Appendix G.
Guideline for Restoring Potable Water Service to Regional Infrastructure

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Guideline for Restoring Potable Water Service to Regional Infrastructure

In Event of Major Disaster and System Disruption

July 2018

WATER SUPPLY FORUM
Serving Snohomish, King & Pierce Counties
Resiliency Project

This Template for Restoring Potable Water Service (Template) may be added to a utility's existing emergency response toolbox for use during significant emergency and/or system disruption. This Template applies to large-diameter (approximately >48-inch) pipelines and reservoirs only.

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Purpose

This document outlines guidance for Water Supply Forum (WSF) members to follow in restoring potable water status in large-scale drinking water supply systems (upstream of retail service). Guidance includes high-level procedures for (1) restoring operations that support potable water status after a large-scale depressurization followed by issuance of an area-wide disinfect-water advisory[1], and (2) demonstrating how to regain potable water status. The focus of this document is microbial contamination. While some of the response activities may also be appropriate for responding to risks posed by chemical contamination, additional steps or precautions may be necessary for verifying that chemical contaminants have been addressed.

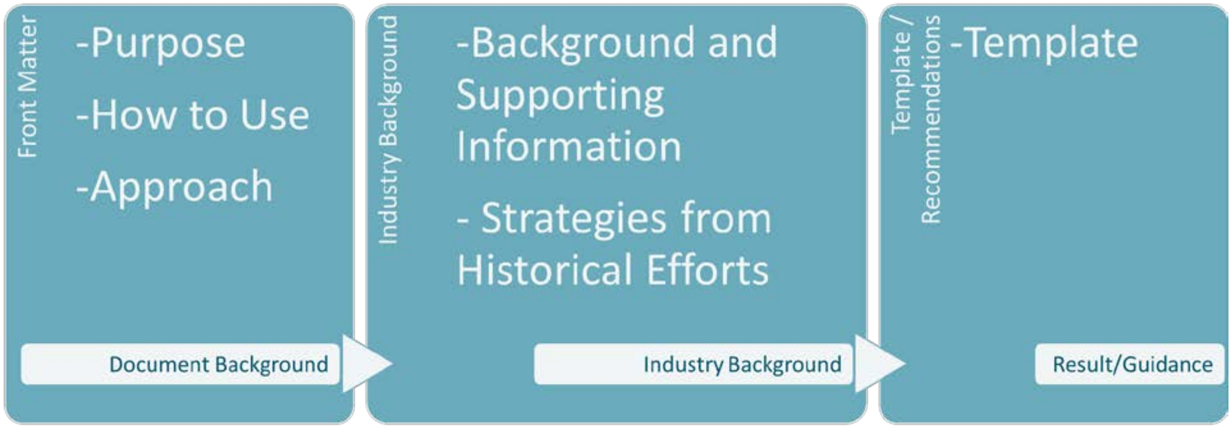
Assumptions

This guidance applies to large-diameter (approximately >48-inch) pipelines and reservoirs which have either experienced an event that has caused depressurization, infiltration from the environment, or conveyance of untreated or poorly treated water. Because of this event, a large-scale disinfect water advisory would be enacted after water supply (quantity and pressure) is adequately restored. These large pipeline sizes generally fall outside of industry standards which have been developed for disinfection of distribution mains (up to 16" in diameter) following construction or repairs (e.g., AWWA C651-14 and Water Research Foundation's report "*Effective Microbial Control Strategies for Main Breaks and Depressurization" that includes* "Good Practices for Preventing Microbial Contamination of Water Mains Field Pocket Guide" [Kirmeyer et al. 2014]). Because of the extent of the event and large size of this infrastructure, it is likely that standard procedures for flushing, super-chlorination, and drainage and cleaning may not be possible. This template was created as a guidance, not as the minimum standard or regulatory requirement.

How To Use this Document

This document is split into three primary areas of discussion as illustrated in the figure below. The front section of the document describes its purpose and how to use it. The middle section gives applicable industry background and historical references toward restoring potability after significant disasters. The final section of this report titled **"Template Procedures"** includes the summarized procedures that have been developed for use by the regional WSF members.

[1] This more general term is used instead of "boil water orders" to reflect that customers may not be able to use natural gas stoves to boil water during an emergency, either due to explosion hazards or interruption of the natural gas supply.



The above figure is a graphical summary of this document: The Template/Guidance is at the end (Page 15)

Document Storage

It is recommended that this Template be stored both electronically as well as in hard-copy format (e.g., 3-ring binder). The reason for dual storage is that, during a major disaster, electronic copies may not be easily accessible. It may even be prudent to store the most recently-updated Template in multiple hard-copy locations and/or on portable flash drives to be kept with key operations staff and management at all times.

Primary Electronic Storage Location:	
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Staff that have portable drives and/or hardcopies:

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Revising and Updating this Document

This plan is managed by the Custodian named above. After it is updated, the following should be done:

1. The date in the header block should be updated;
2. The revision block, below, should be completed by the person(s) performing the update; and,
3. The new version of this document should replace old versions (printed and electronic) on a fairly regular basis (after significant changes and/or every 6-8 months as routine changes are made).

Date	Revision Details	Name

Approach

This section outlines the base assumptions and approach to key issues that were considered when developing this Template.

Goals and Unknown Issues

This guidance is intended to support the direction of utility activities that will safely restore potable water service in large-diameter pipelines and reservoirs such that a disinfect-water advisory can subsequently be lifted.

Unknowns and potential WSF supporting information or discussion points that may significantly alter and/or improve upon this document include the following:

- Procedures developed for sanitary construction and commissioning of large-diameter pipelines.
- Approximate sizes (diameter and length) of regional pipelines.
- Approximate sizes (number and volume) of regional treated water reservoirs.
- Current emergency response procedures that have been shown effective.
- Timelines for recovery – have these been established?
- Typical and emergency flow conditions of the pipelines (typical pressure and flow, partially full or full flow, etc.)

Basis of Approach

The fundamental process for which all procedures will be developed in this guidance (and for which all utility-specific procedures may be developed in the future), should follow this high-level approach:

1. Conduct work in a manner that is as safe and hygienic as possible so as not to harm or cause injury to utility personnel or the public, damage infrastructure or the environment, or cause further/additional sanitary compromise of the water system.
2. Repair damaged or inoperable infrastructure so that it can be safely operated to its intended hydraulic capacity.
3. Establish (or maintain) water flow through water supply infrastructure in order to meet regional demand, regardless of the ability to meet potable water criteria.
4. Request any necessary operational or regulatory waivers that may be necessary to allow utility operations to return to pre-event status.
5. Restore potable water status as rapidly as possible without compromising the above items.
6. Notify stakeholders that potable water criteria are met.

Background and Supporting Information

This section summarizes information that supports the Template recommendations.

General Water Quality Risks

Conveying untreated or partially treated water will introduce pathogens and microbial nutrients to the distribution system. Earthquakes may change raw water quality due to landslides and ground shaking that add particles, organics, and turbidity, or due to mixing of reservoirs with release of anoxic water with elevated nutrients and metals. These changes can make water harder to treat even without any damage to a treatment plant. The chemical supply chain could also be disrupted so severely that the systems end up supplying under-treated water in lieu of no water at all.

Additional loading can come from infiltration of contaminated water, sewage, or chemicals through breaks or backflow/siphon in the distribution system. Pathogens are ubiquitous in the environment and often found in soil and water samples adjacent to the distribution system pipelines (AWWA 2017). Even if the mains stayed intact, the hydraulic surges, vibrations, and changing water quality, and reservoir mixing can release compounds that were previously trapped in the sediments and biofilm. These all present not only potential sources of pathogens, but also provide food, nutrients, and energy sources for microbial growth in the distribution system. Once the source has been mitigated, the risk of persisting or regrowth of pathogens could remain. Microorganisms can be easily removed by flushing as long as they remain in suspension. If they attach to particles, they can become more resistant to disinfectants and physical removal.

Inactivation of Pathogens

Pathogens that are introduced to transmission or distribution system pipe either need to be disinfected/inactivated or removed. This section discusses baseline industry information on the disinfection and/or removal of *Giardia*, bacteria, viruses, and *Cryptosporidium*. As discussed below, by increasing the chlorine level to near the maximum residual disinfectant level (MRDL) of 4 mg/L following an event, the disinfection barrier would be maximized throughout the distribution system. However, presence of chlorine does very little to inactivate *Cryptosporidium*.

Giardia

Giardia are protozoan parasites and very common in the environment. Their cyst-form can survive a few months in cold water and weeks in warmer waters (~20°C) (EPA 2000). The size of *Giardia* cysts are approximately 12 to 15 µm long and 6 to 8 µm wide. These cysts are highly infective but will not replicate/reproduce outside of a mammalian host / within the distribution system. Coagulation and filtration treatment train provides 2-log removal of *Giardia* leaving another 1-log inactivation to disinfection. SPU's Cedar River Plant achieves 4-log inactivation of *Giardia* through their multi-disinfectant process. If any of these processes were lost during the event or intrusion from the environment occurred, the transmission and distribution system should be considered as receiving water with potentially live/active *Giardia* and other potentially pathogenic protozoans.

To achieve inactivation credit, *Giardia* require greater exposure to chlorine than do viruses and bacteria, so they generally control disinfection requirements. For example, at a 2 mg/L residual of free chlorine and water quality conditions of 3^{o}C and pH 8, a 4-log inactivation credit for *Giardia* would require a CT of 384 mg/L•min (i.e., greater than three hours of time exposure to a residual of 2 mg/L, considering 100% baffling efficiency).

Viruses

Viruses are everywhere in the environment as well, but the ones that would infect humans or animals are not expected to proliferate in the distribution system. Viruses are generally sensitive to chlorine disinfection although can be very persistent if attached to larger particles or biofilm. The CT values for virus inactivation by free chlorine is lower than those for *Giardia*.

Virus inactivation requirements, represented by CT value, vary widely depending on disinfectant type and water quality. Based on conservative CT values for virus inactivation (Surface Water Treatment Rule, SWTR), and an approximate water quality condition (between 10 to 25°C, pH = 8), a free chlorine residual of 2.5 mg/L may achieve 2- and 3-log inactivation of virus following 2 and 3 minutes of contact time in a pipeline (plug-flow hydraulic performance of 100%), respectively. The same treatment effect could be achieved by ozone treatment at a residual of 0.25 mg/L for the same contact time, or 10-fold longer residual contact time by chlorine dioxide, or up to 1,000-fold greater contact time with chloramines. The most conservative values for virus inactivation found in the literature were approximately 4-fold greater than that reported in the SWTR. Thus, to combat any suspected viral contamination event in a regional water system, maintaining a free chlorine residual is expected to be the most efficient response.

Bacteria

Bacteria can and will proliferate in the distribution system when conditions are favorable and there is a source of energy and nutrients. Biofilm exist in every main and can harbor pathogenic organisms. Untreated or poorly treated water, infiltration from environment, and dislodged pipeline or reservoir deposits may load the system with live bacteria, organic carbon, metals, nitrogen, phosphorus, and sulfur, and consequently, increase the risk of regrowth. Single bacterial cells suspended in treated drinking water are readily inactivated by residual disinfectants, but when the cells are attached to particles, they become more resistant (e.g. EPA 2010, Friedman et al. 2009).

Bulk water turnover would likely remove the loose, suspended particles released to the water. Flushing velocities would need to be much higher than recommended in the industry standards to actually scour and clean the pipes. If microbial regrowth remains problematic in a certain area, the systems may need to implement more frequent or comprehensive distribution cleaning approach. Very few positive total coliform samples were observed after recovery from the hurricane Katrina (Blair et al. 2006) indicating that flushing to turn over water and strong chlorine residual adequately addressed the bacterial loading.

Cryptosporidium

Cryptosporidium is a protozoan parasite that can be shed in the feces of wild and domestic animals. It is similar to *Giardia* and does not grow or multiply in the water system, requiring a host to multiply. However, due to its ability to form oocysts, it can be persistent and survive months in soil or water (EPA 2001). Oocysts of *Cryptosporidium* are highly infective, somewhat circular in shape, and smaller than *Giardia* with a diameter of between 4 to 6 µm.

Unlike *Giardia*, *Cryptosporidium* is resistant to chlorine disinfection. The systems using surface water sources must have another barrier in place that achieves 2 to 4 log inactivation or removal of *Cryptosporidium*. The filtration treatment plants in the region typically achieve 2 log removals through coagulation and filtration processes. The unfiltered surface water supplies achieve 2 log inactivation using UV treatment. The SPU's Cedar plant, uses both UV and ozone to achieve >3 log inactivation of *Cryptosporidium*. If these processes are not working well or become ineffective due to increasing turbidity or particles in the water, the *Cryptosporidium* barrier would be compromised.

Controlling watershed activities and land use are ways to limit the occurrence of *Cryptosporidium* in the source. Washington State Department of Health (WSDOH) has rated watersheds for microbial contamination based on degree of watershed control, type of development and land use, known sources of contamination, historical coliform levels, and the type of intakes (ODW 2008). The utilities could use these risk rating to assess their sources condition and risk. An earthquake could increase

Cryptosporidium loading at an intake if the earthquake also caused significant flooding, runoff, or animal migration to the areas close to the intakes. It is not likely to add new sources of *Cryptosporidium* into the watershed but could redistribute existing sources. To minimize additional loading, utilities could try to survey and clean the watershed especially around the intakes that may not provide good dilution of runoff water. Millions of *Cryptosporidium* oocysts can be released by one infected animal.

A cryptosporidiosis outbreak in Baker City, OR (2013), was attributed to cattle feces in the watershed which were washed to the water source during a storm event that occurred two weeks prior to the outbreak. Baker City was not treating to remove or inactivate *Cryptosporidium* at the time. Oregon Health Authority (OHA) estimates that approximately 28% (2,780 people) of the Baker City residents were sickened from this outbreak (DeSilva et al 2015, OHA 2014). During the outbreak, raw water turbidity and *E. coli* counts remained typical and well below the regulatory limits giving no indication of source contamination. The city issued a disinfect water advisory and started monitoring for *Cryptosporidium* at the source and in the distribution system. The disinfect water advisory was lifted before the treatment barrier was in place under the following conditions (DeSilva et al 2015, OHA 2014):

- A surface water diversion with the highest oocyst count remained offline until UV treatment was in place, and
- Two consecutive weekly tests from each active intake were negative for *Cryptosporidium*.

The City had to continue testing the presence of *Cryptosporidium* at the active inlets. The advisory would have been reinstated if any two consecutive samples were positive. Although reference publications do not mention if disinfection or flushing were completed after this *Cryptosporidium* event, it is likely that some level of flushing or system turnover was achieved once source samples were negative. Regardless, it does not appear that this higher-than-typical pathogen loading at the source caused a long term, lingering, impact to the distribution system.

Responding to Chemical Risks

Upon contamination due to a chemical source, a Do-Not-Use advisory would likely be issued until a health impact assessment can be completed for the chemical found. Different types of chemicals would require specific responses and cleanup efforts. Protocols described below are only for mitigating microbial risks. It is beneficial for utilities to consider the potential and likely chemical risks to their system and develop mitigation plans prior to a contamination event. The EPA's Water Contaminant Information Tool (WCIT) is free for public water systems and includes chemical and biological hazards and possible mitigation options. It is available online at https://www.epa.gov/waterdata/water-contaminant-information-tool-wcit.

Other valuable chemical-response recommendations for water supply forum members are as follows:

- Establish baseline water quality data that will help to:
    - Understand when the system has returned to normal,
    - Identify that a chemical contamination may have happened, and
    - Identify or narrow down the list of potential contaminants.
- Know potential hazards near sources and along the transmission mains. Consider what could happen, event likelihood, and how to respond. Consider potential spills of gasoline, diesel, oil, jet fuel, and other chemicals stored, conveyed, or transported in the area .
- Develop a risk assessment matrix to prioritize and help identify the most significant hazards.

- Understand ways to treat/remove the chemicals that pose the greatest risk.

Recovery Strategies for Distribution Mains

This Template is based on protocols developed and published in Water Research Foundation (WaterRF) project #4307 (Kirmeyer et al, 2014) and AWWA Standard C651-14 for main disinfection after repair or replacement. Two key differences between these published documents and this Template are that (1) the published procedures have been developed on the assumption of a localized break, which may not adequately represent the risk of a system-wide contamination; and (2) published procedures were developed for distribution system pipes, not large transmission mains. Nonetheless, some key concepts and principles may still be effective. The key steps of flushing, disinfection, and water quality testing protocols from these and other sources are summarized and discussed below.

Flushing

According to AWWA C651-14, the purpose of flushing following main installation or repair is to remove any particulates from the main. Particulates may shield pathogens from disinfectant and allow them to remain undetected during follow-up testing. If deposits of particulates are later disturbed, they may contaminate the water. The flushing recommended in AWWA C651-14 and other industry guidance for distribution system decontamination is conventional flushing (AWWA 2017; Kirmeyer et al. 2014). Conventional flushing is a low velocity flush accomplished by opening hydrants without closing valves that would direct the flow. The goal is to turn over the bulk water. If the purpose of flushing was to clean the pipe surfaces, higher scouring velocity (e.g., 8 feet per second [FPS] for non-scale forming pipe) or other main cleaning techniques (foam swabbing, pigging) would be specified and should be used. See AWWA 2017 for additional discussion of main cleaning practices and applicability.

The main break response protocol (AWWA 2014 and Kirmeyer et al. 2014) specify flushing velocity of 3 FPS which removed close to all 2-4 mm sand particles from 4-inch PVC main. When the PVC mains were artificially tuberculated, the flushing efficiency dropped to 2-log removal of the same sized sand particles. Heavier particles would not be flushed out at this velocity. The smaller sand particles (0.25-0.5 mm) started moving at around 2 FPS velocity. Other studies have referenced flushing velocity of 2 FPS as adequate for removing particles smaller than 0.2mm or 0.15mm (WHO 2004 and Friedman et al. 2003). The lighter peat, silt, and clay particles might be removed at much lower flow velocities.

In an earthquake, the likely response needed is to remove loose solids and particulates from the mains in which case the bulk water turnover is adequate. Increased flow velocity is needed (if possible, achieving 3 FPS) to remove particles as heavy as sand. Main cleaning tools might be useful if contamination or instability of scales persists in certain areas.

The non-scale forming pipes (cement-lined pipes, DI, asbestos cement, steel) tend to form thin layers of deposits that are often enriched with ferric and manganic precipitates (Friedman et al. 2016). Flushing a line at a rate between 2.5 to 3 FPS is not likely to have any significant impact on these long-term deposits unless they were shaken loose during the emergency. Cleaning these pipes would likely require foam swabbing or ice pigging. These two methods removed roughly ten times more solids from an 8" cement-mortar lined iron pipe than unidirectional flushing (UDF) at 6 FPS (Friedman et al. 2016). Pockets of sludge remained in the pipes after the 6 FPS-UDF.

All of these cleaning methods represent challenges for large mains. For instance, the mains would need to have launching and retrieving stations for foam swabs, the ice pigging is often completed by a vendor that may not be available for emergency response or have high enough capacity "ice maker", and there may not be enough water or disposal capacity for UDF at >6 FPS. The utilities should evaluate their transmission mains and how they could possibly clean them if needed to.

Flushing considerations:

- Flushing at 3 FPS is adequate to remove loose deposits and sand particles from non-scale forming pipes. This velocity is not adequate for cleaning biofilm and other cohesive or adhered deposits from the pipe walls. Removal of these deposits or heavier sediments would require higher velocities or other methods.
- The likely response needed is to remove loose deposits and achieve bulk water turn-over.
- Since deposits protect the pathogens from disinfectant, proper physical cleaning of all surface would be recommended if water quality results indicate persisting or reoccurring contamination. This should be in the form of high velocity UDF (8 FPS), foam swabbing, or pigging (although this may not be achievable in >24-inch pipe). Care should be taken and use of aggressive techniques should be avoided on scale-forming pipe such as unlined cast iron.
- Ice pigging and foam swabbing use less water and remove more contaminants but may cause issues with discharge due to more concentrated discharge stream. Ice pigging typically would not be effective for emergency cleaning of large diameter mains (>18-24-inch) since ice production rates are slow, and it would take many days to create enough ice to clean miles of large diameter pipe.
- None of the cleaning techniques is 100% effective for physical cleaning. It is more effective to have a preventative main cleaning program that routinely removes accumulated deposits and prevents on-going accumulation.

Disinfection

AWWA Standard C651-14 details several methods for disinfection that include high chlorine concentration and contact time. None of these methods could be readily applied for a main that would remain in service, and they all involve dangerous levels of chlorine if accidentally served to the public. According to the C651-14 if main is flooded during construction (similar situation to having the main filled with untreated water), it must be cleared of floodwater by draining and flushing with potable water until the main is clean. Then the section is filled with chlorinated potable water, held for 24 hours with a minimum chlorine residual of 25 mg/L. This method would require significant volume for flushing and out of service time for disinfection.

WRF #4307 (Kirmeyer et al 2014) recommends a minimum CT of 100 mg/L•min (with free chlorine) that was shown to provide 4- to 5-log reduction of particle-associated viruses. The results of the risk evaluation suggested that the viruses present the highest infection risk during infiltration of sewage into a broken main. Unfortunately, this level of disinfection was not tested in the field trials and also would not be adequate health protection if *Cryptosporidium or Giardia* were the controlling risk. Achieving more than a 1-log inactivation of *Giardia* would require a higher CT (CT is 85 mg/L•min at 3 °C and pH 8 for 1-log *Giardia* inactivation with free chlorine).

For the transmission mains, CT 100 mg/L•min could be achieved by maintaining 4 mg/L of free chlorine residual in the flowing water for more than 25 minutes (this assumes a 100% hydraulic efficiency of the pipeline). Chloramines are not as effective a disinfectant as free chlorine and the recommendation would be to switch to free chlorine during the emergency.

Disinfection guidance also discusses maintaining clean working practices during repair or replacement. The C651-14 instructs to clean and use 1% chlorine to disinfect all exposed portions of the existing pipe, pipe materials used for repair, handheld materials and tools used to make the repair. Furthermore, the repair site needs to be kept clean, dewatered, and disinfected. These are all practices that should be part of the emergency repair procedures as well.

Disinfection Considerations:

- CT 100 mg/L•min with free chlorine could be achievable in the regional infrastructure under flowing conditions (e.g., 4 mg/L for 25 minutes). It would be adequate for 4 to 5-log inactivation of particle-associated viruses.
- If the main cannot be taken out of service, none of the methods for new or depressurized mains in the C651-14 could be applied.
- Sanitary repair practices as described in the C651-14 should be applied in an emergency situation as well.

Testing

WRF #4307 guidance (Kirmeyer et al. 2014) recommends following the AWWA Standard C651-14 for new mains with regard to sampling after a Type 3 or 4 break (i.e., uncontrolled shut-down or catastrophic breaks that led to loss of pressure at break site or elsewhere in the system). This calls for two sets of samples at the beginning and end of the impacted area, every 1,200 ft of the line and each branch. If trench water or excessive quantities of dirt or debris entered the mains, the standard recommends sampling at every 200 ft. The samples should be taken at least 16 hrs apart or two sets collected 15 min apart after at least 16 hr rest period. The latter would not likely be an option for the transmission main unless it can be taken out of service.

Standard C651-14 does not require any samples for repaired mains that remained under pressure and suggests that one set of samples may be required depending on the sanitary conditions if the main was depressurized or partially dewatered. Standard C651-14 also includes a recommendation to test aesthetic water quality parameters such as chlorine residual, pH, alkalinity, specific conductance, and turbidity before returning the main to service. An HPC limit of 500 CFU/mL is another suggested measure. Based on the WRF members' experience, HPC of 500 CFU/mL is extraordinarily high result and rather than using that as the acceptable limit, the utilities should reference their historical baseline monitoring results. Access to laboratories may also limit the use of the HPC-monitoring in a large-scale emergency.

The testing included in the proposed approach includes:

- Chlorine residual to ensure strong residual,
- Assessment of chlorine demand,
- Identification of areas that may need further cleaning, and

- Coliform and HPC sampling to confirm microbial water quality.

Recommended additional testing that would help ensure adequate turnover has taken place and water quality matches the produced water quality and typical conditions for the system includes:

- Sampling for water quality parameters such as pH, alkalinity, and conductivity (to determine if the conveyed water is close to normal operating conditions or current treated water conditions and possibly help identify localized contamination), and
- Perform tracer-type confirmation of water turnover (e.g., monitoring pH or fluoride changes).

Each utility should test practical water quality parameters that will help them achieve goals and give meaningful results. In addition, the use of field kits to perform this work – although maybe not be the most accurate – might be easily available and provide the best ability to meet goals. Existing on-line instrument monitoring could also be included in the monitoring and tracking but should not be the only method (these may fail in an emergency situation). Furthermore, in future-planning, it is important to consider tracking these parameters under normal operating conditions to build a baseline. It is also important to provide adequate training for staff in how to use test kits and collect representable samples so that personnel are prepared for the recovery process.

Testing Considerations:

- Utilities should build baseline water quality knowledge under normal operating conditions and develop a monitoring plan for the recovery process,
- The industry standard for rescinding an advisory is coliform while other secondary parameters can provide more information on determining potability and confirming recovery, and
- Parameters to be monitored may be system specific due to the unique water quality characteristics and analytical capacity available during a recovery process.

Reservoir Recovery Strategies

Reservoir recovery guidance in this Template is based upon information documented in AWWA Standard C652-11 (AWWA 2011). The AWWA C652-11 addresses quantity of water, conditions of water supplied to tanks, and ability toward collecting representative test samples to document tank hygiene. Every tank or reservoir is different and may have different flow patterns and turnover abilities making it challenging to develop one procedure that would work for all. When tanks or reservoirs receive untreated water, it is critical to ensure that all contaminated water is somehow removed. Each utility should improve upon processes developed in this Template and develop individual procedures to ensure turnover or decide if reservoirs could be taken off service until disinfection and testing have been completed. Issues presented in this Standard are discussed below.

Disinfection

The industry standard, AWWA C652-11, lists three disinfection methods that each use high chlorine concentration and contact time to disinfect the tank. According to the foreword to the AWWA C652-11, high chlorine concentration is needed to provide effective disinfection under varying conditions of pH, temperature, and other factors. The retention time depends on the application method – varying from 30 minutes to 30 hours. The surface application method is the fastest but would require the reservoir to be completely drained before application. AWWA C652-11 mentions pumping the water to the distribution system after the disinfection retention time (and testing) as long as the maximum residual levels are not exceeded (water can be drained or diluted enough to meet the limit). However, the Ten States Standards (2012) recommend wasting the highly chlorinated water from the tank cleaning due to concerns over forming high levels of DBPs (however, it should be noted that DBPs are a secondary concern in an emergency recovery).

AWWA C652-11 also includes underwater inspection and cleaning. This would not be the same as reservoir disinfection although could be useful for removing sediments that may accumulate at the bottom of a tank and prevent thorough disinfection.

All disinfection methods would be options for disinfection and cleaning as long as the reservoir can be taken offline. The significant amounts of sediments that may be present in the reservoir can make the disinfection process inefficient. The sediments should be removed first.

Testing

It can be difficult to obtain representative samples from a large reservoir. The AWWA C652-11 suggests at least one sample per 10 MG of storage volume. Only if results are unsatisfactory would two sets of samples be needed. The Ten States Standards recommend two or more successive sets of samples 24 hours apart before the facility is placed in service. In general, more frequent, depth- or volume-specific sampling should be completed in case of stratification or possibility of short-circuiting.

In addition to chlorine residual and coliform samples, utilities are urged to test for general water quality characteristics similar to the main break response protocol. AWWA C652-11 lists pH, alkalinity, turbidity, color, and specific conductance. Utilities should select the parameters that best work with their water quality and analytical capacity. Field kits are readily available for the listed physical parameters.

Conclusions from Reservoir Recovery

Because of the potential effect of sediment providing shielding from disinfectants, sediments should be removed from reservoirs prior to disinfection. Further data or studies are needed to evaluate if the reservoirs could be adequately cleaned and disinfected while in service after an incident covered by this document. Testing should follow AWWA C652 and include coliform, HPC, and system specific water quality parameters. ATP measurements can provide supplemental information when trying to understand the microbial water quality.

Strategies from Select Historical Recovery Efforts

Earthquakes, hurricanes, flood events, and other catastrophes have had varying impacts on the water systems around the world. Requirements for lifting health advisories are not prescribed and, in most cases, utilities rely upon decisions of local health authorities to determine when water has met potable criteria. Each situation is unique, but commonly accepted guidance on the minimum criteria and expectations for lifting the advisory would allow both utilities and health departments be better prepared for making those decisions.

Typically, causes for disinfect water advisories need to be corrected before an advisory is lifted. WSDOH listed the following generic criteria for rescinding a health advisory: i) meeting public health standards for water quality and treatment, ii) addressing the cause of contamination, and iii) taking steps to prevent future contamination (ODW 2008).

Table 1, below, summarizes criteria or conditions that are or were being used for rescinding disinfect water advisories elsewhere. Documentation was found on three natural disasters that caused wide-spread impacts on the water systems. The commonalities include maintaining pressure and chlorine residual followed by testing for presence of coliform. Clean coliform samples appear as the benchmark for adequate water quality. None of these criteria specified conditions for reservoir cleaning or disinfection.

EPA evaluated Hurricane Katrina response (Blair et al. 2006) and found protocols for rescinding advisories satisfactory. The epidemiological testing concluded no drinking water related illnesses. An inspection report analyzing response in four water systems indicated a disinfect water advisory continued until Louisiana Department of Health was informed systems had power and pressure, were flushed to remove potentially unsafe water, had disinfected the source water supply, and had passed bacteriological sampling generally following modified TCR requirements. For 610 coliform samples collected in four systems, only 0.8% came back positive for total coliform.

Table 1 References for Criteria Used in Lifting Large-Scale Disinfect-Water Advisories

Issue	Louisiana (Hurricane Katrina and Flooding)	California (Northridge Earthquake)	Florida (Hurricane Andrew)	California (SFPUC Recovery Plan)	Texas (Rescinding Disinfect Water Advisories)	New Jersey (State Water Advisory Guidance)
Description of incident or guidance	No written guidance, but the protocol below applied in a flood response and was used during recovery from Hurricane Katrina	6.8-R earthquake, entire city on BWA, extensive infrastructure damage, below criteria for rescinding the advisory	Recovery after category 5 hurricane destroyed communi-ties, caused wide-spread power outages and depressurization	Emergency Disinfection and Recovery Plan after delive-ring partially treated water	General guidelines for rescinding disinfect water advisory	Guidance for issuing and rescinding a disinfect water advisory
Pressure	≥15PSI (if <15 PSI during the incident, the system will be on an advisory until tests show system is free of coliform)	Distribution pressurized and having normal level of leaks	Service restored	n/a	>20 PSI maintained	
Flushing	Required if any coliform sample is positive.			Potable water flushing until event specific targets met (pH and fluoride used as tracers)	Yes, until chlorine 0.2mg/L free/0.5mg/L total residual present and maintained at each reservoir	Sufficient water displacement to eliminate possibly contaminated water
Turbidity					<1.0 NTU if surface water or GWI source	Satisfactory turbidity if applicable
Coliform sampling	At least 50% of the number of regular monthly samples	Two consecutive coliform tests in an area, intensive sampling for several days in a row	Satisfactory coliform results for two consecutive days throughout the system.	Two sets 24hr apart once water quality targets met (second set may be taken sooner)	Representative sites with satisfactory results	Number of samples depends on population served, no less than 3.
Chlorine residual	Minimum 0.5mg/L residual; chloraminated systems recommended to switch to free chlorine; if coliform presence, recommend 4.0mg/L residual with system-wide flushing.	Chlorine residual of 2mg/L (chlorine residual was boosted to 3mg/L at the plant following the earthquake)		Maintain free chlorine residual, target 1mg/L at a specific location in the system		A minimum 0.2mg/L residual throughout the system
Other	Sanitary survey must be completed prior to lifting BWA after a significant event.		Advisory remained in effect long after service restored, problems with communication, close proximity of different systems, and stressed infrastructure.		Must be operating in compliance	Implement corrective action as required
Reference	Blair et al, 2006 and communication with John Williams, Louisiana Health Department, January 2018.	McReynolds and Simmons 1995	Murphy 1994	SFPUC 2013	TCEQ 2017	New Jersey DEP Bureau of Safe Drinking Water, 1999

Additional Recommendations for Improving Recovery

Minimizing impacts of system contamination during disasters will lead to an easier and faster recovery process. Furthermore, increased community infrastructure resiliency will lead to increased water utility resiliency. Therefore, integrated planning approaches that cover many aspects of the community would benefit all utilities and optimize improvements from the efficient use of limited resources. Some ideas for improving resiliency of regional infrastructure include the following:

- Develop an integrated planning approach between agencies and utilities with a goal to minimize risk (impact and likelihood of contamination or physical damage) and help with recovery and functionality during the emergency. Some examples include:
    - Adding back-up power to sewer lift stations,
    - Locating hazardous chemical storage facilities away from critical water infrastructure, and
    - Supporting seismically-sound bridges and road improvements.
- Have images and GPS coordinates of infrastructure. Images taken before and during the emergency might help locate infrastructure and identify trouble spots (e.g., news helicopter footage; Khan 2014).
- Identify areas of the infrastructure that are in high risk or vulnerable areas and considering preemptive ways to address risk and develop a response plan. For instance, infrastructure in areas susceptible to liquefaction or landslides or close to chemical storage or wastewater plants.
- Maintain an active cross connection control program.
- Design new infrastructure to current seismic standards and with ability to flush, disinfect, and sample.
- Preventatively clean transmission mains and regional reservoirs to minimize deposits.
- Implement general water quality monitoring to define normal operating conditions using the methods and parameters you are planning to use during the emergency response.
- Practice and test protocols outlined in this document. This will help to understand level of effort needed during a response.
- Provide training for staff on all aspects of the plan.
- Develop plans to restore system integrity; define items that may be needed and how the utility can obtain these items during emergencies.
- Conduct hydraulic modeling of transmission and distribution systems to understand feasible alternate supply points, key flushing areas, etc.
- Perform proactive inspections and retrofit below-grade, air-vacuum valve vaults that are susceptible to contamination during a pressure loss event.
- Develop proactive UDF and/or conventional flushing plans (supported by hydraulic modeling) that can be rapidly implemented.

Template Procedures

This section summarizes specific procedures that are recommended to be completed so that regional water supply infrastructure can be considered providing potable water.

Lessons Learned from Past Emergencies

When an entire system or a regional, large-diameter main and reservoir system is compromised, it may be impractical to complete system flushing or disinfection responses per industry guidance. Typical industry guidance relies upon tools like unidirectional flushing, pigging, or swabbing and over-night soaking with chlorine. In addition, it is accepted that no main cleaning tools are 100% effective and no distribution systems are free of deposits or risk (Friedman et al. 2016). Based on these issues, several recent emergency response procedures have been documented during major disasters such as Hurricane Katrina and the Northridge earthquake. Importantly, epidemiological evaluation following the Hurricane Katrina recovery concluded that there had been no illnesses attributed to contaminated drinking water (Blair et al 2006). These procedures identify the following four key steps, all of which are needed in order to rescind a disinfect water advisory:

1. **Re-Establish Hydraulic Capacity**: Restore and maintain adequate pressure.
2. **Remove Contaminants**: Achieve water turnover and sediment removal through flushing the system.
3. **Disinfect**: Increase chlorine feed and maintain residual throughout the recovered system.
4. **Validate**: Sample to confirm absence of coliform.

Prior to rescinding a disinfect water notice, the utility should share results of these four steps with WSDOH and obtain confirmation that water meets potable standard and the disinfect water notice can be lifted.

Industry Guidance

In general, industry guidance strongly supports activities that include cleaning, disinfection, flushing or swabbing (when possible), and testing for distribution mains and reservoirs before the water is considered potable and can be served to the customers following repair or replacement (WHO 2004, Water UK 2017, AWWA 2011 and 2014). An important factor to ensure water quality is the use of hygienic working practices during repairs and/or installation (AWWA 2014) because pipe or reservoir deposits can shield microbes from disinfectants and lead to subsequent releases or bacteriological regrowth. As Ainsworth and Holt advise (WHO 2004):

> *"Chemical disinfection, even in relatively high doses, should never be considered a catch-all stage for ensuring hygienic conditions in a new or repaired distribution system; physical removal of all introduced deposits is a critical control stage."*

Four-Step Response Guidance

Based on the above, this Template recommends a four-step response (described in detail below) that includes: Re-Establishment of Hydraulic Capacity (achieve adequate pressure and flow), Remove Contaminants (flushing or hydraulic turnover), Maintain Disinfectant Residual, and Validate (sampling/testing). It should be noted that completing this entire procedure may take many days, depending on the severity of the emergency. A disinfect water notice should remain in place until all steps are completed and WSDOH has confirmed results.

1. Re-Establish Hydraulic Capacity

It is assumed this 'starting point' has already been achieved but is included for completeness. Regional water system infrastructure (including source conveyance, treatment, large-diameter pipelines, large reservoirs) need to operate under acceptable hydraulic conditions. This is to support first response activities and reduce contamination entering the supply system. This step includes the following:

1. Assess watershed and remove obvious sources of contamination such as carrion or debris.
2. Confirm system failure point(s) and respond in a safe manner.
3. Restore integrity and maintain pressure (close to normal/regular operating pressure assumed).
4. Follow hygienic and sanitary working practices during repair or replacement.
5. Restore treatment to the minimum regulatory standards.
6. Ensure disinfect water notice remains in effect.

2. Remove Contaminants

The system should be operated in a manner that supports removal of foreign material. This should be preceded by utilities completing system modeling and/or reconnaissance (prior to an emergency) to understand system capabilities. Adding chlorine can be included (see step 3), but contaminant removal should be completed even if chlorination is not available. This step includes the following:

1. If chlorine is added, ensure that any discharged water is sufficiently dechlorinated.
2. If possible, increase flow for sediment removal in pipelines by achieving 3 FPS velocity. At this rate, pipelines may behave in a self-cleaning manner where loose material and sand is moved downstream. Care should then be taken in areas where sediment may be trapped, such as reservoirs or dead-end pipelines. This work should be done as follows:
   a. Sustain increased flow/velocity operations as long as possible (turnover system at least 3x);
   b. Continually monitor for turbidity to be sure it returns to acceptable levels; and,
   c. Clean known deposits (utilize blow-offs or clean locations with sediment traps).
3. Drain and clean reservoirs or perform reservoir dives (if possible) to remove sediment.

3. Conduct Disinfection

After completing the contaminant removal step, perform chlorination of all wetted areas of the regional transmission system that have been compromised. This step includes completing the following:

1. Add chlorine to achieve at least 2 mg/L residual at all points of the compromised system (e.g., all finished water reservoirs and large-diameter transmission mains), as follows:
   a. Start at the most upstream section of the system to achieve the following conditions;
   b. Add chlorine until well-mixed, steady-state feed conditions are achieved; and
   c. Confirm at least 2 mg/L residual (and less than 4 mg/L) at "exit" of section disinfected.
2. If possible, maintain this condition up to 48 hours in duration with a goal of achieving 4-log *Giardia* inactivation credit in the sections that are disinfected.

4. Perform Validation

After completing disinfection, validate potability with water quality sampling that includes the following:

1. Consider keeping chlorination at an elevated level for a longer duration.
2. Confirm that water entering the system meets acceptable water quality conditions.
3. Achieve at least one complete volume of water turnover through the system being tested
4. Collect samples at the downstream-end of infrastructure being validated at time 'zero' and 16 hours later as follows:
    a. One set for finished water at the treatment plant.
    b. One set at each reservoir outlet.
    c. One set at the end of each large-diameter pipe length and before subsequent reservoirs.
    d. Each set of samples includes
        i. 1 sample measured for chlorine residual (as mg/L),
        ii. At least 3 samples measured for total coliform bacteria (as present or absent).
5. Validation that the part of the system that was sampled can be returned to normal service (e.g., potable water conditions have been achieved) is indicted by the following results:
    a. Chlorine residual is greater than 1 mg/L,
    b. All total coliform bacteria sample results[2] showing "absent", and
    c. Achieving general water quality conditions typical under normal operation (note that these parameters are system specific).
6. Consult with WSDOH and downstream wholesale/retail agencies to confirm the process that must be conducted to restore downstream systems and subsequently lift a disinfect water advisory.

Note that none of the above procedures address how to return distribution system and/or retail/consumer water systems back to service.

The specific general water quality parameters to ensure typical water quality conditions and water turnover could include pH, alkalinity, conductivity, turbidity, and fluoride (fluoride could be used as a tracer for freshly treated water during the distribution recovery). Field kits are available for these parameters. Additionally, the systems could do HPCs as an additional microbial parameter if a lab is available and historical data exists.

[2] Utilities may consider pre-purchasing portable coliform testing kits such as those available from HACH (https://www.hach.com/mel-potable-water-laboratory/product?id=17661156001&callback=pf) in case laboratory services are not available during emergencies.

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