WATERBORNE *SALMONELLA* OUTBREAK IN ALAMOSA, COLORADO MARCH AND APRIL 2008

OUTBREAK IDENTIFICATION, RESPONSE, AND INVESTIGATION

Safe Drinking Water Program

Water Quality Control Division

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Waterborne *Salmonella* Outbreak in Alamosa, Colorado March and April 2008:

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Without human infrastructure, physical and regulatory infrastructure cannot stand alone. The authors would like to thank everyone who gave of themselves to respond to the *Salmonella* outbreak in Alamosa and to contribute to this report.

EXECUTIVE SUMMARY

An outbreak of waterborne disease associated with *Salmonella* in drinking water struck Alamosa, Colorado during March and April 2008. The city of Alamosa's public water system that supplies drinking water to the community became contaminated with *Salmonella* bacteria. Alamosa's population is about 8,900 people. The outbreak resulted in 442 reported illnesses, 122 of which were laboratory-confirmed, and one death. Epidemiological estimates suggest that up to 1,300 people may have been ill. Details on the epidemiological investigation are pending publication by the CDPHE Disease Control and Environmental Epidemiology Division.

Alamosa's drinking water comes from deep artesian wells in an aquifer considered to be a protected groundwater source. Prior to the outbreak, the city's drinking water was not chlorinated for disinfection. A waiver from the statewide requirement for disinfection was granted to Alamosa in 1974. In general, the city was historically in compliance with all health-based drinking water standards, with the exception of the arsenic standard.

A statewide response to the outbreak lasting about one month involving numerous responders was coordinated using the National Incident Management System (NIMS) and Incident Command System (ICS). The Safe Drinking Water (SDW) program within the Colorado Department of Public Health and Environment is responsible for implementing the federal Safe Drinking Water Act in Colorado. During the outbreak, the SDW program responded as part of the ICS to protect public health and provide technical support to the city and to other emergency responders.

During the outbreak residents were advised to drink bottled water, and then the entire water system was flushed and disinfected with chlorine to kill the *Salmonella* bacteria. A boil water order followed the bottled water order, and it remained in place until tests confirmed that the city's water was safe to drink again. Because of the quick operational response and the changes made to the physical infrastructure of the Alamosa public water system, the water in Alamosa has been safe to drink since April 2008. The city has since installed advanced treatment processes and improved system operations.

The investigation involved a detailed review of the water system, historical records, and interviews with city of Alamosa personnel, local health officials and responders to the outbreak. Although there were several possible causes of the outbreak, our conclusion is that an animal source of fecal contamination entered the Weber Reservoir, and then spread throughout the entire system. The Weber Reservoir is a ground-level water storage reservoir near the Weber Well, which was the primary water well in use by the city, prior to the outbreak. The Weber Reservoir had several small cracks and holes that likely allowed the contamination to enter. These breaches may have existed for a relatively long period of time.

The SDW program strives to prevent disease outbreaks. A team of experts is on call 24 hours a day, 7 days a week, 365 days per year to respond to events that may put public health at risk and help public water systems correct the problems that can lead to disease outbreaks. Typically, this team responds to about 50 acute risk events per year. It is not possible to directly state that the

team has prevented disease outbreaks, but the actions taken by the team, including issuing bottled or boil water orders, reduce the risk of waterborne disease. However, severe personnel limitations at the state level have resulted in an inability to address every potential area of risk associated with drinking water in Colorado. This is well-documented, and extends to the 1970s at the SDW program's inception.

As recently as the early 1980s, disease outbreaks associated with drinking water were relatively common in Colorado, often occurring more than once a year. The documented disease outbreaks in the 1980s primarily occurred at systems that failed to adequately treat water from rivers or streams. As a result, the SDW program focused its resources on establishing and enforcing adequate treatment requirements for these systems. Since the 1980s, improvements to physical, regulatory, and human infrastructure dramatically reduced the potential for drinking water supplies to become contaminated and cause disease.

Although the SDW program's resources have increased in recent years, the increases have generally been tied to implementing new regulations, and the emphasis on treatment during inspections remained. Unfortunately, the city had not addressed integrity issues at the Weber Reservoir and those issues were not detected during inspections of the Alamosa water system conducted by the SDW program during the decade prior to the outbreak, including an inspection in August 2007.

The SDW program has developed and is implementing several strategies to further reduce the likelihood of waterborne disease outbreaks in Colorado. These strategies include:

- Prioritize responding to deficiencies at water systems that do not disinfect;
- Review disinfection waivers and withdraw them when needed to protect public health;
- Enhance oversight of sampling, water storage and distribution piping during inspections;
- Update and modify regulations related to disinfection waivers and groundwater disinfection;
- Ensure compliance with requirement for water systems to maintain residual chlorine levels in water distribution systems;
- Revise regulations associated with controlling hazardous cross connections at water systems;
- Ensure that deficiencies identified during inspections are corrected in a timely fashion;
- Launch training initiatives to help public drinking water systems to optimize water storage tank and distribution system operating and maintenance practices; and,
- Develop strategies to enhance response capabilities to drinking water emergencies.

This report provides a comprehensive documentation of the events in Alamosa associated with the disease outbreak including the response, cause, and lessons learned. It is hoped that an improved understanding of this event will help all those involved in the serious business of providing safe drinking water to prevent waterborne disease outbreaks.

PART I: BACKGROUND

INTRODUCTION

In March 2008, the city of Alamosa, Colorado experienced a disease outbreak associated with drinking water. *Salmonella* bacteria contaminated the city's public drinking water supply, leading to 442 reported cases of illness in the community, 122 of which were laboratory confirmed, and one death. Epidemiological estimates suggest that up to 1,300 people may have been ill.

Salmonella outbreaks associated with drinking water are rare. Since the 1970s, the annual number of disease outbreaks associated with drinking water has declined significantly. In recent decades, layers of public health protections have been designed and implemented specifically to prevent disease outbreaks. These include federal and state regulations, monitoring requirements, standards for new physical infrastructure, technologically advanced treatment processes, professional certification of water treatment operators, and improvements in source water protection. Even with these improvements, there are documented outbreaks associated with drinking water each year in the United States.

In the 21st century physical, regulatory, and human infrastructure exists from water source to tap to ensure the safest possible water reaches consumers. In March 2008, that infrastructure failed to prevent the waterborne disease outbreak in Alamosa. However, once the outbreak in Alamosa was confirmed, the drinking water community across Colorado, in partnership with emergency responders and public health professionals, rallied together to respond quickly and return the city and community to normal.

This report has been prepared by the Safe Drinking Water (SDW) Program within the Water Quality Control Division of the Colorado Department of Public Health and Environment (CDPHE). The purpose of this report is to:

1. Document the identification of a waterborne outbreak of *Salmonella* associated with drinking water in Alamosa, Colorado in March and April 2008.
2. Describe the response to the outbreak to eliminate *Salmonella* bacteria from the city's drinking water.
3. Report the follow-up activities conducted by the city and state regulatory agency, including cause investigation.
4. Offer lessons learned and describe modifications to SDW program activities undertaken after the outbreak.

ABOUT ALAMOSA, COLORADO

The city of Alamosa is located in south central Colorado, with nearby 14,000 foot mountain peaks in the scenic San Luis Valley. The city is the county seat and the commercial center of the valley and its community public water system serves 8,900 people directly and over a thousand more through consecutive connections. The drive from Colorado's capital city of Denver to the city of Alamosa is close to 250 miles south and west. Figure 1 shows a map of Colorado.

FIGURE 1: ALAMOSA, COLORADO

At the time of the outbreak, the physical infrastructure comprising Alamosa's community public water system consisted of seven deep artesian wells, two elevated storage tanks, one ground-level storage reservoir, and approximately 50 miles of distribution line. Figure 1 shows a map of the city and major water system components. In February 2008, the month prior to the outbreak, only three of the city's seven wells were serving the distribution system. Water from the wells was not chlorinated prior to distribution; the city had operated under a waiver from disinfection from the State of Colorado since 1974. Waivers of disinfection requirements are granted on a case-by-case basis and are permanent unless the SDW program discovers cause to withdraw the waiver.

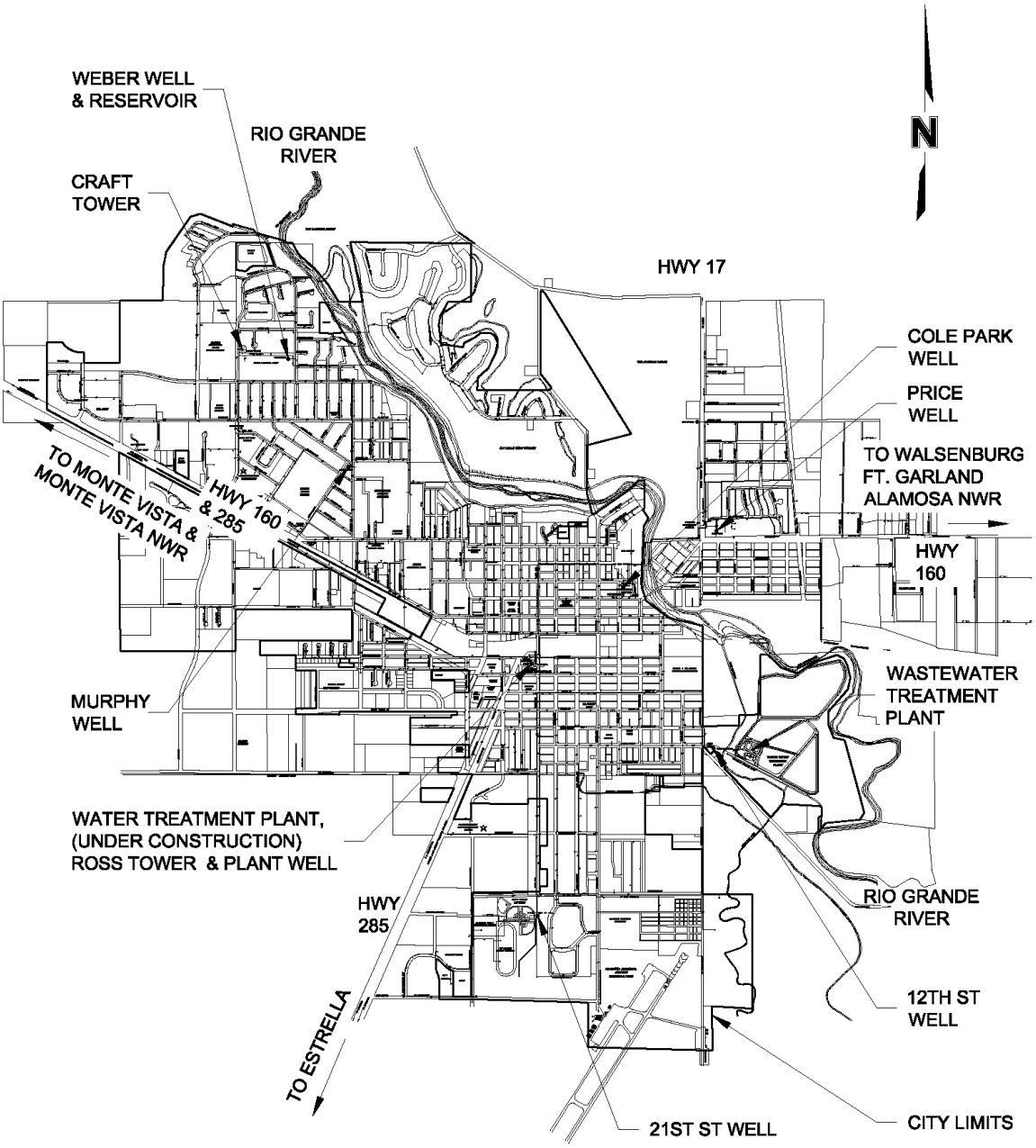

FIGURE 2: CITY OF ALAMOSA PUBLIC WATER SYSTEM, MARCH 2008 (COURTESY OF OLSSON ASSOCIATES)

In the spring of 2008, the SDW program team was aware that, due to naturally occurring arsenic in the well sources, the city had frequently been in violation of the arsenic maximum contaminant level (MCL). A centralized treatment facility, consisting of flocculation, microfiltration and disinfection, had been in the planning stages for several years prior to the

outbreak. It went online in a full service capacity in October 2008, and since that time the city has continually met the arsenic standard for compliance with state and federal drinking water regulations.

In addition to arsenic-related violations, the city had a history of occasional "total coliform positive" results but no other unusual patterns of non-compliance with drinking water regulations related to health effects. There also were no unaddressed significant deficiencies noted during routine sanitary surveys conducted by CDPHE; however, this outbreak investigation did identify a pattern of violations of total coliform sampling procedures that had previously been undetected during routine compliance oversight activities. At the time of the *Salmonella* outbreak in Alamosa, the system had been recently evaluated by engineers from the private sector and the SDW program, and was understood to be maintaining compliance with regulations at a level consistent with protection from acute risk to public health.

ABOUT *SALMONELLA*

SALMONELLA IN DRINKING WATER SOURCES

There are many different varieties, or serotypes, of *Salmonella* bacteria, and they are often spread through human or animal feces. Although rare in drinking water, *Salmonella* bacteria are found in every region of the United States and throughout the world. Millions, or even billions, of germs can be released in the feces of an infected human or animal. *Salmonella* may be found in water sources such as wells that have been contaminated with the feces of infected humans or animals. Waste can enter the water in various ways, including sewage overflows, polluted storm water runoff, and agricultural runoff. Bacteria may also enter the potable water distribution system through deficiencies in water lines and tanks, or by cross-contamination with non-potable water sources.

Disinfection with chlorine is a highly effective means of killing *Salmonella* bacteria. Properly treating drinking water with chlorine, and maintaining residual chlorine in the distribution system, is an important barrier against contamination.

Because *Salmonella* in drinking water is relatively rare, national and state regulations do not require monitoring for *Salmonella* in public water systems. Instead, monitoring for total coliform bacteria is required as an indicator of overall bacteriological quality. Monitoring for chlorine levels also is required in Colorado for water systems that disinfect their water sources.

There have been rare documented outbreaks of disease associated with *Salmonella* in drinking water in recent U.S. history. The two largest outbreaks occurred in Riverside, CA in 1965, and Gideon, MO in 1993.

ABOUT SALMONELLOSIS

Salmonellosis is an infection caused by *Salmonella* bacteria. Infection generally occurs after ingesting food or drink contaminated with feces, by person-to-person transmission, or by contact

with animals. Estimates of the number of *Salmonella* bacteria in an infective dose for a small child found in the literature could be as low as 10 to 100 organisms, with adults likely requiring a higher dose. The outbreak in Alamosa was attributed to a strain called *Salmonella* Typhimurium that contaminated the drinking water supply.

The most common symptoms of salmonellosis include diarrhea, fever, and abdominal cramps. Symptoms typically develop 12 to 72 hours after exposure and usually last 4 to 7 days. Most people recover without treatment. Some people may have severe diarrhea and may need to be hospitalized. In these people, the bacteria may spread from the intestines to the blood, and then to other parts of the body. Death is rare but can occur. The elderly, persons under 5 years of age, and those with weakened immune systems are more likely to have a severe illness.

Laboratory tests can determine if *Salmonella* is the cause of illness. *Salmonella* is generally diagnosed by stool culture. Once the bacteria have been identified, further testing can determine the specific type and the right antibiotics for treatment. Most people do not seek care for their symptoms. Typically, an estimated 38 actual cases occur for each one reported.

PART II: CRISIS AND RESPONSE

IDENTIFYING A WATERBORNE OUTBREAK

There are two surveillance systems that exist to identify a potential drinking water related disease outbreak. One is the routine surveillance of drinking water quality conducted by a public water system. In the case of Alamosa, the city operates the public water system and has the responsibility to monitor drinking water quality at least as frequently as required by state and federal regulations. The other system is the routine surveillance of certain diseases reported by laboratories and medical providers to a network of local, regional and state health departments. The Alamosa outbreak was identified initially by the latter of these two systems. Before water quality testing indicated risk of an outbreak, cases of disease already were being reported through the epidemiologists.

On Wednesday, March 12, 2008, three cases were reported by medical providers to the regional epidemiologist from the Alamosa County Nursing Service, and this information was reported to CDPHE epidemiologist on March 14, 2008. On Monday, March 17, 2008, the epidemiologists working on the outbreak contacted the SDW program team to discuss the outbreak and the possibility that the outbreak was related to Alamosa's public drinking water supply.

Details on the epidemiological investigation that confirmed drinking water as the source are pending publication by the CDPHE Disease Control and Environmental Epidemiology Division, Alamosa County Nursing Service, and the federal Center for Disease Control and Prevention (CDC) Morbidity and Mortality Weekly Report waterborne surveillance publications.

Once an outbreak of *Salmonella* was identified, an emergency situation was declared in Alamosa. Several emergency response teams across the state deployed crews to Alamosa. Throughout this report, events are reported with the date that they occurred. Not all of this narrative is sequential in time, so a timeline of events is included in Appendix A for reference.

SAFE DRINKING WATER PROGRAM ACUTE TEAM DEPLOYMENT

Once the outbreak was suspected to be linked to the drinking water supply by epidemiological evidence, the SDW program assembled an Acute Team and began to plan a response. The Acute Team is a formal cross-program working group within the SDW program that routinely responds to situations experienced by Colorado's public water systems that represent potential acute public health risks. On average, the team responds once a week to issues like upset treatment conditions, line breaks, and total coliform and positive E. coli positive results. The team offers regulatory and operational advice and coordinates with other agencies as needed to support public water systems experiencing difficulties. One of the team's first responses was to direct that water samples be collected across the city on Monday, March 17, 2008, and sent to the lab for total coliform analysis.

It is noteworthy to point out that the SDW program's response at this point in the outbreak was part of a much larger emergency response effort that is not documented in detail in this report. The SDW program's team focused on the public water system from a technical and engineering perspective. However, the overall response effort included other teams from CDPHE, Alamosa County, Colorado's Division of Emergency Management, Colorado National Guard, and many others. All were working within the National Incident Management System (NIMS) utilizing the Incident Command System (ICS) framework to address many other local, state, and national coordination efforts. The ICS framework included a centrally managed Joint Information Center (JIC), Public Information Officer (PIO), and Emergency Operations Center (EOC), all elements of a managed disaster response under Federal Emergency Management Agency (FEMA) guidelines. The SDW program team worked within the ICS to manage certain activities related to inter-agency coordination, bulk water delivery, and public notification of advisories and updates. Details on the overall emergency response have been reported by the CDPHE Emergency Preparedness and Response Division and are not included in this document.

BOTTLED WATER ORDER ISSUED

On March 18, 2008, the SDW program team discussed issuing an order based solely on epidemiological evidence, but no water quality sampling results were available to confirm that drinking water was the source of the outbreak, and there were still some uncertainties in the epidemiological data. On Wednesday, March 19, 2008, the epidemiological data more clearly suggested that drinking water was the source of the outbreak, and the analytical results from 10 drinking water samples collected on Monday showed that one sample was positive for total coliform bacteria, and two samples were noted as turbid, or cloudy, by the laboratory. People were getting sick from salmonellosis across the city, and drinking water was officially the suspected source. To protect the public from being exposed to *Salmonella* in their drinking water, the SDW program team and Colorado's Chief Medical Officer decided to issue an order to Alamosa requiring them to advise the public not to consume water straight from the tap. Five days later, on March 24, 2008, the CDC laboratory results confirmed the presence of *Salmonella* in the public water system.

Three key considerations played into the decision to issue a bottled water order, and to choose that type of order instead of a boil water order. It was clear to the CDPHE team that it was not safe to consume drinking water from the city's public water system because of epidemiological evidence of *Salmonella* contamination and sample results from March 17. The team considered that Alamosa had a long history of naturally occurring arsenic levels above state and federal standards. Anticipating the potential need to disinfect the city's water system with chlorine, and to flush water from the system at high velocity, there was significant concern that arsenic could be elevated during those processes to levels high enough to cause acute risk to public health. A second consideration was that the source of contamination was unknown, so it was uncertain if other contaminants could have been in the drinking water. Additionally, boiling water would concentrate arsenic and potentially other contaminants in the water to an unknown extent.

A boil water order would not have protected the public from potentially high arsenic levels. On the other hand, issuing a bottled water order without proper preparation to ensure sufficient

supplies of bottled water, or bulk supply of similar quality, could create other undesirable outcomes for the city, including insufficient supplies in the area stores and impacts on the city's businesses. Although a bottled water order would create hardships and concerns about water availability, the department team determined that such an order was the best course of action as it would be most protective of public health.

Orders of this nature are commonly employed in Colorado to require public notification of a potential acute risk to health and to order water systems to advise their customers to either drink bottled water ("bottled water advisory") or to boil water from the tap before drinking ("boil water advisory"). However, a bottled water order for such a large system in response to an actual disease outbreak was unprecedented in Colorado and presented a major public health challenge along with severe community disruption and economic impacts.

With a bottled water order in place, the SDW program team next devised a plan for further response, including collecting and evaluating additional water quality data and requesting mutual aid from other public water systems and partners. The team also determined that the entire distribution system in Alamosa, including 50 miles of distribution line and 3 tanks, likely needed to be disinfected and flushed.

INITIAL DATA COLLECTION

On March 19, 2008, the day of the bottled water order, hard facts on up-to-the-minute water quality in the city's distribution system were scarce. Simple field test kits for chlorine, which may be a quick and meaningful tool for determining areas of poor water quality, could not be applied in a system with no chlorine disinfection. That meant samples needed to be collected, transported, and then analyzed in a laboratory setting.

As a result, the SDW program team set out a plan to collect samples and transmit them to the lab as expeditiously as possible. This was no small task due to limited access to comprehensive laboratory facilities, as well as very limited service for speedy or overnight delivery or courier services to other laboratories outside the San Luis Valley. Fortunately, a certified lab in Alamosa was available to analyze many of the samples collected; others required transportation to the Denver area or out of state. Logistics associated with collecting the samples and transmitting them within required hold times for samples was labor intensive and required significant coordination throughout the outbreak response.

As discussed above, on March 19, 2008, analytical results from water samples taken earlier in the week were beginning to become available, and one of the results indicated the presence of total coliform bacteria. A summary of the data collected during the outbreak is included in Appendix B and a map of selected results is included in Appendix C. The team procured sample equipment specifically for *Salmonella* from the CDC lab in Atlanta, GA and from the state lab located in Denver. On March 20, 2008, members of the SDW program team were onsite in Alamosa collecting samples to verify the presence of *Salmonella* in the drinking water. Results reported on March 24, 2008 confirmed the presence of *Salmonella* throughout the city's water

system and confirmed the absence of *Salmonella* in the East Alamosa water system which was completely separated from Alamosa's water system at the time of the outbreak.[1]

In addition to water samples, the team also collected samples of animal fecal material on the ground in several locations around the northern part of the city on March 21, 2008. This included the area of the Weber reservoir and parks and open space nearby. Of the samples, five were most likely from geese, and five were likely from deer. The samples were analyzed in the laboratory and were found to be negative for *Salmonella*.

The SDW program team did not perform a detailed evaluation of the city's water system physical infrastructure at the time the initial water and fecal samples were collected; however, the Colorado Water/Wastewater Agency Response Network (CoWARN) crews deployed on March 20, 2008 provided support for investigating and responding to deficiencies in the city's water system.

COWARN AND LOCAL PARTNERS

CoWARN was called to respond to the *Salmonella* outbreak in Alamosa on March 19, 2008. CoWARN was launched in September 2007 and members include public and private water and wastewater utilities, as well as industry support organizations and government partners. The purpose of the CoWARN network is to support water and wastewater utilities' ability to respond to and recover from emergencies. In an emergency, CoWARN can provide immediate assistance to member utilities. The network established for mutual aid was critical to Alamosa's ability, and the SDW program team's ability, to effectively respond to the situation in Alamosa.

The CoWARN website (www.cowarn.org) provides a forum for establishing and maintaining emergency contacts and communicating specialized needs and resources, in real time, in response to emergencies at water and wastewater systems. At 1 p.m. on March 19, 2008, the SDW program team issued a standby notice to all CoWARN members by email and on the CoWARN website. CoWARN members were requested to be on standby for a potential event at a water system in southern Colorado.

Later that day, at 4:30 p.m. on March 19, 2008, CDPHE announced a need for equipment to respond in Alamosa, including a need for tanker trucks, portable water containers and disinfection equipment. Within hours of notifying the CoWARN network of a need for resources, member utilities were starting their response to meet Alamosa's needs. Within two hours, Denver Water, Aurora Water, and Fort Collins Utilities had lined up crews, equipment, water containers and a tanker truck to send to Alamosa.

Participation in CoWARN is voluntary and there is no obligation to either provide assistance or receive assistance. In 2007, when the leadership team of CoWARN was building the framework

[1] As a point of clarification, East Alamosa Water District was a separate water system at the time of the outbreak in March and April 2008. It was not connected to the city of Alamosa's water system. That has since changed and at the time of this writing, the city of Alamosa now serves water to East Alamosa.

for the mutual aid network, they established an agreement and protocols for matching resources and needs among water and wastewater utilities statewide, in advance of a real emergency. In the case of Alamosa, without outside assistance, the emergency response would certainly have been delayed and may have taken much longer to complete. One reason for this was that many utilities may have responded more slowly as legal, liability, and reimbursement issues were worked out. With CoWARN's mutual aid agreement, those issues were addressed in advance.

On March 21, 2008, Alamosa signed the mutual aid agreement, establishing a formal and legal working relationship between the city and other mutual aid partners. Having signed Mutual Aid Agreements in place was critical for quick response and mutual aid between Alamosa and other utilities. CoWARN's important emergency response role in Alamosa cannot be overstated, and in this report CoWARN is highlighted throughout the discussion of the response following the bottled water order.

Having the right specialized water treatment equipment available was critical to a quick response. Just as important was having access to a network of specialized and certified water treatment operations professionals who were skilled at installing and operating the equipment. On their own, few water systems have the technical expertise, personnel, equipment and supplies to develop a plan and deploy the resources necessary for disinfection and flushing on the scale of an entire city, and in a short period of time. Because Colorado has established CoWARN, a mutual aid network for water and wastewater utilities statewide, Alamosa had nearly immediate access to supplies and human resources to assist with the response. With CoWARN, experienced crews from across the state were working with the city within 24 hours. Within 48 hours, equipment, crews, and supplies began arriving onsite to start work.

ALTERNATE WATER SUPPLIES

Throughout the response to the outbreak, the SDW program team fielded multiple requests for assistance from businesses seeking approval or technical assistance to connect to an alternate water supply, and responding to such requests created a significant resource demand. Such businesses included supermarkets and restaurants that depended on a safe source of drinking water to prepare and sell food to the community. Without the ability to rely on water provided by the city, businesses sought state approval for alternative sources of water, primarily in the form of bulk delivery of safe water from a reliable source to onsite tanks and pump systems. Each request was, in essence, a request to form a public water system on an emergency basis. In response to these requests, the SDW team's engineers and scientists worked as quickly as possible to approve designs and establish proper procedures that would ensure the safety of the public and also support businesses staying open to serve the community to the greatest possible extent.

DECISION TO DISINFECT AND FLUSH

By Thursday, March 20, 2008, the SDW program team suspected that *Salmonella* had contaminated the entire water system in Alamosa. Lab results confirming that was the case were not available until Monday, March 24, 2008, but the team did not delay taking action.

On that Thursday, Denver Water crews from CoWARN met with the SDW program team at the CDPHE office in Denver, and with Alamosa personnel on the phone, to develop a strategy to disinfect and flush Alamosa's entire water distribution system with chlorine, including the storage tanks and nearly 50 miles of distribution lines. At the time, it was recognized that this would be a significant effort and an unprecedented task. Initially the team estimated that the effort may take three to four weeks, or longer, to complete. Of particular concern was the age of some of the distribution lines in the city and the condition and operability of the valves in the system.

In spite of the challenges ahead, known and unknown, the team decided that any plan to eliminate *Salmonella* from the city's public water system must include a process to systematically and thoroughly disinfect each tank and every foot of distribution line. Various technical options, and their feasibility and impact on the public also were considered.

The city provided an electronic version of a map via email illustrating all distribution lines, tanks, water sources, streets and other landmarks. Fortunately, CDPHE had in-house computing resources to be able to print it out on large scale plotters in Denver for the team to use for planning. Information from the detailed map was critical at the time to understanding the scope and scale of the disinfection and flushing process that was required. The team reviewed the map and consulted the American Water Works Association (AWWA) standards for guidance on recommended techniques for disinfection of water mains and water storage facilities. AWWA standards C651-05 and C652-02 were used by the team for planning the disinfection process. Both standards reference coliform bacteria as an indicator of bacteriological quality. During the response in Alamosa, it was assumed that a process effective to disinfect water for total coliform would also be effective for disinfecting water for *Salmonella*. Follow-up testing after disinfection of Alamosa's system confirmed that the process was effective and tests for total coliform and *Salmonella* were negative.

In addition to reviewing technical standards, the team also read reports on similar outbreaks of *Salmonella* associated with drinking water. The two immediately identified were those in Gideon, Missouri (1993) and in Riverside, California (1965). In the case of Gideon, the outbreak lasted several weeks, sickening about 650 people, and resulted in seven deaths. That outbreak was eventually attributed to contamination from a storage tank; however, the cause was not identified initially and the Gideon water system was not systematically disinfected and flushed at the time. The Riverside outbreak sickened an estimated 18,000 people and resulted in three deaths. No specific source of contamination was identified. In both cases, the water system was supplied with unchlorinated groundwater. To prevent recurrences of *Salmonella* and prolonging the outbreak, the team confirmed that a complete disinfection of Alamosa's entire distribution system was the appropriate and conservative operational outbreak response approach.

AWWA standard C652-02 describes three methods for water line disinfection using chlorine. In Alamosa, the team decided to implement a modified version of the continuous feed method. Under this method, the chlorine dose is 25 milligrams per liter (mg/L) for a hold time of 24 hours. At the end of the 24 hour period, the chlorine residual should be no less than 10 mg/L. This approach was intentionally conservative. At the time, the contamination source was

unknown, and the chlorine demand in the distribution system was unknown, so the team prepared to closely monitor chlorine residual as part of the disinfection and flushing procedures. During the flushing process, water velocity was controlled to reduce the likelihood that the distribution system would be damaged, and minimize disturbance to any biofilms, scale or sediment that may contain high levels of secondary parameters of concern, such as arsenic, lead, and copper.

For water storage facility disinfection, the AWWA standard describes three methods using chlorine. Two of these methods describe filling and holding the tank for a period of 24 hours with a defined amount of chlorine. Considering the configuration of Alamosa's distribution system, the team decided to follow a procedure to fill and hold Alamosa's three storage tanks at a minimum of 25 mg/L of chlorine for 24 hours. This dosage of chlorine exceeded the requirements of the standard. As in the distribution system line disinfection, the chlorine demand was unknown, so this was a conservative decision. The water held in the tanks was used again to flush the distribution lines with a high level of chlorine. The team monitored the chlorine residual closely throughout the disinfection and flushing process.

A dose of 25 mg/L is on the order of 25 times a typical concentration of chlorine in drinking water, and more than 5 times the concentration recommended for a swimming pool. The federal and state standard for maximum residual chlorine level in drinking water is 4 mg/L. Because the chlorine dose used in Alamosa was so much higher than the maximum drinking water standard, it was critical to communicate to the public when water at their tap was not safe for use. The Emergency Operations Center (EOC) in Alamosa (part of the ICS system in place) led this aspect of emergency response.

To simplify communication with the public the EOC developed messages with a traffic signal theme. When water was unsafe for use, the public was notified that the condition was "red." Flyers printed on red paper were distributed door to door by teams of volunteers notifying the public not to use the water. When chlorine levels were lowered to safer levels for limited use, but the water was not yet safe for drinking, the public was notified that the condition was "yellow." When the water at the tap was finally deemed safe to drink, the condition went to "green." Throughout the process, the public was notified through a coordinated effort by the EOC. The SDW program team assisted this process by recommending and reviewing language to use in the notices distributed to the public.

DISINFECTING AND FLUSHING THE CITY'S WATER SYSTEM

On the evening of March 20, 2008, following the planning meeting held at CDPHE, a team led by Denver Water and coordinated with other CoWARN members began arriving in Alamosa to begin preparing the system for disinfection and flushing. They brought equipment and supplies with them. By the next day, Denver Water crews were in place and working side by side with city and CDPHE personnel. Additional supplies and equipment arrived from Denver Water, Aurora Water, and South Adams County Water and Sanitation District. Meanwhile, a Fort Collins Utilities tanker truck was taken out of storage, disinfected, tested, and on the road by the

weekend of March 22-23, 2008. All of the responding utilities were members of the CoWARN mutual aid network.

Previously operating under a disinfection waiver, there was no chlorine present in the distribution system, nor was there chlorination equipment installed at the city's wells at the time of the outbreak. In order to set up a continuous feed of chlorine to the distribution system, the city needed to first set up chlorination equipment. Because a new water treatment plant was under construction, city personnel were able to quickly obtain chemical feed equipment from the new plant site and set up a continuous sodium hypochlorite feed at the Weber wellhead. CoWARN partners also offered additional supplies, including emergency chlorine feed equipment and chemicals.

STARTING AT THE WEBER RESERVOIR

The crew of operators from the city along with CoWARN and CDPHE responders started disinfecting the city's distribution system on Friday, March 21, 2008. The first step was to drain, disinfect, and remove sediment from the city's Weber reservoir. The Weber well feeds into this ground-level reservoir, then a booster pump system pumps water into the city's distribution lines.

When the crew entered the reservoir, they identified some holes in the corners of the reservoir through which daylight could be seen. The holes were patched that weekend. No other holes were apparent in the roof; however, cracks were visible on the roof and sides of the tank. The crew did not observe any sign of infiltration through the walls or floor once the reservoir was completely drained. Further, the field crew also looked for any evidence of birds in the tank, including droppings or nests, and none were found.

Cleaning the Weber reservoir and completing repairs continued until Saturday morning, March 22, 2008. Prior to refilling the reservoir, a chlorination system was set up at the Weber well, which is the only water source for the reservoir. The system was designed to inject chlorine into the flow stream at 25 mg/L. Once that was complete, the walls were sprayed with a separately made, high-chlorine level (50 mg/L) solution and the reservoir was refilled.

Field crews completed the process of filling the reservoir with the 25 mg/L chlorine levels by approximately 5 p.m. local time on Saturday, March 22, 2008. This water remained in the reservoir until approximately 8 a.m. on Monday, March 24, 2008. Water from the reservoir was periodically sampled for chlorine testing and the chlorine residual remained in the range of 24 to 25mg/L throughout the process. This approach met or exceeded the team's original disinfection plan in accordance with the AWWA standard.

On Monday, March 24, 2008, CoWARN posted a need for 10 additional water distribution system operators to assist crews in Alamosa to disinfect and flush the water distribution system. Distribution system operators from Aurora Water were deployed later in the afternoon in response to the request. Dozens of other CoWARN members also began offering experienced personnel, equipment, chemicals, and other resources. At this point in time, the field crews were preparing to begin disinfecting the city's two elevated towers and then systematically flushing

the city's 50 miles of distribution line. Appendix A contains a timeline of events around this period.

FLUSHING 50 MILES OF DISTRIBUTION LINE

The process of disinfecting the city's system started with introducing high levels of chlorine, on the order of 25 mg/L, into the distribution system and directing that superchlorinated water to the elevated storage tanks. On Monday, March 24, 2008, the crew began by holding the Craft Tower for 24 hours with a high dose of chlorine, and then the water was flushed from north to south in sectors through the city. The entire city is designed as one pressure zone, so the field crews divided the city into three sectors for operational management of field crews and notification of the public. Figure 2 illustrates these sectors. Flushing progressed through the city from Sector 1, then Sector 2, then Sector 3.

Throughout the week, additional distribution system operators arrived on site from CoWARN partners and from the State of Nebraska to relieve crews and assist with flushing and sampling operations.

Meanwhile, other CoWARN members coordinated communications from the CDPHE Emergency Operations Center. They were in constant communication with city and SDW program team personnel onsite, and they maintained the CoWARN website continuously, including updating needs for specialized equipment and personnel and offers of support. This network of communication was also critical to ensuring the public was notified when chlorine was introduced to the system at levels that were considered unsafe for contact (condition "red") or for only limited use (condition "yellow").

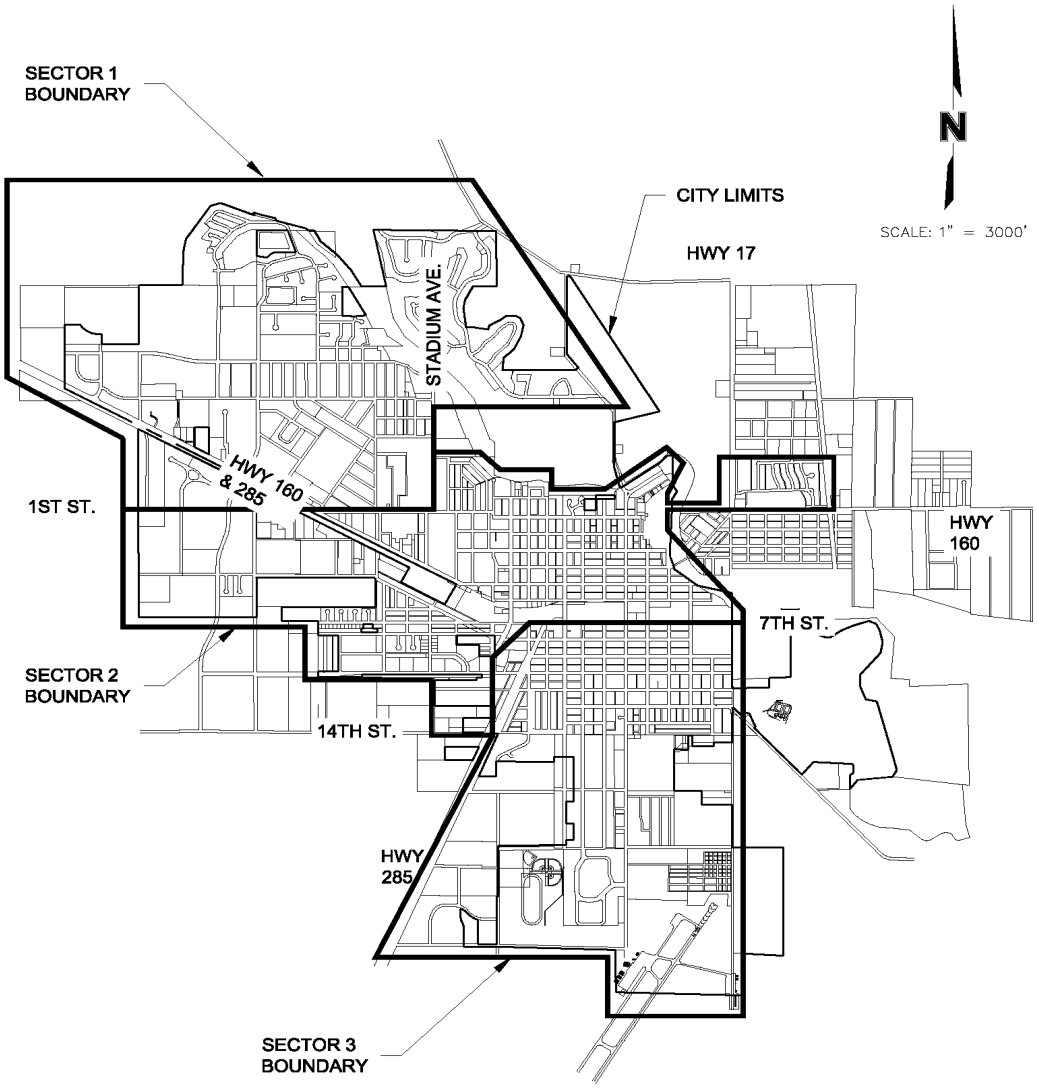

FIGURE 3: SECTORS FOR DISTRIBUTION SYSTEM DISINFECTION AND FLUSHING (COURTESY OF OLSSON ASSOCIATES)

The high levels of chlorine were a risk not only to the public, but also to the workings of the city's wastewater treatment facility. Wastewater treatment facilities rely in part on biological activity for treatment and a high dose of chlorine would have likely damaged the plant processes.

As phases of flushing continued, additional technical resources, including certified wastewater operator professionals, equipment and supplies, were needed to support staff at the city's wastewater treatment facility. Timely action was needed to ensure that Alamosa's wastewater treatment facility did not experience an upset from the high levels of chlorine in the water. This was critical to preventing potentially serious environmental contamination. Another call for resources went out to the CoWARN network.

On Thursday, March 27, 2008, Metro Wastewater Reclamation District experts met at the CDPHE office in Denver, with Alamosa, CDPHE, Aurora Water/Reuse, and Pinery Water and Wastewater District personnel on the phone, to develop a strategy to address Alamosa's needs. Later that day, Metro Wastewater crews were deployed to Alamosa with equipment and provided support for the city's wastewater collection and treatment system.

Wastewater treatment professionals from the city and CoWARN partners monitored the sewage inflow for chlorine levels and were prepared to either divert the flow to sludge holding ponds or add sodium bisulfite, if necessary. Both flow diversion and dechlorination techniques were employed during the flushing to ensure that chlorine levels entering the wastewater treatment facility were not elevated. City staff and responders also closely monitored the operation and performance of the wastewater treatment facility. These efforts were successful in avoiding an upset at the wastewater treatment facility. Such an upset would have been a risk to fish and bird habitat in the Rio Grande river, and could have potentially damaged habitat that is a national wildlife refuge.

Disinfecting and flushing the city's distribution system, including three tanks and 50 miles of pipeline took a total of 13 days, from commencing the disinfection of the Weber Reservoir on Friday, March 21, 2008, through Wednesday, April 2, 2008. This was significantly less than the original estimated time of three to four weeks. Throughout the process, field teams collected water samples citywide to analyze for chlorine levels, bacteria, and other secondary parameters of concern. These efforts are detailed in the next section. Results from samples collected throughout the city confirming the system was free from bacteria were reported by the lab on Thursday, April 3, 2008. On that date, the SDW program team rescinded the bottled water order and replaced it with a boil water order.

DATA COLLECTION – BEFORE LIFTING THE ORDERS

Teams of water professionals conducted extensive water quality sampling throughout the response to the outbreak. The results of this sampling are discussed here in a primarily qualitative manner. In addition to water quality sampling, two samples also were collected from sediment removed from the Weber reservoir. A summary of water quality data collected is included in this report in Appendix B.

There were several purposes to the water quality monitoring that was conducted during the outbreak response: to identify the presence of bacteria, including *Salmonella*; to track chlorine residuals in the progress of disinfecting and flushing the system; and to ensure that secondary water quality problems did not emerge. During the outbreak, the emphasis of the sampling was on the quality of the water provided at the tap. Accordingly, sampling was conducted in order to gain a comprehensive understanding of water quality at customers' taps throughout the distribution system. Absent in these sample results are those representative of water directly from the city's groundwater sources at the wellheads. For purposes of the outbreak investigation, those samples may have proven whether the source of the *Salmonella* was from the groundwater wells. However, at the time of the outbreak, the cause investigation was secondary to the emergency. Further, the SDW program team determined that the wells were screened hundreds of feet below the surface in a confined artesian aquifer, which was considered at the time a highly unlikely source for *Salmonella* bacteria. It would have been beneficial to have collected water samples from the wellheads at the time of the outbreak and in hindsight this is a lesson learned.

BACTERIA

Once the SDW program team was alerted of a potential outbreak on Monday, March 17, 2008, and the public drinking water supply was suspected as the source, the team moved quickly with only limited available staff and equipment. Samples were collected by the city and local health department on March 17, 2008. Later in the week two of the SDW program team's engineers traveled to Alamosa to collect samples for *Salmonella* throughout the water system. It's noteworthy to recall that at this time the city's water supply was not being disinfected.

Nearly all samples throughout the system prior to disinfecting and flushing the system were confirmed to be total coliform negative with notable exceptions on March 17, 2008 and March 21, 2008. All samples were negative for E. coli, a type of bacteria commonly used to test for the presence of wastewater.

On March 17, 2008, one of ten samples collected by the city was total coliform positive near the Craft Tower. Of the other nine samples negative for total coliform, there were two other unusual samples that were noted as "turbid" by the laboratory, indicating that the water was cloudy, and not normal, and that pathogens may be present.

On the same day, March 17, 2008, four total coliform samples were collected by the county health department, although the results of these were not reported until much later. One of the four was positive for total coliform and the others were negative.

Five samples were collected by Denver Water crews on March 21, 2008, and three were total coliform positive: the Weber tank effluent, the Craft Tower effluent, and a sink at the wastewater treatment plant at the far southeast part of town. The positive samples from the Weber Reservoir effluent and Craft Tower effluent are particularly important to gain insight as to where the contamination originated.

The Weber Reservoir is not connected to the distribution system and receives water only from the Weber well, which did not indicate contamination. The positive sample from the Weber Reservoir effluent is a strong indication that the Weber Reservoir was the location where the contamination originated. Further, contaminated water pumped to the distribution system from the Weber reservoir probably entered the Craft Tower and caused it to test positive for coliform bacteria as well. Water from the Craft Tower could not have flowed back into the Weber Reservoir because of the system design, therefore it was deemed unlikely that the Craft Tower was the original point of contamination.

Samples that were total coliform negative were collected from the Weber well and Cole Park well, and near the city's public works offices. It is particularly noteworthy that the Weber and Cole Park wells were negative because they supplied all the water to the system in early March 2008, while the Weber Reservoir effluent sample was positive for total coliform.

Disinfection and flushing of the system was a sustained effort from Friday, March 21, 2008 through April 2, 2008. As the disinfection and flushing was conducted by field crews, the SDW team continued to sample for total coliform bacteria throughout the distribution system. As an additional quality check after a sector of the city was disinfected and flushed, the water was tested for total coliform bacteria and *Salmonella*. With one exception, these samples resulted in confirmation that the process was effective and there was an absence of bacterial contamination in the water.

The single case of a positive *Salmonella* sample collected after disinfection and flushing occurred in a sample collected on March 30, 2008 in the business center of the city with the oldest water lines. This sample was positive for *Salmonella* using a polymerase chain reaction, or PCR, analysis, but culture-negative. In the area where the positive sample was collected, the field crews had decided to lower flushing velocities due to concerns about line and valve integrity. After the single positive *Salmonella* result was reported by the lab, the field crews returned to that area of town and repeated the disinfection and flushing process. Follow-up samples all were negative for total coliform and *Salmonella*, leading to the team's decision on April 3, 2008 to modify the bottled water order to a boil water order.

Before the boil water order was lifted, the SDW team collected samples across the city. The results of this water quality sampling proved that water throughout the system was free of coliform bacteria and *Salmonella*, and supported the decision to finally lift the boil water order on April 11, 2008.

CHLORINE RESIDUALS

At the time of the disease outbreak, the city was operating under a disinfection waiver from the state. The city was not disinfecting the source water and there was no chlorine residual in the distribution system. In the immediate response to the outbreak, chlorination equipment was installed at the city's wells so that the entire system could be dosed with a high level of chlorine and then flushed to eradicate *Salmonella* from the system.

After the immediate response, the SDW program team required continuous chlorine disinfection of the system from the wells to the extremities. The city has continuously chlorinated its water supply since late-March 2008.

From the time of the initial response to the outbreak through present day, chlorine residual monitoring has been conducted throughout the city. There were three primary reasons these samples were collected and analyzed. In the initial response, the samples were collected to ensure that a high enough dose of chlorine was consistently applied to sufficiently disinfect the tanks and distribution lines and exterminate *Salmonella* bacteria. Field teams collected samples throughout this process to ensure that target chlorine levels were achieved.

A second reason the samples were collected was to characterize and track the chlorine demand in the system. Because the system had not been continuously and routinely disinfected and flushed prior to the outbreak, it was unknown if the field team would be able to maintain a stable chlorine residual. A stable residual would illustrate that a large and unpredictable chlorine demand did not exist somewhere in the distribution system. High and/or unpredictable demand for chlorine may indicate ongoing contamination. Stable chlorine residuals would also indicate that the condition of the physical infrastructure itself had a generally stable chlorine demand. Throughout the disinfection and flushing process, the data indicated a negligible chlorine demand, less than 1 mg/L, during the initial phases of disinfection and flushing and a typical demand less than 0.5 mg/L after maintaining a residual of 1-2 mg/L during routine operations. This addressed the team's concerns about the potential for ongoing contamination and the stability of the chlorine demand in the city's distribution system.

The third reason chlorine residuals were collected was to ensure that the city maintained sufficient continuous disinfection throughout the distribution system. The city has been successful at maintaining the appropriate level of residual disinfection since the time of the outbreak to the present.

SECONDARY PARAMETERS OF CONCERN

When the SDW program team made the decision to disinfect and flush the storage tanks and the entire distribution system, there were several immediate concerns about how that process would impact the physical infrastructure as well as water quality in the system. Accordingly, the water quality sampling conducted around this time was designed to address not only immediate acute bacteriological contamination, but also potential acute and chronic health risk levels of arsenic, lead, copper, and disinfection byproducts. This potential increase in acute or chronic health risks was considered in the context of consuming tap water outright and also boiling it before drinking - thereby potentially concentrating contaminants to some extent, depending on the length of time the water was boiled.

Samples collected by field crews were generally from residential taps in the city throughout the flushing period. The results of this sampling showed that while arsenic levels increased somewhat, from about 26 micrograms per liter to about 32 micrograms per liter, the increase was not significant enough to create a concern for the public. Results of the sampling indicated that none of the secondary parameters, except arsenic, exceeded the relative MCLs or action levels

set by federal and state regulation. Thus, the SDW team determined that there was no acute risk associated with levels of secondary parameters.

Due to the nature of the sampling, in theory it is possible that there were brief transient peaks in secondary parameters that were not measured in the field; however, there are no data from this period indicating that this happened. At the time of the outbreak, the SDW program team had some awareness of this as an issue; however, the SDW team was not able to quantify the impact in the timeframe of an emergency response. Consulting with internal and external technical experts, the team came to a general agreement that high doses of chlorine would potentially release inorganic heavy metal contaminants from distribution system scales and biofilm and it would be important to be cautious about monitoring the distribution system for parameters secondary to the *Salmonella* contamination.

Based on the results of sampling for secondary parameters, the team determined that the risk to the public from associated chronic or acute health risk was low. This information played into the team's decision on April 3, 2008, to modify the bottled water order to a boil water order, and again for the decision on April 11, 2008 to finally lift the boil water order and return the community to condition "green": safe to drink the tap water once again.

STORAGE TANK SEDIMENT

All three of the city's water storage tanks contained some amount of sediment at the bottom at the time of the outbreak. It's likely that the sediment was sand from the aquifer formation that was pumped through the well casings and into the city's water distribution system. Two samples of sediment were collected from the Weber storage reservoir and analyzed for the presence of *Salmonella* bacteria. In accordance with recommendations from the Centers for Disease Control and Prevention, the samples should have been refrigerated immediately and analyzed within 24 hours. This did not occur with either sample. Further, there are no official chain-of-custody records for either sample. A description of the two samples is included here for completeness. The sample results for both were negative, but because of sampling methodology, the results are inconclusive.

The first sample was collected during the effort to disinfect Weber reservoir on March 21, 2008. On that date, a Denver Water employee collected a small (approx. 6 oz) jar of sediment from a bucket of material that was shoveled from the east side of the Weber Reservoir, at the access door. The bucket was filled prior to using wash-down water or disinfecting the tank. The level of water in the tank at the time the sample was collected was approximately six inches.

At the time the sample was collected the team was focused on pressing emergency response priorities and there were no plans in place to have it analyzed for *Salmonella* or any other parameter for investigative purposes. The sample was not refrigerated and no special handling procedures were used. The sample was transferred to a CDPHE employee who transported it to CDPHE offices in Denver on Monday, March 24, 2008. It remained unrefrigerated until April 2, 2008 when the sample was transported to the state lab where it was later analyzed for *Salmonella* and the results were PCR and culture negative.

A second sample of sediment from the Weber Reservoir was collected later, on March 26, 2008, by the Pueblo County Health Department. The sample was collected from the pile of sediment removed from the reservoir and placed outside during the clean-out. The sample was taken from about 6 to 8 inches from the top of the pile where it was still moist. The sample, which may have represented sludge from the bottom of the tank was collected and placed in a plastic bag some time before noon. Reports indicated that sediment was piled on two to three sides of the reservoir and that the sample was described as tarry and black sludge, not sand. The sample did not appear to be soil, but was discolored sediment. The sample was delivered to the laboratory in Denver on March 27, 2008. The sample results were reported about a week later and were PCR and culture negative for *Salmonella*.

PRELIMINARY FIELD INVESTIGATION

In March and April 2008, the SDW team's physical and human resources were dedicated primarily to emergency response activities: coordinating and staffing disinfection and flushing of the system; collecting and transporting field samples; assisting with bottled water supply mobilization efforts; sampling bulk water from tanker trucks mobilized to Alamosa; assisting businesses that could develop their own water supplies; and working around the clock to bring the water system back to a safe operating condition. An added complexity to managing the activities during the initial days of the outbreak was that the emergency response escalated immediately prior to and during the Easter holiday weekend. At all times, protecting public health was the top priority. Thus, the preliminary field investigation into the cause, though important, was a secondary or perhaps even tertiary priority at that time.

Meanwhile, the SDW program team also had the responsibility of maintaining continuous communication with other responders in the ICS emergency response system, including serving as a technical expert resource on all drinking water matters. At the time, the team worked with others internal to the department (emergency response staff, epidemiologists, consumer protection specialists, and the executive director's office) as well as external interests (e.g. city leadership and public works operational staff, the incident command's emergency operations center, the National Guard, media representatives, the Governor's office, EPA, CDC). Much of these communications were successfully coordinated through department emergency response staff, however many of the messages and operational decisions required input and review by the SDW program team's handful of technical experts who were also managing and coordinating operational and field activities and communications in Alamosa.

Coordination with department emergency response staff was generally successful; however, SDW team resources were continuously required as emergency response staff are not trained in drinking water system operations. The SDW program team would have benefitted from additional highly qualified human resources to coordinate with the department emergency response staff to ensure that outgoing messages had a high level of technical review.

The preliminary investigation focused primarily on the city's storage facilities and potential cross-connections in the distribution system. Being at ground level, the Weber reservoir was the most easily accessible to the field crews and SDW program team, so it was the first to be

investigated. The Weber reservoir was clearly in poor condition, with cracking and noticeable holes in the corners of the concrete structure. Further, there was significant sediment in the bottom of the tank, 12 to 18 inches deep by some estimates, and the city public works staff had no records or memory of the last time the tank had been disinfected. The city later reported that the reservoir was last drained and cleaned out in 1984. There were no obvious signs of animal habitation inside Weber Reservoir on March 21, 2008 when it was taken out of service and the field crews began repairing and disinfecting it.

On March 28, 2008, a SDW program representative observed the repaired reservoir and the surrounding area within a security fence bordering the site. At that time, there were no readily-observable signs of animal presence inside the fence, including animal feces. There were no bird droppings around or on top of the reservoir and no nests or bird droppings inside the pump house. The door to the pump house had been left continuously open for much of the previous week. On March 28, 2008, this individual did discover a "clump" of three large feathers about 2.5 inches long with three smaller (about one-inch long) feathers attached to them inside the pump house. The lab was unable to analyze the feathers for *Salmonella*. However, the feathers are a sign that animals may have spent some amount of time inside the fence surrounding the Weber Reservoir or inside the pump house itself.

The other two storage facilities were also a focus of preliminary investigation in March and April 2008. CDPHE imposed a requirement for the city to retain a professional tank inspection firm to inspect the Ross Tower and the Craft Tower prior to lifting the boil water order. The inspectors identified some deficiencies that were repaired at the time.

The Ross Tower, a 150,000 gallon cylindrical shaped tower located near the center of the city, is the older of the two. The inspection on April 2, 2008 showed that the tank had a significant amount of sediment at the bottom and the inspectors recommended that the sediment be removed from the tank. The tower also needed a new hatch and there were minor deficiencies in places at the seams and in the tank vent. The tank did have missing bolts, and there were signs that bird feces could have flushed into the tank during a storm event; however, bird feces samples collected at the tank were negative for *Salmonella*. The tank also required a high pressure wash and the application of an anti-fungal solution and a bird repellant coating. The city entered into a contract on April 7, 2008 with the tank inspection firm to correct these and other safety-related deficiencies. It is noteworthy that the inspectors did observe some bird fecal matter on top of the tank, but they did not discover nests or other signs of ongoing habitation.

The newest of the city's storage facilities is the Craft Tower, a 500,000 gallon spheroid shaped tank located on the north side of the city. This tank also was inspected by a professional tank inspection firm on April 2, 2008. The Craft Tower was in better condition than the Ross Tower. The inspector noted that this tank also had a significant amount of sediment at the bottom and recommended that it be drained and flushed to remove sediment. As with the Ross Tower, inspectors did observe some bird fecal matter on top of the tank, but they did not discover nests or other signs of ongoing habitation. The inspectors recommended a high pressure wash and the application of an anti-fungal solution and a bird repellant coating and minor repairs to the roof vent. The city entered into a contract to replace the vent on the Craft Tower.

Concurrent with the emergency response and the inspection and repair of the city's three storage facilities, a team from CoWARN assisted the city with assessing the distribution system for potentially hazardous cross-connections. The city was not in compliance with state regulations requiring cross-connection control in the public water system. The assessment and subsequent site inspections in March and April 2008 identified three locations in the city where a potentially extreme hazard cross-connection existed. Two were mortuary facilities, and one was a combined meat packing and restaurant property. Reduced pressure zone devices designed to prevent cross-connections were installed by April 8, 2008 at these extreme hazard locations. Over 100 other sites around the city were noted as taps with potential cross-connections as well, but they were not deemed to be an extreme risk at the time.

None of the three potentially extreme hazard cross-connection locations in the system appeared to be a source of *Salmonella* contamination that caused the outbreak, primarily because there was no clear source of *Salmonella* at the sites. The meat-packing facility was not a slaughterhouse; packaged meats were trucked in for processing. The mortuaries had no clearly unsafe conditions. Further, there was no evidence at the time of a previous low-pressure event in the distribution system that may have created a backflow condition. Later analyses of system flows since the outbreak also did not clearly indicate that a backflow event had occurred around that time.

BACK TO THE NEW NORMAL

On Thursday, April 3, 2008, the SDW program team modified the bottled water order to a boil water order as the Alamosa water system was preparing to return to normal. Since the start of the response two and a half weeks earlier, three tanks and 50 miles of distribution lines had been disinfected and flushed to destroy bacteria. Water samples had been analyzed for bacteria and secondary parameters to ensure that the acute and chronic risk to the public was attenuated. Chlorine levels were lowered into the high end of the standard range for drinking water supplies (one to two mg/L). The city, CoWARN crews, and contractors were working to repair the city's infrastructure. Alamosa residents were eager to leave "red" and "yellow" behind and go to condition "green," announcing that the city's tap water was safe to drink once again.

GOING TO GREEN

The letter from CDPHE issuing the boil water order on Thursday, April 3, 2008 contained a list of activities the city was required to complete prior to the order being lifted. This included a written response from the city including information on data collected, a narrative of disinfection and flushing operations and certification that certain system repairs to the water storage tanks were completed, and high-hazard cross connections were appropriately addressed. CDPHE also had decided to wait to finally lift the boil water order until all water system samples collected were analyzed by the laboratories and the results proved that the water was safe. Meanwhile, field crews from CoWARN and CDPHE returned home after having worked 24 hours a day to bring the system back to normal. The SDW program team assembled documentation, debriefed with field staff, communicated through the ICS on progress, and prepared for the administrative

task of finally lifting the order. These efforts continued through the weekend of April 5 and 6, 2008. The SDW program team and department leadership readied to lift the boil water order early the next week, nearly three weeks after the original bottled water order was issued.

GIARDIA AND CRYPTOSPORIDIUM ANALYSES

As the SDW program team was preparing to lift the order, a representative from EPA Region VIII learned via the federal ICS communications structure that the CDC in Atlanta had discovered some evidence of Giardia and Cryptosporidium DNA in water samples collected in Alamosa on March 20, 2008, the week before the system was disinfected and flushed. During a telephone conversation with SDW program leadership, the EPA official communicated this new information. These pathogens, typically found in river water, leaks, or shallow wells, can also cause severe gastrointestinal illness. No one from CDPHE had previously heard this news due to a failure to communicate between the responding organizations. Although CDC had been aware of the results for at least a week prior, CDC staff in Atlanta apparently did not contact CDPHE directly because of the way ICS structure at the federal level dictates the pathway for such communications.

On Tuesday, April 8, 2008, the news from CDC created a new crisis for the SDW program team, for several reasons. First, this immediately delayed plans to lift the boil water order, with the impacts rippling through the entire ICS network. Secondly, chlorine is not as effective against Giardia and Cryptosporidium cysts as it is against bacteria like coliform and *Salmonella*. Chlorine can kill bacteria outright. Cysts typically need to be either filtered out of water to remove them, or alternatively given a significantly higher dose of chlorine or an alternate disinfectant. This immediately changed the way the SDW program team saw the problem of disinfecting the city's distribution system. Third, the sources of Giardia and Cryptosporidium can be very different from *Salmonella*. Their presence would change the focus of the investigation and create a much broader set of possible causes. Also, but not least important, is that detection of Giardia and Cryptosporidium cysts in water requires complex sampling apparatus and time-intensive and specialized analytical procedures that only are performed by a few laboratories. In order to confirm that the system was free from Giardia and Cryptosporidium contamination, additional testing would be required. Consequently, the SDW program team made the decision to conduct Microscopic Particulate Analysis (MPA) on water samples from the city's distribution system with the intent to rule out the possibility of viable Giardia or Cryptosporidium pathogens in the city's public water system.

Because field crews had returned home, taking their equipment with them, there was once again a scramble for resources. Late in the afternoon on Tuesday, April 8, 2008, SDW program staff contacted CH Diagnostic in Berthoud, Colorado, one of the labs in Colorado that performs MPA analyses, to obtain equipment. Engineers from the CDPHE office in Pueblo prepared for another unanticipated field event. This was a significant change in momentum for all the responders involved, just as all were preparing to close out the boil water order and return the city to normal.

Part of the challenge with the rush to conduct MPA analyses was the distance between Alamosa and Berthoud, Colorado, nearly 300 miles. In both locations there was also very limited

overnight pick-up and delivery service. The CH Diagnostic staff packed MPA test equipment in time for the last overnight delivery drop-off of the day at 5 p.m., Tuesday, April 8, 2008 for next morning delivery in Pueblo, Colorado. CH Diagnostic also made a commitment to rush analyses as fast as possible once they received samples, so they modified their operations accordingly.

In the meantime, the SDW team in Denver and Pueblo worked with Alamosa public works staff to organize the field activities that needed to happen the next day. On Wednesday April 9, 2008, the equipment from CH Diagnostic arrived in Pueblo. At that time, two of the SDW program engineers traveled from Pueblo to Alamosa with plans to conduct the MPA test procedure at locations around Alamosa's distribution system.

The MPA test requires a certain volume of water to flow through a special 1-micron absolute filter for a period of time. The field team quickly realized that the runtime for the tests in the field would be the primary factor in how quickly the results would be available. With the city still under a boil water order, there was pressure for results as soon as possible. On Wednesday, the team changed course and instead of running the filtration step of the MPA procedure in the field per normal procedure, an alternate procedure was used. That alternate procedure, recommended by CH Diagnostic, required field crews to collect bulk water samples in 7-gallon containers and then transport them to Berthoud for filtration in the lab.

The 300 mile distance again became a logistical issue. The bulk samples were collected throughout the day on Wednesday, April 9, 2008. In order to get them to the lab the next day there were two options: fly the samples out of Alamosa's regional airport or drive them that night for early morning delivery on Thursday. The team chose the latter, with one crew driving them from Alamosa to Denver, then transferring them in the middle of the night to another vehicle. A second driver was on standby and drove the second leg to the lab in Berthoud.

On Thursday, April 10, 2008, and Friday, April 11, 2008, CH Diagnostic in Berthoud analyzed all bulk water samples from Alamosa and found no Giardia or Cryptosporidium cysts. While a typical turnaround time for this type of analysis is two to three weeks, with a rush order the results were available within two days. With evidence confirming the absence of Giardia and Cryptosporidium, the team made the decision to lift the boil water order.

On further review, the CDC later reported that samples in question showed only generally weak signals from a DNA analysis of the March 20, 2008 water samples in Alamosa. They did not clearly identify that viable Giardia or Cryptosporidium cysts were in fact present; the results simply suggested that some segment of DNA associated with one of those types of organisms may have existed in the samples. This kind of analysis was essentially experimental, and it cannot be concluded that the system was recently, or ever, truly contaminated with viable Giardia or Cryptosporidium cysts.

In addition, the epidemiological data did not suggest waterborne transmission of either Cryptosporidium or Giardia. No cases of Cryptosporidium were reported during the outbreak time frame. Three cases of Giardia were reported; however, it was determined that they were unlikely to be related to the city's drinking water.

In summary, although these results spurred a necessary and tremendous effort to assure public health protection before the boil water order was lifted, these results are essentially inconclusive with respect to the cause investigation.

LIFTING THE ORDER – WITH CONDITIONS

By Friday, April 11, 2008 the city had completed all the requirements outlined in the letter sent by CDPHE on April 3, 2008 issuing the boil water order. All follow-up sampling was complete, confirming that the water was safe to drink. CDPHE rescinded the boil water order by letter on April 11, 2008. The public was notified that the condition was "green" and it was again safe to drink tap water in the city; the mayor donned a green shirt to celebrate the occasion.

The April 11, 2008 letter lifting the boil water order included a number of conditions mandating the city to take additional actions to repair the city's Ross Tower and to plan for additional repairs to both the Ross Tower and Craft Tower. Additionally, the Weber Reservoir was permanently disconnected from Alamosa's drinking water system. While this letter marked the end of the boil water order, it was only one milestone in continuing efforts for the city and SDW program staff to work together to investigate the cause of the outbreak and to ensure that additional improvements to the city's public water system were made.

PART III: POST-CRISIS

AFTER THE EMERGENCY: APRIL-OCTOBER 2008

On April 11, 2008, the public was notified that the boil water order for the city of Alamosa had been lifted and that it was once again safe to drink water from the tap. Thus ended the response for many of those working with the city through the outbreak. The Incident Command System teams stood down, the CoWARN responders returned to their own communities, and many of the CDPHE staff and leadership were attempting to return to normal routines. For the SDW program, however, there still was an ongoing investigation into the cause, regulatory obligations to meet, and ongoing work with the city regarding repairs to the city's physical infrastructure and start up of the new centralized water treatment plant.

This section covers activities conducted by the SDW program from the time the boil water order was lifted in April 2008 through the issuance of a formal Enforcement Order by CDPHE to the city in October 2008. This includes efforts to investigate the cause of the outbreak and to finalize the terms and conditions for regulatory enforcement that would ensure drinking water provided to the public by Alamosa's public water system would continue to be safe.

SCOPE OF THE INVESTIGATION

In order for bacteria to enter Alamosa's drinking water system, it would have had to come from a failure in the integrity of the city's water sources, storage facilities, or distribution lines in such a manner and at the right place and time for bacteria to enter the system. Accordingly, the investigation work that commenced in April attempted to identify all potential sources of the bacteria, and all potential integrity failures by which bacteria could enter city's water system.

One initial clue came from laboratory testing that indicated that the serotype and pulsed-field gel electrophoresis (PFGE) pattern of *Salmonella* associated with the outbreak was rare. This rare pattern matched samples from the Alamosa drinking water and affected patients during the outbreak confirming drinking water as the source of exposure to *Salmonella*. According to data from the CDC national reporting database, PulseNet, before the outbreak this serotype and PFGE pattern had been identified 31 times in Colorado starting in 2000 when 12 cases were identified around the state. One of the 12 cases was a child from Alamosa whose source of infection was not identified. In the United States this serotype and PFGE pattern has been primarily reported from patients in Colorado, Wyoming and Texas. Seven non-human specimens were identified in a national database during the period 2005-2008 from Wyoming and Oregon. Four were from birds, one a mule deer, one feline, and one unknown. This information confirms the likelihood of the particular strain of *Salmonella* existing in the natural environment in the western United States. This also indicates that there was likely a single source of contamination into Alamosa's water system, as opposed to multiple sources.

Based on initial response and investigation work, there was no indication that deliberate and malicious tampering with the city's water system was the cause of the *Salmonella* contamination.

This was reported by responders in the field and also through the NIMS Incident Command System teams. Absent other compelling evidence, the SDW program team proceeded with the investigation with an understanding that the contamination was not intentional.

Thus, from April through October 2008 the team formulated a draft scope of work for the disease outbreak investigation that became an attachment to the formal Enforcement Order in October 2008. The scope of work identified a listing of all potential integrity failures at the wells, storage facilities, and distribution lines, possible causes of such failures, and the need for a more complete literature review of other similar outbreaks worldwide. The next section of this report details the accomplishments associated with the scope of work and the conclusion of the investigation.

ENFORCEMENT ORDER ON CONSENT

On October 10, 2008, CDPHE signed an Enforcement Order on Consent ("consent agreement") for violations related to the *Salmonella* outbreak. The requirements of the consent agreement were discussed between CDPHE and the city and were agreed upon in advance. The consent agreement clarified outstanding requirements and ongoing expectations as they related to the *Salmonella* outbreak and Alamosa's operation of its public water system. Requirements included: continuous chlorination of the well sources, ongoing monitoring of water quality in the distribution system, cooperation with CDPHE on the investigation into the cause of the outbreak, and submittal of other technical and administrative documentation.

The consent agreement issued by CDPHE served several purposes. First, as the primacy agency for ensuring compliance with federal drinking water regulations and standards, CDPHE was obligated to proceed with appropriate enforcement actions toward the city. The agreement fulfilled that obligation. Secondly, the agreement outlined a course of operations and water quality monitoring to ensure that drinking water in Alamosa would continue to be as safe as possible following the outbreak. Third, the city agreed to provide requested information, documentation, data, and performance of work necessary to complete the outbreak investigation. Following the issuance of the Enforcement Order on Consent in October, the SDW program's next priority was concluding the investigation into the cause of the *Salmonella* outbreak. The city of Alamosa has cooperated with this investigation. As of this writing, the city's efforts to gain full compliance with cross connection control requirements continue.

CONDUCTING THE INVESTIGATION

The documented scope of work for the disease outbreak investigation was included in the consent agreement. The SDW program team has systematically proceeded with the investigation based on this scope, expanding on certain aspects where appropriate.

WATER SYSTEM FACILITIES AND FLOWS

In March 2008, the city had seven active wells, three water storage facilities, and 50 miles of distribution line. Figure 1 illustrates the location of these facilities as of March 2008. As part of the investigation into the cause of the *Salmonella* outbreak, the SDW program team gathered and evaluated operational records, statements from the city, and available data about the water system.

WELLS

Of the city's seven wells used as drinking water sources, only three were used to supply drinking water from early February 2008 prior to the disease outbreak. On average during that time, the Weber well supplied 75 to 80 percent of the water for the city, with about 15 to 20 percent pumped from the Cole Park and less than 5 percent on average from the 12th Street well.

The Weber well pumped directly into the Weber storage reservoir through a perforated header along the roof of the reservoir. The header was designed to aerate the well water and remove hydrogen sulfide gas. From the Weber reservoir, water was pumped again directly into the distribution system. The Cole Park well and 12th Street well pumped directly into the distribution system with no storage reservoir.

According to documentation submitted to CDPHE by the city, no significant repairs or maintenance work was done on any of the wells connected to the city's potable water system in the year prior to the outbreak. In 2006, there was some work on the 12th Street and 20th Street well pumps.

The city was able to provide limited well construction details for the wells. Based on the information available, the well permits were issued between 1963 and 1983. Records also appear to indicate that original well construction was as early as 1936 for the Cole Park well and 1956 for the Weber well.

In general, the city's wells have some grouting near the surface, and are cased with solid casing to 500 to 900 feet below the surface. After that depth segments of perforated casing exist to depths 900 to 1,800 ft, depending on the well. The city's wells all flow under artesian pressure and are designed and constructed to draw water from deep confined aquifers.

While it is not noted clearly on the well construction logs or related documentation, each of the wells does penetrate very shallow groundwater in an unconfined aquifer. The Rio Grande flows along the eastern border of the city and all the wells penetrate shallow alluvium near the river

banks. The Weber well and Cole Park well both are near shallow wetlands areas that are riparian habitat. Neither well is designed or constructed to draw flow from shallow groundwater.

The city has stated that no repairs or replacements were recently conducted on any of the well casings. The SDW program team was able to review videos captured by professional well inspectors for the Cole Park and Weber wells. These two wells provided most of the water supply for the city at the time of the outbreak. Two videos were reviewed for the Weber well, one from 1996 and one from 2009. A comparison of these videos illustrates that the Weber well casing has significant corrosion which appears to have worsened from 1996 to 2009. The Weber well has several areas of concern, especially at depths up to 300 feet; however, it is unclear to what extent the casing has been damaged to allow contamination to enter into the well. The Weber well also appears to have two lines penetrating the well casing at a few feet below the top of the well casing. Based on interviews with city personnel, it is believed that these are overflow lines that meet in a common header controlled by a single valve, then daylight to a nearby vault. A visual inspection of the vault in July 2009 showed that there was no flap valve or cover on the end of the overflow line. The videos of the Weber well also illustrate an offset and clear discontinuity in the casing at about 950 feet that has been present since at least 1996. By comparison, a review of a video from 2001 illustrates that the casing of the Cole Park well appears to be in generally good condition. Other than the videos, detailed reports from the professional well inspectors are not available for either well.

In 2004, the SDW program published reports for over 1,700 public water systems statewide as part of a source water assessment and protection project. Six of the city of Alamosa's wells were assessed at the time and the city received a report on the susceptibility of these wells to different potential sources of contamination, including underground storage tanks, septic systems, known waste disposal sites, and others. A rating of total susceptibility was calculated for each source based on a computer model that considered a combination of proximity to a potential source of contamination and the magnitude of the threat of that source. Development of the ratings did not include an onsite review. Five of the six wells were determined to have low or moderate susceptibility to contamination. The Cole Park well was the only one to have a high total susceptibility rating. This was based on the presence of two nearby industrial facilities and six tank facilities. The wells in service at the time of the outbreak were not associated with a high risk of bacteriological contamination that would indicate a high likelihood that *Salmonella* contamination occurred at the wells.

In addition to the potable public water system, the city also maintains a non-potable water system used for irrigation. Prior to the *Salmonella* outbreak, the only dedicated non-potable system was the irrigation system for half of the city's golf course. According to statements provided by the city, this non-potable system is not connected with the potable system in any way. The non-potable system has its own dedicated water source.

TANK OPERATIONS

At the time of the outbreak, the city was operating two elevated storage tanks, the Ross and Craft towers, and one surface level storage reservoir, the Weber reservoir. The SDW program team reviewed tank level data for February and early March 2008 for both elevated tanks to determine whether any unusual conditions appeared to exist during that time period. Specifically, the team looked for evidence of unusual pressure drops or patterns in tank drawdown and fill cycles that were out of the ordinary.

Based on a review of the data, only minor differences in routine operations on two days during that time period were noted: February 12, 2008 and February 20, 2008. On February 12, there was an unusual drop in the level of both the Ross and Craft towers, indicating the possibility of a change in system pressure that was out of the ordinary. The data seem to indicate that both the Ross and Craft tanks had a level drop around 2 p.m. It took approximately one day to return to the normal diurnal pattern of tank levels. Similarly, on February 20, the Ross tower experienced a drop in tank level of several feet during an otherwise normal fill pattern for that time of day. Concurrent with the Ross tower level drop was a smaller level drop at the Craft tower that registered about the same time. This also possibly indicated a change in system pressure that was not in the normal pattern.

According to a statement from the city's water superintendent, operational conditions on both dates coincided with work being performed at the new water treatment plant. On February 12, the city's contractor needed water to fill and test the clearwell on the new treatment plant. According to the city's statement, the contractor opened the valve "too fast," then subsequently continued to fill the clearwell at a slower rate. About 225,000 to 250,000 gallons were used to fill the clearwell. On February 20, there was another smaller draw of water to top off the clearwell.

To better understand the nature of flows in the city's distribution system during the weeks leading up to the outbreak, the SDW program retained an engineering consulting firm to create a computer model of the city's water system. Through that work, it was determined that it was unlikely that the increased demand placed on the system at the time they filled the clearwell significantly impacted the distribution system pressure. The modeling work estimated that the clearwell was filled with a volume of 225,000 gallons and the Craft and Ross towers had a combined volume of approximately 694,000 gallons. By filling the clearwell, approximately 32 percent of the volume of the two towers was used (if they were both full at the time of use). The withdrawal should not have been enough to cause adverse system pressures that would potentially draw contamination into the system, but it would make the wells pump more frequently to fill the towers.

Further, according to a written statement, the city's opinion was that all operations data were normal for that time of year. They stated that there were no data showing any significant pressure drops, unusual pumping patterns, or any data supporting unusually long detention times in any of the storage facilities that would indicate a problem with the operation of the potable water system. The most recent leak repair reported by the city was a tap blown off in the Price neighborhood on the east side of the river. Leak repair did not have a significant impact on

pressures within that neighborhood, or anywhere else in the distribution system, and occurred at least a month prior to the outbreak.

In summary, based on a review of the tank level data and correspondence from the city, tank operations in the city were generally under normal operating conditions for the time of year, with the exception of the dates that the clearwell was being filled at the new water treatment plant. Even under those relatively unusual conditions, it was concluded that the pattern of operations in the distribution system was unrelated to the disease outbreak.

WATER QUALITY DATA BEFORE THE OUTBREAK

As a public water system, the city of Alamosa is governed by the Colorado Primary Drinking Water Regulations and accordingly monitors certain water quality parameters for regulatory compliance. In addition to those required by regulatory mandate, there are other related data that have been collected over the years that characterize the quality of the city's water.

In general, the city has historically been in compliance with all health-based state and federal standards, with the exception of the arsenic maximum contaminant level. Due to naturally occurring arsenic in the well sources, the city was in violation of the arsenic standard. A centralized treatment facility, consisting of flocculation, microfiltration and disinfection, had been in the planning stages for several years prior to the outbreak. It went online in a full service capacity in October 2008, and since that time the city has continually met the arsenic standard for compliance with state and federal drinking water regulations.

Salmonella rarely occurs in drinking water, and accordingly there is no infrastructure, physical, regulatory or human, established to monitor for *Salmonella* in drinking water on a routine basis. Other pathogens much more common in drinking water, including Giardia, Cryptosporidium, E.coli, are monitored directly or by surrogate to verify water is not contaminated. In general, the total coliform laboratory analysis is used as a surrogate to monitor risk to public health associated with bacteriological quality of drinking water. Total coliform results are reported as either present/positive (presence of bacteria) or absent/negative (absence of bacteria).

As part of this investigation, the SDW program team reviewed data submitted for compliance with the Total Coliform Rule since 2001. Prior to this outbreak, the city of Alamosa's water system operated for several years without significant bacteriological violations, or noteworthy historical patterns of total coliform present test results. In accordance with the federal Total Coliform Rule, Colorado regulations require Alamosa to collect 10 samples per month for total coliform bacteria in the distribution system, and the samples were not supposed to be collected on just one day during the month. According to state records, one sample collected in June 2002, one from August 2002, four from November 2002, and one from July 2003 tested positive for total coliform. None of the required repeat sampling resulted in additional positive results. None of these instances resulted in a violation of the Total Coliform Rule, with the exception of November 2002. In November 2002, the city was issued a non-acute MCL violation because

fours samples were positive for bacteria. As recently as early March 2008, city water was tested and reported absent for total coliform.

While a pattern of violations related to the presence of total coliform bacteria did not exist, a post-outbreak review of reported data indicates that samples were generally taken at entry points to the distribution system at six of the city's wells, and the Weber Reservoir effluent. Also, samples generally were all taken on the same day, with two samples collected simultaneously at some locations. This sampling method is not in compliance with the Total Coliform Rule. Only occasionally were other locations representative of water in the distribution system sampled. Of particular significance, the 10 total coliform samples collected on March 5, 2008 for regulatory compliance immediately prior to the identification of the outbreak all were taken from the city's wells in this manner, with the exception of one sample collected from the Weber Reservoir effluent. All of the samples from that day were negative for total coliform.

While a report prepared by SDW program staff documenting the city's August 2007 sanitary survey stated that Alamosa's monitoring plan was acceptable, the plan, did not specifically identify the Total Coliform Rule sampling locations. Although the city has since conformed their sampling procedures to the requirements of the Total Coliform Rule, the historical data showing compliance are in fact inconclusive. Although not required for regulatory monitoring, other data were reviewed by the SDW program to characterize the city's water prior to March 2008. There are a few noteworthy attributes that make the city's water unusual. First, water from the wells has a relatively high temperature. As the water flows from the deep wells, the average temperature is generally above 75 degrees Fahrenheit. Secondly, the wells are also high in hydrogen sulfide gas, which creates aesthetic problems related to taste and odor. Thirdly, the wells have relatively high dissolved silica content. Silica is not typically a major concern related to drinking water quality; however, it can impact the treatability of water through certain processes. For Alamosa, the high silica levels were a driving factor behind the process selection for the new centralized water treatment plant.

As part of the investigation, the SDW program also requested and received a statement from the city describing any customer complaints received during the period January through March 2008. The city stated that virtually all of their service calls during the period came in January and were related to frozen water services lines and/or meters. The city did get more of these service calls than normal in January because of prolonged cold weather in that month. The city reported no other apparent patterns of complaints during that time. According to the city, this was similar to what happened during a similar cold spell pattern that occurred in December 2006.

STORAGE FACILITIES – WEBER, CRAFT, AND ROSS

As part of the investigation into the outbreak, a review of design, operation, and maintenance of the city's three water storage facilities was conducted. The following is an overview of each of the facilities.

WEBER RESERVOIR

The Weber Reservoir is a 320,000 gallon rectangular concrete reservoir, a portion of which is constructed below grade, with a berm constructed to near the top. Approval of the design and construction of the reservoir was issued by CDPHE in 1979 and it was constructed in the same year. The most recent inspection of the reservoir was in 1997 by a professional inspection firm. According to the July 9, 1997 inspection report, the reservoir's roof, exterior wall surface and foundation were in satisfactory condition; however the inspector noted that the exterior corners were in poor condition and the exterior walls and foundation had some cracking, spalling, and exposed aggregate. The same inspection report also indicated that the interior condition of the tank was generally good, with minor exposed aggregate and sediment an average of one inch deep on the floor of the reservoir. The only specific recommendations made by the inspector at the time were to clean the reservoir and inspect it every three to five years. There is no evidence that the recommendation to routinely clean and inspect the reservoir was addressed by the city in subsequent years.

The Weber well pumps water into the reservoir through a perforated header that begins in the east end of the reservoir and runs to the west for over half of the roof length. The water flows out of the header and falls to the water surface below, creating some aeration to reduce levels of naturally occurring hydrogen sulfide gas. Water is pumped out of the reservoir through a pipe about 12 inches from the bottom of the east side of the tank.

In 2006, city personnel conducted a visual inspection and the city's engineering consultant also performed a cursory inspection. No significant structural issues were identified at the time, and the decision was made for the tank to remain in service as part of the potable system until the start-up of the new water treatment plant. Then, the tank would continue to serve as a non-potable water reservoir, as it continues to do today.

The most recent sanitary surveys conducted by SDW program engineers were in 1999, 2002, and 2007. Federal regulations regarding sanitary surveys did not require that storage tanks or distributions systems be covered by sanitary surveys prior to December 1, 2009; however, Colorado requirements did include these elements. Prior to the Alamosa outbreak, due to its personnel limitations, the SDW program focused primarily on treatment issues during sanitary surveys. The Weber Reservoir was not included in the facility inventory database at the time of the Alamosa sanitary survey in 2007. The person conducting the survey did observe the Weber well, which is adjacent to the Weber Reservoir. A thorough inspection of the Weber Reservoir did not take place. However, the general condition of the Weber Reservoir was discussed with the system operator, as was the fact that the reservoir was slated to be taken off line when the

new treatment system became operational in 2008. No deficiencies associated with the Weber Reservoir were reported in any of the surveys. In response to a question relating to the hydraulic configuration of the tank, inlet and outlet piping, and the potential for any cross-connection between potable and non-potable water at this location, the city provided a written statement explaining that there is a 4-inch drain line at the bottom of the reservoir that runs to a manhole with an air gap and which continues by gravity to the city's storm drainage system. The line enters the manhole and bends at a 90 degree angle vertically creating a 4-foot air gap. The water spills from the top of the outlet to the bottom of the manhole and enters an 8-inch gravity line connecting to the storm water collection system. There is a valve between the reservoir and the manhole to control the drainage from the reservoir, which is normally in a closed position.

According to the city, in order for a cross-connection to occur, the valve between the reservoir and the manhole would have to be opened and the drain line leaving the manhole would have to be blocked in some way to allow the manhole to fill with water to the top of the air gap. Should this happen, water would almost certainly spill over the top of the manhole due to pressures generated by the head in the reservoir, and the levels in the reservoir would drop to equalize the pressure. Neither of these events occurred in the past year, or previously based on existing records and experience of the city's operations staff. In the city's statement, it was noted that it is theoretically possible for a cross-connection to occur, but they have no reason to believe that one did during the time period in question.

The city also provided a written statement that there were no significant construction activities near the Weber Reservoir in March 2008. Bresnan Communications did replace one of their cables just south of the reservoir in that time period. The city inspected their work during construction and it did not impact the reservoir or the lines leading to or from it.

The Weber reservoir was drained on March 21, 2008 as part of the initial response to the outbreak. There are no plans to return it to service as part of the city's potable system. However, the city's long-term water system plan prior to the outbreak was to remove the reservoir from potable service when the new water treatment plant went online, and to use the reservoir to store water for irrigation. The city began using the reservoir in that capacity beginning with the irrigation season in spring 2009.

The Weber reservoir was in poor condition and poorly maintained for a number of years. Of all the potential sources of *Salmonella* contamination, it seems most likely that contamination may have entered the Weber reservoir. This could have occurred due to fecal matter that was carried through rain or snowmelt through cracks in the roof and sides of the tank. Another possibility is that small animals, such as birds or small mammals entered into the tank through one of the larger holes.

It is believed that the tank was relatively warm during cold winter months due to the naturally warm water from the Weber well and vented warm air through the holes, making it an attractive location for wildlife to gather. During January 2009 members of the SDW program team observed numerous footprints from small animals in the snow inside the fence surrounding the reservoir, confirming the presence of wildlife inside the fence. According to interviews with city

personnel, small mammals such as rabbits were sometimes seen in the area near the reservoir. In July 2009, another inspection of the Weber reservoir by the SDW program team showed that the tank still had some cracks in the concrete structure and bird feces were observed on the top of the tank including one of the repaired corners. This all seems to indicate that wildlife was regularly present at the site of the Weber reservoir and could have been a vector for *Salmonella* contamination.

CRAFT TOWER

The Craft Tower is a 500,000 gallon spheroid elevated tank. This tank was constructed in 1984. The most recent inspection prior to the outbreak was in July 1997 by a professional inspection firm. At that time the tower was in generally good condition, with some blistering and corrosion of surface materials. There were no comments made at the time indicating poor sanitary conditions that would impact water quality.

In response to the outbreak, the tank was inspected another time by a professional inspection firm on April 3, 2008. The SDW program team reviewed the reports of this inspection at the time of the outbreak and interviewed the inspection firm personnel in the spring of 2009. Based on the information gathered, the vent in the Craft Tower was in need of minor repair at the time of the outbreak. Fecal matter from birds was observed on the top of the tower at that time, sediment and debris were noted inside the tank. The inspectors recommended maintenance and repairs, including cleaning and recoating the interior and pressure washing the exterior.

Based on a review of records and discussion with city personnel, the city did not maintain a routine of flushing, disinfecting, or removing sediment from the tank as part of routine operations. In April 2008, the city performed some of the recommended maintenance and repairs. Replacing the tank vent was added to the repair list in May 2008, and the city indicated that this repair was completed. In June 2009 another inspection and thorough cleaning was completed by a professional tank diving services firm. Additional maintenance activities are planned for 2010.

ROSS TOWER

The Ross Tower is a 150,000 gallon cylindrical elevated tank. The date of construction of this tank is unknown, but it was likely built in the 1930's or earlier, based on estimates from city personnel. No written records are available for the most recent inspection or clean-out of the Ross Tower prior to the outbreak; however, city personnel have stated that it was repainted inside and out around 1985. This was likely the last time the tank was cleaned prior to the outbreak. It was scheduled to be inspected in 1997, but this inspection did not take place reportedly because divers from the inspection firm were not able to access the tank while it was in service due to the configuration of the access hatches.

On April 2, 2008, the tank was inspected by a professional firm in response to the outbreak. The tank also was removed from service for repairs and cleaning. During clean-out, an estimated 145 gallons of sediment were removed from the bottom of the tower. Based on a review of records and interviews with tank inspectors, the Ross Tower was in need of minor sanitary repairs and more significant emergency safety repairs in April 2008. Minor sanitary issues included some gaps at the seams between structural panels in the tank, and fecal matter from birds observed at the top of the tower. It is possible that fecal matter could have been flushed into the tank from holes created by missing bolts. The inspectors recommended maintenance and repairs, and work was completed in April 2008.

Based on a review of records and discussion with city personnel, the city did not maintain a routine of flushing, disinfecting, or removing sediment from the tank as part of routine operations. After the outbreak, the city improved its maintenance and operations plan for the Ross Tower and all tanks. At this time, the Ross Tower is used exclusively for untreated water storage for the new water treatment plant. No treated water is stored in the Ross Tower.

As part of the investigation, in June 2008 the SDW program team obtained two 500 milliliter (mL) samples of sediment collected from the Ross Tower and examined it in the lab visually and using a simple optical microscope. One of the 500 mL samples was visually examined. The bulk sample did not contain large specimens of material; it was primarily silty and sandy sediment. Both 500 mL samples were passed through sieves at #8, #16, and #20 mesh screens and rinsed.

A small sample from the #8 sieve was observed under an optical microscope. It contained small pebbles, estimated between 0.1 centimeter (cm) and 1 cm in diameter. There also appeared to be a small piece of wooden material and a seed pod. A sample from the #16 sieve included smaller rock fragments and what appeared to be very small steel balls. The source of the small steel balls is unknown; it is possible that it could have been birdshot or residue from a previous sandblasting operation. There also appeared to be small insect fragments. A sample from the #20 mesh contained smaller rock fragments and even smaller steel balls. None of the samples contained evidence of small bones, feathers, or other organic matter that would indicate infestation or habitation of animals in the Ross Tower.

DISTRIBUTION SYSTEM

Alamosa's distribution system contains over 800,000 gallons of water in about 50 miles of distribution line. According to engineering reports, the system is composed primarily of polyvinyl chloride (PVC), concrete-asbestos, and cast-iron pipe. A small amount, about 1,800 linear feet, is high density polyethylene (HDPE). The newer PVC pipe is generally less than 15 years old. The concrete-asbestos and cast-iron pipe is typically older than 20 years, with some of it installed in the early part of the twentieth century.

According to records and communications from city personnel, at the time of the outbreak, the city did not have an active distribution system maintenance and flushing program or a cross-connection control program. Distribution system operations were typically limited to responding to line breaks.

As part of the investigation, the SDW program employed an engineering consulting firm to model the flow of water in the distribution system around the time of the outbreak. In general, over 75 percent of the water being pumped to the system was from the Weber well through the Weber reservoir at the time of the outbreak. Another 20 percent of the water pumped was from the Cole Park well, with the remainder coming from occasional pumping of the other wells.

With information available, including results from the hydraulic model of the system, it is difficult to pinpoint the defined area of influence of each water tower. In general, the Craft Tower typically received water from the Weber Reservoir. Subsequent hydraulic modeling of the Alamosa water system demonstrated that it is unlikely that contaminated water from the Ross Tower would have had a significant influence on the north part of town where the Craft Tower is located.

Further, model results indicate the area of influence of the Cole Park well did not extend to the Weber well or Craft Tower, and was confined primarily to the downtown area. Thus, any northward flow would have been from the Ross Tower, which would not have had a large influence on water quality in the north part of town. *Salmonella* bacteria were found in the northern reaches, and in fact all over the city's distribution system. This supports the conclusion that the source of bacteria was in the north part of the city near the Weber well.

HOW MUCH *SALMONELLA*?

This investigation included an estimation of the quantity of bacteria required to contaminate a system of water storage facilities and distribution lines the size of Alamosa's in its entirety with an infective dose of *Salmonella* for humans. Estimates of the number of *Salmonella* bacteria for an infective dose to a small child found in the literature were as low as 10 to 100 organisms, with adults possibly needing a higher dose. Based on telephone surveys, about 40 percent of infants in Alamosa were sick during the outbreak.

At the time of the outbreak it is estimated that at least 800,000 gallons of water were contained in the city's distribution lines and at least another 800,000 gallons of water in the city's storage tanks. Based on sampling results, by March 20, 2008 all 1.6 million gallons of water in the city's system were likely contaminated. If a person consumed as little as two cups of water to receive 100 *Salmonella* organisms, the associated level of bacteria would be estimated on the order of 1.3 billion organisms systemwide. Feces from a single infected bird in the acute phase of infection may contain on the order of 10 million to 1 billion organisms per gram. Much lower shedding rates occur at other stages of infection. Conditions for bacterial growth may have been favorable in storage tank sediments and distribution system biofilms due in part to the lack of

disinfectant. Thus, it is possible that a relatively small amount of animal fecal matter caused the outbreak.

OTHER EVENTS OF INTEREST

The SDW program team investigated other events of interest that may have resulted in unusual or unique environmental conditions that could provide additional clues to the source of *Salmonella*.

Precipitation and snow melt

Precipitation and temperature data were reviewed for January through March 2008, the months prior to and at the beginning of the outbreak. Noteworthy events included a snowfall of 6.7 inches on February 5, 2008, about a month prior to the outbreak, followed by a period of warming with daytime temperatures above freezing from February 12-17, 2008 and again from February 20, 2008 through March 2, 2008. Other than this pattern, there was no additional significant rain or snowfall (more than 1.3 inches) prior to March 6, 2008, the date of the first suspected case of *Salmonella*.

The Weber reservoir was full of warm water throughout the winter and according to city staff snow rarely builds up on top of the roof. It is possible that the snowfall, followed by rapid warming created conditions of surface flow on or near the Weber tank that carried bacterial contamination from animal feces into the tank through above or near surface fractures in the concrete. Another possibility is that the snowmelt provided a mechanism for bacterial contamination from animal feces to be transmitted through the near surface soils and into the city's very shallow groundwater table. At least part of the year it is suspected that the elevation of the bottom of the Weber tank is below the top of the saturated groundwater table. Because the Weber tank was full at the time, and because of the relatively flat topography in the area, it is unlikely that contaminated groundwater would have entered the tank. Another possibility is that contaminated groundwater entered the casing of the Weber well, which is in aging condition, and contaminated the water system as well pumps drew shallow groundwater and introduced it to the water system. Although this may have occurred, sampling results do not support the theory.

River Stage Data

Based on a review of U.S. Geological Survey (USGS) gage data for the Rio Grande River in Alamosa for January through March 2008, there were no unusual flows in the Rio Grande River, which flows through the city. The gage height remained at a relatively constant 3.55-3.56 ft for the period January 16, 2008 through March 11, 2008. This indicates no significant flooding or shift in the subsurface hydrology caused by significantly changing river conditions around the time of the outbreak.

Fires

There were no fires in the city around the time of the outbreak that would have either impacted water infrastructure directly or indirectly by creating unusual demands on the water system or transient low pressure conditions from fire flow.

Low Pressure Events

Based on a review of tank level and pumping data for January through March 2008, there were no unusual low pressure events. On February 12 and 20, 2008, there were significant draws on the system related to construction at the new water treatment plant. These draws are evident from the tank level records on both dates. Detailed information about these occurrences is in the previous section of this report under "Storage Facilities." These flows probably did not create low pressure events in the system. No other information about system operations or customer complaints indicated that a low pressure event occurred at any other time around the time of the outbreak.

Special Events

According to a written statement from the city, there were no special events in the city from January 1, 2008 through March 31, 2008 other than the normal seasonal sporting events that occur every year at that time.

Construction and/or Maintenance Activities

According to a written statement from the city, all construction activity involving excavation was suspended during the period January 1, 2008 through March 31, 2008 due to weather. Adams State College continued above ground construction of Plachy Hall on Stadium Drive and El Rio Avenue during this period but did not perform work on water or sewer line connections until July 2008.

Seismic Activity

In March 2009, the SDW program team requested information from USGS about any unusual seismic activity around the time of the outbreak that may have impacted the subsurface hydrogeology in the region. In an email response to this request dated April 1, 2009, the USGS stated that they had searched their earthquake database and determined that there was no seismic activity located within a 75 kilometer (km) radius around with city during the period from October 1, 2007 through April 1, 2008. During the same period, there were six events on the east side of the Sangre de Cristo mountains, east of Alamosa, and within a 150-km radius. All but one of those events were located in an area of natural gas wells in western Las Animas County, Colorado, and western Colfax County, New Mexico. The email response further stated that "unless the Alamosa water supply comes from aquifers that include the east side of the Sangre De Cristo Range, it would seem that there was no earthquake activity during that period that could have affected the water supply."

Vandalism or Tampering Events

According to a statement from the city dated January 14, 2009, there were no vandalism or tampering events related to the city's water system in the year prior to the outbreak. There were moderate levels of graffiti at different locations throughout the city, but none that targeted the water facilities.

Staffing Changes

The city did not experience any changes in its public water system operational staff around the time of the outbreak.

ADDITIONAL DATA COLLECTED AFTER THE OUTBREAK

In the spring of 2009, the SDW program team conducted three rounds of water quality sampling in the surface water environment in Alamosa and in the city's water system. The purpose of the sampling was to characterize source water quality during the spring season and to gain a better understanding of the prevalence of *Salmonella*.

The sampling events were conducted in February, April, and May 2009. During each event, grab samples were collected from ambient surface water where birds and deer had been previously observed. Samples were collected during all three events from the wetlands area northeast of Craft Drive and Park Avenue. Samples were analyzed for temperature, pH and *Salmonella*. No samples were positive for *Salmonella*. Additional samples were collected from a private lake northwest of Lakewood Drive and Riverwood Drive in the northern area of the city during February and April 2009. These samples were also analyzed for temperature, pH, and *Salmonella*. No samples from the lake were positive for *Salmonella*. Based on the samples collected from the ambient environment, there is evidence that *Salmonella* was not prevalent or widespread in the city's natural surface water during the spring of 2009. No similar water quality data were collected during the outbreak, so this result is inconclusive as it pertains to the investigation.

Samples from the city's Weber well and Cole Park well also were collected and analyzed for turbidity, temperature, pH, *Salmonella*, total coliform, heterotrophic plate count, *Salmonella*, TOC, and nutrients. Microscopic particular analyses also were performed for each well. Over the three events, there was a slight increase in turbidity at the wells, and a slight increase in TOC at the Cole Park well. There was a low level of heterotrophic bacteria in each of the wells. The wells were negative for total coliform and negative for *Salmonella*.

During the spring of 2009, additional samples were collected from the Weber reservoir (untreated raw water) and from the outlet of the Craft Tower (treated water). None of the samples were positive for total coliform or *Salmonella*. This suggests that *Salmonella* did not exist either in the Weber reservoir or the city's distribution system at the time of the sampling in 2009.

REVIEW OF EPIDEMIOLOGICAL REPORTS

As part of preparing this investigation report, the SDW program team was in communication with county and state epidemiologists about the pattern of the outbreak and details regarding specific cases. According to the epidemiological evaluation of the outbreak, there were 442 reported cases of illness, 122 of which were laboratory-confirmed, and one death. Epidemiological estimates suggest that up to 1,300 people may have been ill.

The Alamosa County health department and the CDPHE epidemiologists are preparing separate reports with a detailed emphasis on surveillance, analysis, and their response to the outbreak. Details of specific cases, including case maps, are protected information for privacy reasons. However, generally speaking, there is no observable statistically significant pattern in the case history of this outbreak that points to a single, specific location where contamination was introduced to the water system.

Figure 3 illustrates the epidemic curve for the *Salmonella* outbreak in Alamosa. Based on the disease onset dates illustrated in this figure, and the number of cases reported each day, it is estimated that *Salmonella* was introduced to the city's water system sometime between March 3 and March 5, 2008. By March 10, *Salmonella* was probably present throughout the entire distribution system. A detailed evaluation of the early confirmed cases of *Salmonella* with disease onset dates from March 6 through March 10 also do not reveal where the original source of contamination occurred. This is in part because surveys of the early cases indicate that the individuals had multiple potential exposure locations around the city, including areas with high overall water usage that likely became contaminated relatively quickly. Overall, based on a review of the epidemiological data and associated reports, the case history of the *Salmonella* outbreak in Alamosa does not form a pattern that identifies the exact location where the contamination originated. However, the fact that people throughout the entire system, and visitors to the area who stayed only briefly, all got sick indicates that the likely source of contamination would be a location that supplied the most water that could reach the entire system. Contamination emanating from the Weber Reservoir best fits that overall fact pattern.

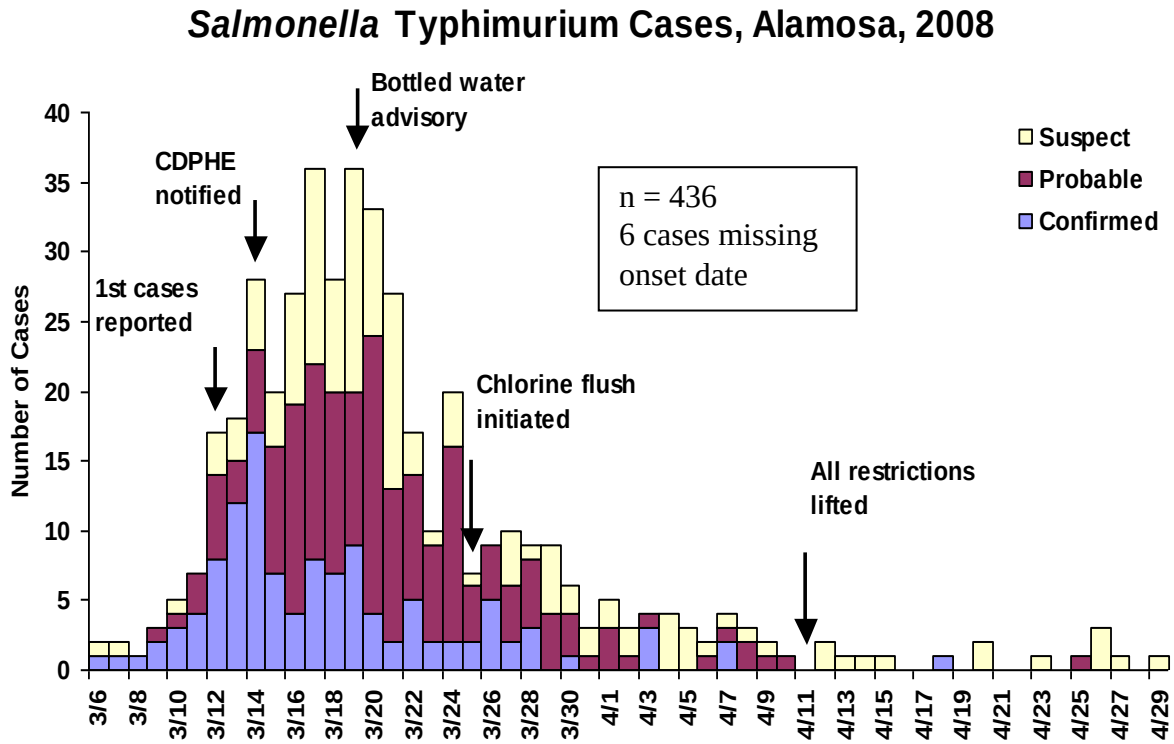

FIGURE 4: EPIDEMIC CURVE

LITERATURE REVIEW

As indicated earlier in this report, the SDW Program team became very interested in prior reports of similar disease outbreaks and other related literature very early during this incident. The team worked closely with CDC to assemble the most relevant material that could provide useful information. During the outbreak and over the subsequent months, numerous literature articles were reviewed, including 15 reports/papers regarding previous *Salmonella* outbreaks in the U.S. and abroad, as well as several other relevant papers and communications with various experts (references 1 to 29 in Appendix E). Appendix E summarizes only those references deemed most relevant to the Alamosa outbreak cause investigation, and a brief discussion is included below.

- Where a contamination source was identified, an animal source was often confirmed or suspected, and a wide range of animals can be carriers of *Salmonella*. A report from the early 1970s showed that a large water reservoir could be contaminated with *Salmonella* from birds. This also was very possible in the Alamosa case based on the DNA analysis of the *Salmonella* strain. The 1999 USGS report states that bird mortality caused by *Salmonella* Typhimurium has increased since 1980, and Colorado is shown to have had eight avian outbreaks from 1983-1997. Studies from Norway and Tasmania, Australia also show how *Salmonella* can find a reservoir in wildlife populations, and that

unchlorinated drinking water is a key risk factor for human illnesses. Outbreaks occur most frequently in winter and spring. Small rodents and mice are also listed as common sources of *Salmonella*.

- Contamination, when the source was confirmed, was often introduced at a storage tank. Similarly, the Campylobacteriosis outbreak in Greenville, Florida was suspected to be caused by bird feces contamination in a final treatment tank.
- *Salmonella* outbreaks typically occur when there is non-existent or ineffective disinfection. This was the case in Alamosa as well.
- Sampling for total coliform bacteria is not very reliable to detect *Salmonella* contamination. This also was observed during the Alamosa outbreak.
- Based on the Riverside epidemiological report, *Salmonella* survival studies, and other literature, a low infective dose of 10 to 100 organisms in drinking water may be sufficient to cause illness. Also, the bacteria can survive in drinking water or biofilms for at least a week, depending on the level of contamination. It also is possible that *Salmonella* can grow to some extent in the sand in the bottom of a tank, or in biofilm that may exist in the distribution. This supports the flushing approach taken in response to the Alamosa outbreak.
- Animals infected with *Salmonella* can shed 10 million to 1 billion bacteria per gram of feces during the acute phase of infection, whereas animals recovering from infection or simply carrying the bacteria may shed 10,000 to 100,000 organisms per gram of feces, or less.
- Most, if not all, the outbreak investigators were left with at least some unanswered questions, and in some cases the contamination source remains unknown. There are now, and likely always will be, some questions about the Alamosa outbreak that cannot be answered, primarily because the likely contamination date range was about March 3 to 5, 2008, whereas the waterborne nature of the outbreak was not confirmed until about two weeks later.

Overall, the literature review, in conjunction with all the information gained during the investigation, supports the likelihood that an animal source of *Salmonella* bacteria entered the Weber Reservoir and then contaminated the remainder of the Alamosa drinking water system. Additionally, the literature review supports the extensive disinfection and flushing work done in the distribution system and other measures taken to protect public health like disinfecting and sampling water hauling trucks prior to allowing them to provide drinking water to the public.

REVIEW OF STATE PUBLIC WATER SYSTEM FILE

The SDW program team conducted a file review of historical records on the city's system, including information about the city's disinfection waiver, sanitary surveys, and other records. A disinfection waiver was requested by the city on September 15, 1969 and initially was not approved. Later, the waiver was approved on December 17, 1974, but with cautionary language further advising the city to consider disinfecting the water supply "as an additional safeguard."

Sanitary surveys were conducted regularly by representatives of the state health department, and based on file records inspectors did not note any significant deficiencies associated with the city's water system operations or infrastructure.

Since 2004, the city had actively been on a path to install centralized treatment for arsenic removal. This was mandated under an Enforcement Order on Consent, originally dated February 2005. The treatment plant went online serving water to the Alamosa community in the fall of 2008 and arsenic levels have been in compliance since then.

As discussed previously in this report, the city did not have other known patterns of non-compliance at the time of the outbreak. In 2002 the city had six positive total coliform samples, and in 2003 they had one positive total coliform sample. All positive results were followed by negative results in repeat sampling. One non-acute MCL violation of the Total Coliform Rule was issued in November 2002.

Predicated upon the lack of significant results demonstrating noncompliance with other standards or requirements, the priority for Alamosa had centered on addressing the long-standing issue of high arsenic levels in source water. Additionally, since the new drinking water treatment plant being constructed would include disinfection, enhancing the existing system, prior to the *Salmonella* outbreak, did not appear to be the most pressing or significant issue for the city.

PART IV: INVESTIGATION AND OBSERVATIONS

CLOSING THE INVESTIGATION

Multiple possibilities were explored as the potential source of the Alamosa outbreak. It cannot be stated with complete certainty what happened during the first week of March 2008 to contaminate the water system. It must be remembered that the potential for a waterborne outbreak was not even identified to the state until March 14, 2008, and that investigations into the water system did not begin until March 17, 2008. However, known issues with the water system that could have potentially caused this outbreak have been reviewed by the investigation team, and have been addressed sufficiently to substantially reduce the risk of another outbreak associated with the drinking water system in the future in Alamosa.

While a few causes remain theoretically possible, the most likely cause was that the cracks and holes in the Weber Reservoir allowed animal waste to contaminate the water therein, which was then pumped to the rest of the distribution system. Table 1 summarizes the most significant facts that point to the Weber Reservoir as the entry point for contamination. The Weber well and reservoir system supplied over 75 percent of the city's water supply at the time of the outbreak. Further, *Salmonella* contamination was found throughout the system. Of the two primary wells in service around the time of the outbreak, only the Weber Well and Reservoir were most capable of supplying water to the entire system. This conclusion was derived from efforts to reconstruct flows using a hydraulic model of the city's distribution system.

It also is likely that the original contamination source came from a single animal or small group of animals that contaminated one location in the water system. This type of *Salmonella* and its DNA pattern has been found previously in Colorado, Texas, and Wyoming wildlife and *Salmonella* with the same DNA pattern was found in all the water samples throughout the distribution system and in the patients. In other words, if there had been several different types of animals or multiple contamination points, it is likely that there would have been different etiologic agents (pathogens), or at least different DNA patterns.

The entire volume of the Weber reservoir theoretically is exchanged with new water multiple times per day, due to system demand drawing from the reservoir and well pumping that replenishes the reservoir from the Weber well. It is believed that *Salmonella* could have propagated at least to some extent in the sediment in the bottom of the Weber reservoir and the city's distribution system, based on available information on water quality. It is also possible that the source of contamination, although theoretically small in quantity, could have been continuous or repeated, at least for some period of time.

Table 1: Investigation Summary:
Contamination of the Weber Reservoir

- Sanitary defects in the reservoir, including cracks and holes in the concrete structure large enough to allow entry of small animals and runoff from the roof.
- Evidence of wildlife presence near the reservoir in winter conditions, and a photograph of bird feces on a repaired corner of the tank (taken in July 2009).
- Over 75 percent of water in distribution system at the time of the outbreak came from the Weber well and passed through the Weber Reservoir.
- *Salmonella* contamination was found the throughout the system, and only the Weber Reservoir supplied water to the whole system.
- On March 21, 2008, samples for the Weber well (which pumps to the Weber Reservoir) and Cole Park well were total coliform negative, whereas the sample from the Weber Reservoir was total coliform positive.
- Literature review, in conjunction with the other information gained during the investigation, supports the likelihood that an animal source of *Salmonella* bacteria entered the Weber Reservoir and then contaminated the remainder of the Alamosa drinking water system.
- Small quantities of animal feces could contaminate the entire distribution system at a level consistent with an infective dose.
- In the weeks prior to the outbreak, there was a relatively significant snowfall event followed by a warming period. Snowmelt could have been a vector for contaminated feces or other material into the Weber Reservoir.

Considering that the contamination was likely introduced at the Weber reservoir, it is possible that one animal or group of like animals repeatedly contaminated the tank over a period of time so as to introduce sufficient waste to create a continuous source of *Salmonella*. Another possibility is that a single contamination event occurred at one point in time, perhaps in the west end of the tank where water may have been relatively stagnant. Water in a stagnant part of the tank would not have been exchanged routinely as system demand and well supplies created a regular pattern of flow in the tank. In that case, *Salmonella* could have grown over an extended period of time in that area until it reached an infective dose level and caused an outbreak. Based on the information available, either possibility is plausible, and numerous other possibilities exist.

The investigation yielded suggestions for future research that may be taken up by other investigators. Some ideas include studying:

- Potential sources of *Salmonella* for the quantity of bacteria required to contaminate a water system like Alamosa's with an infective dose of *Salmonella*.
- The ability and pace of propagation of *Salmonella* bacteria in the water quality matrix that existed in Alamosa at the time of the outbreak.
- The ability for *Salmonella* to exist and propagate in sediment in an unchlorinated water storage tank over an extended period of time.
- The ability for *Salmonella* to exist and propagate in sediment, scale, and biofilm in unchlorinated water distribution lines over an extended period of time.

LESSONS LEARNED

In the 21st century, those members of the water profession who dedicate their careers to ensuring the provision of safe drinking water in the United States most commonly speak in terms of regulatory requirements and calculated risk – not outbreaks, cases and deaths. The Alamosa *Salmonella* outbreak in the spring of 2008 was the kind of event that drinking water professionals spend their days and sometimes nights working to prevent from ever happening. This happens quietly, continuously, and largely unnoticed by the public.

A public water system is defined in the Colorado Primary Drinking Water Regulations as a water system that serves 25 or more people or 15 or more service connections more than 60 days out of the year. According to estimates from the EPA, public water systems provide drinking water to 90 percent of Americans. In Colorado alone, safe drinking water is delivered by about 2,000 public water systems governed by the Safe Drinking Water Act, serving houses, apartments, restaurants, schools, and campgrounds across the state.

Sometimes though, something goes wrong. There is a failure in the physical, regulatory, or human infrastructure and the water delivered to the tap is not safe to drink. In an effort to learn from the outbreak in Alamosa, this section discusses opportunities for the SDW program and public water systems to improve, outlines changes in the SDW program strategies and practices

that are designed to be preventative, and identifies areas that went well during the outbreak response and investigation.

OPPORTUNITIES TO IMPROVE

As discussed previously, the city had no other known patterns of non-compliance with drinking water regulations related to health effects, with the exception of exceeding the health-based standard for arsenic. Further, the city had no unaddressed deficiencies noted during routine sanitary surveys conducted by CDPHE, although the sanitary surveys conducted prior to the outbreak did not include a comprehensive investigation of the city's distribution system infrastructure.

At the time of the *Salmonella* outbreak in Alamosa, the system had been evaluated in the previous year by engineers from the private sector and the SDW program. By all common measures, the city was maintaining compliance with regulations at a level consistent with protection from acute risk to public health. Clearly, however, there was a failure of the combined physical, regulatory, and human infrastructure that resulted in this outbreak. On reflection, the authors offer the following lessons learned from this experience.

Emphasize oversight of total coliform sampling and storage and distribution systems

The primary drinking water regulations require that public water systems regularly analyze the microbiological quality of representative and properly collected samples from the distribution system using the total coliform test. This requirement reflects the fact that this testing, properly conducted, is particularly effective at detecting ongoing, constant microbiological contamination that may be present at each sampled location. The test is also designed to detect incidence of intermittent microbiological contamination that may be present at each sampled location.

Prior to the outbreak, the city of Alamosa did not have a significant history of total coliform sampling that showed the presence of bacteria. The city has very deep wells which generally reflect good bacteriological quality. Although the SDW program team reviewed the results of the city's total coliform sampling, it did not scrutinize the city's total coliform sampling methods or its storage and distribution management system. Subsequently, this investigation identified that the city of Alamosa had not historically been collecting total coliform samples that were representative of water quality in the distribution system, and sampling was not done in compliance with the Total Coliform Rule. Because proper bacteriological sampling procedures conducted at the right locations is critical to determine compliance with the primary drinking water regulations, the SDW program team determined that it needs to make the oversight of these procedures a priority.

To ensure the quality of tap water, robust distribution and storage operation and maintenance programs are needed at public water systems. A history of total coliform absence is not enough to ensure safe bacteriological quality, especially in an unchlorinated system. The water storage and distribution system itself must be properly operated to maintain its integrity and protect the public's supply of safe drinking water from contamination. As it is possible that only a small

quantity of animal feces contaminated the Alamosa system, it is particularly important for water systems to develop and implement robust plans for sampling, and storage and distribution system operation and maintenance programs, including a cross connection control program. This includes, but is not limited to, increased monitoring and response to system-specific triggers related to water quality, system pressure, infrastructure condition, cross connections, repair practices, dead ends, and customer complaints.

A significant lesson learned is to emphasize oversight of these critical operations so that all future sanitary surveys comprehensively cover the basics, including accurate and up-to-date total coliform sampling plan and sample collection, distribution and storage components, and complete operations and maintenance plans. Training and technical assistance offered to public water system personnel also should put more emphasis on correct total coliform sampling and storage tank inspections and maintenance.

Inventory and track all water storage facilities

There are no federal requirements for storage facilities to be included in sanitary surveys of public water systems that use groundwater as their primary source. This is scheduled to change effective December 1, 2009, and as of that date sanitary surveys of groundwater systems will be required to cover storage facilities and numerous other aspects of the technical, managerial, and financial capacity of each system. It is significant, however, to note that state sanitary survey requirements at the time of the outbreak did include an obligation to inspect storage facilities, although federal requirements did not.

With limited resources, the SDW program made an effort to prioritize tracking water storage facilities in the SDW program database starting in about 2002. Tracking and inspecting these facilities, however, is relatively new for the SDW program in Colorado, and the Weber Reservoir was not in the database inventory at the time of the outbreak. Indeed, tracking these facilities is not a difficult task on its own, but the underlying reasons they are not tracked is because of competing and higher priority tasks for both inspectors and data managers. Placing higher emphasis on tracking water storage facilities could assist in earlier identification of sanitary and maintenance issues.

Prioritize detecting and addressing deficiencies at water systems that do not disinfect

Public water systems with disinfection waivers should be looked at with a higher level of scrutiny to detect significant deficiencies. Once deficiencies are identified, they would need to be prioritized for follow up activities. The SDW program did prioritize Alamosa in recent years as a very high program priority to address the arsenic violations. Many resources were spent on addressing that issue program-wide, from enforcement to engineering to financial solutions. Protection of bacteriological quality was not an identified deficiency at the time of the outbreak and did not have the same level of emphasis as the arsenic violations.

The regulatory infrastructure is designed to have multiple barriers in place to protect public health, and Alamosa lacked certain treatment and non-treatment barriers that exist at many other public water systems. Alamosa's history of total coliform monitoring revealed no noteworthy

patterns of the presence of bacteria in the city's system. Routine monitoring for total coliform did not predict an outbreak of *Salmonella* in the city's drinking water supply. However, because sampling wasn't done in compliance with the Total Coliform Rule (well source samples versus true distribution samples), historical data are inconclusive.

Of all the regulated public water systems in Colorado, Alamosa had not been prioritized for assistance or enforcement related to issues other than their arsenic violations. At the time of the outbreak there was a perfect storm of multiple defects emerging that together created a riskier situation than was thought to exist. The city's water system was being operated under a disinfection waiver, with limited cross connection control, and no documented system, schedule or records, of disinfecting and flushing lines and storage facilities. Further, two of the city's storage facilities had significant integrity problems from aging and lack of maintenance.

Prioritize the periodic review of disinfection waivers

Federal regulations do not require public water systems using groundwater as their primary source to disinfect the water at the source or in the distribution system. Further, many communities, especially those operating under disinfection waivers, are very resistant to chlorinating their drinking water. Communities resistant to chlorination commonly cite the cost of treatment or the complaints regarding the taste of chlorinated water.

Although no federal mandate ever existed, the state health department in Colorado began requiring disinfection of public water supplies years before the federal Safe Drinking Water Act was passed in 1974. This requirement has been waived by the state health department on a case-by-case basis over the years.

According to historic records, Alamosa's disinfection waiver was issued five years after the city applied in 1969. In 1969 the state strongly recommended that Alamosa employ disinfection treatment, but then granted the waiver in 1974. Through the 1970s and 1980s there were numerous opportunities to re-evaluate the waiver in the context of total coliform positive results. The state's SDW program always has faced tough decisions on assigning resources to competing priorities; that has resulted in prioritizing other activities over the review of disinfection waivers in the past. Starting in 2007, however, the SDW program team recognized the need to revisit the waivers. The outbreak in Alamosa confirmed waiver review as a priority.

Total Coliform bacteria monitoring is not a good indicator for Salmonella

During this disease outbreak, most samples taken in the distribution system were absent for total coliform while people drinking water from the city were being exposed to *Salmonella* and getting sick. This was also the case in the Riverside, CA and Gideon, MO *Salmonella* disease outbreaks. Total coliform monitoring, by itself, is not sufficient, especially for systems that do not disinfect. Indeed, it is not possible to sample unchlorinated drinking water frequently enough or for all the pathogens that could be present. This is a strong argument for all water systems to provide disinfection, as is the possibility that only a small quantity of animal feces may have caused the Alamosa outbreak.

It has been noted in this report that Alamosa was not collecting its total coliform samples properly. In light of the above discussion, it is possible that even if the total coliform samples collected on March 5, 2008 were collected properly, that they would have been negative.

Address resource needs for Safe Drinking Water program

The Safe Drinking Water Program has been, and is now, under-resourced to provide a robust level of oversight to the approximately 2,000 public water systems in Colorado. This has been the case since the inception of the program in the early 1970s, and has been periodically documented over that course of time.

EPA issued a report in November 1974 after conducting a detailed evaluation of the SDW program in Colorado. A key conclusion was that the program was severely under-resourced. The report stated, "A false sense of security might well exist concerning the safety of water supplies in Colorado. Colorado's water supply program is not meeting its responsibility of protecting the quality of water served to the State's citizens and visitors. This situation is a direct result of the lack of resources allocated to water supply activities." The program staff consisted of about 13 employees, but many split duties between programs, such as swim pools, septic systems, plumbing inspections, and solid waste, and did not devote all of their time to safe drinking water activities. Thus, the actual level of full time equivalents (FTE) devoted to safe drinking water was considerably lower.

In 1974, EPA advised the state that 23 FTE fully devoted to safe drinking water would be needed by 1977. Additional records from the 1970s are scant, but it is believed that resource levels for the SDW program did increase slowly, until November 1977 when Colorado adopted regulations and became the primacy agency to implement the 1974 federal Safe Drinking Water Act.

Detailed records of staff levels and program evaluations from the late 1970s to mid-1980s are not available, but anecdotally, staff from those times report that the program did gain resources, but not in sufficient quantity to keep up with the pace of changing drinking water regulations. In particular, the 1986 Safe Drinking Water Act amendments substantially enhanced the regulatory provisions to protect public health, but Colorado's inability to add resources to properly implement the program almost led to EPA's revocation of Colorado's Safe Drinking Water Act primacy authority. The FTE level for the SDW Program stood at about 12 FTE by 1989. In 1994 EPA began the formal process to withdraw primacy authority. At the time, Colorado was cited by EPA for inadequately adopting and implementing new regulations including surface water treatment rules, not properly processing or reporting chemical or radiological data, and rarely taking any type of enforcement action. The program staff level was about 17 FTE, compared to the 33 FTE minimum level that EPA believed was necessary for satisfactory program performance. Detailed records of how this situation was resolved are not available, but it appears that the SDW program was able to gain some additional funding from the legislature and utilized some federal employees on a temporary basis. By 1995, the SDW program had about 20 FTE, and EPA did not withdraw primacy.

However, this process nearly repeated itself after the passage of the 1996 Safe Drinking Water Act amendments. Colorado did not have resources to adopt the associated new regulations in a

timely fashion and requested extensions from EPA for adopting these new regulations to enhance public health protection. In February 2001, EPA granted an extension request regarding nine significant regulations/issues. In a June 2001 SDW Program audit, EPA again noted insufficient resources being devoted to enforcement. Between 2001 and 2004 the SDW Program added some FTE, but it would not be until 2005 that Colorado was fully caught up with adopting the required regulations to maintain primacy authority. While Colorado was able to adopt these new regulations, the gap in resources needed to implement them grew.

In 2004 EPA conducted another audit of the SDW program and concluded that the program was still substantially under-resourced. In 2004 the program staff level was 37 FTE compared to the minimum 72 FTE level that EPA, and other staff resource models, believed was necessary at that time. For later years in this decade, the minimum staff level necessary was estimated to increase to 82 FTE, in large part due to an entire new suite of regulations addressing microbial contamination and disinfection byproducts. The regulations impose more complex and stringent requirements, including increasing oversight of surface water treatment plants in the wake of the Cryptosporidium outbreak in Milwaukee that occurred in 1993.

The SDW program has been aware of these resource shortfalls and has been successful in gaining resources, albeit not rapidly enough to fully close the gap. This situation has been publicly reported to the state legislature in the 2005 Senate Bill 276 report, and subsequent long bill "Footnote" reports (Footnote 109 in 2007 and Footnote 55 in 2008). With the support of stakeholders and the state legislature, both general funding for the SDW program and fees applied to public water systems have increased in recent years. By 2008, at the time of the Alamosa outbreak, the SDW program staff level stood at about 54 FTE, and in 2009 stands at about 67 FTE, still well short of the minimum necessary. The SDW program will again be working with stakeholders to gain their support for additional funding.

What does this mean for program performance in 2009? Because of increasing resource levels obtained in the 2000s, the SDW program has made significant improvements. All of the federal regulations promulgated in the latter half of this decade have been adopted on time in Colorado, and we are slated to maintain full primacy authority from EPA for the foreseeable future. Colorado is able to take timely and appropriate enforcement actions in response to the most serious drinking water violations and conducts routine compliance inspections as required by the federal Safe Drinking Water Act.

The SDW Program also takes swift action when it becomes aware of potential acute health risks at public drinking water systems, responding to about 163 such incidents between January 1, 2006 and December 31, 2008. It is not possible to directly state that these actions have prevented disease outbreaks, but the actions, including issuing bottled or boil water orders, reduce the risk of waterborne disease. Colorado can be proud that about 97 percent of our population served by community public water systems receives drinking water that meets all health-based standards, significantly exceeding EPA's national target of 90 percent.

However, there are still serious deficiencies in the program primarily due to a lack of resources. For example, while the SDW program is able to issue enforcement orders to systems with

violations, it is not always possible to follow-up on those orders in a timely fashion to ensure that the offending public drinking water system is taking adequate steps to quickly gain compliance. Additionally, as we have learned from the Alamosa outbreak, while the SDW program has been completing inspections at required frequencies, the inspections were not comprehensive enough to detect significant deficiencies in storage and distribution system infrastructure. Furthermore, once inspection findings are issued to public water systems, the SDW program struggles to follow-up on violations and infrastructure deficiencies discovered during inspections. Indeed, it was reported in April 2009 that about 120 community water systems in Colorado may have unresolved significant deficiencies, or may have resolved them, but the SDW program is unable to adequately track these efforts. More recent improved data shows that this number may be down to 73 communities in the fall of 2009.

Another area of significant weakness is in oversight of non-community water systems. These systems meet the definition of a public drinking water system, but do not serve year-round residents; examples include rural school districts and campgrounds. There are about 1,165 such systems in Colorado, but the SDW program has historically focused on community water systems, and provided only a bare minimum level of oversight to non-community systems. A non-community system experienced a waterborne disease outbreak of norovirus in 2007, and the SDW program has subsequently been attempting to enhance its oversight of these systems.

The SDW program intends to continue its efforts to work with stakeholders and the legislature to gain adequate resources to conduct a more robust oversight program. The SDW program understands its strengths and weaknesses, and is working toward prioritizing activities to get the best public health protection possible with its limited staff, while still meeting basic regulatory requirements.

Try to find resources who can work on the cause investigation up front

During the crisis response, it may have been beneficial to have had additional highly specialized resources available from other agencies on an emergency basis, including EPA, to support the SDW program team's response and investigation into the cause of the outbreak, especially during the first few days of the initial response. A team with additional resources could have performed duties such as:

- Conducting a detailed survey of the system;
- Sampling in many more locations including all wells and storage tanks to preserve information relevant to the cause;
- Additional sampling in the environment, including ambient waters, wetlands, wildlife survey and feces sampling;
- Preparing detailed drawings;
- Acting as journalists to track and document field activities in writing and through photography;
- Tracking, quality checking, and assembling analytical data from field crews and labs; and
- Serving as a dedicated investigation team.

However, these resources would have needed to deploy to Alamosa with about one day notice, and worked all through the Easter weekend, potentially impacting religious observances, and for an indeterminate amount of time after that. Furthermore, effectively managing the additional resources would have required assistance and support from city personnel and close coordination and direction from the SDW program team. This simply may not be possible during an event of Alamosa's magnitude, even with more resources. In any similar event, the first priority must always be to protect public health, and help get the system back to normal. In a situation like the one in Alamosa, a complete, comprehensive and ideal investigation may not be feasible, and the investigation may be a secondary or tertiary priority.

Potential partners may have included the EPA, private engineering consultants or other program or department staff with a strong background in public water system design and operations. The SDW Program will be developing further strategies to enhance response capabilities including developing partnerships and emphasizing investigation aspects.

LESSONS FROM THINGS THAT WENT WELL

The Salmonella outbreak in Alamosa was identified very quickly

When the water system failed, the public health network of epidemiological surveillance picked up the outbreak quickly. The regional epidemiologist in Alamosa identified the outbreak and alerted the state within days of the first noted cases of *Salmonella*. Further, having both state public health professionals and the Safe Drinking Water program in the same department of state government facilitated quick communications once the outbreak was suspected. Figuring out the cause of a disease outbreak is like trying to solve a mystery, and often takes a long time. However, in this case, the outbreak was confirmed to be waterborne and associated with the city's drinking water supply within about one week of the first reported case. The emergency response to the outbreak in Alamosa was swift, comprehensive, and effective in large part because of the speed of identifying that the source of the outbreak was the city's drinking water.

A mutual aid network of water and wastewater utilities was critical to a fast, effective emergency response

Following the terrorist attacks of September 11, 2001, the SDW program became eligible for federal grant funds specifically to improve emergency response capacity for public water systems in Colorado. These funds were used to hire one person who facilitated the formation of an association of water and wastewater utilities, CoWARN, agreeing to offer mutual aid during emergencies.

Due to CoWARN involvement, Alamosa was able to respond more quickly to the *Salmonella* outbreak. Without CoWARN, the response time to completely disinfect and flush the city's water system would have taken substantially longer. The need for emergency resources was posted one afternoon and immediately CoWARN teams started to scramble across the Front Range. The next day, a team meeting was called in the CDPHE offices in Denver. The day after that, people and equipment were in the field with equipment and resources to disinfect and flush

the entire water system. The timeliness was outstanding, and it brought experienced talent to the response team, including distribution system and cross connection experts from larger systems. Most of the city or SDW program staff does not have the same kind of experience or training as many of the CoWARN responders to perform the kinds of emergency operations required during the outbreak.

Aspects of the National Incident Management System (NIMS) Incident Command System (ICS) were very helpful

The Incident Commend System was very effective in coordinating media communications, bulk water distribution, volunteer efforts, and communication with the public, including the CDPHE CoHelp line. The department's Emergency Preparedness and Response Division (EPRD) was instrumental in coordinating efforts from inside and outside the department. Internally, the Water Quality Control Division, Consumer Protection Division, Disease Control and Environmental Epidemiology, Laboratory Services Division and other divisions all worked closely with EPRD within the ICS. Specifically, the department's Emergency Operations Center (EOC) was instrumental in providing a centralized location for staff from the involved divisions to gather and hold telephone and video conference calls with multiple agencies.

Also, the local emergency response teams are not typically staffed with people who have expertise in water systems and their operation. It significantly enhanced the response efforts to have someone from the SDW program in the command center in Denver and would have been even more beneficial to have SDW Program staff present in the command center in Alamosa.

The local and state laboratories rapidly provided sample results

Most of the samples collected could not be analyzed in the field for the parameters of interest, so having the right laboratory facilities was very important to a successful response to the outbreak in Alamosa. Transportation was a complex logistical issue because of the travel time from Alamosa to the state lab in Denver, so some samples were tested locally while others required coordinated efforts for transportation to other laboratories. The labs were able to adapt their operations to meet the need for quick and accurate water quality sample results, which helped speed the response and recovery efforts. All the laboratories, including the federal CDC laboratories, worked extremely hard during the outbreak to quickly turnaround analytical results, including specialized analyses like *Salmonella* and DNA fingerprinting.

Highly qualified technical subject matter experts on the SDW program team were critical to a quick, effective state response to a problem with drinking water supply.

Public water system design and operations are specialties in the fields of public health and environmental science and engineering. Having highly qualified and experienced human resources on the CDPHE team proved critical to being able to quickly address the outbreak with an appropriate technical solution. Most members of the SDW program team who responded were licensed professional engineers and skilled environmental protection specialists with significant experience working with the physical, regulatory and human infrastructure of public

water systems, especially in acute situations. Without this quality of human resources on the SDW program team, the response would not have been as quick or effective.

The technical background and experience of the SDW program's acute team was particularly beneficial in developing and implementing the staged approach to implementing the bottled water order and boil water order and advising on the disinfection and flushing of Alamosa's water system.

MODIFICATIONS TO PROGRAM ACTIVITIES, PRIORITIZATION, AND STRATEGIES.

Since the outbreak in Alamosa in the spring of 2008, the Safe Drinking Water Program in Colorado has made modifications that reprioritize oversight of public drinking water systems in several ways so as to prevent a similar outbreak from occurring in the future. This change in strategies and practices is designed to improve the ability of the program to prevent waterborne disease outbreaks.

The SDW program has developed and is implementing several strategies to further reduce the likelihood of waterborne disease outbreaks in Colorado. These strategies include:

- Prioritize responses to deficiencies and violations for water systems that do not disinfect;
- Routinely review all disinfection waivers and withdraw waivers where appropriate to protect public health;
- Enhance oversight of total coliform sampling, water storage, and distribution systems during inspections, and collect inventory information on these facilities;
- Update and modify regulations related to disinfection waivers and groundwater disinfection in general;
- Ensure compliance with the requirement for water systems- to maintain residual chlorine levels in water distribution systems;
- Revise regulations associated with controlling hazardous cross connections at water systems;
- Ensure that deficiencies identified during inspections are corrected in a timely fashion;
- Launch training initiatives to help public drinking water systems optimize their water storage tank and distribution system operating and maintenance practices; and,
- Develop strategies to enhance response capabilities to drinking water emergencies.

CONCLUSION

Thanks to a system of epidemiological surveillance and robust networks of communication, the *Salmonella* outbreak in Alamosa was identified very quickly, within days of the first reported case. Ultimately, the outbreak results in 442 reported cases of illness, 122 of which were laboratory-confirmed, and one death. Epidemiological estimates suggest that up to 1,300 people may have been ill.

Once suspicion of an outbreak was reported to the Safe Drinking Water Program, the emergency response was swift, effective, and well-coordinated with many other agencies using the National Incident Management System (NIMS) and the Incident Command System (ICS). During the outbreak residents were advised to drink bottled water while the entire system was flushed and disinfected. Then, they were advised to boil their water until lab testing could confirm that the city's water was safe to drink again.

At the time of the outbreak in March 2008, the city of Alamosa was not disinfecting drinking water being provided to the public, so it was more susceptible to bacterial contamination than public water systems that chlorinate or provide other means of disinfection. Because of the quick operational response and the changes made to the physical infrastructure of the Alamosa public water system, the water in Alamosa has been safe to drink since April 2008. In October 2008, the city began operating a new water treatment plant with advanced treatment processes and continuous disinfection.

A comprehensive investigation into the cause of the outbreak has resulted in identification of the most likely cause: animal waste contaminating the city's ground-level water storage reservoir. The concrete structure of the reservoir was compromised at the time of the outbreak with cracks and holes. Records indicate that the reservoir had not been regularly maintained, and it is likely that the reservoir had been in poor condition for an extended period of time. Unchlorinated water in the tank was probably contaminated with animal waste that was carried into the reservoir by small animals entering the reservoir itself or through snowmelt. This investigation identified a number of missed opportunities to detect and address deficiencies that increased the risk of contamination in Alamosa's public water system. These include non-compliance with requirements to properly assess drinking water for total coliform bacteria and failure to prioritize the repair of the Weber Reservoir to preserve its integrity.

While *Salmonella* outbreaks associated with drinking water are rare, outbreaks with other pathogens associated with drinking water do occur nationally every year. From 1972 through 2006, the federal Centers for Disease Control and Prevention reported a total of 628 disease outbreaks at community and non-community public drinking water systems. In Colorado, however, disease outbreaks associated with drinking water do not happen every year, and they have become increasingly rare since the 1970s. From 1972 through 2008, Colorado documented 64 outbreaks and almost 12,000 reported cases of illness associated with drinking water. Based on the best available data, the number of drinking water outbreaks and illnesses by decade are summarized below:

- 1972 - 1979: 17 outbreaks associated with 6,370 cases
- 1980 - 1989: 41 outbreaks associated with 3,810 cases
- 1990 - 1999: 2 outbreaks associated with 132 cases
- 2000 - 2008: 4 outbreaks associated with 1,410 cases

The investigation into the Alamosa outbreak of 2008 confirmed that the physical, regulatory, and human infrastructure had all failed in some way to protect the public's safe drinking water supply. The Safe Drinking Water Program in Colorado has since made modifications that reprioritize oversight of water systems in several ways so as to improve public health protection and reduce the likelihood of a similar outbreak occurring in the future.

This report has provided a comprehensive documentation of the events in Alamosa associated with the disease outbreak including the response, cause, and lessons learned. It is hoped that an improved understanding of this event will help all those involved in the serious business of providing safe drinking water prevent future waterborne disease outbreaks.