Haitian isolates were similar to the *Vibrio cholerae* strains currently circulating in South Asia and parts of Africa, and not to strains isolated in the Gulf of Mexico, those found in other parts of Latin America, the prototype El Tor biotype strain, or to strains isolated in Australia (CDC, unpublished data; Chin et al., 2011). Most importantly, the 2010 Haitian strain was not of a new type but is a close relative of existing strains circulating at present in other parts of the world.

The antimicrobial resistance profile of the *Vibrio cholerae* strains isolated in Haiti showed resistance to the antibiotics sulfisoxazole, trimethoprim-sulfamethoxazole, furazolidone, streptomycin, and nalidixic acid, and reduced susceptibility to ciprofloxacin (Chin et al., 2011; CDC, 2010). The strains were susceptible to azithromycin and tetracycline, which also predicts susceptibility to doxycycline.

5.3 Molecular genetics to study the Haitian *Vibrio cholerae* strains' origin

To understand the evolutionary origin of *Vibrio cholerae* isolated in Haiti, the Independent Panel examined the results of published and unpublished studies using high throughput primary DNA sequencing techniques. Several research groups in different parts of the world assisted us by providing published and unpublished molecular evolutionary data. The DNA sequence data of the entire genetic material of the Haitian strains were compared with DNA sequences of entire genetic material derived from a global collection of other standard *Vibrio cholerae* strains.

The following information on molecular evolutionary studies was available at the time of writing this report:

- The CDC group compared the entire genetic material (genome sequence) of 15 strains of *Vibrio cholerae,* including draft sequences of 3 Haitian strains (Peter Gerner-Smidt, CDC, personal communication). The analysis showed that the Haitian strains tightly clustered with recent isolates from South Asia (India, Pakistan, Sri Lanka) and a recent isolate from Cameroon, which seems to have originated from the same ancestor as the Haiti strain but which has diverged away from it significantly. This CDC data showed that the Haitian strains were different to *Vibrio cholerae* from the United States Gulf coast and the 1991 cholera outbreak strains that were isolated in Peru. In addition, CDC concluded that all the Haiti strains were identical, which would indicate a common source.

- The Harvard Cholera Group used the most recently developed method (third-generation single-molecule real-time DNA sequencing) to compare the entire genome sequences of the Haitian strain with two strains from Bangladesh and one isolated in South America (Chin *et al*., 2011). This group also compared their primary DNA sequence data with previously obtained sequences from 23 different strains of *Vibrio cholerae* available online in the public domain. A nearly identical relationship was shown between the Haitian isolates and the variant seventh pandemic El Tor O1 strains that are predominant in South Asia. No relationship was observed between the South American isolates (indicating that this strain is not related to the early-1990's cholera epidemic in South America) or with the African strains isolated between 1970 and 1998.

- Strains from Haiti were used in an as yet unpublished study by the Wellcome Trust Sanger Institute in Cambridge, Great Britain (Mutreja *et al*., manuscript submitted for publication) to understand the lineage of strains of *Vibrio cholerae* O1 responsible for the seventh pandemic. Whole genome sequences of 154 *Vibrio cholerae* isolates (including three independently obtained from Haiti) were examined. With the exception of one isolate from a water sample in Australia, all other strains in the Sanger collection had been isolated from clinical cases of cholera. The results of this study indicated that the Haitian strains were all identical and most closely related to strains of *Vibrio cholerae* from the Indian subcontinent and distinct from strains of *Vibrio cholerae* isolated in Africa, Bahrain, Germany, Indonesia, Vietnam, Malaysia, and South America.

- The Emerging Pathogens Institute at Gainesville, Florida analyzed *Vibrio cholerae* O1 isolated from 16 patients with severe diarrhea within the first three weeks of the outbreak onset who were treated at a hospital in St. Marc. The samples were analyzed using a molecular typing method known as Multiple-Locus Variable number tandem repeat Analysis (MLVA). This method utilizes the naturally occurring variation in the number of tandem repeated DNA sequences found in many different loci in the genome of a variety of microorganisms. The molecular typing profiles are used to study transmission routes, to assess sources of infection, and also to assess the impact of human intervention, such as vaccination and use of antibiotics on the composition of bacterial populations. The genetic diversity of a total of 187 individual isolates of *Vibrio cholerae* O1 picked from the 16 stool samples showed minimal diversity, consistent with a single point source for the 2010 Haiti epidemic (Ali *et al*., 2011).

- Scientists at the International Vaccine Institute in Seoul, Korea (Dr. Dong Wook Kim, personal communication) also found that the MLVA type of 40 Haitian isolates was similar to strains from the Indian subcontinent. A separate study by the group at CDC (Peter Gerner-Smidt, CDC, personal communication) using Pulse Field Gel Electrophoresis (PFGE), another discriminatory molecular typing technique propagated by the PulseNet International network, found that the closest match of the PFGE type of the *Vibrio cholerae* strains isolated in Haiti was with the PFGE type found in strains from South Asia, including countries such as Pakistan, Sri Lanka, and India from where PFGE patterns of recent strains of *Vibrio cholerae* O1 were available in the CDC database for comparison.

- More significantly, the nucleotide sequence of the *ctxB* (the gene for the B subunit of cholera toxin) of the Haitian strains was found to have three coding mutations as opposed to only two seen in typical classical strains of *Vibrio cholerae* O1 or in the original hybrid variants first described (Nair et al., 2006). This genetic polymorphism of the *ctxB* gene was observed earlier in Kolkata and Orissa in India, and in the West African countries of Nigeria and Cameroon (Choi *et al*., 2010; Kumar *et al*., 2009; Quilici *et al*., 2010). However, the core genome of the Haitian strains resembled more closely the one found in the South Asian strains and to a lesser extent the one found in the African strains, which once again points to a South Asian origin of the Haitian strains.

5.4 Recent Preliminary Data from Nepal Strains

Genetic typing data on the Nepal strains of *Vibrio cholerae* O1 isolated between 2007 and 2010 was recently made available to the Independent Panel from the International Vaccine Institute in Korea (Dong Wook Kim, personal communication). The Nepal collection included 9 *Vibrio cholerae* O1strains (5 Ogawa and 4 Inaba) isolated in 2007, 5 Ogawa strains each from 2008 and 2009, and 2 Ogawa strains isolated in 2010. The Nepal strains were compared with 7 Ogawa strains isolated in 2010 in Haiti and with other south Asian strains. The whole genome sequences of the Nepal strains are still in the process of being completed. In the interim, MLVA, a simpler genetic typing method uses repeated sequences of DNA throughout the chromosome of the bacteria (knows as tandem repeats) to detect minor differences between strains, has been used to characterize and compare these strains with isolates found at the same time in other parts of the world. This analysis allows the comparison of genetic differences between strains that would seem similar by more basic methods.

The results of the MLVA studies of the strains isolated during the cholera outbreak in Haiti indicate that they are all very closely related (highly clonal), indicating a possible single source of contamination, which corroborates previous findings. In contrast, the *Vibrio cholerae* O1 strains isolated between 2007 and 2010 in Nepal showed small variations in their MLVA profiles from year to year. The strains circulating in Nepal seemed to be influenced intermittently by strains coming in from neighboring countries of the Ganges Delta. Included among these different Nepal strains, some of the MLVA types isolated in 2009 belonged to the Asian type of strain.

The results also showed that the Nepal strains isolated between 2007 and 2010 contained the same three mutations found in the genes coding for the B subunit of the cholera toxin as the ones found in the strains isolated since 2010 in Haiti and in South Asian and West African countries since the late 1990s. A careful analysis of the MLVA results and the ctxB gene indicated that the strains isolated in Haiti and Nepal during 2009 were a perfect match. The strains isolated in Haiti are also perfect matches by MLVA and ctxB gene mutations with South Asian strains isolated between or since the late 1990's.

5.5 Summary

The available molecular data from whole genome sequence and comparisons of smaller specific parts of the genomes of the *Vibrio cholerae* strains responsible for the outbreak of cholera in Haiti show a remarkable consistency. They all indicate that the Haitian strains are: 1) clonal (genetically identical) indicating a point-source for the outbreak; and, 2) very similar but not identical to the South Asian strains of *Vibrio cholerae* O1. It must be emphasized, however, that the Haitian strains have certain minor traits not found in collections from other parts of the world, which is consistent with the micro-evolution that takes place continuously within the El Tor biotype as it moves from continent to continent and even country to country.

The analysis of available data refutes the argument that the Haitian strains arose indigenously from the Haitian environment. The Haitian strains did not originate from the native environs of Haiti but as a result of human activity in an area that promoted the dissemination of the organism. The presence of riverine settings that merge into an estuarine environment, which is an optimal setting for rapid growth of *Vibrio cholerae* O1, is likely to have contributed to the rapid spread of the pathogen. This has happened before in many parts of the world.

The precise country from where the Haiti isolate of *Vibrio cholerae* O1 arrived is debatable. Preliminary genetic analysis using MLVA profiles and cholera toxin B subunit mutations indicate that the strains isolated during the cholera outbreak in Haiti and those circulating in South Asia, including Nepal, at the same time in 2009-2010 are similar.

Overall, the combined results from the epidemiological, water and sanitation, and molecular analyses allowed the Independent Panel to develop conclusions and recommendations, which are presented in the next sections.

6 Conclusions

The Independent Panel of Experts on the Cholera Outbreak in Haiti presents the following conclusions based on the epidemiological, water and sanitation, and molecular analysis investigations that were conducted.

The evidence does not support the hypotheses suggesting that the current outbreak is of a natural environmental source. In particular, the outbreak is not due to the Gulf of Mexico strain of *Vibrio cholerae,* nor is it due to a pathogenic mutation of a strain indigenously originating from the Haitian environment. Instead, **the evidence overwhelmingly supports the conclusion that the source of the Haiti cholera outbreak was due to contamination of the Meye Tributary of the Artibonite River with a pathogenic strain of current South Asian type *Vibrio cholerae* as a result of human activity.**

This contamination initiated an explosive cholera outbreak downstream in the Artibonite River Delta, and eventually, throughout Haiti. The explosive spread was due to several factors:

1) Tens of thousands of Haitians use the Meye Tributary System and Artibonite River waters for washing, bathing, drinking, and recreation, and were thus exposed to cholera;
2) Thousands of Haitian agriculture workers are regularly exposed to the Artibonite River water, particularly in the rice paddy fields;
3) The canal system and delta of the Artibonite River provided optimal environmental conditions for rapid proliferation of *Vibrio cholerae;*
4) The Haitian population lacked immunity to cholera;
5) Many areas of Haiti suffer from poor water and sanitation conditions;
6) Infected individuals fled to their home communities from the initial outbreak locations, and in the process dispersed the disease;
7) Infected individuals rapidly concentrated where treatment was available;
8) The South Asian type *Vibrio cholerae* strain that caused the outbreak causes a more severe diarrhea due to an increase in the production of a classical type of cholera toxin and has the propensity of protracting outbreaks of cholera; and,
9) The conditions in which cholera patients were initially treated in medical facilities did not help in the prevention of the spread of the disease to other patients or to the health workers.

The introduction of this cholera strain as a result of environmental contamination with feces could not have been the source of such an outbreak without simultaneous water and sanitation and health care system deficiencies. These deficiencies, coupled with conducive environmental and epidemiological conditions, allowed the spread of the *Vibrio cholerae* organism in the environment, from which a large number of people became infected. **The Independent Panel concludes that the Haiti cholera outbreak was caused by the confluence of circumstances as described above, and was not the fault of, or deliberate action of, a group or individual.**

The source of cholera in Haiti is no longer relevant to controlling the outbreak. What are needed at this time are measures to prevent the disease from becoming endemic.

7 Recommendations

Based on the findings as presented in this report, the Independent Panel of Experts on the Cholera Outbreak in Haiti makes the following recommendations to the United Nations, the Government of Haiti, and the international community:

1) The Haiti cholera outbreak highlights the risk of transmitting cholera during mobilization of population for emergency response. To prevent introduction of cholera into non-endemic countries, United Nations personnel and emergency responders traveling from cholera endemic areas should either receive a prophylactic dose of appropriate antibiotics before departure or be screened with a sensitive method to confirm absence of asymptomatic carriage of *Vibrio cholerae*, or both.

2) United Nations missions commonly operate in emergencies with concurrent cholera epidemics. All United Nations personnel and emergency responders traveling to emergencies should receive prophylactic antibiotics, be immunized against cholera with currently available oral vaccines, or both, in order to protect their own health and to protect the health of others.

3) To prevent introduction of contamination into the local environment, United Nations installations worldwide should treat fecal waste using on-site systems that inactivate pathogens before disposal. These systems should be operated and maintained by trained, qualified United Nations staff or by local providers with adequate United Nations oversight.

4) To improve case management and decrease the cholera case fatality rate, United Nations agencies should take stewardship in:
   a) Training health workers, especially at the treatment center level;
   b) Scaling-up the availability and use of oral rehydration salts at the household and community level in order to prevent deaths before arrival at treatment centers; and,
   c) Implementing appropriate measures (including the use of cholera cots) to reduce the risk of intra-facility transmission of cholera to health staff, relatives, and other patients.

5) To prevent the spread of cholera, the United Nations and the Government of Haiti should prioritize investment in piped, treated drinking water supplies and improved sanitation throughout Haiti. Until such time as water supply and sanitation infrastructure is established:
   a) Programs to treat water at the household or community level with chlorine or other effective systems, handwashing with soap, and safe disposal of fecal waste should be developed and/or expanded; and,
   b) Safe drinking water supplies should continue to be delivered and fecal waste should be collected and safely disposed of in areas of high population density, such as the spontaneous settlement camps.

6) The international community should investigate the potential for using vaccines reactively after the onset of an outbreak to reduce cholera caseload and spread of the disease.

7) Recent advances in molecular microbial techniques contributed significantly to the investigative capabilities of this report. Through its agencies, the United Nations should promote the use of molecular microbial techniques to improve surveillance, detection, and tracking of *Vibrio cholerae*, as well as other disease-causing organisms that have the potential to spread internationally.

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Annex A: Supplemental Epidemiological Data

In the table below, the home communities of the 404 patients that were hospitalized at St. Nicolas Government Hospital in St. Marc that arrived on October 20th, 2010 with cholera are detailed.

Community	Cases	Percent of total	Community	Cases	Percent of total
Acul Baster	9	2.2	Poteneau	2	0.5
Balaguerre	3	0.7	Potno	3	0.7
Belanger	2	0.5	Preval	1	0.2
Bertrand	3	0.7	Pt Tambour	1	0.2
Block Hauss	1	0.2	R Brillant SM	1	0.2
Bocozel	6	1.5	Rosignol	5	1.2
Boudette GP	50	12.4	Saint Marc	9	2.2
Chevreau	9	2.2	Sanoi	7	1.7
Colmini	1	0.2	Savarie	1	0.2
Danache	48	11.9	Theard	1	0.2
Daquin	8	2	Ti Bera	12	3
Desdunes	3	0.7	Timonette	1	0.2
Dipson/Dupson	5	1.2	Verettes	2	0.5
Dobeye	1	0.2	Villard	87	21.5
Dorbeil	2	0.5	Unknown	7	1.7
Drouin	1	0.2			
Dubuisson	10	2.5			
Duclas	4	1	**Total**	**404 cases**	**100%**
Gerve	1	0.2			
Gilbert	3	0.7			
Giton	1	0.2			
Grand Moulin	4	1			
Grand Saline	2	0.5			
Haute Feuille	1	0.2			
Jacko	1	0.2			
K F Peye	2	0.5			
Lapati	1	0.2			
Lascirie SM	2	0.5			
Lubin	7	1.7			
Moreau	2	0.5			
Parent	2	0.5			
Petit Bera	3	0.7			
Pinsson	8	2			
Pisto	27	6.7			
Poirier	26	6.4			
Pont Sonde	4	1			