Comprehensive Waterworks Evaluation and Cost Estimate

City of Richmond, VA

Virginia Department of Health, Office of Drinking Water

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For clarity, the following table of abbreviations is presented. This may not encompass the entirety of all abbreviations used throughout this report.

Table 1: Abbreviations and Description

Abbreviation	Description
CAO	Chief Administrative Officer
CIMS	Crisis Information Management System
CIP	Capital Improvements Plan
COR	City of Richmond
DCAO	Deputy Chief Administrative Officer
DECPR	Richmond Department of Emergency Communications, Preparedness and Response
DEQ	Department of Environmental Quality
DHRM	Department of Human Resource Management
DPU	Department of Public Utilities
EL	Elevation
EOM	Emergency Operations Manual
ERP	Emergency Response Plan
GPM	Gallons Per Minute
IC	Incident Commander
IMT	Incident Management Team
kV	Kilovolts
MGD	Million Gallons Per Day
MVA	Megavolt-amperes
NOAV	Notice of Alleged Violation
ODW	Office of Drinking Water
PLC	Programmable Logic Controllers
PS	Pump Station
PWSID	Public Water System ID
RRA	Risk and Resiliency Analysis
SCADA	Supervisory Control and Data Acquisition
SEH	Short Elliott and Hendrickson, Inc.
UPS	Uninterruptible Power Supply
VAC	Virginia Administrative Code
VDACS	Virginia Department of Agriculture and Consumer Services
VDEM	Virginia Department of Emergency Management
VDH	Virginia Department of Health
VFD	Variable Frequency Drive
VGS	Virginia Department of General Services
VRLA	Valve Regulated Lead Acid
WEBEOC	Web Emergency Operations Center
WTP	Water Treatment Plant

Executive Summary

At approximately 5:45 a.m. January 6, 2025, the City of Richmond (COR) Water Treatment Plant (WTP) experienced a power outage resulting from a winter weather event with snow and ice formation. The automatic power transfer switch, called a “bus tie,” intended to connect power from a backup feeder failed, leaving the facility without power for approximately 1 hour and 20 minutes. During the power outage, water flow continued in the WTP by gravity through the filtration system, into the subsurface clearwell and quickly flooded the underground equipment rooms. Backup systems intended to close water process valves and protect the underground equipment rooms during outages were not functional. The power outage and subsequent water inundation in equipment rooms caused an extended disruption in water production. Water storage volumes and system pressure throughout the COR water distribution system dropped below safe levels for consumption. A Boil Water Advisory was issued by the COR at approximately 4:30 p.m. on January 6, 2025. By January 8, 2025, production was partially restored, and normal production was restored on January 9, 2025. On January 11, 2025, after adequate pressure was restored to flush lines, disinfect, and test distribution sites to confirm that water was safe for human consumption the COR lifted the boil order.

This event, collectively known as the COR’s water crisis, prompted the Office of Drinking Water (ODW), Virginia Department of Health, at the direction of Governor Glenn Youngkin, to promptly investigate. Through an emergency contract process, ODW engaged Short Elliott Henderson, Inc. (SEH) to perform an independent, third-party, root cause evaluation to accurately describe what happened, what did not, effectiveness and timeliness of communication, and other analysis to be described in a report of findings, observations, and recommendations.

To accomplish these tasks, SEH mobilized a team of 10 licensed professional engineers and 10 additional engineering support staff delivering almost 1,500 hours of work in 60 days. The team consisted of senior level experts in the fields of water process engineering, electrical engineering, instrumentation and controls, hydraulic engineering, and water treatment plant design.

Working closely with the ODW and with the cooperation of the COR, SEH conducted a deep dive into the existing COR WTP design drawings, maintenance records, consultant reports, capital improvement program documents, COR Department of Public Utilities (DPU) communications, DPU organizational charts, notes from interviews with DPU staff, ODW and Environmental Protection Agency sanitary surveys, ODW incident writeups, and Supervisory Control and Data Acquisition (SCADA) data.

This initial data review preceded an intensive 3-day site visit conducting detailed process-by-process review. The investigation team split into groups based on engineering specialty. Separate groups toured process, electrical, and controls equipment at the WTP. Another group toured key facilities in the water distribution system, including water storage tanks and booster pump stations. The DPU provided operational and maintenance staff to explain the function and condition of the processes and associated electrical and controls equipment. During these site visits, SEH interacted with DPU staff and asked questions about the conditions at the WTP and water distribution system as well as the specific events surrounding January 6, 2025.

Executive Summary (continued)

Upon completion of the site visit, the SEH team continued its review and analysis into the existing records and decided to focus on two distinct parts. The focus for Part 1 is a Root Cause Analysis, which develops ideas and suggestions to identify the root causes of the water crisis. Part 2 is a Waterworks Needs Assessment, which advises ODW and COR as to recommended measures to prevent future occurrences of system failures increasing the waterworks reliability and resiliency.

Part 1: Richmond Water Crisis Root Cause Analysis

Analysis:

The SEH team, working in coordination with the ODW, and with the cooperation of the COR DPU staff, developed a detailed timeline of events beginning with the declaration of the state of emergency by the COR Mayor on January 5, 2025, to the lifting of the Boil Water Advisory on January 11, 2025. The timeline includes the date and time of the event including a description of the event, internal communication, external communication, and the source of the data. This timeline definitively represents the series of events immediately prior to the water crisis and through its conclusion. The timeline shows WTP staff diligently working on recovery operations while there were delays in communication between the WTP staff, DPU, neighboring jurisdictions, and external agencies, which hindered the response efforts.

Using the 6M Root Cause Analysis technique, SEH engineers assessed the six key factors contributing to the water crisis. These factors consist of Manpower, Machines, Materials, Methods, Mother Nature and Measurements. SEH determined the following failure modes as key factors to the water crisis.

- Emergency Preparation (Methods).
- Primary Power Failure (Machines).
- Electrical Switchgear Alarms No Longer Alarm to Control Room (Measurements).
- Winter Mode (Methods).
- Backup Power Failure – Switchgear Bus Tie Failure (Machines).
- Generator Requires Manual Startup (Machines).
- Lack of Qualified Electrical Staff on Night Shift (Manpower).
- Clearwells: Lack Overflow Pipes and Overflow to Filtered Pump Rooms and Filter Pipe Galleries (Materials).
- Location of Pumps: Does Not Provide Flooded Suction. Pumps Experience Issues with Suction Lift (Materials).
- Clearwell Volume and Operation Freeboard is Minimal (Materials).
- Clearwell Interconnection Reduces Redundancy of Parallel Plant Design to Clearwell Overflows (Materials).
- Poor Housekeeping Practices Created the Primary Pathway for Overflow into Plant 1 (Methods).
- UPS Value Controls Failed to Close Filter Effluent Valves (Measurements).
- UPS Batteries Not Included on PM Schedule (Methods).
- Filter Effluent Valve Manual Operation Not Feasible During Filter Gallery Flooding Event (Machines).

Executive Summary (continued)

- Godwin Pump Flow Not Sized for Full WTP Flow (Machines).
- Plant Staff Immediate Response Focused on Ineffective Dewatering (Methods).
- Godwin Pumps Prime Slowly (Machines).
- Pump Motors and Electrical Equipment Located Below Hydraulic Grade of WTP (Machines).
- UPS for Various Programable Logic Controller Failed and Connectivity was Lost (Measurements).
- Incorrect SCADA data until midnight January 6, 2025 (Measurements).
- Network Switches Were Not Maintained with Up-to-Date Drivers (Methods).
- Some Plant 2 Filter Valves Require Hydraulic System Pressure to Operate (Machines).
- Byrd Park Reservoir had Reduced Capacity Due to Capital Project (Materials).

The critical failures were further analyzed using a cascading failure analysis. Critical failures leading to the water crisis occurred sequentially from top to bottom as follows:

- Severe Weather – State of Emergency.
- Primary Power Failure (Failure of Primary Winter Mode Feed).
- Summer vs Winter Mode (Practice of using Winter Mode).
- Switchgear Bus Tie Failure.
- UPS Valve Closure Failure.
- Clearwell: Lack of Gravity Overflow, Insufficient volume.
- Pumps and Electrical Equipment Located Below Hydraulic Grade Line.

Examination of each of the items above was performed utilizing a “why” analysis. The resulting analysis determined the failures were largely a result of a managerial environment where WTP staff works with known issues that increase risk of WTP failures. This environment fosters general acceptance and normalization of critical unacceptable issues, so the appropriate level of concern is not conveyed to leadership and DPU. Staff accept substandard conditions as normal, such as increased manual operation of the WTP, slow progress in replacing critical equipment, limited training and practice for power outages, and lack of standard operating procedures. WTP staff focuses on individual roles to keep the WTP operating and not the primary objective of delivering safe, reliable water to the community.

Conclusions & Recommendations:

Based on the Richmond Waterworks Root Cause Analysis, SEH arrived at the following conclusions:

- A loss of primary and backup power systems on January 6, 2025 stopped forward flow from the clearwell to chlorine contact tanks while gravity flow from filters to clearwell continued.
- Uninterruptible Power Supplies (UPS) intended to close the Effluent Valve system and stop flow into the clearwell failed leading to catastrophic flooding of pumps and equipment that led to extended water crisis.
- DPU’s lack of testing and verification of the UPS system and functional testing of this failsafe was the cause of the water crisis.

Executive Summary (continued)

- The underlying known issue of clearwell overflow and flooding of basement is a critical failure point that DPU staff worked around for decades. Valve operation is the critical last line of defense and the UPS did not work to close the valves to stop the flooding.
- DPU staff manages working through challenges such as flooding, manual operation, inoperative priming systems, and other problematic and fixable issues such that the working conditions became part of the culture. DPU staff deal with issues and inconveniences by just focusing on individual tasks at hand to keep the plant running.
- General acceptance and normalization of problematic issues at the WTP resulted in high risk for a water crisis. DPU staff accepted an inappropriate level of concern, such that problems were not assigned to fix or repair, or to communicate these issues. This normalized operations that needed to change. Neither consultants nor regulators raised red flags concerning the WTP design limitations over many years, which gave DPU staff the false impression that problematic issues were not urgent to address.
- Overall, the DPU team needed to focus on their individual tasks at hand to keep the plant running and did not focus on the primary objective of delivering safe reliable water to the community.

Given the conclusions above, SEH provides recommendations for capital improvements, operational procedures, maintenance procedures, and emergency preparedness. The following key recommendations as listed in the analysis:

1. Address the immediate causes of plant shutdown following the power failure through the following:
    a. Eliminate the use of “winter mode” as normal mode of power.
    b. Implement a UPS preventative maintenance schedule.
    c. Ensure that all relevant filter valves are closed by the control system upon loss of power, including valves that may be open during a backwashing cycle.
    d. Provide an automatic transfer system for the existing backup generators.
2. Address the underlying vulnerability that critical electrical equipment is not in spaces that are subject to clearwell overflows and flooding.
3. Improve automation at the plant.
4. Conduct a structural evaluation of the clearwell top slab for differential pressure conditions that result when the clearwell level rises. Some portions of the top slab are pressurized at design water surface elevations shown on the hydraulic profile and are further pressurized when the water level is elevated during disruptions in pumping capacity.

Part 2: Richmond Waterworks Needs Assessment

To improve the reliability and resiliency of the COR Waterworks, SEH conducted a Waterworks Needs Assessment identifying critical infrastructure and potential vulnerability, which may contribute to a future water crisis. This assessment makes recommendations for capital improvements, maintenance practices, and evaluates the existing condition of the waterworks, system by system. The major elements of the assessment include:

- Comprehensive on-site evaluation of the physical condition, capacity, reliability, performance, and operational and maintenance procedures of the City.

- Evaluation of compliance with current Virginia Administrative Code (VAC) Chapter 590 (12VAC5-590, eff. 06/2021), which regulates public waterworks and serves as the design standards for plant capacity by the Virginia Department of Health (VDH).
- Evaluation of general deficiencies and recommendations for potential improvements

Additionally, ODW should consider working with the Board of Health to improve and update certain regulatory requirements to better address grandfathered and legacy design issues. The Regulations, at 12VAC5-590-50, states that compliance with certain parts of the Waterworks Regulation (Part III. Manual of Practice for Waterworks Design) is not required for existing waterworks in operation before the effective date of the code, June 2021. This regulation allows legacy designs to exist, which should be changed when older water treatment plants make upgrades.

The report is separated into chapters consisting of an introduction, the water treatment plant, the distribution system, and recommending improvements and estimated costs. The WTP chapter include multiple elements of the water treatment process including: 1) Source Water Intakes (James River and Kanawha Canal), 2) Pre-sedimentation, North, and South Basins, 3) Raw Water Pump Station, 4) Water Treatment Plant 1 and Plant 2, and 5) Residuals Settling Lagoon. The distribution system chapter describes the condition of the 12 pump stations, which includes the 3 at the WTP in one section. Another section addresses the 10 water storage facilities and their related valves and piping.

Each section of both the WTP and the distribution system chapters are further detailed with descriptions, purpose, and element of each feature including dimensions, volume, and capacity. Operations and maintenance considerations are addressed for each element as well as heating, ventilation, air conditioning, and electrical conditions. Finally, a record of observations and recommendations are made for each feature. The final chapter consists of two comprehensive tables, one for the WTP and one for the distribution system. Each table describes the feature, area of concern (operations, safety, end of life, and notes), improvement items, estimated construction cost, contingency, total construction cost, engineering cost, and budget cost.

In summary, to increase long-term reliability and resiliency, SEH engineers identified and estimated $31.9 million of recommended improvements at the WTP and an estimated $32.0 million of recommended improvements to the distribution system. It is likely that some of these recommended improvements are currently included in the COR capital improvement plan, and timeframe for the needed improvements vary based on condition and age.

Conclusion:

The SEH team provided a thorough and professional review of the events leading to the Richmond water crisis as well as an assessment of the infrastructure needs contributing to the water crisis or required improvements to increase the reliability and resiliency of the waterworks. Observations and interviews with WTP staff demonstrate individual commitment and expertise, but they also highlight institutional complacency through the acceptance and normalization of known issues. While staff works diligently to keep the WTP running on a daily basis, the primary strategic objective of delivering safe, reliable, water is overlooked. The WTP needs to produce all the water demanded by the system every day with a reasonable allowance for predictable outages. The distribution system needs to distribute all the water demanded every day with enough volume in storage to handle WTP outages. SEH recommends focusing on these primary strategic objectives and prioritizing infrastructure projects and managerial practices to increase the WTP long-term reliability and resiliency.

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