NATIONAL WATER RESEARCH INSTITUTE
18700 Ward St. • Fountain Valley, CA 92708 • (714) 378-3278

Memorandum

Date: June 15, 2022

To: Wendy Steffensen
Environmental Project Manager, LOTT Clean Water Alliance

From: James Crook, PhD, PE, Panel Chair
Kevin M. Hardy, JD, Executive Director, NWRI

Subject: NWRI Independent Expert Advisory Panel for LOTT RWIS
Panel Meeting 6 Recommendations

The National Water Research Institute (NWRI) is pleased to provide this memorandum from the NWRI Peer Review Panel to review the LOTT Clean Water Alliance Reclaimed Water Infiltration Study (RWIS) project. The Panel met online on March 29, 2022, to review presentations on the Draft Final Human Health Risk Assessment (HHRA) and a preliminary cost/benefit analysis from the LOTT project team.

The purpose of the NWRI Panel is to provide a third-party peer review of the technical, scientific, regulatory, and policy aspects of the RWIS project. Results of the study will be used to help policymakers make informed decisions about reclaimed water treatment and use in the future.

NWRI Peer Review Panel Members

- Chair: James Crook, PhD, PE, BCEE, Environmental Engineering Consultant
- Paul Anderson, PhD, ARCADIS
- Michael Dodd, PhD, University of Washington
- Michael Kenrick, PE, LHG, Geoengineers, Inc.
- Edward Kolodziej, PhD, University of Washington
- John Stark, PhD, Washington State University

More information about NWRI is provided in Appendix A. More information about the Panel members is in Appendix B. The agenda for the meeting is in Appendix C. A list of meeting attendees is in Appendix D.

Pre-Meeting Review Materials

The Panel thanks the LOTT project team for providing the following excellent project materials to review before the meeting:

- DRAFT Human Health Risk Assessment-LOTT RWIS, prepared by Intertox (March 18, 2022).
- Cost/Benefit Analysis (Task 4) for RWIS, prepared by HDR (March 23, 2022).

Panel Findings and Recommendations

The principal findings and recommendations of the Panel are based on the presentations about the Draft Human Health Risk Assessment (HHRA) and the Task 4 Cost/Benefit Analysis that were given by the project team at Meeting 6 on March 29, 2022.

The Panel appreciates the high quality of the project team's presentations and pre-meeting review materials.

The Panel was given 11 questions, which included 7 questions on technical information related to the HHRA and 4 questions about communicating risk to the public. The following section lists the questions that LOTT provided, followed by Panel responses and recommendations.

Additional comments and recommendations that are not in response to questions follow in a later section and in appendices. The Panel noted than an economic analysis to understand how treatment decisions would affect consumer cost would be useful in the cost/benefit analysis. The Panel calculated the potential impact on ratepayers and included its analysis in the section **Additional Panel Comments**, along with a short discussion of the possible effects of reduced Drinking Water Equivalent Levels (DWELs) in the future. The Panel also provided detailed supplemental information on calculating lifetime risk in Appendix E.

Technical Review Questions and Responses

1. In the Human Health Risk Assessment, the findings of the probability risk assessment (PRA) appear to corroborate the risk assessment findings. Is this an accurate interpretation?

Panel Response: Yes, the results of the PRA corroborate the expectation that the findings of the HHRA using deterministic methods are conservative and protective of public health.

2. a. Are the treatment train alternatives included in the cost/benefit analysis appropriate?

   b. Are there different trains/processes you would recommend be considered?

Panel Response: The Panel considers the combinations of treatment system alternatives that were presented to be appropriate and typical for similar systems.

The Panel suggests that it might be worth looking into ultraviolet and hydrogen peroxide (UV/H_20_2) or ozone and hydrogen peroxide (O_3/H_20_2) coupled with granular activated carbon (GAC) after the advanced oxidation process (AOP). It also may be worth evaluating if nitrosamines are present in reclaimed water before chlorination. GAC is effective if precursors are a concern and it is typically relatively cost effective to implement.

If LOTT determines that advanced treatment is indeed desirable and decides to evaluate potential options, it may also be worth exploring UV/H_2O_2 and biologically activated carbon plus granular activated carbon (BAC/GAC) or UV plus BAC/GAC as alternatives to ozone plus BAC/GAC or UV/H_2O_2 and reverse osmosis (RO), assuming the primary aims of incorporating these trains are mitigating PFAS and nitrosamines as prioritized CEC classes.

Using UV/H_2O_2 or UV only (at UV fluences typical of UV/H_2O_2) coupled with BAC/GAC may provide additional capacity to remove preformed N-nitrosodimethylamine (NDMA) or other nitrosamines via direct photolysis if significant levels of nitrosamines are present in the reclaimed water before chlor(am)ination. These options can also provide capacity for nitrosamine precursor oxidation if UV/H_2O_2 is used and the removal of nitrosamines, their precursors, and PFAS in the subsequent BAC/GAC steps. Using BAC/GAC instead of RO could also provide improved removal of nitrosamines—and considering that RO does not remove them completely and requires disposal of RO reject streams—while also providing high levels of nitrosamine precursor and PFAS removal.

In the event that pre-formed nitrosamine levels in the reclaimed water are minimal and that nitrosamine levels detected in samples analyzed thus far primarily arise from precursor pools during post-chlor(am)ination, then there would not likely be much benefit to UV/H_2O_2 plus BAC/GAC or UV plus BAC/GAC. In fact, such processes might have the disadvantage of lower nitrosamine precursor removal than could be achieved by ozone plus BAC/GAC treatment.

To inform potential treatment process selection, the Panel recommends that the LOTT Project Team monitor reclaimed water for baseline pre-formed NDMA/nitrosamines versus post-chlor(am)ination NDMA/nitrosamine formation potentials.

If contaminant removal/degradation beyond PFAS and nitrosamines is desired, the Project Team could consider UV/H_2O_2 plus BAC/GAC or O_3/H_2O_2 plus BAC/GAC with delayed addition of H_2O_2. This delay allows pre-oxidation of nitrosamine precursors by ozone

before it is converted to hydroxyl radical (•OH) if dissolved organic carbon (DOC) levels are sufficiently low that maintaining an ozone residual for up to several minutes is feasible. A potential advantage of either approach over ozone plus BAC/GAC could be higher levels of •OH exposure and increased non-selective oxidation of a broader array of contaminants before passing through BAC/GAC media.

If the primary goal of advanced treatment is targeted removal of PFAS and NDMA/nitrosamine precursors, rather than pre-formed NDMA or other nitrosamines or a broader array of contaminants in general, GAC alone may present an effective, much simpler, and more cost-effective option (as noted by the Project Team).

3. Because the risks of using reclaimed water for groundwater recharge appear to be low, the near-term recommendations may focus on continued monitoring and data gathering, rather than changes to treatment levels at this time. Does the Panel feel that this a reasonable approach?

Panel Response: The Panel agrees that, based on the current analysis, the potential risks associated with groundwater recharge are low and the water is safe.

The Panel notes that many projects that introduce reclaimed water into groundwater aquifers use either a carbon-based or reverse-osmosis-based treatment step to remove trace constituents, although the reasons for doing so are not always driven by trace chemical detection and assessment of related risks. Given the long history of LOTT recharge and data collection, it is not clear what system issues or reclaimed water characteristics should prompt implementation of new treatments or processes. Generally, additional treatment (often membrane- or carbon-based) is commonly employed at similar facilities that infiltrate recycled or highly treated municipal wastewater to groundwater systems to both attain specific treatment outcomes and as a precautionary measure.

It may be worthwhile to consider implementing GAC-only treatment as a proactive and cost-effective approach to mitigating the two classes of compounds of concern. GAC-only treatment could have the added advantage of providing an in-place protective barrier that would help to address PFAS and nitrosamine precursors class-wide and may be of special importance in the case of PFAS. This approach would also offer a treatment step that could use existing filtration infrastructure at the Martin Way Reclaimed Water Infiltration Plant and could be readily incorporated into future advanced treatment configurations that use ozone plus BAC/GAC or other BAC/GAC approaches.

4. Please comment on the concept of continued monitoring of chemicals of concern. Initial thoughts for a sampling plan include:

    a. Test for NDMA, nitrosamines, PFPeA, and broader suite of PFAS.

b. Sample reclaimed water quarterly.

c. Sample in groundwater monitoring wells twice annually.

d. Re-evaluate risk from these chemicals within X years.

Panel Response: Timing sample collection for the LOTT monitoring plan might consist of the following elements.

a. Quarterly sampling is recommended for reclaimed water that will be infiltrated into the groundwater basin for all chemicals of concern currently prioritized because they have an elevated potential to pose a potential risk to humans or the environment, especially for a comprehensive suite of PFAS compounds and the key nitrosamines. This monitoring frequency will track the highest priority compound classes and deepen understanding of their occurrence/concentrations in the reclaimed water data set, which is somewhat sparse in replicates and depth. Before and after sampling might be recommended for any major changes to the treatment system or key operational parameters.

b. Twice-a-year system sampling is recommended for a broader suite of chemicals of emerging concern (CECs) in recycled water, which will help the Project Team to understand longer term trends in CEC occurrence, concentration, and treatment system performance as the community grows and changes. As scientific knowledge deepens, the Project Team can add, incorporate, or remove additional CECs and chemical classes, as needed.

c. Given the slower dynamics of groundwater systems, the Panel recommends twice-a-year sampling of downgradient wells (plus a couple of background wells) and high-priority/drinking water wells for CECs as part of the system monitoring plan. At a minimum, the higher priority compounds should be monitored, although it is not unreasonable to also include a broad assessment of CECs in groundwater wells once a year to establish trends with time.

   In the event that reclaimed water monitoring indicates substantial changes in a particular CEC concentration or if CECs not previously detected at significant levels are detected regularly, including such CECs in the analytical suite for scheduled groundwater monitoring is recommended.

d. Response to question 4d is included in the Panel response to question 5.

5. There may be a periodic update of this study to account for new/different residual chemicals, improved scientific understanding of potential toxicity, degradation

rates, etc. Ongoing industry research will inform decisions about need, timing, and focus for future studies. One suggestion is that the study be updated every 10 to 20 years. What is the Panel's opinion on the frequency of the study update?

Panel Response: The Panel recognizes that LOTT will be collecting additional monitoring data on an ongoing basis and as pointed out in LOTT's question to the Panel, toxicological benchmarks (DWELs) and other factors used in the evaluation are updated regularly. Therefore, the Panel recommends a two-tiered approach to updating the evaluation of potential human health and ecological risks posed by use of reclaimed water.

The first tier would use adaptive management to identify, on a regular basis, changes in CEC concentrations and/or trends and toxicity data that could lead to a substantial change to the current conclusions of the HHRA and ecological risk assessment (ERA). When potential risks are high, these updates will warrant an expedited reassessment of potential risk and the possible need for changes in the wastewater treatment system.

The Panel wonders if it might be possible to use the spreadsheets developed as part of the HHRA and ERA to conduct this ongoing assessment by entering and evaluating updated monitoring data as they are collected to see if estimated risks change in important ways. Part of the adaptive management program could also be to monitor and regularly update toxicity benchmarks used by the spreadsheets and to identify new CECs from other studies that should be considered for inclusion in the RWIS monitoring program.

The second tier would consist of an overall update of the comprehensive HHRA and ERA less frequently (every 5 to 10 years) to confirm that potential risks associated with the use of reclaimed water remain acceptable.

6. a. Based on study findings and/or recharge facility siting criteria developed elsewhere, do you have suggestions for standards that could be applied for siting future recharge facilities, such as distance or travel times between a recharge site and a downgradient receptor such as a drinking water supply well?

   b. Does the Panel have examples of how municipalities regulate and permit recharge sites with regard to unregulated residual chemicals?

Panel Response: The following responses correspond to the questions above.

a. Our understanding is that the Washington Administrative Code (WAC Chapter 173-219) calls for a minimum physical setback of 200 feet, along with Sanitary Control Areas around water supply wells, as outlined in WAC 246-290-135 which addresses wellhead protection, referencing EPA guidance for delineation of wellhead protection areas, travel times etc. The Panel notes that hydraulic residence time in

the subsurface, which affects expected contaminant attenuation during subsurface transport more directly, is more important than physical setbacks.

b. Orange County Water District (OCWD) is a good model to base extensive characterization of chemical contaminants in both recycled wastewater and also for infiltration of wastewater-impacted river water containing high percentages of wastewater effluent (indirect, unplanned, potable reuse scenario). Many of the LOTT CEC discussions are similar to issues that OCWD has addressed, and OCWD has extensive institutional knowledge that LOTT may be able to take advantage of.

   Besides OCWD, the Hampton Roads SWIFT project uses some advanced treatment to remove residual chemicals from recycled water. It might also be a good resource and template for LOTT. https://www.hrsd.com/swift

   Truckee Meadows Water Authority might have some insights and data for its OneWater Nevada efforts. https://tmwa.com/onewater-nevada/

   Altamonte Springs might also have some relevant data and examples to follow up with. https://www.altamonte.org/659/Reclaimed-Water

7. One of the driving reasons for conducting this study was to gather local information about residual chemical fate and transport in this climate and determine if results might differ substantially from research conducted in warm, dry areas. Is it accurate to conclude that results are similar to research done elsewhere, and/or that such research could be applied to inform resource management decisions here?

Panel Response: The unique conditions in Western Washington should be considered when making resource management decisions in the LOTT service area. While the Panel expects that many aspects of CEC occurrence, fate, and transport in subsurface reclaimed water systems reported elsewhere may be similar to those for Western Washington, LOTT should keep in mind that Western Washington has distinct or unique seasonality, hydrology, and hydrogeology. While results from other projects can be applied to this system, the Panel notes the potential for unique CEC occurrence or transport outcomes.

Communication questions

8. Does the Panel have suggestions or examples of how to explain the meaning of PRA results to a public audience?

Panel Response: The slides presented by Intertox during the Panel meeting contained much of the key information needed to convey how a PRA works. Those slides could be augmented with a slide or two showing what an input distribution represents. For example, adding some stick figures on different parts of the distribution to represent variation in

body weight could show how each part of the body weight distribution represents a different body type.

Similarly, for drinking water ingestion, graphics of glasses of water could be used to show the different intakes represented by different parts of the distribution.

Perhaps the best way to show the results of the PRA is to use a probability density function figure with the x-axis on a log scale. Such a figure could demonstrate that most people fall in the middle of the risk distribution, and that some fall in the low end (provide possible reasons, such as short exposure duration or they drink little tap water) and some in the high end (long exposure duration, they drink lots of tap water). The Project Team could discuss acceptable PRA risk benchmarks developed by the states of Oregon or Florida to show how regulatory agencies judge whether the estimated range of risks is acceptable.

Communication Strategies

Examples of detailed communication strategies and guidelines include:

Water Recycling and Media: Guidelines for Communication, published by the Australia Water Recycling Centre of Excellence in December 2014, by J. Motion and M. Kearnes. (downloadable PDF) (https://water360.com.au/wp-content/uploads/2021/11/Guidelines-for-Media-Communication-100815.pdf)

Model Communication Plans for Increasing Awareness and Fostering Acceptance of Direct Potable Reuse, published by WateReuse Foundation in 2015, by Mark Millan, Patricia A. Tennyson, and Shane Snyder. The research and plans are free to WateReuse members, $45 for nonmembers. (https://watereuse.org/watereuse-research/13-02-model-communication-plans-for-increasing-awareness-and-fostering-acceptance-of-direct-potable-reuse/)

Communications Tools & Resources, published by WateReuse Foundation. A collection of white papers, case studies, infographics, signage, videos, and policy briefs. Free to WateReuse members. (https://watereuse.org/educate/fact-sheets/)

9. Given the low level of risk for the two chemicals of potential concern identified in the HHRA, do you have suggestions for communicating the relative risk reduction that would be achieved with an advanced treatment train?

Panel Response: One way to communicate the relative risk reduction is to put the risks into a broader context than just the EPA's or other agency's allowable risk ranges and paradigms. For example, Michael Blastland and David Spiegelhalter (The Norm Chronicles, Basic Books, 2014) have developed the concept of a micromort, defined as a one in one million (1×10^{-6}) risk of death. That risk can either be the number of micromorts accumulated by a specific activity or how long it takes to accumulate a micromort engaging in that activity.

Being alive is a good example of the difference. Every day of living in the United States is equal to 1.3 micromorts, a 1.3×10^{-6} chance of dying (not including suicides). That is the same as saying it takes a US resident about 18.5 hours of simply being alive to accumulate a micromort. Keep in mind that the cancer risks estimated in the HHRA are of increased cancer incidence, not death. Not all cancers are fatal. So, the micromort comparison is conservative. The book contains a list of activities and associated micromorts. Perhaps a table of some of those could help put the estimated reclaimed water risks into perspective. It is hard for most people to appreciate how small and common a 1×10^{-6} risk is.

Micromorts can also be used to put the risk reduction associated with treatment into perspective. The current arithmetic average lifetime excess cancer risk (LECR) from NDMA is 2.9×10^{-7} (from Intertox's Appendix F). With GAC, that LECR drops to 1.4×10^{-8}, a reduction of 2.8×10^{-7} (see below for more details about the estimated reduction in LECR associated with GAC). That reduction equals 0.28 micromorts, or about the amount of micromorts one accumulates in five hours of living.

The Project Team could estimate the cost to save a life-year if an advanced treatment train is added and compare those costs to other public health improvement measures. It is a bit more of an esoteric comparison than micromorts as most people are not well-versed in the concept of life-years saved. A draft calculation based on general information gleaned from the internet and the presentations made by the Project Team during the last meeting is presented as an attachment and would need to be updated and refined if the Project Team is going to use it as another perspective.

That draft calculation finds the cost to save a life-year using GAC at 1 MGD is about $30 million and using ozone is about $97 million. These costs can be compared to the costs of other regulations and are likely to be in the higher end of the range, typical for chemicals in the environment, compared, for example, to occupational, transportation, and medical life-saving intervention costs.

For more information, see Appendix E for information on calculating lifetime risk and the Additional Panel Comments section for information on estimating annual costs per household.

10. Based on the study findings, what conclusion statements would the Panel make about the general safety of using reclaimed water to replenish groundwater?

Panel Response: The communication resources mentioned in the response to Question 8 explain how to communicate the safety of reclaimed water to the public.

11. What conclusion statements come to mind about the study effort in general?

Panel Response: The LOTT Project Team has presented a comprehensive and well-conceived body of work for the RWIS project, including a thorough analysis of CEC fate, transport, and risks for this site. This, like any analysis, has uncertainties. It is important to recognize and acknowledge these uncertainties, such as the presence of compounds in reclaimed water whose identity, concentration, and toxicity remain unknown, while at the same time recognizing that the current analysis and its conclusion that the water is safe uses methods and data that represent commonly accepted practices, are widely used, and are scientifically sound.

The Panel recognizes the many accomplishments of the LOTT Project Team and appreciates their cooperation and receptiveness to the Panel's recommendations.

Additional Panel Comments

The Panel wondered if the Project Team identified the source of PFOA/PFAS in the groundwater samples? Where is it being introduced into the wastewater treatment system or making its way into the groundwater?

Cost-effective source control solutions may be available if a specific source is disproportionately contributing PFAS to the recycled water or recharge system. The Project Team should evaluate source control options to mitigate CECs that have the greatest potential to pose unacceptable risk. It may be possible to track sources within the sewer system to isolate and identify CEC sources.

Estimated Monthly Customer Cost

Evaluating the projected increases in average monthly costs per household is a common way that utilities communicate project costs to their customers. Adding this detail to the cost-benefit analysis may support decision making about additional incremental treatment and public health improvement.

The Panel recommends that the Project Team develop a rough estimate of expected monthly cost increases that would be borne by its customers if additional treatment were to be installed to see if it matches the Panel's estimates presented in the following paragraphs. If LOTT anticipates receiving external matching funds from state or federal sources to mitigate such costs, the Panel is interested to learn about such plans.

The Panel did a rough calculation of the monthly cost per household for advanced treatment. According to the LOTT website, it serves 125,000 people. According to the United States Census, Thurston County has 2.5 people per household. That would mean that LOTT serves about 50,000 households (125,000÷2.5=50,000).

At 1 MGD, GAC has the lowest 20-year present value of $5.8 million and RO-UV/$H_2O_2$ has the highest at $76 million, according to the cost-benefit slides presented in Meeting 6. Dividing those present value costs over 50,000 households results in a 20-year cost range

of $116 to $1,520 per household. Dividing that cost over 240 months (20 years x 12 months) results in a monthly cost range of $0.48 to $6.33 per household.

At 5 MGD, the 20-year per household cost ranges from $384 to $4,380 and the monthly cost per household over 20 years ranges from $1.60 to $18.25.

The Panel would be interested to know about wastewater treatment bills for LOTT households and whether these estimated cost increases represent a substantial or a marginal increase in the monthly rate. Even without that information, the monthly costs don't seem large and may represent an increase the community may be willing to accept.

Effects of Lower DWELS

The Panel notes that based upon recent reassessments conducted by the EPA on the toxicity of certain PFAS compounds, the Drinking Water Equivalent Levels (DWELs) may decrease for those PFAS compounds due to a decrease in the allowable daily exposure to those compounds. Lower DWELs and allowable daily exposure may change the broad conclusion that the water is safe and may require a reassessment of treatment implementation and processes. As described in the response to Question 5, LOTT should periodically monitor changes in DWELs to confirm that risks remain acceptable.

The Panel recommends that LOTT consider whether a monitoring approach instead of treatment is sensitive to a potential one to three orders of magnitude change in DWELs for PFAS compounds. The concentrations of these compounds—while considered safe today—and whose concentrations may remain stable in the future, appear to have the greatest potential to be found to pose a potential risk to humans in the future due to lower DWELs. LOTT may want to weigh the costs and benefits of preemptively acting to mitigate the possibility that the potential risk associated with these compounds in reclaimed water may increase in the future.

One approach that LOTT could take to support treatment decision making is a sensitivity analysis that estimates the margin of safety (MOS) for compounds with the highest estimated potential risks. This analysis evaluates how a one- to three- orders of magnitude reduction in the DWEL might affect the need for additional treatment. If the MOS is greater than 1 after DWELs are reduced, it indicates that relatively large changes in DWELs will not change the conclusion that reclaimed water is safe for groundwater replenishment at the current level of treatment. If the margin of safety is less than 1, then further evaluation could quantify the degree of conservatism in estimating potential risk. After further evaluation, if the MOS is still less than 1, then changes in treatment could be identified to increase the MOS, and the costs of additional treatment could be weighed against the likelihood that the DWEL for the compounds with the highest estimated risks will, in fact, decrease. This sensitivity analysis may give LOTT useful information when considering the costs and benefits and timelines of additional treatment.

Conclusion

The purpose of the NWRI Panel is to provide an independent, third-party expert peer review of the technical, scientific, regulatory, and policy aspects of the HHRA and the Cost-Benefit Analysis for the LOTT RWIS project.

Please direct questions to Suzanne Sharkey, Project Manager, at ssharkey@nwri-usa.org.

Appendix A • About NWRI

Disclaimer

This report was prepared by an Independent Expert Advisory Panel (Panel), which is administered by National Water Research Institute. Any opinions, findings, conclusions, or recommendations expressed in this report were prepared by the Panel. This report was published for informational purposes.

About NWRI

A 501c3 nonprofit organization, National Water Research Institute (NWRI) was founded in 1991 by a group of California water agencies in partnership with the Joan Irvine Smith and Athalie R. Clarke Foundation to promote the protection, maintenance, and restoration of water supplies and to protect public health and improve the environment. NWRI's member agencies include Inland Empire Utilities Agency, Irvine Ranch Water District, Los Angeles Department of Water and Power, Orange County Sanitation District, and Orange County Water District.

For more information, please contact:

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Appendix B • Panel Member Biographies

Chair: James Crook, PhD, PE, 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 and the WateReuse Association's 2005 Person of the Year. In 2016 he received the California WateReuse Presidential Award. Crook received both an MS and PhD in Environmental Engineering from the University of Cincinnati, and a BS in Civil Engineering from University of Massachusetts.

Paul Anderson, PhD, is a Principal Scientist for ARCADIS US, Inc. Since 2000, Paul Anderson has researched the presence and effects of pharmaceutical ingredients and personal care products in surface water. His research began with developing a screening level model that predicts the concentration of human pharmaceuticals and other compounds released from wastewater treatment plants. He helped develop a database that summarizes peer-reviewed literature on aquatic toxicity,environmental fate in surface water, and treatment plant removal of pharmaceuticals.

Anderson has over 35 years of experience in human health and ecological risk assessment. He has a PhD and an MA in Biology from Harvard University and a BA in Biology from Boston University.

Michael Dodd, PhD, is an Associate Professor in the Department of Civil and Environmental Engineering and an Adjunct Associate Professor in the Department of Environmental and Occupational Health Sciences at the University of Washington (UW). Dodd's research focuses on characterizing chemical and photochemical redox processes in aquatic systems, particularly in eliminating pollutants and pathogens during water and wastewater treatment. Focus areas include modeling the behavior of chemical and microbiological contaminants during chemical oxidation and disinfection processes, developing assays to quantify the impacts of such processes, and engineering novel approaches to centralized and decentralized water treatment. Dodd has a PhD in Environmental Sciences from the Swiss Federal Institute of Technology-Zurich (ETH-Zurich), an MS in Environmental Engineering and a BS in Civil Engineering from Georgia Institute of Technology.

Michael Kenrick, PE, LHG, is Senior Consultant Hydrogeologist with GeoEngineers in Redmond, Washington. Since the Covid pandemic, Kenrick has been working remotely from

his new home in Devon, England. 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.

Edward Kolodziej, PhD 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 MS and PhD in Environmental Engineering at University of California at Berkeley, and a BS in Chemical Engineering from the Johns Hopkins University.

John Stark, PhD 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 in 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 on salmon, zebra fish, and aquatic invertebrate health and assessing the impact of pesticides on endangered butterflies. Stark holds a PhD in Entomology and Pesticide Toxicology from University of Hawaii, an MS in Entomology from Louisiana State University, and undergraduate degrees in biology and forest biology from S.U.N.Y. and Syracuse University, respectively.

Appendix C • Meeting Agenda

NATIONAL WATER RESEARCH INSTITUTE

Independent Expert Advisory Panel for LOTT Clean Water Alliance
Reclaimed Water Infiltration Study

Meeting 6

March 29, 2022

Location	Contacts
Zoom	Suzanne Sharkey: 949.258.2093
See Outlook invite for login information	Mary Collins: 206.380.1930

Meeting Objectives

- Update the Panel on the draft final Human Health Risk Assessment and the preliminary draft Cost Benefit Analysis
- Facilitate interaction between the Panel, the LOTT project team, and the Science Task Force
- Allow time for the Panel to begin drafting the recommendation report

OPEN STAKEHOLDER WORKSHOP: 11:00 a.m. to 12:30 p.m.

11:00 a.m.	Welcome, introductions, and review meeting objectives and agenda	Kevin Hardy, NWRI, and Jim Crook, Panel Chair
11:10 a.m.	Reorientation to project and timeline	Wendy Steffensen, LOTT
11:15 a.m.	Brief on the Human Health Risk Assessment	Gretchen Bruce, Intertox
11:40 a.m.	Presentation of the Cost Benefit Analysis	Jeff Hansen, HDR
12:15 p.m.	Panel Q & A	Facilitated by Jim Crook
12:30 p.m.	Wrap up with Science Task Force	

CLOSED PANEL WORKING SESSION: 12:30 to 2:00 p.m.

12:30 p.m.	Closed Panel working session	Facilitated by Jim Crook
2:00 p.m.	Adjourn	

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LOTT Clean Water Alliance Reclaimed Water Infiltration Study: Panel Meeting 6 Agenda

NWRI Independent Expert Advisory Panel

- Chair: James Crook, PhD, PE, Environmental Engineering Consultant (Boston, MA)
- Paul Anderson, PhD, ARCADIS US, Risk Assessment Consultant (Chelmsford, MA)
- Michael Kenrick, PHG, GeoEngineers (Redmond, WA)
- Edward Kolodziej, PhD, University of Washington (Tacoma, WA)
- Mike Dodd, PhD, University of Washington (Seattle, WA)
- John Stark, PhD, Washington State University (Puyallup, WA)

RWIS Project Team

- Lisa Dennis-Perez, LOTT
- Joanne Lind, LOTT
- Wendy Steffensen, LOTT
- Jeff Hansen, HDR
- Shane McDonald, HDR
- Brittany Duerte, HDR
- Gretchen Bruce, Intertox
- Kate McPeek, Windward Environmental

Science Task Force

- Peter Brooks, City of Lacey
- Erin Conine, City of Olympia
- Carrie Gillum, City of Tumwater
- Kevin Hansen, Thurston County
- Erica Marbet, Squaxin Island Tribe
- Koenraad Mariën, Washington State Department of Health
- Hans Qiu, Washington State Department of Ecology
- Dan Smith, City of Tumwater
- Art Starry, Thurston County

National Water Research Institute

- Kevin M. Hardy
- Mary Collins
- Suzanne Sharkey

Appendix D • Meeting Attendees

P Brooks
Gretchen Bruce
Erin Conine
BM Conkey
John Cusick
Lisa Dennis-Perez
Carrie Gillum
Jeff Hansen
Kevin Hansen
Matt Kennelly
Joanne Lind
Christine Marbet
Hannah McLean
Jane Mountjoy-Venning
Hans Qiu
Darlene Schanfaid
Dan Smith
Art Starry
Wendy Steffensen
Jay Swift
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Appendix E • Calculating Lifetime Risk

Based on the PRA, the arithmetic mean LECR from NDMA, absent additional treatment, is 2.9×10^{-7} (from Intertox's Appendix F). Over the next 70 years, the standard EPA assumption for a lifetime, 2.9×10^{-3} additional cancers would be expected in the population assuming an exposed population of 10,000 people (2.9×10^{-7} excess lifetime cancer risk per person x 10,000 people = 2.9×10^{-3} excess cancers in the next 70 years). Note that the assumption of 10,000 people is just an assumption. The Project Team likely has a much better estimate of the size of the population potentially exposed to compounds in reclaimed water.

Assuming that cancer is always fatal (which is not the case) and it takes all 70 years of a life (rarely the case) the calculation results in 0.2 life-years lost (2.9×10^{-3} cancers x 70 years of life lost per cancer = 0.2 life-years lost).

With GAC or ozone treatment added, the decrease in the highest NDMA risk level is 21-fold, from 2.9×10^{-6} to 1.4×10^{-7} based on the cost-benefit slides. Assuming that same reduction is true for the arithmetic mean, results in arithmetic mean excess lifetime cancer risk from NDMA with GAC of 1.4×10^{-8} leading to an expected number of cancers in the exposed population of 1.4×10^{-4} (1.4×10^{-8} excess lifetime cancer risk per person x 10,000 people = 1.4×10^{-4} excess cancers in the next 70 years). Using the same assumptions as above results in 0.01 life years lost (1.4×10^{-4} cancers x 70 years of life lost per cancer = 0.01 life years lost).

Based on these assumptions, if the treatment is upgraded, 0.19 life years would be saved (0.2 life years lost with current treatment – 0.01 life years lost with improved treatment = 0.19 life years saved). If GAC at 1 MGD has a 20-year cost of $5.8M, that treatment results in a cost of about $30 million to save a life-year ($5.8M ÷ 0.19 life years saved = $30 million). If the 20-year cost of ozone is $18.5 million, the cost to save a life year is about $97 million.

These costs can be compared to the costs of other regulations. They are likely to be in the higher end of the range, which is typical for chemicals in the environment compared, for example, to occupational, transportation, and medical intervention costs.

As mentioned above, a key unknown assumption is population size. If the population is 100,000, the costs to save a life-year decrease by 10 times ($3 million to $9.7 million). If population is only 1,000, the costs to save a life-year increase by 10 times ($300 million to $970 million). Also, a key assumption is that a cancer results in a full 70-year lifetime lost. If it is only 7 years (1/10th of a lifetime lost, if someone dies of cancer at age 63, instead of age 0 as assumed above), the costs to save a life-year would be 10 times higher. All the above costs get substantially higher for a 5 MGD capacity.

It is also important to keep in mind that the arithmetic mean estimates of LECR from the PRA are not best estimates. Though some inputs to the PRA used distributions, many did not, including the EPC. Also, the cancer slope factor is an upper confidence bound, not the best estimate. To get the best estimate of the cost to save a life-year, ideally, best estimates are used for all inputs. This is also where distinguishing between uncertainty-based distributions and variability-based distributions is key. For parameters whose distribution represents variability, the arithmetic mean needs to be used when estimating the cost to save a life-year. For parameters whose distribution represents uncertainty, the full distribution can be used to capture the uncertainty in the costs to save a life-year.