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Strategies to Minimize Sediment Contamination and Transport in Distribution Systems

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Strategies to minimize sediment contamination and transport in distribution systems

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Executive Summary

Drinking water storage tanks serve an important role in water distribution systems worldwide. They are not only used for emergency water supply needs such as firefighting emergencies, power outages, and water main breaks, but also to maintain and minimize pressure fluctuations within the distribution system. The infrequent use of the water within the drinking water storage tanks can lead to deterioration of the disinfectants within the water and subsequent biological, or radiological issues can develop.

Another potential problem is the buildup of sediments within a drinking water storage tank. These sediments can come from corrosion of the tank itself or be introduced somewhere else in the system and can increase disinfectant demand or provide a haven for microbials to grow. Fortunately, steps can be taken to reduce the effects of sediments within drinking water storage tanks.

This report looks to aggregate knowledge and research on sediments within drinking water storage tanks and highlight key ideas that will allow for system operators to better reduce the chance of water quality degradation.

Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The Center for Environmental Solutions and Emergency Response (CESER) within the Office of Research and Development (ORD) conducts applied, stakeholder-driven research and provides responsive technical support to help solve the Nation's environmental challenges. The Center's research focuses on innovative approaches to address environmental challenges associated with the built environment. We develop technologies and decision-support tools to help safeguard public water systems and groundwater, guide sustainable materials management, remediate sites from traditional contamination sources and emerging environmental stressors, and address potential threats from terrorism and natural disasters. CESER collaborates with both public- and private-sector partners to foster technologies that improve the effectiveness and reduce the cost of compliance, while anticipating emerging problems. We provide technical support to EPA regions and programs, states, tribal nations, and federal partners, and serve as the interagency liaison for EPA in homeland security research and technology. The Center is a leader in providing scientific solutions to protect human health and the environment.

This report aggregates EPA conducted research on sediments within drinking water storage tanks and highlights key ideas within that body of research. This report will give water system operators and the broader research community a resource to use when planning future research in this area. This report can also be used as a resource for ideas on how to better manage sediments in water distribution system tanks.

Gregory Sayles, Director
Center for Environmental Solutions and Emergency Response

List of Tables

Acronyms and Terms

DBP	Disinfection By-products
I/O	Inlet/Outlet
DWDS	Drinking Water Distribution Systems
CFD	Computational Fluid Dynamics
CBR	Chemical, Biological, Radiological
VoF	Volume of Fluid
UDF	User Defined Functions
NGS	Next Generation Sequencing
DO	Dissolved Oxygen
FWSFs	Finished Water Storage Facilities
TOC	Total Organic Carbon
TIC	Total Inorganic Carbon
OTU	Operational Taxonomical Unit
FLA	Free Living Amoebae

1.0 Introduction

Drinking water storage tanks serve several important functions, which include but are not limited to providing an adequate water supply in the case of firefighting emergencies, power outages, water main breaks, or other system failures. The water level elevation in storage tanks helps to 1) maintain water distribution system pressure, and 2) minimize fluctuations caused by changes in customer demand or system operating conditions.

One problem, however, is that the drinking water quality in finished water storage tanks can deteriorate over time and present biological, physical, and chemical water quality issues, some with potential health impacts. For example, chlorine or other disinfectant residuals may decrease, disinfection by-product (DBP) levels may increase, and taste and odor issues can develop. In addition, pH can increase, tank materials can corrode, and iron and manganese can precipitate (Mays, 2001). Lastly, sediments, which accumulate on the tank floor, can increase disinfectant demand, microbial growth, DBP formation, and turbidity (USEPA, 2002).

These water quality problems can be attributed to multiple factors:

- Long residence times of water in the storage tanks
- Poor mixing of water in the storage tanks
- Inadequate maintenance and cleaning of the storage tanks

Fortunately, steps can be taken to improve water quality in storage tanks. Water quality can be improved by increasing mixing; reducing residence time; monitoring water quality on a routine basis; inspecting, maintaining, and cleaning tanks regularly; modifying inlet/outlet (I/O) locations; and optimizing operations by modeling retention times and mixing characteristics. More than half of the drinking water systems using at least one of these practices can maintain the water quality in their storage tanks.

For many years, the U.S. Environmental Protection Agency's (EPA's) Center for Environmental Solutions and Emergency Response (CESER) (formerly the National Homeland Security Research Center (NHSRC)) has been conducting tank sediment research studies and collecting data on tank sediments to better understand how sediments might be resuspended from tank bottoms and transported back into water distribution systems. Various reports, technical briefs, and presentations have been prepared. From these studies, researchers hope to highlight the tank operating conditions that could reduce the resuspension of sediments and assist in the removal of sediments from tanks.

Section 2 of this report provides a summary of each of the research studies, presentations and published articles, and reports focusing on sediments and drinking water distribution tanks to be discussed further in this report. Section 3 provides the study objectives, findings, and conclusions of each of the sediment and water distribution storage tank research projects. Findings from the sediment tank research are summarized in Section 4 of this report. Section 5 contains a list of all the references used to compile this compendium report.

2.0 Research in the Study of Sediments and Water Distribution Storage Tanks

This section provides a summary of each of the research studies, presentations and published articles, and reports focusing on sediments and drinking water distribution tanks to be discussed further in this report. Section 3 provides additional information on each of the research projects, including the study objectives, findings, and conclusions. Table 1 provides a summary of the topics covered by the drinking water distribution systems (DWDS) storage tank sediment research studies covered in this report.

Table 1. Storage Tank Sediment Research Summary

	Research Topic				
Research Title and Location in this Report	CFD	Bench-scale experiments	Pilot-scale experiments	Physical characteristics of sediment	CBR contaminants in sediment
Section 3.1: Sediment Resuspension and Transport in Water Distribution Storage Tanks	X	X			
Section 3.2: Modeling and Experimental Testing of Sediment Resuspension in Water Distribution Storage Tanks	X	X	X		
Section 3.3: Physical and Compositional Characteristics of Finished Water Storage Facility Sediment				X	
Section 3.4: Assessing the Microbiome of Distributed Water and Biofilm Communities using Conventional and Metagenomic Approaches in Water Storage Tanks					X
Section 3.5: Insights into the Drinking Water Microbiome of a Drinking Water Tank Simulator: Implementing Metagenomic Approaches to Understand the Tank Ecosystem		X	X		X
Section 3.6: Technical Brief: Adherence of Chemical, Biological, and Radiological Contaminants to Sediments Found in Water Storage Tanks					X

Section 3.7: Metagenomic Profile of Microbial Communities in Drinking Water Storage Tank Sediment after Sequential Exposure to Monochloramine, Free Chlorine, and Monochloramine					X
Section 3.8: Evaluation of Monochloramine and Free Chlorine Penetration in Drinking Water Storage Tank Sediment Using Microelectrodes				X	X
Section 3.9: Opportunistic Pathogens and Microbial Communities and Their Associations with Sediment Physical Parameters in Drinking Water Storage Tank Sediments					X

CFD – Computational fluid dynamics
CBR – Chemical, Biological, Radiological

3.0 Summary of Sediments and Water Distribution Storage Tanks Research

3.1 Sediment Resuspension and Transport in Water Distribution Storage Tanks

American Water Works Association Journal, June 2016.

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This article presented studies of particle resuspension and movement in water distribution storage tanks during filling and draining cycles. An operational simulation study was performed to determine when and where different sized particles were resuspended from the tank bottom and transported during filling and draining cycles at low- and high-flow rates. A parametric simulation study was performed to determine the impact of parameters such as particle size, flow rate, I/O diameter and location, and filling versus draining on the shear stresses and potential for particle resuspension on the tank bottom. Experimental testing was also performed with a small-scale water tank to investigate particle resuspension during filling and draining cycles with different particle sizes and densities (glass beads and silica sand). The test results were compared with simulations to verify the modeling approach. Finally, the use of a raised I/O line was investigated for mitigating particle resuspension.

Results of the operational study revealed that resuspension from the tank bottom generally occurred near the I/O line (within 2.5 m) and immediately following the start of either the filling or draining processes. Simulated shear stresses along the bottom wall were greater during draining and led to more particle resuspension than during filling. Up to 25% of particles were resuspended, but less than 1% was removed from the tank during draining. Smaller particles were more susceptible to resuspension and entrainment and, once entrained in the fluid flow, particles were typically carried further away from the I/O during the filling cycle, making them less susceptible to removal during draining.

Results of the parametric study demonstrated that particle size, flow rate, and I/O location were found to be important factors for particle resuspension. Smaller particles were more susceptible to resuspension, especially during filling. Higher flow rates, draining (versus filling), and I/O lines located near the side wall (versus at the center of the tank) yielded greater particle resuspension. Particle resuspension was positively correlated to the amount of momentum flow, or jet effect, through the I/O. Reducing the flow rate or increasing the diameter of the I/O reduced the momentum flow and the potential for particle resuspension. Although these simulations only considered cylindrical tanks with a single I/O pipe along the bottom of the tank, the general results should be applicable to other tank configurations as well.

The tools and methods developed in this study can be applied to alternative configurations to obtain more representative assessments. However, this model makes simplifying assumptions regarding the shape of particles and the lack of cohesion among particles. These assumptions would likely tend to overestimate the amount of particle resuspension in the model relative to actual situations in which sedimentation and cementing occur or in which oddly shaped particles exist. Mixtures of particle sizes may also reduce the amount of particle suspension by creating protective pockets for smaller particles.

To mitigate the potential for particle resuspension near the I/O line, a raised I/O was investigated. Simulation results showed that using a raised I/O line extending 15 to 30 cm (6 to 12 inches) above the 3 million gallon tank bottom substantially reduced the number of particles resuspended in the tank during filling and draining. Small-scale tests were performed to investigate particle resuspension during filling and draining in a 1.2 m (4 ft) diameter water-filled tank with a 2.0 cm (0.8 inch)-diameter I/O located in the center of the tank. Measured and simulated velocities along the tank bottom during draining matched well, with velocities increasing rapidly close to the drain. The simulated radial extents of particle resuspension during filling generally matched the data, and results confirmed that the extent of resuspension was significantly lower during filling than during draining. Both modeling and experiments showed that a raised inlet reduced particle resuspension and removal during filling and draining.

These modeling studies and the experimental testing demonstrate that sediment resuspension in storage tanks and transport back into water distributions can occur under normal tank operating conditions.

3.2 Modeling and Experimental Testing of Sediment Resuspension in Water Distribution Storage Tanks

Office of Research and Development National Homeland Security Research Center. EPA/600/R-15/288. April 2016 (www.epa.gov/homeland-security-research).

Principal Investigator: Regan Murray

This report presented studies of particle resuspension and movement in water distribution storage tanks during filling and draining cycles. Two computational studies were performed: (1) an operational study of a 11,000 m^3 (3 million gallon) water tank to determine when and where different sized particles were resuspended from the tank bottom and transported during filling and draining cycles at low and high flow rates; and (2) a parametric study to determine the impact of parameters such as particle size, flow rate, I/O diameter and location, and filling vs. draining on the shear stresses and potential for particle resuspension on the tank bottom. Testing was also performed with a small-scale water tank to investigate particle resuspension during filling and draining cycles with different particle sizes and densities (glass beads and silica sand).

The test results were compared to simulations of the physical tests conducted in order to verify the modeling approach. Finally, the use of a raised I/O line was investigated to mitigate particle resuspension.

In the operational study, the resuspension and movement of different sized particles (0.01-, 0.1-, and 1-mm diameter) were simulated during subsequent filling and draining cycles in the tank. Two different flow rates were used based on representative minimum and maximum flow rates provided by the Albuquerque Water Authority. Key results of the numerical simulations were as follows:

- Particle resuspension from the tank bottom generally occurred immediately following the start of either the filling or draining process.
- Smaller particles were more susceptible to resuspension and entrainment.
- Once entrained in the fluid flow, particles were typically carried further away from the I/O during the filling cycle, making them less susceptible to removal during draining.
- Greater shear stress during draining led to more particle resuspension than during filling.
- Recirculation zones near the I/O were observed.

A parametric study was performed to determine the impact of particle size, flow rate, I/O diameter and location, and filling vs. draining on the shear stress and potential for particle resuspension on the tank bottom. Key findings were as follows:

- Particle size, flow rate, and I/O location were found to be important factors for particle resuspension.
    - Smaller particles were more susceptible to resuspension, although the difference was less during draining than filling.
    - Higher flow rates yielded greater resuspension.
    - I/Os located near the side wall (vs. at the center of the tank) yielded greater resuspension.
    - Draining yielded greater resuspension of particles than filling.
- Particle resuspension was directly correlated to the amount of momentum flow, or jet effect, through the I/O. Reducing the flow rate or increasing the diameter of the I/O reduces the momentum flow and the potential for particle resuspension.
- Placing the I/O near the center of the tank rather than near the side wall reduced particle resuspension during filling.

To mitigate the potential for particle resuspension near the I/O line, a raised I/O was investigated. The hypothesis was that this would reduce the shear stresses near the I/O and reduce the potential for particle resuspension. The extension pipe configuration (with varying extension heights) was added to the 2D axisymmetric tank model that had been previously used in the operational study. Key results were as follows:

- During filling, a pipe height extending 15 cm (6 inches) above the center of the tank bottom substantially reduced the number of particles resuspended.
- During draining, a pipe height extending 30 – 61 cm (12 – 24 inches) above the center of the tank bottom substantially reduced the number of particles drained from the tank.

Small-scale tests were performed to investigate particle resuspension during filling and draining in a 1.2 m (4 ft) diameter water-filled tank with a 2 cm (0.8 in) diameter I/O located in the center of the tank. Photos and videos were recorded before and after each filling and draining event to determine where particles were resuspended from the tank bottom. Tracer tests were also performed to characterize the flow patterns and velocity fields. Finally, mitigation measures were investigated by raising the pipe inlet, which was normally flush with the tank bottom, 1 cm (0.4 in) above the tank bottom. Key results were as follows:

- Measured and simulated velocities along the tank bottom matched well up to approximately 5 cm from the drain, including the region where particles were resuspended.
  - Velocities along the tank bottom were very small away from the inlet (<1 cm/s), but increased exponentially within 2 – 3 cm from the I/O to above 10 cm/s.
- Resuspension of particles was limited to within approximately 1 cm from the I/O during filling and draining cycles for the flow rates used in the study.
- Smaller particles yielded a greater radial extent of resuspension from the I/O during filling and draining cycles.
- Particles less dense than the silica sand (e.g., glass beads) exhibited greater resuspension.
- During the fill-drain-fill-drain cycle, fewer large particles were drained when compared to the drain-only scenario. This is likely because during the fill cycle, particles close to the inlet were resuspended and deposited further away. When the drain cycle commenced, there were fewer particles near the inlet to be drained. However, a greater fraction of the smaller particles was drained when compared to the drain-only scenario. A possible reason may be that the small particles remained entrained during filling and were subsequently drained, and the fill-drain-fill-drain sequence caused additional perturbations and shear stress that enabled a greater number of smaller particles to be drained.
- Model predictions of resuspension generally matched experimental data for glass beads, and generally over predicted the amount of resuspension for silica sand. The non-spherical shape of the sand may have reduced the amount of resuspension in the tests.
- Both modeling and experiments showed that a raised inlet reduced particle resuspension and removal during filling and draining.

- Minimum height to completely mitigate particle movement near the I/O was found to be approximately 3 - 8% of the head of water.
  - In the tests, an extension of 1 cm (0.39 inches) mitigated particle movement with a maximum head of water of 30 cm (12 inches).
  - In the models, an extension of approximately 0.38 m (1.3 ft) mitigated particle movement with a head of water of 4.9 m (16 ft).

3.3 Physical and Compositional Characteristics of Finished Water Storage Facility Sediment

Small Systems Webinar Series: Tank Mgmt & Distr. Sys. Optimization, Cincinnati, OH

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The purpose of this study was characterizing the characteristics of water tank sediments across the United States. The physical properties and elemental composition of sediment vary widely across cities as well as within the same distribution system, illustrating the complexity in parameters that contribute to the nature of sediment. Factors such as source water, finished water quality, drinking water treatment processes, and storage can differ between distribution systems. Tank operation, filling and draining patterns, construction materials, tank shape, size and height, and time intervals between cleaning frequencies can also impact sediment properties.

Because only sediment close to the I/O of the tank is at risk of resuspension (Ho et al., 2016), research should focus on assessing sediment within a close radius of the outlet. While there are clearly differences among water tank sediments, samples in this study were collected at the will and convenience of several water systems in contact with EPA or from secondary sources and may not be representative of sediments nationwide.

The physical properties of sediment characterized in this study may be used as more accurate inputs in water tank sediment resuspension and draining models. Shear stress along the bottom wall is the critical parameter for determining particle resuspension. Whether this shear stress is sufficient to suspend sediment depends primarily on particle size and, to a lesser degree, density (USEPA, 2016).

The average particle density of all sediment in this study (1.99 grams per cubic centimeter (g/cm^3)) was lower than the density of silica sand (2.65 g/cm^3), which is used in many sediment resuspension models (Ho et al., 2016; Beheshti and Ataie-Ashtiani, 2008). In 24 of 28 cases, the particle density of the sampled sites had a specific gravity less than silica sand. This would indicate that current models may be underestimating resuspension.

Large differences in particle shape were also observed in the sampled sediment. Many samples had oblong, flat, or platy particles as small as 0.106 mm in diameter. Non-spherical particles affect particle resuspension and draining by lowering the settling velocity compared to a perfectly shaped particle of the same volume and density (Dietrich, 1982). One model over predicted resuspension for silica sand, while glass beads perfectly fit the model in validation studies. The authors speculated this was due to the non-spherical shape of the silica sand (USEPA, 2016).

Sediment resuspension models account for particle shape differences by using the Corey shape factor in the calculation of the movability number (USEPA, 2016; Beheshti and Ataie-Ashtiani, 2008; Dietrich, 1982). Resuspension models typically use a shape factor of 0.7 because it corresponds to the shape of a coarse grain of sand and is typical of the sediment found in streams (USEPA, 2016). However, this may not be accurate for the sediment found in water storage tanks because particles precipitating out of water can create crystalline shapes not typical of particles found in stream sediment. Calculation of the average Corey shape factor in the sediment samples was beyond the scope of this study but should be considered for future work.

3.4 Assessing the Microbiome of Distributed Water and Biofilm Communities using Conventional and Metagenomic Approaches in Water Storage Tanks

Office of Research and Development, National Homeland Security Research Center (NHSRC). March 2019.

Principal Investigators: Randy Revetta (ret.) and Vicente Gomez-Alvarez.

The purpose of this research is to determine how and why these opportunistic waterborne pathogens can persist within storage tank systems and how to implement effective water management plans to mitigate exposure risks to pathogens. A whole metagenome-based approach using sophisticated molecular tools (e.g., next generation sequencing [NGS]) was used to assess the microbial composition and the metabolic potential in these communities.

This data will help researchers:

1. Understand how implementation of water management plans can improve water quality in finished water storage facilities in DWDS.
2. Use a storage tank system simulator to test hypotheses and methods involving the waterborne microbial community including pathogens such as *Legionella*, *Mycobacteria*, Amoebae and viruses.

The results of these studies include:

- Determining the important chemical and microbial parameters to evaluate and measure to ensure a successful water management plan in storage tanks.
- Understanding and developing a monitoring system for storage tanks that could be implemented through a water management plan.
- Studying the interaction of disinfectant residual, retention time, DPB formation, and the occurrence of pathogens.
- Determining the effects of different treatment options on chemical and microbial water quality, including the microbial community.
- Monitoring biofilm formation and microbial dynamics of opportunistic pathogens and the occurrence and distribution of antibiotic resistant genes.

The approaches used in these studies helped develop and improve strategies for controlling pathogens and maintaining disinfectant levels while controlling DBP formation with an emphasis on water storage tanks in large and small drinking water systems. Such information is critical to the design of effective management practices and ultimately helps to prevent waterborne disease and safeguard human health.

3.5 Insights into the Drinking Water Microbiome of a Pilot Scale Drinking Water Tank Simulator: Implementing Metagenomic Approaches to Understand the Tank Ecosystem

U.S. Environmental Protection Agency, Office of Research and Development. Water Quality Technology Conference (WQTC) Presentation, November 2019.

Principal Investigators: Vicente Gomez-Alvarez and Randy Revetta (ret.).

Understanding changes in the microbial communities in storage tanks is essential for monitoring the biological stability to ensure a healthy ecosystem. Water management programs could be used to greatly enhance the ability to predict responses to disturbances in the ecosystem. Metagenomics involves the sequencing and application of bioinformatics to study the genetic material recovered directly from environmental samples. These metagenomic data are uncovering vast diversity, abundant uncultivated microbial groups, and novel microbial functions.

The results of these studies include:

- Metagenomic approaches allow the genomic analysis of unculturable microbes and the role of relevant functions in storage tank ecosystems.
- Established that drinking water storage tanks are complex ecosystems with highly diverse bacterial communities structured as a function of both environment [bulk water vs. sediment] and sediment depth [top and bottom].
- Demonstrated the advantages of using pilot-scale drinking water simulators to test and understand the dynamics of the storage tanks.

- This information could be incorporated into water management programs/guidelines and greatly enhance our ability to predict responses to disturbances in DWDS.

3.6 Technical Brief: Adherence of Chemical, Biological, and Radiological Contaminants to Sediments Found in Water Storage Tanks

U.S. EPA, National Homeland Security Research Center (NHSRC). 2014.
Technical Contact: Jeff Szabo (szabo.jeff@epa.gov).

To help define the potential difficulties involved in remediating water tanks if they become contaminated with CBR agents, EPA conducted a study to determine the extent to which contaminants adhered to tank sediments. The study involved donated sediment and drinking water samples collected from 25 tanks located in 12 different states. The tanks contained finished water that originated from both ground and surface water sources. The amounts collected and the characteristics of the sediments varied widely. Eight of the samples contained sufficient water and sediment to use in the contaminant adherence study.

Experimental conditions optimized the amount of contact between the sediments and contaminated drinking water through centrifugation (cesium and lindane) and settling (*E. coli* and *BaS*), so that potential adherence could be observed. In a water storage tank, the degree of contact will depend on conditions in the tank, as well as characteristics of the contaminants and the sediments.

In general, the biological contaminants adhered more readily than the chemical contaminants. Overall, pH differences in the contaminated drinking water were often within the experimental uncertainty of the measurements, thus no significant differences could be observed.

The results of this investigation suggest that when sediment is present, chemical and biological contaminants may adhere to the sediment. (USEPA, 2014).

3.7 Evaluation of Monochloramine and Free Chlorine Penetration in Drinking Water Storage Tank Sediment Using Microelectrodes

Environmental Science and Technology, 2019

Hong Liu[1], David G. Wahman[2], and Jonathan G. Pressman[2].

1 Oak Ridge Institute for Science and Education (ORISE) Post-Doctoral Fellow at U.S. Environmental Protection Agency, Cincinnati, OH 45268
2 National Risk Management Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, OH 45268

This study seeks to identify nutrients and disinfectants and the depth of penetration within the sediments located in DWSTs using monochloramine and free chlorine sensitive microelectrodes.

A Teflon cup reactor was filled with 2 cm of sediment from a chloraminated system located in Louisiana. The sediment was then exposed to monochloramine for 4 months, free chlorine for 2 months, and finally monochloramine again for 2 months. As part of the study, the levels of temporal monochloramine, free chlorine, dissolved oxygen (DO), pH, ammonium, nitrite, and nitrate were measured via the microelectrodes.

Microelectrodes were successful in detecting water chemistry and microbial nitrification activity within the drinking water samples. Neither monochloramine nor free chlorine ever penetrated the entirety of the 2cm deep sediment layer during any of the three phases of the trial. The increased ammonium, nitrite, and nitrate levels detected in phase 2 of the study proved that even during a free chlorine burn nitrifying bacteria can survive within the sediment layer.

This study also highlights the importance of regular cleaning and maintenance. Reducing the amount of sediment within a DWST can not only improve performance but improve water quality by eliminating environments that favor microbial communities.

3.8 Metagenomic Profile of Microbial Communities in a Drinking Water Storage Tank Sediment after Sequential Exposure to Monochloramine, Free Chlorine, and Monochloramine

Environmental Science and Technology: Water, March 2021

Vicente Gomez-Alvarez[1], Hong Liu[2], Jonathan G. Pressman[1], David G. Wahman[1].

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2. Oak Ridge Institute for Science and Education (ORISE) Post-Doctoral Fellow at U.S. Environmental Protection Agency, Cincinnati, OH 45268

The purpose of this study was to investigate the microbial communities within drinking water sediment samples and correlate this data to chemical profiles to better understand biotic and abiotic characteristics. Using metagenomics, this study explores:

1. The microbial diversity and dominant microorganisms
2. Taxonomic composition
3. Specific genes involved in biotransformation processes

Common thought suggests that disinfectants would have a negative effect on the microbial populations within FSWFs, but this study found that sediments hosted a greater microbial biodiversity and biochemical processes that are similar to complex ecosystems outside of drinking water distribution systems. The sediments provide stability and protection against environmental stressors (disinfectants) while also providing favorable metabolic conditions and the possibility of genetic transfer between populations.

Most of the species discovered are ubiquitous to sediments and are associated with the phylum Proteobacteria. With the ammonia present from chloramine formation, there was evidence of a nitrifying community within the sediment, which can lead to system failure.

The results of this study show that understanding the behavior of microbial communities is key to risk management and prevention, as well as evaluating the biological stability of any FSWF system.

3.9 Opportunistic Pathogens and Microbial Communities and Their Associations with Sediment Physical Parameters in Drinking Water Storage Tank Sediments

Pathogens, September 2017

Ke Qin[1], Ian Struewing[2], Jorge Santo Domingo[3], Darren Lytle[4], Jingrang Lu[5].

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The purpose of this study was to examine the occurrence and densities of OPs, the microbial community structure, and their relationships with sediment elements. OPs were determined using genus/species specific qPCR assays and microbial community analyses were performed using next generation sequencing.

The occurrences and densities of OPs are consistent with previous research done on drinking water distribution systems. Free-Living Amoebae (FLA) have been correlated to increased occurrences of Legionella spp. and *Mycobacterium spp.* and were found in higher levels in sediment rather than water, suggesting that they are more tightly bound to sediments that could be harboring more OPs. The co-occurrence of amoebae, *Legionella spp*., and *L. pneumophila* in the sediments, and their relatively higher densities in the sediment samples than in water, suggest that sediments can serve as reservoirs of OPs in storage tank water and can potentially be released into the distribution system. The microbial compositions of the sediment and water samples obtained from the same site indicate that there are interactions between the two matrices. Anything that may be attached to the sediment could be resuspended and reenter the DWDS. Both OPs and microbial communities are positively associated with AL and K found in sediments due to pipe corrosion. These results show the importance of maintaining appropriate levels of disinfectant residual in the system and the benefits of regular sediment removal.

4.0 Conclusions and Summary

Although drinking water storage tanks serve several important functions, the water quality in these tanks can deteriorate over time and present biological, physical, and chemical water quality issues, some with potential health impacts. Unless used frequently or cleaned regularly, a substantial build-up of sediments can occur in tanks. These sediments can contain material that has sloughed off from corroded tank linings or material brought into the tank from the source water. Although rare, waterborne illnesses have resulted from organisms introduced into the tank when open vents, hatches, or inadequate covers allow organic debris birds, or other animals to gain access. The type and quantity of sediments vary widely depending on many factors including: the amount of water passing through the tank, the characteristics of the water, the amount of mixing the water receives in the tank, tank design, and the tank's maintenance schedule.

Modeling studies and experimental testing were used to demonstrate that sediment resuspension in storage tanks and transport back into water distributions can occur under normal tank operating conditions. CFD models predict particle resuspension and movement in water distribution storage tanks during filling and draining cycles, giving researchers an insight into the mixing characteristics in water tanks. Parameters investigated included I/O line location and diameter, flow rate, particle size, and filling versus draining cycles. Simulation results showed that smaller particle sizes, higher flow rates, and draining cycles yielded the greatest potential for particle resuspension, which was generally limited to regions near the I/O line (within 2.5 m) and immediately following the start of either the filling or draining processes.

Simulated shear stresses along the bottom wall were greater during draining and led to more particle resuspension than during filling. Up to 25% of particles were resuspended, but less than 1% was removed from the tank during draining. Smaller particles were more susceptible to resuspension and entrainment and, once entrained in the fluid flow, particles were typically carried further away from the I/O during the filling cycle, making them less susceptible to removal during draining. Therefore, to be most effective at inducing particle resuspension, the I/O should be located near the tank wall.

Research also found that a pipe extending from the I/O line into the tank (slightly above the bottom floor) significantly reduced the potential for particle resuspension in both the computational models and the experiments. During filling, a pipe height extending 15 cm above the center of the tank bottom substantially reduced the number of particles resuspended. However, during draining, a pipe height extending 30 – 61 cm above the center of the tank bottom substantially reduced the number of particles drained from the tank.

The physical properties and elemental composition of sediment can vary widely across cities as well as within the same distribution system, illustrating the complexity in parameters that contribute to its nature. The density and porosity, particle size distribution, and elemental composition of sediment varies widely between DWDS. The bulk density of the sediment reflects its porosity. The greater the bulk density, the lower the porosity of the sediment. Particle density represents the density of the material that makes up the sediment and is an important parameter in particle transport. The physical properties of sediment may be used as more accurate inputs in water tank sediment resuspension and draining models. Shear stress along the bottom wall is the critical parameter for determining particle resuspension. Whether this shear stress is sufficient to suspend sediment depends primarily on particle size and, to a lesser degree, density.

DWDS have been found to be potential sources of waterborne illnesses from the growth of specific pathogens associated with larger microbial communities, known as biofilms. Excess water retention time may also cause a depletion of disinfectant, which can create an environment favorable to microbial contamination and enhanced DBP formation. Sediment accumulation and biofilm formation enhance the growth and accumulation of pathogens, cause nitrification, physically block valves and pipes, and release particles into the DWDS. Through research studies, it was concluded that if water tanks became contaminated with CBR agents, these contaminants could adhere to tank sediments. Of these contaminants, the biological contaminants adhered more readily than the chemical contaminants.

Sediment studies help researchers understand how implementation of water management plans can improve water quality in finished water storage facilities in DWDS. When it comes to the potential public health risks relative to DWDS, it is important to understand the biotic and abiotic characteristics of these systems which amplify these risks.

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