NATIONAL WATER RESEARCH INSTITUTE

FINAL Panel Report for Meeting #2

LOTT Clean Water Alliance
Reclaimed Water Infiltration Study

Based on an NWRI Independent Advisory Panel Meeting
Held on November 17, 2017 (Panel Meeting #2)

Prepared by:
NWRI Independent Advisory Panel
to Review the LOTT Reclaimed Water Infiltration Study

Prepared for:
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Submitted:
January 12, 2018

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Publication Number: NWRI-2017-15

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ACRONYMS

CNS	Central nervous system
DBP	Disinfection byproduct
HAA	Haloacetic acid
KBr	Potassium bromide
L	Liter
LOTT	LOTT Clean Water Alliance
mgd	Million gallons per day
mg/L	Milligrams per liter
mL	Milliliters
MSDS	Material Safety Data Sheets
NH_3-N	Ammonia nitrogen
NWRI	National Water Research Institute
PPCP	Pharmaceuticals and personal care products
SAT	Soil aquifer treatment
SF_6	Sulfur hexafluoride
THM	Trihalomethane
USEPA	United States Environmental Protection Agency

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1.0 PURPOSE AND HISTORY OF THE PANEL

In 2013, the National Water Research Institute (NWRI) of Fountain Valley, California, a joint powers authority and 501c3 nonprofit, appointed local and national water industry experts to an Independent Advisory Panel (Panel) to provide a credible, third-party science-based review the "Reclaimed Water Infiltration Study" proposed by the LOTT Clean Water Alliance (LOTT) of Olympia, Washington.

The multi-year scientific study by LOTT is focused on determining potential human and/or ecological health risks from the infiltration of reclaimed water into local groundwater – particularly, the impacts of pharmaceuticals and personal care products PPCPs) – and approaches to reduce those risks. The goal of the LOTT study is to help policymakers make informed decisions about future reclaimed water treatment and uses.

1.1 Description of the Reclaimed Water Infiltration Study

The LOTT Clean Water Alliance is a wastewater utility whose members include the Cities of Lacey, Olympia, and Tumwater, and Thurston County in Washington State. Currently, most of the wastewater is treated at the Budd Inlet Treatment Plant and discharged into Budd Inlet at the southern tip of Puget Sound. As part of its long-range plan to manage wastewater, LOTT is engaged in increasing the production of Class A Reclaimed Water, the highest quality of reclaimed water as determined by the Washington State Departments of Ecology and Health.

LOTT has built a Reclaimed Water Satellite System to produce 2-million gallons per day (mgd) of reclaimed water. The system includes the Martin Way Reclaimed Water Plant, which employs a membrane bioreactor for primary, secondary, and tertiary treatment. The water is then piped to the Hawks Prairie Reclaimed Water Ponds and Recharge Basins, where it circulates through five constructed wetland ponds that also serve as a public park and ecosystem for local wildlife. The water then flows into recharge basins to infiltrate into the aquifer.

LOTT also produces about 1 mgd of Class A Reclaimed Water at its Budd Inlet Treatment Plant by treating the secondary effluent with tertiary sand filtration. Most of this reclaimed water currently is used for irrigation, toilet flushing, water features, and process uses within the treatment plant. Additional infiltration sites, including the Henderson site, are currently planned for future application.

Questions and concerns about the infiltration of reclaimed water have been raised. To address these questions, LOTT is engaged in a multi-year scientific study to achieve the following:

1. Provide scientific data and community perspectives to help policymakers make informed decisions about future wastewater and reclaimed water treatment and uses.

2. Ensure that the scientific study and public involvement processes are credible, objective, transparent, responsive, and responsible.

3. Foster meaningful, community-wide dialogue about water quality, reclaimed water, groundwater recharge, risk assessment, and related watershed issues.

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The primary study question is as follows:

> *What are the risks from infiltrating reclaimed water into groundwater because of chemicals that may remain in the water from products people use every day, and what can be done to reduce those risks?*

Environmental assessments, including surface water and groundwater sampling, geologic exploration and testing, and laboratory analysis, have been or will be completed during various study phases. The nature of these sampling programs, contaminants to be monitored, sampling locations, and sampling frequency have been developed through the study scoping effort as preliminary information, planning data, and study needs were assessed among key project stakeholders. The recharge basins at the Hawks Prairie site, which are already in operation using reclaimed water, will be used as the primary site to address the questions about fate and transport.

1.2 Current Status of the Reclaimed Water Infiltration Study

LOTT and the project team currently are engaged in Task 2 of the Reclaimed Water Infiltration Study, which is focused on assessing treatment effectiveness. Specifically, the focus is on a tracer test and groundwater quality characterization, which will be conducted from January to October 2018.

The tracer test will be used to: (1) determine travel times and downgradient flow paths of the reclaimed water as it moves through the vadose zone and aquifer, and (2) inform groundwater modeling to characterize the longer-term fate and transport of residual chemicals in reclaimed water. The two tracers under consideration include potassium bromide (KBr) and sulfur hexafluoride (SF_6).

The purpose of water quality monitoring will be to assess water quality changes that occur over time in the subsurface as a result of the infiltration of reclaimed water. In particular, water quality monitoring will be used to (1) determine the effectiveness of soil aquifer treatment (SAT) at attenuating residual chemicals and nutrients, and (2) assess the mixing and dilution that will occur as reclaimed water travels downgradient from the recharge basins. In 2017, lysimeters and additional monitoring wells were installed at and around the Hawks Prairie recharge area to support water quality modeling of the vadose zone and groundwater system.

The scope of this effort will involve infiltrating approximately 0.5 to 1 mgd of reclaimed water into the aquifer using two half-acre cells within Basin 4 of the Hawks Prairie Recharge site. LOTT has proposed to alternate the reclaimed water between the cells to create 7-day wetting and drying cycles.

1.3 Purpose of the Panel

The expert Panel was organized in 2013 by NWRI at the request of LOTT to review the study efforts and advise the project team at specific milestones to ensure a credible, independent, transparent, and science-centered review of the scope, field work methods and results, modeling development, and outcomes of the Reclaimed Water Infiltration Study. Background information about the NWRI Panel process can be found in **Appendix A**. A list of panel activities from 2013 to present is provided in **Appendix B**.

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1.4 Members of the Panel

The Panel is made up of six experts in areas related to the infiltration of reclaimed water, including water reuse and public health criteria, environmental engineering, hydrogeology, human and ecological toxicology, and other relevant fields. Panel members include:

- Chair: James Crook, Ph.D., P.E., Environmental Engineering Consultant (Boston, MA)
- Richard Bull, Ph.D., MoBull Consulting (Richland, WA)
- Michael Kenrick, P.E., LHG, GeoEngineers (Redmond, WA)
- Edward Kolodziej, Ph.D., University of Washington (Tacoma/Seattle, WA)
- John Stark, Ph.D., Washington State University (Puyallup, WA)
- David Stensel, Ph.D., P.E., University of Washington (Seattle, WA)

Brief biographies of the Panel members can be found in **Appendix C**.

1.5 Changes to Panel Membership

The first Panel meeting was held on February 18-19, 2014, and the second held in November 2017. During that time, the following changes occurred to the membership of the Panel:

- Mr. Kenrick, a hydrogeologist, replaced Roy Haggerty, Ph.D., an environmental geologist with Oregon State University, as a member of the Panel.

- Dr. Stark, an expert in ecological risk assessment, replaced toxicologist Evan Gallagher, Ph.D., of University of Washington.

- Dr. Kolodziej, an environmental engineer and chemist, replaced Jennifer Field, Ph.D., a toxicologist and chemist with Oregon State University.

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2.0 PANEL MEETING #2

A 1-day meeting of the Panel was held on November 17, 2017, at LOTT's administrative offices and WET Science Center in Olympia, Washington. This meeting represents the second time the full Panel has met to review LOTT's Reclaimed Water Infiltration Study.

2.1 Pre-Meeting Material

Prior to the meeting, LOTT provided the following background material and reports to the Panel:

- *LOTT Clean Water Alliance Reclaimed Water Infiltration Study – Draft Hydrogeologic Characterization Report, On-Site Wells and Lysimeter Installation (TASK 2.1.1.A), Off-Site Monitoring Wells (TASK 2.1.2.C), Hawks Prairie Area* (a 358-page document prepared by HDR for LOTT, dated October 27, 2017)

- *LOTT Clean Water Alliance Reclaimed Water Infiltration Study – Draft Work Plan, Tracer Testing and Water Quality Monitoring of Treatment Effectiveness (TASK 2.1.3), Hawks Prairie Area* (a 154-page document prepared by HDR for LOTT, dated November 6, 2017)

2.2 Meeting #2 Attendees

All Panel members attended Meeting #2. Other attendees included NWRI staff, LOTT staff and consultant team members, and members of the Science Task Force (which is made up of technical experts from the Cities of Lacey, Olympia, and Tumwater, Thurston County, the Squaxin Tribe, and the Washington State Departments of Ecology and Health). A complete list of Panel meeting attendees is included in **Appendix D**.

2.3 Meeting #2 Agenda

Staff from NWRI, LOTT, and the consultant team collaborated on the development of an agenda for Meeting #2, which is included in **Appendix E**. The agenda was based on meeting the following objectives:

- Review and discuss the hydrogeologic characterization report and tracer test work plan.
- Facilitate interaction and questions and answers between the Panel and LOTT's project team.
- Allow time for the Panel to meet in a closed session to discuss the information presented and begin drafting recommendations.
- Tour the recharge basins at the Hawks Prairie Recharge site.

The meeting commenced with presentations from LOTT staff and the project team on the following topics:

- Orientation to the Project and Timeline
- Hydrogeologic Characterization Report
- Draft Tracer Test/Water Quality Monitoring Work Plan

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Time was allowed for questions and discussion between LOTT staff and project team, Panel members, and Science Task Force following each presentation. After the presentations, the Panel then met in a closed session to develop a draft report outline, which is expanded upon in this report. At the end of the meeting, the newest members of the Panel went on a site tour of the Hawks Prairie Recharge site. The tour included:

- **The layout of Basin 4**, including the distribution piping that infiltrates reclaimed water, above-ground well caps for Wells 15 and 16, and above-ground caps for the lysimeter and probe instrumentation.

- **Current recharge practices at Basin 3**. Reclaimed water was currently being delivered to Basin 3. Notably, the water delivered to half of Basin 4 will be four times the amount observed at Basin 3.

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3.0 FINDINGS AND RECOMMENDATIONS

The principal findings and recommendations derived from the material presented and discussed during Meeting #2 are provided below. The findings and recommendations are organized under the following categories:

- General Comments
- Orientation to the Project and Timeline
- Hydrogeologic Characterization Report
- Draft Tracer Test/Water Quality Monitoring Work Plan
- Panel Response to LOTT's Questions regarding the Tracer Work Plan
- Panel Response to Additional Questions from LOTT

3.1 General Comments

The following comments pertain to the Panel's overall review of the Reclaimed Water Infiltration Study.

- **Meeting #2 Materials and Presentation**.
    - The Panel appreciated the pre-meeting material, presentations, and site tour of the Prairie Hawks Recharge site.
    - In the future, please number the presentation slides for ease of reference.
- **Panel Meeting #2 Report Schedule:** The tracer test and groundwater quality characterizations are scheduled to begin January 2018. Due to this schedule, LOTT requested that the Panel submit its draft final report for Meeting #2 by December 15, 2017.
- **Study Scope**. The study as presented succeeds at evaluating water quality performance and system performance, but needs to be linked to the broader context of potential interaction with downgradient drinking water wells. Discuss this aspect of the scope of the study, which is lightly developed. For example:
    - As written, and consistent with the stated goals of Task 2 of the study, the current experimental design and data collection efforts described below are most effective in defining aquifer hydraulics and contaminant attenuation rates for the area in relatively close proximity (<3,500 feet) to the infiltration basins. These data will help to resolve aquifer flow paths and describe relationships between hydraulic retention time and contaminant attenuation for time scales of 6 months or less. The Panel notes that the current scope of Task 2 (and, more likely, an output of later project tasks) does not focus on understanding aquifer hydraulics and water quality impacts over longer time scales (>6 months) or defining potential effects at downgradient drinking water wells and drinking water consumers at greater distances (>3,500 feet) from the infiltration basins.

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- **Communication of Study Results**. Clarify how the results of the tracer test and groundwater quality characterization will be presented to and used with the public and regulators.

- **Data from past studies by LOTT.** Because reclaimed water has been used for spreading at the Hawks Prairie site for 10 years or more, the Panel suggests that it would be useful to summarize historical reclaimed water and groundwater data (e.g., flows, water quality data). This data may help put in context certain data and/or observations based on current or future studies.

3.2 Orientation to the Project and Timeline

The following comments pertain to the presentation provided on the structure, framework, status, and timeline of the Reclaimed Water Infiltration Study.

- The Panel appreciated the update on the status and schedule of the study.

- The Panel would like to receive more information about monitoring for potential interactions with downgradient drinking water wells, particularly from the standpoint of bromide (see Sections 3.4 and 3.5). In addition, the Panel would like more information on methods that have been used to identify, classify, and quantify sources of non-municipal waste inputs into sewers (e.g., industrial, commercial, medical facilities, and permitted discharges). How was this information used to inform the study design?

3.3 Hydrogeology Characterization Report

The following comments pertain to the draft report and presentation provided on the hydrogeologic characterization of the Hawks Prairie site, particularly focusing on (1) on-site wells and lysimeter installation, and (2) off-site monitoring wells.

- The report provides a good summary of the known and suspected hydrogeology of the Hawks Prairie recharge area. Substantial work has been accomplished to increase the spatial understanding of hydrogeologic conditions beneath and around the LOTT Hawks Prairie managed aquifer recharge site.

- One aspect revealed by the data is the degree of heterogeneity in terms of hydraulic conductivity values and aquifer composition. The identification and characterization of geologic layers are paramount in developing the understanding of local hydrogeology, and LOTT has done an excellent job in the latest round of well installations by using the best technology in the form of sonic drilling. This method provides continuous cores of the subsurface formations, which reveal fine-scale layers of sands with silts that may have an important role in the movement of recharge water through the vadose zone. The data advanced the understanding of perched groundwater zones encountered beneath Basin 4 during drilling for the lysimeter installations.

- On a broader scale, the work conducted to date has enhanced the understanding of the Shallow Aquifer, confining layer, and deeper Sea Level Aquifer. The main constraints to this work have

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been finding suitable drilling sites for new monitoring wells and securing the associated access agreements.

  - These constraints have restricted the spatial distribution of the well network, thereby limiting the well network's coverage of the complex and potentially multi-faceted groundwater flow paths that infiltrated reclaimed water will follow as it reaches the water table.

  - Because the monitoring wells are unlikely to capture all variations in the flow paths, the Panel cautions that predictions of groundwater movement may be over-generalized, and that the real system will behave in a more spatially variable manner.

- Understanding the groundwater flow at a managed aquifer recharge project is complicated by the creation of a groundwater mound that may dissipate recharge water away radially from the centroid of the recharge area. At least, in theory, it is what the textbooks would suggest in uniform aquifer conditions; however, the presence of regional groundwater flow in the Shallow Aquifer, determined to be generally from northeast to southwest across the facility footprint, can distort the shape of the mound and, therefore, the direction of spreading from the centroid, especially if other variables are present.

- Variables at the Hawks Prairie site that could distort the groundwater mound include substantial changes in saturated aquifer thickness and a suspected thinning or "pinching out" of the underlying confining layer.

  - The interpretation of the water-level data from the set of completed wells suggests that the saturated aquifer thickness declines significantly to the southeast, becoming effectively zero at MW-22, where the well installed just above the confining layer has been measured as dry. The confining layer still has appreciable thickness (~55 feet), as logged in the adjacent deeper well MW-21, but the water levels recorded in the nested pair of wells installed below and above the aquitard (MW-21 and MW-22, respectively) are so close as to be effectively identical.

  - This finding is significant because it confirms that (a) the Qf aquitard is absent to the southwest of the Hawks Prairie site and (b) the Shallow Aquifer and the Sea Level Aquifer are in direct hydraulic communication.

  - The conditions to the southwest of the Hawks Prairie site contrast with conditions directly beneath the site and extending to the north and east, where the Qf aquitard is 80 to 190 feet thick and sustains a vertical gradient of 9 to 45 percent across the upper confining units of the Qf aquitard.

- The groundwater level contours suggest that the confining layer may be absent below significant areas of the Shallow Aquifer to the southwest of the Hawks Prairie site, especially in the area between Wells 11, 20, and 27. Co-mingling likely occurs, with groundwater and infiltrated recharge water from the Shallow Aquifer entering the Sea Level Aquifer within closer proximity to the Hawks Prairie site, such that the travel time to the Sea Level Aquifer and its production wells may be significantly reduced.

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3.4 Draft Tracer Test/Water Quality Monitoring Work Plan

The following comments pertain to the presentation provided on the draft work plan for tracer testing and water quality monitoring of treatment effectiveness in the Hawks Prairie site.

- The Panel suggests that LOTT verify the dosage calculation in Table 4-3 on "Estimated Potassium Bromide Mass, Concentration, and Flow Rates Required for Tracer Test at 1 mgd Reclaimed Water Recharge Flow Rates." Information provided by LOTT following Meeting #2 shows that two separate dosage calculations (to achieve average bromide concentrations of 20 mg/L or 50 mg/L in the recharge water, respectively) appear to have become conflated in the single calculation shown in Table 4-3.

- Regarding mixing the tracer:

    - The Panel recommends bypassing the constructed wetlands at the Hawks Prairie site for the tracer addition effort. If the wetlands are bypassed, and if there is no free chlorine residual in the effluent distribution system, it could be most effective to add the tracer at the end of the wastewater treatment plant and allow it mix in the distribution system before the effluent discharges to the recharge basin.

    - If access to the treatment plant is not allowed, or if there are concerns that a free chlorine residual in the distribution system could contribute to low concentrations of brominated DBPs in the effluent before it reaches the recharge basin, then the tracer could be added at the recharge basin. During the Panel's visit to the Hawks Prairie site during Meeting #2, it appeared that the logical place to add the tracer is a centralized mixing box located at the recharge basin.

    - The Panel recommends maximizing the possibility for effective mixing and tracer dilution by (a) choosing an additional location as far upstream of the recharge area as possible and (b) promoting hydraulic or mechanical mixing within the distribution pipework to the degree possible.

    - The Panel recommends that LOTT sample the infiltration basin for trihalomethanes (THMs) during the tracer test.

- In addition to measuring total coliform, the Panel recommends measuring *E. coli* as a water quality parameter to evaluate the potential for fecal organisms to contaminate recharge water. Although it is unlikely there will be significant migration of coliform and *E. coli* in the subsurface, it is possible that coliform could be introduced into the wetland system.

3.5 Panel Response to LOTT's Questions regarding the Tracer Work Plan

LOTT compiled a list of questions directed to the Panel and the Science Task Force. The Panel's responses to these questions are provided below.

Question 1 – The current Tracer Test Work Plan calls for sampling 26 wells (Slides 1-2). It is possible that some proposed sampling locations for tracer may be redundant. If the proposed sampling plan

was streamlined to 19 wells (Slides 3-4), instead of the 26-well layout as shown in the current work plan, what effect would the changed monitoring well network have on the overall study?

Panel response to Question 1:

- The streamlined work plan seems reasonable to the Panel.
- The Panel has the following comments:
    - The proposed tracer testing involves accepted hydrogeologic methods and procedures. The resulting data will provide significant value that is a requirement for defensible model development and calibration.
    - The Panel has questions about the heterogeneity of the system (See Section 3.3).
    - Concentration of the tracer may vary due to inadequate mixing in the spreading basins.
    - The Panel suggests adding a monitoring well in the area where groundwater contour lines suggest aquifer comingling may be occurring (i.e., between MW-11 and MW-22).

Question 2 – Should the tracer test attempt to characterize interaction between the shallow and deep aquifers southwest of the Hawks Prairie site?

a) Would it be useful to evaluate samples from deep monitoring well MW21 as part of the tracer test? The well is near the intersection of the shallow and deep aquifers, and there is interest in knowing if the tracer will appear in the deep aquifer and that location.

b) Is the proposed monitoring well network sufficient to characterize the potential effects of the shallow/deep aquifer interaction on water quality? Currently there is no monitoring well to the east (downgradient) of deep well MW21 to evaluate water quality in the deep aquifer where the shallow and deep aquifers meet.

Panel response to Question 2:

- The Panel agrees that the tracer test should characterize the interaction between the shallow and deep aquifers southwest of the Hawks Prairie site to the extent possible; however, the study will be constrained by the distribution of available monitoring wells.
- The Panel recommends sampling Deep Wells MW-21 and MW-23. Sampling can be done once or twice a month, as feasible.
- Regarding the schedule: Clarify the use of Deep Well M-21 or Shallow Well M-22. These two wells are listed on the monitoring schedule as alternatives to each other, but they are not located in the same aquifer.

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Question 3 – Constructed Wetlands

Should the study account for the potential role of the constructed wetlands? (The constructed wetlands were not designed to provide treatment, although they may do so. Future infiltration projects will likely not include wetlands.)

a) The work plan states that for the first half of 2018, reclaimed water used for all recharge operations will flow first into the LOTT wetland ponds and then into the recharge basins. For the second half of 2018, the reclaimed water will be routed directly into the recharge basins and will bypass the wetland ponds.

   i. Is this the best plan? Should half the study period include the wetlands and half the study period not include the wetlands? Or should the reclaimed water either flow through the wetlands or bypass the wetlands for the duration of the tracer test?

   ii. If the study is constructed so that for half of the study period the wetlands are included, and for the other half the wetlands are bypassed, the four sampling events will be split; two when the wetlands are included and two when they are bypassed. What potential effect of changing the wetlands variable have on interpretation of the data?

b) If the wetlands are bypassed, the results will present a "worst case scenario" because soil aquifer treatment (SAT) will only occur in the recharge basins, instead of in both the recharge basins and the wetlands. Also, there may be less variability in the results because the inclusion of the wetlands would create another variable. The results from the bypassed-wetlands scenario will be more applicable to future infiltration sites, which are unlikely to include added wetlands. If the wetlands are included, however, the study results will reflect how the Hawks Prairie site is operated currently.

   i. If the wetland ponds are bypassed, could the resulting higher levels of chlorine in the reclaimed water negatively affect the microorganisms in the vadose zone, change the degree to which the microorganisms would contribute to SAT, and influence the results of the study?

   ii. If the wetland ponds are bypassed and a dechlorination agent is added to the reclaimed water, could that negatively affect the microorganisms in the vadose zone, change the degree to which they would contribute to soil aquifer treatment, and impact the results of the study?

   iii. If the wetlands are bypassed, will it affect the study in such a way that the findings will not be directly applicable to the Hawks Prairie site?

Panel response to Question 3:

- Without more data about the potential for the removal of contaminants through the constructed wetlands or the concentration of the chlorine residual in the reclaimed water, the Panel cannot answer this question. For example, if there is minimal removal of the more persistent trace contaminants found in the previous groundwater sampling, then bypassing the wetland should not affect the applicability of this study to the Hawks Prairie site.

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- Bypassing the wetlands would allow for a cleaner experiment and better model for the proposed long-term system operations.

- If the wetlands are bypassed during the tracer experiment, the LOTT project team could still evaluate changes to water quality that could occur when reclaimed water travels through the wetlands. For example, sampling could be conducted at the start of the tracer study to at least determine: (1) the wetland capability to reduce trace contaminants in the reclaimed water; and (2) any water quality effects that the wetlands effluent has on contaminant removal when water from the wetlands travels through the vadose zone below the recharge ponds.

- If LOTT decides to further study the wetlands alternative, the Panel has the following comments:

    - Changing the wetland variables would complicate data interpretation.

    - Sampling methods need to be improved to evaluate the performance of the constructed wetlands, which could help with future project design.

        - Composite samples for trace contaminants should be collected from the effluent at the reclaimed water treatment plant. These samples should provide an accurate indication of the influent load to the wetlands and the infiltration beds. Effluent concentrations in wastewater treatment systems vary over a diurnal pattern. Influent flowrates vary also, but the Panel's understanding is that the reclaimed water satellite facility receives a constant flow rate. An example of variations in influent concentrations is the typical pattern for influent ammonia nitrogen (NH_3-N): Most of the NH_3-N to the treatment facility is from urine, which is higher in both concentration and total load to facilities at certain times of the day, especially in mid- to late-morning hours and in the late afternoon. Many trace contaminants (e.g., household chemicals, drugs, and hormones) are derived from urine; therefore, their concentration can be expected to vary over the day. Consequently, a single grab sample to characterize the treatment performance of the wetland, as well as the load to the wetland and infiltration basin, is not representative of average conditions.

    - Column testing may be needed to determine how chloramine affects SAT, although discussions with LOTT's project team indicated that chloramines are dissipated in the first two inches of the vadose zone. Furthermore, dechlorination agents like thiosulfate are fairly reactive and should not travel very far into the subsurface.

Question 4 – Ecological considerations for tracer chemicals.

c) Two conservative tracers, bromide and sulfur hexafluoride (SF_6), are proposed to measure travel time of groundwater flowing from Basin 4 through the vadose zone and groundwater.

i. Potassium bromide is the preferred salt for the bromide tracer. The recommended concentration of potassium bromide delivered to the recharge basins is 50 mg/L over a 7-day period, which will result in downgradient maximum concentrations of 12 to 3 mg/L at distances of 250 to 2,500 feet. Standing water in the basin will contain 50 mg/L KBr. Is there a risk to wildlife to have standing water in the recharge basin with

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such a high salt (KBr) concentration (due to the introduction of the tracer prior to water flowing into the basin)?

ii. ***Is there a risk to microorganisms in the vadose zone due to the high salt (KBr) concentration from the tracer?***

iii. ***Will the KBr or SF_6 tracers potentially impact the microorganism population and/or effectiveness of soil aquifer treatment/degradation?***

Panel response to Question 4:

- Public health issues:

  - It would be useful for LOTT and/or its project team to estimate (a) the bromide concentration expected at the closest drinking water well and (b) how long after the tracer addition that bromide concentrations may occur. It also would be important to know what water treatment processes are provided for the extracted drinking water. This information can help determine relative risk and if any actions are warranted to reduce risk, such as adding a process at the drinking water well if needed to remove bromide during the tracer study.

- The Panel concludes there is no indication that wildlife will be harmed by the presence of the tracer in the recharge ponds because (a) the tracer will be present for only a short time period, and (b) the proposed bromide concentration of 50 mg/L is equal to or less than that of seawater.

- If incomplete mixing occurs, there may be a risk of creating high-concentration hot spots of bromide. Microbes are sensitive to bromide, and the effect of the tracer on the microbial community depends on the bromide concentration. Based on limited scientific literature (see the comments below), the Panel cannot conclude that there will be no effect to the microbial community.

  - The Panel also notes that nearly all hydraulic and water quality changes will affect the microbial community structure and function to some degree. It is likely that the microbes can recover function and community abundance with time; however, to limit any adverse effects on microbial populations, effective mixing is recommended to avoid the potential for hot spots.

  - Thorough mixing also would help to maintain the capability for contaminant attenuation in the vadose zone and improve the quality of the tracer data for subsequent hydraulic modeling.

- A study by Bech et al. (2017) on the effect of potassium bromide addition on the degradation of three pesticides for four soil types suggests there will be little effect, if any, on the soil microbial population at the potassium bromide concentrations to be used in the proposed study (50 mg/L). A comparison of the abundance of operational taxonomic units (OTUs) from 16 S amplicon sequencing between experiments with and without pesticides, and potassium bromide showed no significant effect on the abundance of the majority of species. In cases

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where an effect was observed, there was still a significant abundance of bacteria. These results suggest that potassium bromide at the concentrations to be used may not be high enough to have a significant effect on the soil microorganisms.

Question 5 was removed from the list of questions.

Question 6 – Is the data representative?

a) ***The tracer test plan calls for four water quality sampling events. Are four events adequate to obtain the data needed to accurately answer the study questions?***

Panel response to Question 6:

- Four quarterly sampling events over a 1-year period are normal and representative for groundwater sampling.

- Because groundwater moves slowly, it is important to allow sufficient time to elapse between successive samples to ensure that groundwater quality data are statistically independent.

- Gibbons (1994, pages 163 and 185) recommends sampling groundwater no more than quarterly to increase the likelihood of obtaining statistically independent data.

Question 7 – The RWIS is designed for 1 MGD recharge for 6-12 months. Does the Panel feel that the water quality results produced by the study will be representative of the full-scale project, which will recharge 5 MGD across eight basins for the duration of the project (assume 30-40 years)?

Panel response to Question 7:

- The groundwater flow, mound development, and spatial extent of the recharge water flow path(s) may change substantially under greater recharge loading. Groundwater modeling may be used to examine the effect of increasing the scale of recharge operations, but changing the scale would increase the uncertainty of the predictions. LOTT may reduce uncertainty and improve confidence in the model and study predictions going forward by maintaining ongoing operational monitoring of the full-scale project, including periodic reassessment and recalibration of the groundwater model.

- If this study can establish a clear relationship between the hydraulic retention time and the attenuation/removal of constituents, then the LOTT project team could scale the results up to 5 mgd. If the tracer test can be used to predict the expected hydraulic retention times at the different monitoring wells, and these hydraulic retention times are stable for different seasons and different operational conditions, then the project team can develop quantitative relationships between hydraulic retention time and water quality parameters. These relationships are expected to be valid at higher recharge rates. To confirm validity, the Panel recommends that the project team calculate the expected change in hydraulic retention time to monitoring wells that may occur when the hydraulic loading rate is increased. This type of analysis should be possible once the hydraulic modeling of the aquifer is completed.

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3.6 Additional Questions from LOTT

LOTT requested the Panel's feedback on the following three additional questions.

1. ***Does the Panel agree with the proposed use of potassium bromide (KBr) tracer, to be delivered to the recharge basins at a concentration of 50 mg/L? (See Chapter 4, pp. 23-25)***
   Panel response:

   - It is the Panel's opinion that (a) the likely impact on human health from proposed use of potassium bromide (KBr) tracer at a concentration of 50 mg/L can be evaluated as described below and (b) the use of KBr is unlikely to cause a risk to wildlife; however, the Panel cautions that potential "hot spots" of KBr created by incomplete mixing may create some elevated risk in some downgradient drinking water wells, which will not be addressed in the analysis.

   - Because the bromide tracer will be deliberately added at a concentration of 50 mg/L to an aquifer that supplies drinking water wells that may be downgradient from the location of the tracer addition, it is incumbent on LOTT to assure the public consuming the water that the bromide addition will not adversely affect public health.

     - The Panel calls LOTT's attention to the need to ensure that the health risks associated with introducing high concentrations of bromide tracer into a drinking water source are minimal.

     - An assessment of the probability of potential health consequences is required. In the case where bromide will be used as a conservative tracer of water flow, a large amount of potassium bromide tracer will be introduced into the reclaimed water spreading basin(s) over a 7-day period.

     - There are two pathways by which elevated bromide can contribute to adverse health effects: (a) through direct absorption of bromide into the body; and (b) indirectly by changing the nature and amounts of disinfection byproducts produced when water containing elevated bromide is disinfected for use as a drinking water source.

   - Bromide is known as a normal constituent of the body and has a low level of toxicity, but if there are downgradient drinking water wells, the probability is high that the exposure of bromide to consumers of the infiltrated water will be 50 to 100 times greater than background (0.025 mg/L) as the plume of bromide works its way through the aquifer(s).

     - The information in the Material Safety Data Sheets (MSDS) for potassium bromide is not sufficient to draw conclusions about the safety of doses that will be experienced.
     - Bromide has a relatively long terminal half-life (100 to 300 hours in rats). The steady state concentration in total body water will steadily increase as the bromide is consumed each day (see Cousins et al., 2002; Sosa and Stone, 2010). Using the rat

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half-life, it will take 20-60 days of intake for bromide to reach steady state in the body (rule of thumb is 5 times the half-life).

  - In particular, the long terminal half-life for humans that is implied but not estimated in Cousins et al. (2002) is as least as long as the half-life for rats. The half-life probably reflects the fact that bromide mixes with total body water in a similar fashion as chloride does. There appear to be some "deep" compartments for bromide from which it is released slowly that have not been thoroughly characterized.

- The influence of bromide on disinfection byproduct (DBP) formation can be assessed by evaluating the formation potentials for the different classes of DBPs in downgradient drinking water wells (or a sampling point located on the path to drinking water wells).

  - This effect is most easily addressed with all nine halo acetic acids (HAA9) and regulated trihalomethane (THM4) classes of byproducts because the analytical methods for these DBPs are well established in the drinking water community. Many other classes of DBPs are produced, but the toxicological data available for those classes are more limited. It is important to realize that the construction of the HAA5 and THM4 regulations are tenuously linked to risk.

  - To properly address risk, it is necessary to use estimates of concentrations of each chlorinated, brominated, and mixed bromo-chloro byproducts in these classes as they vary widely in their carcinogenic potency to arrive at an accurate estimate of the impact of increased amounts of brominated byproducts (Hua et al., 2006).

  - Nevertheless, the U.S. Environmental Protection Agency (USEPA) used the epidemiological data that associated bladder cancer risk most closely to brominated derivatives (Regli et al., 2015). It is an easier analysis even though none of these compounds have been shown to induce bladder cancer (tacitly recognizing that the THMs are not the carcinogens, but using the amount of bromine substitution in this class as a surrogate for the extent of bromine substitution in other DBPs).

- The Panel recommends that LOTT should: (a) estimate the dose of bromide that humans might be exposed to over the likely period of increased exposure to bromide resulting from the introduction of the tracer; and (b) estimate the incremental increase in cancer risk that would ensue from the greater formation of brominated DBPs formed when water containing bromide is withdrawn from the aquifer and disinfected for use as drinking water.

  - **Appendix A** provides a short discussion of the health issues associated with elevated bromide intake and suggests an approach that might be used to assure the public that the tracer test is unlikely to cause adverse health effects.

  - Any analyses performed should be presented to the Panel for review.

2. Does the Panel agree with the proposed use of sulfur hexafluoride (SF_6) in the groundwater monitoring wells? (see Chapter 4.2, pp. 26-27)

Panel response:

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- SF_6 has been used as a tracer in other groundwater infiltration systems (see NWRI, 2004); however, the Panel was concerned that the data for safety are based on studies conducted as far back as the 1950s, before modern concerns of toxicity had evolved. Only a few peer-reviewed papers have been published since that time outside of medical/clinical journals.

    - SF_6 is used extensively in medicine as a contrast agent that is administered intravenously (Morel et al., 2000) or with as much as 79 percent SF_6 in inhaled air (Ostlund et al., 1992) and in certain clinical procedures (see Harada et al., 1984; Hattori et al., 1994).

    - A review of 352 consecutive echo contrast examinations in 274 patients (Geleijnse et al., 2009) with the product SonoVue found mild adverse reactions in two of 198 patients (1 percent) with single dose (usually <1.0 mL iv total injection as stabilized bubbles of the gas) examinations or in two of 76 patients given multiple examinations. Severe reactions were observed in three patients that were associated with allergic reactions. Allergic reactions to SF_6 cannot be ruled out, but it is more probable that these effects were due to other components of the administered bubbles, such as polyethylene glycol, which is used as a stabilizer.

- In addition to the study mentioned above, a pharmacokinetic study of the elimination of SF_6 in 12 subjects (seven men, five women) given SonoVue at doses of 0.03 or 0.3 milligrams per kilogram (mg/kg) body weight (Morel et al., 2000) found that SF_6 was eliminated from the blood with a terminal half-life of between 5 and 7 minutes; therefore, SF_6 does not bioaccumulate.

    - The Panel recommends that LOTT review the doses administered in these studies (especially Geleijnse et al., 2009 and Morel et al., 2000) and compare them to doses that people could experience from the amounts of SF_6 introduced into the aquifer(s) at the proposed concentrations of 0.07 to 0.01 millimoles per liter.

    - It is important to note the low level of toxicity of SF_6 implied in these studies is consistent with older data (Hodge et al., 1958 and those cited within the MSDS).

3. Can the Panel provide feedback on the proposed streamlined sampling plan?

Panel response:

- The Panel feels the streamlined sampling plan, which calls for collecting samples from 19 wells instead of the 26 illustrated in the original tracer test work plan, is reasonable.

- See also the Panel's Response to Question 1 in Section 3.5.

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APPENDIX A: BACKGROUND ON THE NWRI PANEL PROCESS

About NWRI

For more than 20 years, NWRI – a science-based 501c3 nonprofit and joint powers authority located in Fountain Valley, California – has sponsored projects and programs to improve water quality, protect public health and the environment, and create safe, new sources of water. NWRI specializes in working with researchers across the country, such as laboratories at universities and water agencies, and is guided by a Research Advisory Board (representing national expertise in water, wastewater, and water reuse) and a six-member Board of Directors (representing water and wastewater agencies in Southern California).

Through NWRI's research program, NWRI supports multi-disciplinary research projects with partners and collaborators that pertain to treatment and monitoring, water quality assessment, knowledge management, and exploratory research. Altogether, NWRI's research program has produced more than 300 publications and conference presentations.

NWRI also promotes better science and technology through extensive outreach and educational activities, which includes facilitating workshops and conferences and publishing White Papers, guidance manuals, and other informational material.

More information on NWRI can be found online at www.nwri-usa.org.

About NWRI Panels

NWRI also specializes in facilitating Independent Advisory Panels on behalf of water and wastewater utilities, as well as local, county, and state government agencies, to provide credible, objective review of scientific studies and projects in the water industry. NWRI Panels consist of academics, industry professionals, government representatives, and independent consultants who are experts in their fields.

The NWRI Panel process provides numerous benefits, including:

- Third-party review and evaluation.
- Scientific and technical advice by leading experts.
- Assistance with challenging scientific questions and regulatory requirements.
- Validation of proposed project objectives.
- Increased credibility with stakeholders and the public.
- Support of sound public-policy decisions.

NWRI has extensive experience in developing, coordinating, facilitating, and managing expert Panels. Efforts include:

- Selecting individuals with the appropriate expertise, background, credibility, and level of commitment to serve as Panel members.
- Facilitating hands-on Panel meetings held at the project's site or location.

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- Providing written report(s) prepared by the Panel that focus on findings and comments of various technical, scientific, and public health aspects of the project or study.

NWRI has coordinated the efforts of more than 40 Panels for water and wastewater utilities, city and state agencies, and consulting firms. Many of these Panels have dealt with projects or policies involving groundwater replenishment and potable (indirect and direct) reuse. Specifically, these Panels have provided peer review of a wide range of scientific and technical areas related water quality and monitoring, constituents of emerging concern, treatment technologies and operations, public health, hydrogeology, water reuse criteria and regulatory requirements, and outreach, among others.

More information about the NWRI Independent Advisory Panel Program can be found on the NWRI website at http://nwri-usa.org/Panels.htm.

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APPENDIX B: PREVIOUS PANEL ACTIVITIES

The following list includes information about the activities of the Independent Advisory Panel to Review the Reclaimed Water Infiltration Study for the LOTT Clean Water Alliance. These activities span the period of 2013 to 2017.

2013

- The Panel was established by the National Water Research Institute (NWRI).

2014

- **Panel Meeting #1**: A 2-day meeting of the Panel was held on February 18-19, 2014, at LOTT's administrative offices and WET Science Center in Olympia, Washington. This was the first time the Panel met to review LOTT's Reclaimed Water Infiltration Study. The focus of the meeting was on the proposed scope of work for the Reclaimed Water Infiltration Study. The product of this meeting was a 28-page Panel report dated August 1, 2014.

2017

- **Subcommittee Meeting #1**: On March 31, 2017, a Subcommittee of the Panel met with members of LOTT's Project Team using a web-enabled conference call to discuss hydrogeological aspects of the *Reclaimed Water Infiltration Study Work Plan: On-Site Wells and Lysimeter Installation and Off-Site Monitoring Wells, Hawks Prairie Area* (dated February 22, 2017). The Subcommittee documented its findings and recommendations in a memorandum to LOTT dated April 28, 2017.

- **Follow-Up to Subcommittee Meeting #1**: LOTT asked the Subcommittee to review an addendum **(**Dated May 9, 2017) to the *Reclaimed Water Infiltration Study Work Plan: On-Site Wells and Lysimeter Installation and Off-Site Monitoring Wells, Hawks Prairie Area* (dated February 22, 2017). The Subcommittee documented its comments on the work plan addendum in a memorandum to LOTT dated May 24, 2017.

- **Pre-Meeting Conference Call in Advance of Panel Meeting #2**: A web-enabled conference call was held on October 11, 2017, between NWRI, LOTT, and the Panel. During this call, the LOTT Project Team provided an update on the work accomplished to date and the tasks remaining in the study. LOTT's presentations focused on the results of the water quality characterization and an introduction to the tracer test.

- **Panel Meeting #2**: A 1-day meeting of the Panel was held on November 17, 2017, at LOTT's administrative offices and WET Science Center in Olympia, Washington. This meeting represents the second time the full Panel has met to review LOTT's Reclaimed Water Infiltration Study. The focus of the meeting was on tracer testing and the hydrogeologic characterization of the Hawks Prairie recharge area.

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APPENDIX C: PANEL MEMBER BIOGRAPHIES

Chair: James Crook, Ph.D., P.E., is an environmental engineer with more than 45 years of experience in state government and consulting engineering arenas, serving public and private sectors in the United States and abroad. He has authored more than 100 publications and is an internationally recognized expert in water reclamation and reuse. Crook spent 15 years directing the California Department of Health Services' water reuse program, during which time he developed California's first comprehensive water reuse criteria. He also spent 15 years with consulting firms overseeing water reuse activities, and is now an independent consultant. He currently serves on several advisory panels and committees sponsored by NWRI and others. Among his honors, he was selected as the American Academy of Environmental Engineers' 2002 Kappe Lecturer, the WateReuse Association's 2005 Person of the Year, and the 2016 California WateReuse Presidential Award. Crook received both an M.S. and Ph.D. in Environmental Engineering from University of Cincinnati, and a B.S. in Civil Engineering from University of Massachusetts.

Richard Bull, Ph.D. became Professor Emeritus at Washington State University on his retirement in 2003. Formerly, he served as a senior staff scientist at DOE's Pacific Northwest National Laboratory; Professor of Pharmacology and Toxicology at Washington State University; and Director of the Toxicology and Microbiology Division in the Cincinnati Laboratories for USEPA. Bull has continued work as a Consulting Toxicologist and researcher with MoBull Consulting (Richland, WA), where he conducts studies on the chemical problems encountered in water for water utilities and for federal, state, and local governments. His early research focused on central nervous system effects of heavy metals, and progressed to studies of carcinogenic and toxicological effects of disinfectants and disinfection by-products, halogenated solvents, acrylamide, and other contaminants of drinking water. He has served on international scientific working groups of the World Health Organization, and of the International Agency for Research on Cancer addressing carcinogenic activity of a wide number of regarding various environmental contaminants and medical devices. Bull served several terms as a member USEPA's Science Advisory Board and as Chair of the Drinking Water Committee and served as a member and/chair of several committees convened by the National Academy of Sciences. Bull holds a Ph.D. in Pharmacology from University of California, San Francisco, and a B.S. in Pharmacy from University of Washington.

Edward Kolodziej, Ph.D. is Associate Professor at the University of Washington, where he holds joint appointments in the Division of Sciences and Mathematics (UW Tacoma) and the Department of Civil and Environmental Engineering (UW Seattle). He works on a variety of local and regional water quality issues, especially those focused on organic contaminants, through The Center for Urban Waters in Tacoma, WA. Kolodziej's interests include water quality and contaminant fate in natural and engineered systems, especially focusing on interdisciplinary approaches to complex environmental issues affecting water and ecosystem health. His research has been published in Science, and featured in news media such as Nature, Scientific American, U.S. News and World Report, Yahoo Health News, BBC Radio's "Inside Science", and the Huffington Post among others. Kolodziej earned an M.S. and Ph.D. in Environmental Engineering at University of California at Berkeley, and a B.S. in Chemical Engineering from the Johns Hopkins University.

Michael Kenrick, P.E., LHG, is Senior Principal Hydrogeologist with GeoEngineers in Redmond, Washington. His expertise includes: aquifer hydraulics, well testing; groundwater modeling; infiltration, flow and seepage; percolation and recharge; groundwater chemistry and quality; and water rights assessments. Kenrick trained as a civil engineer and hydrogeologist and has applied knowledge from a career serving commercial and municipal clients in key water-related sectors including groundwater, water supply, stormwater infiltration, artificial recharge, water reuse, dewatering for the mining and construction industries, and environmental assessment. He gained experience in the UK, Europe, Africa, and Asia before moving to Seattle in 1985, where he honed hydrogeologic methods for groundwater issues in the Pacific Northwest.

John Stark, Ph.D. is a Professor of Ecotoxicology and Director of the Washington Stormwater Center at the Washington State University Research and Extension Center in Puyallup. His research addresses the development of hazard and risk assessment for aquatic organisms inhabiting rivers and streams in the Pacific Northwest. Stark is an expert in population modeling and has developed population-level risk assessments based on matrix and differential equation models. Recent projects involve determination of the effects of stormwater low impact development on salmon, zebra fish, and aquatic invertebrate health and assessing the impact of pesticides on endangered butterfly species. He has published more than 125 peer-reviewed journal articles, numerous book chapters, and a book entitled "Demographic Toxicity: Methods in Ecological Risk Assessment." He is a member of the Puget Sound Partnership Science Panel, has served on the Pesticide Advisory Board for the Washington State Department of Agriculture. Stark holds a Ph.D. in Entomology and Pesticide Toxicology from University of Hawaii, an M.S. in Entomology from Louisiana State University, and undergraduate degrees in biology and forest biology from S.U.N.Y. and Syracuse University, respectively.

David Stensel, Ph.D., P.E., is Professor Emeritus of Civil and Environmental Engineering at University of Washington. Prior to his academic positions, he developed and applied industrial and municipal wastewater treatment processes, with a focus on biological nutrient removal. His research has included developing process improvements on technologies including membrane bioreactors, anaerobic digestion, fixed film, onsite nutrient removal systems, and granular activated sludge. He has authored or coauthored more than 150 technical publications, including the fourth and fifth editions of the Metcalf and Eddy Wastewater Engineering book, a noted reference and authority on wastewater treatment unit processes and design. His work has been funded by federal agencies, utilities and WE&RF. Recent awards include: Frederick Pohland Medal, American Academy of Environmental Engineers and Association of Environmental Engineering and Science Professors, Washington State Academy of Science, Pacific Northwest Clean Water Association Individual Distinguished Service Award, and Water Environment Federation Fellow. Stensel holds a Ph.D. and MSE in Environmental Engineering from Cornell University and a BSCE in Civil Engineering from Union College.

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APPENDIX D: PANEL MEETING #2 ATTENDEES

Panel Members

- Chair: James Crook, Ph.D., P.E., Environmental Engineering Consultant (Boston, MA)
- Richard Bull, Ph.D., MoBull Consulting (Richland, WA)
- Michael Kenrick, PHG, GeoEngineers (Redmond, WA)
- Edward Kolodziej, Ph.D., University of Washington (Tacoma, WA)
- John Stark, Ph.D., Washington State University (Puyallup, WA)
- David Stensel, Ph.D., P.E., University of Washington (Seattle, WA)

National Water Research Institute

- Suzanne Sharkey, Water Resources Scientist and Project Manager
- Gina Vartanian, Communications Manager

LOTT Clean Water Alliance Project Team

- Lisa Dennis-Perez, LOTT
- Ida Fischer, HDR
- Peter Fox, Arizona State University
- Jeffrey Hansen, HDR
- John Koreny, HDR
- Wendy Steffensen, LOTT

Science Task Force

- Donna Buxton, City of Olympia
- Kevin Hansen, Thurston County
- Erica Marbet, Squaxin Island Tribe
- Koenraad Mariën, Washington State Department of Health
- Hans Qiu, Washington State Department of Ecology
- Julie Rector, City of Lacey
- Dan Smith, City of Tumwater
- Art Starry, Thurston County

NATIONAL WATER RESEARCH INSTITUTE

Independent Advisory Panel for LOTT CWA Reclaimed Water Infiltration Study

AGENDA

November 17, 2017

Location	Contact
LOTT Clean Water Alliance 500 Adams Street, NE Olympia, WA	**Suzanne Sharkey (NWRI)** (714) 378-3278 (office) (949) 258-2093 (mobile)

Meeting Objectives

- Review and discuss the hydrogeological report and the tracer test work plan
- Facilitate interaction/Q & A between the Panel and the LOTT project team
- Allow time for the Panel to meet in a closed session to discuss the information presented and begin drafting recommendations
- Tour the Hawks Prairie site

OPEN SESSION begins at 7:30 am in the Board Room. Attended by Panel, LOTT Project Team, Science Task Force, and NWRI staff.

7:15 am	Continental breakfast provided	
7:30 am	Welcome/Introductions/Review Agenda	Jim Crook, Panel Chair
7:35 am	Orientation to project and timeline	Wendy Steffensen, LOTT
7:45 am	Hydrogeology Report Briefing	Jeff Hansen and John Koreny, HDR
8:30 am	Tracer Test Work Plan	Jeff Hansen and John Koreny, HDR

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9:15 am	Panel Q&A Period	Facilitated by Jim Crook
10:00 am	Wrap-Up with Task Force	

CLOSED SESSION begins at 10:00 am. Attended by Panel and NWRI.

10:00 am	Panel discusses the information presented and begins to draft recommendations.	Moderated by Jim Crook, Chair

WORKING LUNCH begins at 11:30 am. Attended by Panel, LOTT Project Team, and NWRI.

12:00 pm	Panel returns to closed session.
2:00 pm	**PANEL MEETING ADJOURNS**
2:15 pm	Tour of Hawks Prairie Site to observe the five wetland ponds, eight recharge basins, wells, and lysimeters.
3:30 pm	**TOUR ENDS**

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APPENDIX F: DIRECT EFFECTS OF BROMIDE

The dose of bromide can be approximated by integrating the daily intake of bromide from drinking water from the location of the farthest downstream monitoring well to generate a breakthrough curve. The curve can be used to estimate both the daily doses and total dose of bromide that might be experienced. Because the data provided by the LOTT project team are insufficient to project bromide concentrations in potentially downgradient drinking water wells, the Panel suggests using the most distant monitoring well on the path to any drinking water well as a surrogate. These modeling efforts would provide a basis for developing a worst-case estimate of exposure to bromide. The magnitude of this dose can be confirmed by analyses over the period during which elevated bromide concentrations are detected at the surrogate well, or at drinking water wells when the tracer reaches them.

The doses of critical sensitive populations should be explicitly addressed using USEPA estimates of drinking water consumption across age groups. These doses can be compared to levels of bromide that have resulted in the blood of individuals with bromism. The daily exposures can be integrated over the active exposure time and extended through the washout period of bromide from the body, referencing existing pharmacokinetic models (see Cousins et al., 2002). A terminal half-life of bromide in humans has not been established, but the terminal half-life of bromide in the blood of rats has been reported to range from 100 to more than 300 hours, depending upon the animal's sodium intake (Pavelka et al., 2005). The maximal steady-state blood levels of bromide will be achieved at a time approximately 5 times the half-life (20 to 60 days based on the rat data). The Panel suggests the steady-state levels from documented exposures can be used as indications of effect/no-effect levels rather than formal use of the pharmacokinetic model.

Direct exposure to bromide can cause adverse health effects, including: (a) central nervous system (CNS) effects, (b) thyroid effects; (c) effects of prenatal exposure on postnatal development and brain development; and (d) skin eruptions. The key adverse health effects studies reviewed by the Panel include Sangster et al. (1992) and van Gelderen et al. (1993). These studies establish serum/plasma levels of bromide associated with no-effect doses administered over extended periods of time (8 and 12 weeks, respectively). If the terminal half-life of bromide in the rat is predictive of humans, then serum/plasma concentrations in these studies should represent steady-state levels. The effects on both CNS and serum/plasma thyroid hormone concentrations were examined. Sangster et al. administered 1 mg/kg day^{-1} of bromide to males and non-pregnant females. Blood levels were 6.4 mg/L in controls and 78 mg/L in treated individuals. There were no changes observed in physical examinations taken before, during, and after the experiment. Van Gelderen et al. (1993) employed doses of 0, 4, and 9 mg/kg day^{-1} to healthy female volunteers. Bromide was administered for the first three menstrual cycles (approximately 12 weeks), and analyses were conducted at the end of exposure and following three additional menstrual cycles after the termination of treatment. No significant differences in thyroid hormones between groups were noted, but changes in alpha-1 and beta bands of the EEG were recorded. There was no difference in visual-evoked responses among the groups. This study established a no-effect dose level of 4 mg/kg day^{-1} and a no-effect blood level of 257 mg/L.

Neither the USEPA nor WHO has established a guideline for bromide. The WHO 2017 guidelines suggest that for a range of intakes between 0-4 mg/kg day^{-1} derived from van Gelderen et al. (1993), and assuming a 50-percent relative source contribution for water, the upper limit of the range would correspond to a 6-mg/L level for adults. WHO suggests an upper limit of 2 mg/kg day^{-1} for a 10-kg child. This limit does not conform to the approach taken by USEPA (2004), which used a 95-percent confidence limit to determine the consumption for children 0-1 month of age (i.e., nursing children). The USEPA's

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approach conforms to a drinking water consumption of 1 liter (L) by a 3.3-kg child, which would correspond to 0.7 mg/L of drinking water.

There are many documented case studies of bromism that have been associated with the excessive and chronic consumption of bromide salts used as sedatives and to control epileptic seizures in infants as well as adults, a group of bromoureides that had various therapeutic uses, organic compounds given in the form of bromide salts, brominated alkanes used in anesthesia, and brominated vegetable oil (Lugassy and Nelson., 2009). CNS effects of bromide have been reported in cases of exposure of humans and animals (mostly dogs) to pharmaceuticals containing one or more bromide salt or brominated organic compounds that are metabolized to bromide. As a result, the estimates of dose are reasonably accurate relative to human data for other chemicals. More importantly, measures of serum/plasma bromide concentrations associated with these doses have been made in many of the studies (representative publications include: Nuki et al., 1966; Whybrow and Ewing, 1966; Boyles and Martin, 1967; Moles et al. 1981; Frances et al., 2006; Hsieh et al., 2007; and Horowitz, 2008). A single study recorded symptoms of bromism in a female consuming bromide at 21 mg/L from drinking water (Brenner, 1978), which is a much lower dose to produce bromism than reported in other studies. In this case, the serum bromide level was 383 mg/L. It may be that this woman had other undocumented exposures to bromide. Symptoms disappeared with one week of hospitalization. Non-toxic serum/plasma bromide concentrations with respect to the CNS effects are estimated to be 400 mg/L (Sosa and Stone, 2010), but the levels observed by van Gelderen et al. (1993) should be considered most reliable. Lower effect levels of 250 and 310 mg/L were reported for two cases (Battin and Varkey, 1982). Consequently, one might choose a lower value of 100 mg/L serum/plasma levels as the no-effect level (i.e., approximately one-third of a lowest-observed-adverse- effect blood level [LOAEL]).

The observation that bromide blood concentrations were rapidly reduced after exposure to bromide was curtailed and almost all symptoms appeared reversible within the same time period. An uncertainty factor (UF) should be selected to account for within species variability (100/10 = 10 mg/L in serum or plasma). This blood level would be achieved-with a dose of 1-mg bromide/kg day^{-1} (35 mg/L in drinking water for an adult male consuming 2 liters of water per day); however, this value does not address doses associated with age and sex specific water intake should be used to extend estimates of dose to sensitive groups (USEPA, 2004). The concentrations derived here for adults are slightly higher than WHO's values because of different assumptions of body weight relative to the USEPA values; however, taking this factor into account would not lead to an acceptable level for newborns above 1 mg/L.

Absorbed bromide is incorporated into thyroglobulin as bromine in place of iodine (Buchberger et al., 1990). No indications were found in the literature that this reaction interferes significantly with thyroid function; however, intakes of sodium bromide doses of 4, 8, and 16 g/kg progressively depressed serum free thyroxin concentrations observed with an iodine deficient diet Buchberger et al., 1990). The extreme nature of this experiment precludes its use as a basis for risk assessment.

With respect to the effects of bromide on growth and brain development, it appears that this effect occurred with treatments much greater than the human exposures documented above (2.4 g NaBr/L from the 5th to the 15th day of gestation). LOTT should acknowledge the existence of this paper, indicate the enormity of the dose, and the probability that this effect would not be seen at doses that do not affect the thyroid (Sangster et al., 1982; van Gelderen et al., 1993).

The skin eruptions reported with bromide exposure are less straightforward because two of the four case reports reviewed involved exposures of chemists in the workplace, where exposures were not

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limited to bromide (Cohen et al., 2001). The nature of the skin eruptions as described were not consistent with other reports of bromism. Nevertheless, both women were diagnosed with bromism. A third case was associated with the long-term consumption of bromides and a high serum bromide (Oda et al., 2016). The exposure was complicated by a use of an over-the-counter preparation, bromovaleylurea (the Panel only had access to an abstract of this publication). LOTT should review the article by Oda et al. to see if the serum bromide levels are presented and to judge the usefulness of this paper for judging risks from bromide.

The final case report involved skin eruptions in a newborn from consuming bromide in its mother's milk that contained high levels of bromide 15 days after parturition (1,200 mg/L). The mother had been administered potassium bromide and chloral hydrate for several days before delivery. The last dose was the day of parturition. Bromide was cleared from milk over the next 20 days. It is difficult to put this case in the same framework because blood concentrations were not reported for the mother or the child. Judgements will have to be made based on the one milk concentration of bromide measured 15 days postpartum. The mother's milk concentration would have likely been maximal the day after parturition and likely much higher than the 1,200 mg/L measured the 15th day of parturition. On the basis of the Panel's brief examination of these studies, it seems the skin eruptions do not appear until much higher doses of bromide than required for CNS or thyroid effects.

Effects of bromide on formation of disinfection byproducts when water is withdrawn and treated
Bromide contributes to the formation of disinfection byproducts upon addition of disinfectants to a drinking water source. All disinfectants contribute to byproduct formation, although the type or amounts produced vary among disinfectants. The chief issue is that elevated bromide concentrations increase the amount of DBPs produced (bromine has a higher molecular weight than chlorine) and, more importantly, the speciation among byproducts (e.g., elevated bromide will increase the bromine-to-chlorine ratio in the byproducts formed) (Hua et al., 2006; Sun et al., 2009). Estimates of the impact of increased mass of THM4 resulting from bromide concentrations of 50 µg Br-/L (i.e., 1/1,000 of the bromide being added as a tracer) indicated that the increased amounts of brominated DBPs could increase bladder cancer risk to between 10^{-4} to 10^{-3} lifetime risk in approximately 90 percent of the 201 water treatment plants evaluated (Regli et al., 2015). This result does not bode well for mg/L concentrations that might be present in the water for some time as a result for the use of bromide as a tracer. These estimates do not incorporate generally higher carcinogenic potencies of some of the brominated byproducts relative to their strictly chlorinated analogs in experimental animals (i.e., chloroform, dichloroacetic acid, and trichloroacetic acid).

LOTT may address this problem by measuring the formation potentials of the THM4 and HAA9 in water containing projected concentrations of bromide at the first drinking water well. The formation potentials will represent higher levels of DBPs than would be formed in actual drinking water disinfection, so these levels should be considered worst case. Considering the time involved for the bromide to reach a drinking water well, a monitoring well projected to have the longest travel time could be used as a surrogate sampling site. A detailed analysis of the speciation of the THM4 and the distribution of bromine substitutions can be used to predict the speciation in the HAA class (Obolensky and Singer, 2005; Bull et al., 2009). It is important that the organic content of the water used for these studies be consistent with that found at the monitoring well. It is suggested that the initial analyses of these data use health effects metrics used in Regli et al. (2015), which are based on epidemiological data; however, note that this construct may be modified using the slope factors for individual THMs.

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If the distribution of bromine is such that it forms predominantly bromoform, the predicted cancer risk may be smaller than the estimate derived from the epidemiology data, because bromoform is a weaker carcinogen than either bromodichloromethane or dibromochloromethane. A parallel issue may exist with the HAA9; however, tribromoacetic acid is fairly unstable in drinking water. Dibromoacetic acid is more stable and is more carcinogenic risk than dichloroacetic acid, but less than bromochloroacetic acid. There are no cancer data available on monobromoacetic acid, dibromochloroacetic, or tribromoacetic acid. Monochloroacetic acid was negative in a bioassay conducted by the National Toxicology Program (NTP) (1992). Risk assessments of individual DBPs can be accessed online in the USEPA IRIS program. The NTP reports can be accessed online as well.

See Figure 1 for the dose response for cancer induction of the haloacetic acids that have been tested. Note that Figure 1 was constructed by R.J. Bull for a publication that is in preparation and is provided here as a courtesy assist to in LOTT's efforts to assess risks. Please do not distribute the figure or individual elements of the figure without explicit permission from R.J. Bull.

LOTT is reminded that the doses of DBPs arising from excess bromide in disinfected water will occur for a limited period of time; therefore, the contribution of excess brominated byproducts should be restricted to the increment added to the total lifetime dose received during the time that bromide concentrations were increased in the groundwater at the monitoring well.

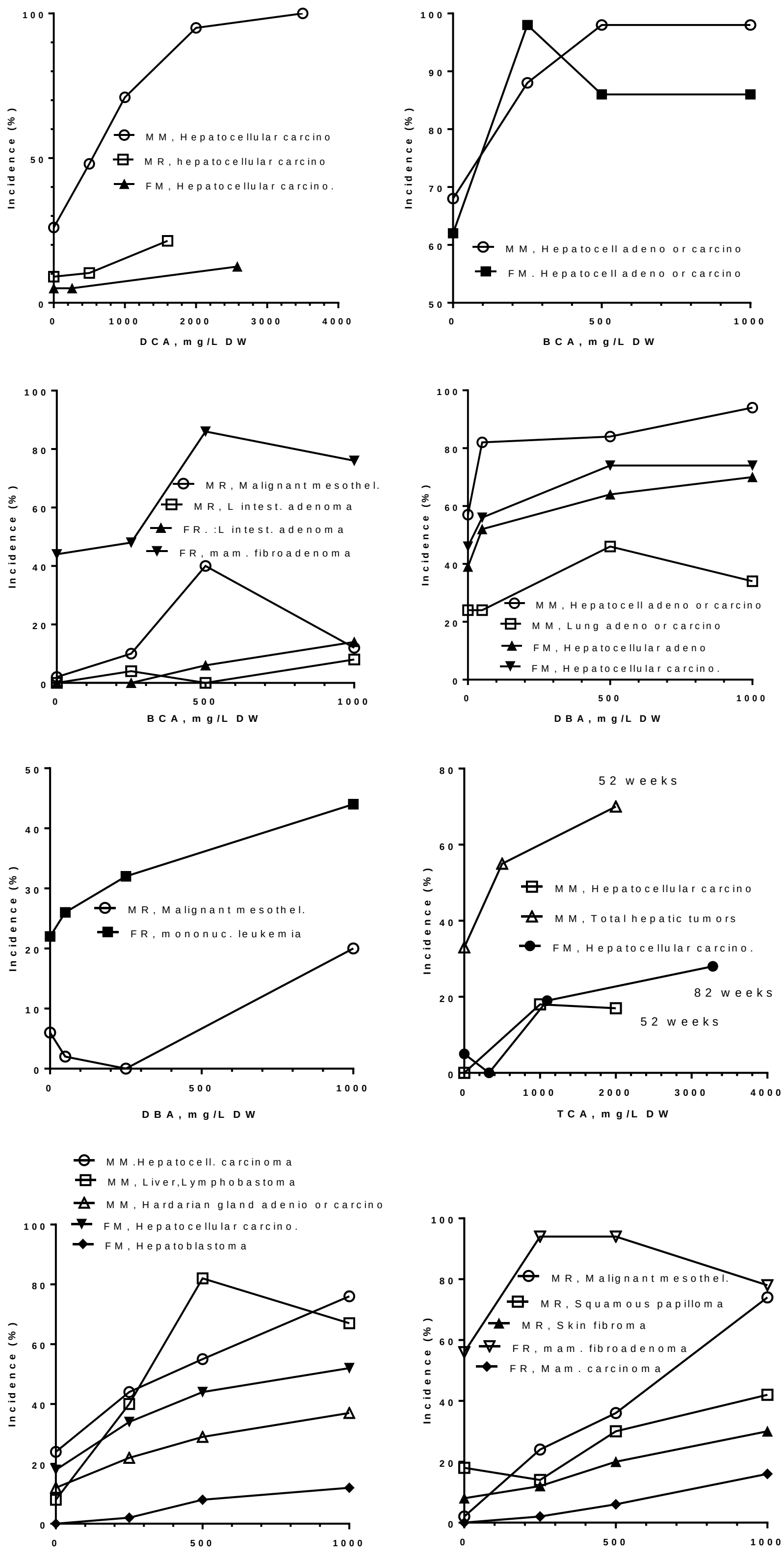

Figure 1. Dose response data for cancer induction in rats and mice treated with various di- and tri-bromochlorohaloacetates. Studies pictured: DCA from DeAngelo et al., 1996 and 1999, and Pereira 1996; BCA from NTP 2009; DBA from NTP 2007; TCA from Bull et al., 1990; Pereira 1996; BDCA from NTP 2014. **These figures are provided as a courtesy to LOTT. Do not distribute.**

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