Esther Kronenberg

Hello,
I write as a member of the Clean Black Lake Alliance in Olympia WA. Our organization's mission is to advance lake management strategies that do not rely on herbicides and other toxic materials to control lake vegetation. Instead we advocate the use of mechanical harvesting, installation of effluent interceptor projects such as constructed marshes and wetlands, stormwater nutrient capture using biochar, upstream filtration and fertilizer runoff reduction to control algae and excess lake vegetation.

I am attaching a technical memo by Thurston County's hydrogeologist who studied 58 water wells around the Tri-Lakes area which is dominated by Type I CARAs and overlaps part of the area protecting Olympia's McAllister Wellfield, its primary drinking water source. The area is ringed with many on-site septic systems.

The study found that "significant groundwater contamination does exist, and is likely related to OSS, but that other sources probably contribute to nitrate loadings." (Page 1) It also found Chemicals of Emerging Concern (CECs), including pesticides and herbicides in an initial screening. (Page 10) There are hundreds, if not thousands, more of these CECs, all of which threaten to contaminate our drinking water. (See Figure 12, Page 11)

The study also found that the downward pull of hydraulic gradients, increased in part by heavy deeper groundwater pumping, is causing vertical movement of contaminants to deep aquifers below confining layers. (Page 14)

This should be deeply concerning to Ecology as it permits the use of herbicides in lakes. Ecology must assume that these herbicides, and other CECs will end up in our deepwater aquifers in areas that are populated, due to the presence of deep water wells causing a downward hydraulic gradient, and OSSs.

I urge Ecology to only permit the use of these dangerous chemicals to situations where the public health is threatened. Their use DOES result in the contamination of our drinking water aquifers in certain areas, like Thurston County. It is more important to protect our drinking water than to rid a lake of nuisance weeds.

Some other points - I am happy to see Ecology describing how much algae is beneficial, and though a nuisance, is not a public health threat.
I would urge Ecology to cite research as to whether the percentage of the littoral zone where herbicides may be applied will not increase predation risk and lower dissolved oxygen. Ecology should include text that herbicides may increase dissolved oxygen causing release of phosphorus from sediments, thereby exacerbating harmful algae blooms. Does Ecology know how many plants can be killed before dissolved oxygen levels rise?

I was concerned to read that Tier 2 analyses are not done for lakes with high water quality. How is it in the public interest to degrade high quality water? Does Ecology require that listed species be identified in these high quality lakes, and the effect of degrading the water quality would have on these listed species?

For example, the Olympic mudminnow requires dense vegetation to secure its eggs. Can Ecology ensure this threatened species' survival by adding language to protect the dense vegetation conditions needed by the Olympic mudminnow?

Thank you for this opportunity to comment and for your diligence in protecting the water resources of our State.

Uploaded Tech Memo 77 - Tri-lakes area

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Water Resources Technical Memo 77

Tri Lakes Modeling and Sampling to Evaluate OSS/Septic Impacts to Groundwater

Prepared by:

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February, 2023

Summary and Purpose

Between March and October 2022, fifty-eight water wells were sampled in the Tri-Lakes area for total coliform, E. coli bacteria, and nitrate-nitrogen. Ten samples were also analyzed for Chemical of Emerging Concern (CECs). Groundwater flow and transport modeling was used to assist in the selection of sampling locations. This sampling was completed with funding from the Washington State Department of Health (WSDOH) in compliance with a quality assurance project plan approved by WSDOH.

The Tri Lakes area of Thurston County includes Hicks, Pattison, and Long Lakes (see Figure 1). These lakes are interconnected and ultimately flow into Woodland Creek which discharges to Henderson Inlet. The lakes are surrounded by densely clustered onsite sewage systems (OSS) (see Figure 2). Figure 2 also depicts the locations sampled for the project. This area is dominated by Type I Critical Aquifer Recharge Areas (CARAs). The study area also overlaps the western part of the McAllister Geologically Sensitive Area (MGSA) protecting Medicine/McAllister Springs and the critically important McAllister Wellfield serving the City of Olympia. Groundwater and surface water protection in the Tri Lakes area have been a concern to residents and policy makers for decades.

Despite these sensitivities, historically Thurston County has not had sufficient data to change OSS policy when cost and implementation obstacles are high. For example, questions remain regarding the extent to which drinking water and surface water may be adversely impacted by OSS sources. Since the late 1970s, programs have been developed to reduce the discharge of nutrients from OSS, and to identify areas where OSS should be considered for conversion to public sewer to protect water resources and public health.

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This study is intended for consideration by County management, external entities and elected officials in the process of considering their policies. However, the report is advisory only; policy changes may depend on numerous other factors.

Over the past 20 years, significant improvements in knowledge have made available new resources to evaluate OSS options – and to distinguish OSS from other potential contaminant sources. Prior to this study, Thurston County Water Resources program built a MODFLOW-NWT groundwater flow model (now at versions v198 [steady-state flow] and v253 [transient flow]) and the MT3D-USGS solute transport model (v23) for the Tri Lakes area of Thurston County (Bedekar et al, 2016; Niswonger et al, 2011). Initial model results suggested that the known small domestic and small community water supply systems (Group B) might be impacted by contamination from OSS – but are infrequently sampled in some cases. Larger and deeper wells that are part of larger community water supply systems are frequently sampled and were considered somewhat less likely to be contaminated by OSSs.

However, field validation of the model-based extent and concentrations of contamination from OSS systems had not previously been conducted. An important purpose of this project was to collect *new* data that could be used to evaluate the current groundwater quality while calibrating the groundwater modeling so that a first assessment of the location and severity of potential groundwater contaminant impacts could be made. Also, validating the effectiveness of modeling could allow it to be used more widely in Thurston County for forecasting future contaminant movement, and to provide an early warning system for public drinking water systems.

The results of this project indicate the initial source delineations and modeling were largely correct: significant groundwater contamination does exist, and is likely related to OSS, but that other sources probably contribute to nitrate loadings. Modeling using best-available assumptions was found to underestimate actual nitrate concentrations.

Prior Work

Septic systems are the primary method for wastewater disposal in rural Thurston County. Thurston County has undertaken several major studies of the impacts of OSS on groundwater including in the important Tri Lakes area, where 'legacy' OSS were installed. In this study, "Legacy" OSS were installed at spatial densities above those permitted by modern design standards.

In Thurston County, few major nitrate source types are as widespread as wastewater from OSS. In most cases, direct correlation between a particular potential nitrate source and a groundwater sample containing nitrate is not possible. Therefore, in practice, it is difficult to distinguish nitrate source types without extensive groundwater sample analysis (Seiler, 1999; Seiler et al 1999; Seiler, 2005). Better assessment of these questions was part of the genesis of this study. In addition, OSS are not designed to reduce concentrations of nitrate, nor are they designed to reduce concentrations of the many substances in wastewater used for consumer, pharmaceutical, pesticide/herbicide or industrial purposes.

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Some of the work to improve water quality prior to this study comes from the progressive steps already undertaken with respect to wastewater:

- Formation of LOTT Clean Water, the wastewater utility serving the cities of Lacey, Olympia, Tumwater, and Thurston County, largely through sewered infrastructure.
- Sewerage General Plan (1990) requirements to re-evaluate appropriate OSS densities as data become available.
- Thurston County Sanitary Code updates to reduce allowable OSS/septic system densities (1990s)
- Thurston County Sanitary Code updates to add a Nitrate Assimilative Capacity test requirement before approving some new OSS (mid-2000s)
- Summit for Elected Officials: Water Quality and OSS (2011)
- Septic loading risk analysis (2013)
- Groundwater contaminant (nitrate) transport modeling in the Scatter Creek aquifer demonstrated significant issues with OSS loadings to groundwater, probably exacerbated by lawn fertilizers and small agriculture or point-loadings from permitted facilities. These results suggested that other parts of Thurston County would benefit from predictive modeling (2012-2014)
- Septic-to-Sewer project (2015)
- Compilation of OSS locations and estimated wastewater loadings (2014-2016)
- Calculation of updated wastewater loadings from OSS using residency/occupancy data (2016-present)
- LOTT reassessments of sewerage needs (ongoing)
- Groundwater flow modeling using MODFLOW-NWT (steady-state version v198; 2020)
- Groundwater transport modeling using MT3D-USGS (version v23 using the steady-state MODFLOW-NWT flow model v253 [as of late 2022]).

The Septic-to-Sewer project conducted from approximately 2012 through 2014 (with updates to the present), produced an inventory of known OSS in city limits or urban growth areas in conjunction with a focused effort to identify areas of persistent groundwater contamination (see Thurston County, 2015; Morgan, 2016). The high-spatial-density 'legacy' OSS systems (generally installed before current regulations) in the Tri Lakes area emerged as a potential threat to water quality. Updating of the septic location inventory (2016-present) using residency/occupancy data, among other data sources, further increased the calculated septic densities for the Tri Lakes area.

These findings confirmed prior work in the Tri Lakes area focused on disconnecting or abandoning shallow private wells in favor of public water service, as well as updating the OSS inventory.

Figure 2 depicts the loading to groundwater from OSS calculated for the Tri Lakes area based on the best-available OSS loading data (see Appendix D). Colors are coded according to Thurston County Board of Health Resolution H-2-1996 (Thurston County Board of Health, 1996) defining nitrate concentrations:

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- Blank – groundwater recharge is below the Early Warning Level (EWL) of 2.0 mg/L
- Yellow – groundwater recharge is equal to or above the Early Warning Level (EWL) of 2.0 mg/L, but below 4.0 mg/L
- Orange – groundwater recharge is equal to or above the Contaminant Action Level (CAL) of 4.0 mg/L, but below 10 mg/L
- Red – groundwater recharge is equal to or above the Federal Safe Drinking Water Act (SDWA) Maximum Contaminant Level (MCL) of 10.0 mg/L

The calculation of nitrate loading requires two values: wastewater flowrate and nitrate concentration:

- [Loading (mg/day)] = [Nitrate Concentration (mg/L)] * [Wastewater Flowrate (L/day)]

Initial (source) concentrations of nitrate were calculated for each model cell (see Thurston County, 2022, for the methodologies used). These were input to the MT3D solute transport model as 'source' concentrations, as described below.

Both the wastewater flowrate and nitrate concentration can be calculated using reasonable assumptions for wastewater from OSS. The usefulness of the calculated loading depends upon using a regularized unit of land area across which the different values for nitrate loading can be normalized. Land parcels with variable sizes do not meet this need. Instead, a regularized (square) grid was used – the same square grid used for both the groundwater flow and transport models, with an equal-cell-size of 200x200 feet (40,000 square feet, or slightly less than one acre).

The geospatial output was a point shapefile, with point attribute values for the centroid of each model cell. Each point contains metadata with the initial nitrate concentration at each cell in milligrams per liter (mg/L). Each point was further indexed with the MODFLOW model cell indices [I,J,K] used to assign MODFLOW recharge (steady state), and to allow importation into the MT3D solute transport model (v23 - constant source concentration) for further analysis.

Note that nitrate loading data represent the shallowest probable nitrate concentration due to OSS impact. However, in practice – and in part because of shallow nitrate/bacteria contamination - most wells are intentionally installed with open intervals *significantly below* the zone impacted by OSS. Unfortunately, this creates a statistical bias in groundwater samples that there is no shallower contamination; this effect often leads to the erroneous conclusion that shallow groundwater is uncontaminated. To correct this bias, shallow monitoring wells were also sampled to represent shallowest groundwater nitrate.

In the northern part of Thurston County, deeper wells are installed to avoid shallow OSS contamination (a practice well-known to drillers). Because these wells are often protected by overlying confining layers, nitrate sample results are typically close to background concentrations. This positive outcome incentivizes drilling deeper – but masks the presence of potentially-contaminated shallow groundwater.

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Nitrate mass loading assists the evaluations of the total mass of nitrate reaching groundwater – and then surface water (this migration is calculated primarily using the groundwater transport model MT3D). These can better assess the proportions of nitrate derived from OSS reaching groundwater, streams, and lakes.

Using the updated OSS inventory for the Tri Lakes area, county-wide nitrate loading described in Appendix D was applied across the study area and used as the input to the SSM Module (Source-Sink Mixing) of the groundwater transport model MT3D-USGS based on the MODFLOW-NWT ground-surface water flow model running county-wide.

Numerous hotspots that were identified in the Tri Lakes area indicate that OSS are likely to cause exceedances of the Federal Safe Drinking Water Act Maximum Contaminant Level (MCL) of 10 mg/L in some areas (see red-shaded cells in Figure 2; model results in Figure 3 and 4). Many of these clusters of wastewater loading points were installed before an OSS regulatory structure existed, or under regulations that have since been superseded.

Modeling done for this study is one of the tools that can now be used more often to assess risks and focus water quality efforts. Modeling the water quality impacts from OSS and possibly other urban/suburban sources could help assess where sewers would be of greatest benefit. This project is a logical follow up to the septic-to-sewer project and there are a good number of public drinking water sources in the area, so it is logical that both WSDOH and the Thurston County Health Department should be involved. By using modeling to prioritize the best locations for confirmatory sampling, such a project could help with questions about whether to extend sewer. Updating of the Sewerage General Plan (now nearly 30 years old) might also be one outcome. This information can also help policy makers and staff evaluate the impacts of new development proposals. The information can also be used by WSDOH to evaluate the susceptibility rating of public drinking water sources in the area.

Sewer system expansion is, however, a much more extensive process involving treatment system capacity, engineering feasibility and numerous financial considerations far beyond the scope of this study. However, this study can help inform where such further investigations might best support water quality improvements.

Hydrogeology, MT3D Transport Modeling and the Selection of Candidate Wells

The MODFLOW-NWT and MT3D simulations quantitatively evaluated groundwater flow and solute transport for a conservative, non-reactive modeled solute that can be considered similar to the actual physical transport properties of nitrate. The six-layer flow and transport models included the important aquifers and confining layers in the study area. Table 1 includes the estimated well depths where known, the model layer from which pumping is presumed to have occurred, and the probable aquifer pumped. Using the historical USGS nomenclature for the study area (Drost et al, 1999), the major aquifers simulated in the MODFLOW and MT3D models were:

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- Layer 1: The 'Vashon Recession' (Q_{vr}) aquifer is present through most of the study area. Known contamination and recent modeling suggest that OSS may impact this aquifer in significant concentrations (above MCL of 10mg/L). Significant discharge from this aquifer feeds the three lakes and Woodland Creek as baseflow, exposing them to additional contamination.

- Layer 2: The 'Vashon Till' (Q_{vt}) is generally a confining layer present through most of the study area. Known contamination and recent modeling suggest that OSS may have penetrated this layer significant concentrations (above the MCL of 10mg/L).

- Layer 3: The 'Vashon Advance' (Q_{va}) aquifer is present throughout the area. Known contamination and recent modeling suggest that contamination passes through overlying Vashon till confining layer and impacts this aquifer. Some discharge from this aquifer feeds the three lakes and Woodland Creek as baseflow, probably also exposing them to contamination.

- Layer 4: The Kitsap Formation (Q_f) is not generally known as an important aquifer in the study area, yet some wells appear to be completed in this formation.

- Layer 5: The 'Sea Level' (Q_c) aquifer is a major drinking water supply aquifer for northern Thurston County. Known contamination and recent modeling suggest that contamination may pass through overlying confining layers to impact this aquifer.

- Layer 6: Deeper aquifers (TQ_u – Tertiary-Quaternary aquifers, undifferentiated) were modeled and may receive contaminants. There is some known deeper contamination, for which the source is unknown; modeling suggest OSS may contribute contamination to the sands that make up this deeper aquifer – contamination that has previously been difficult to trace.

Note:

In some cases sampled wells' depths are not known. Logs may not be available, and the exact formation from which water is pumped remains unclear. Table 1 provides the estimated model layer and named aquifer, if known, for sampled wells only.

Figure 12 presents these model layers as defined in the groudwater flow (MODFLOW_NWT v253) and solute transport (MT3D-USGS v23) models used in this project.

For simplicity in this report, Figure 3 depicts the extent of solute transport (qualitatively similar to nitrate) determined by MT3D-USGS modeling of Layer 3 at a simulated duration of 14,600 days (MODFLOW-NWT v253, MT3D-USGS v23), while Figure 4 depicts Layer 5 from the same simulation pair. Figure 12 depicts the extent of contamination vertically in cross-section B-B', from south to north across the study area.

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This simulation utilized a total of 11,577 'wastewater generation points' (each point is equivalent to the wastewater generated by one household's OSS. The loading from these was aggregated into 4,490 model "source" cells at the resolution of 200x200 foot model grid cells. Nitrate loadings for these grid cells were input to the SSM Module (Source Sink Mixing) of the MT3D transport model of Thurston County.

Transport modeling produces a full 3D solute transport field over time that can be animated. Several animations were made of solute migration simulating nitrate movement.

Selection and Sampling of Wells

Prior to this project, several hundred wells were believed to exist in the study area. Many of these wells were mapped or sampled as part of prior investigations from the 1980s through the 2000s. Concerns about water quality resulted in many of these wells being disconnected or abandoned as homes were connected to public water supply systems. This was a successful public health approach – but the number of domestic wells remaining in the Tri Lakes area remained uncertain.

Candidate wells for field sampling were seleted by comparing expected pumping wells' intake zones with the corresponding MT3D model-calculated solute concentrations at a model time of 14,600 days (approximately 40 years' model duration). This time duration was chosen from the estimated buildout date for the majority of OSS in the Tri Lakes area to the present with a modal distribution year of about 1980 (see Figure 10).

Prioritization of the approximately 100 most-likely-contaminated wells using this process was augmented with other criteria such as:

- Known prior groundwater quality problems at wells already in Thurston County water quality database
- The well is known or very likely to be shallow
- Larger served population for community water supply systems, prioritizing Group B small community system wells.

Based on the prioritized wells, residents were first sent letters and then postcard mailings to determine if the owner was receptive to sampling. Numerous wells from this process were found to be unavailable for sampling as many wells reportedly either no longer existed, or owners refused/ignored the sampling request. To locate additional wells, Health Department staff went door-to-door in the project areas and were able to secure additional wells for sampling. Additionally, both the Thurston County Public Utility District #1 and the City of Lacey granted access to multiple wells. Eight county-owned monitoring wells were also sampled in areas with densely clustered OSS, to evaluate a potential 'worst-case' scenario. The locations of final sampled wells are shown on Figures 2, 3 and 4. Table 1 (appended) provides the field data, well depth if known and the probable aquifer pumped, while Table 2 below provides a summary of the numbers of wells initially expected in the study area, by class of well.

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Table 2 - Well Types Sampled for the Project

Class of Well	Count of Pumping Wells in Study Area by Well Class	Wells Sampled for this Project	Typical Aquifer (see Table 1 for details)
Public Supply Group A Systems	57	12	TQ_u, Q_c
Public Supply Group B Systems	39	18	Q_c, TQ_u
Domestic	421	20	Q_{vr}, Q_{va}, Q_c
Monitoring	-	8	Q_{vr}
Totals	**554**	**58**	

Sample Analysis Results

The collected data are fairly representative of public, private, and monitoring wells in the project area. Brief summaries are as follows:

Results of Bacteriological Sample Analyses

Only 4 of 58 (7%) of wells sampled had detections of total coliform bacteria and the range of detection was 2 – 17 MPN/100ml. MPN refers to the Most Probable Number [MPN] of total coliform bacteria colonies per 100 milliliters of sampled water. Three of the four wells with total coliform detections were monitoring wells, and one was a domestic well. The owner of the domestic well was notified of this result. Additionally, no wells had detection of E. coli bacteria (typically associated with human wastewater).

Results for Nitrate

Table 3 below compares the nitrate (as N) sample data with the USEPA maximum contaminant level (MCL), and action levels established by Thurston County policy and the type of well sampled. It is important to note that human health effects from nitrate are not known to occur at nitrate-nitrogen levels below the MCL; however, note below that other substances present in groundwater samples may have different toxicity profiles (see the CEC data presented later).

Table 3 - Comparison of nitrate (as N) with regulatory criteria

	Group A	Group B	Domestic	Monitoring	Total
Exceeds MCL				1	1
Exceeds TRIGGER		1	4	4	9
Exceeds CAL		1	1	1	3
Exceeds EWL	6	3	6		15
Below BACKG	6	13	10	2	31

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MCL: 10 mg/L
TRIGGER: Federal and State trigger level for increased monitoring: 5 mg/L
CAL: County Critical Action Level: 4 – 9.9 mg/L (only results 4 - <5 mg/L counted for this report)
EWL: County Early Warning Level: 2 – 3.9 mg/L
BACKG: County Background: < 2.0 mg/L

See Table 1 for the depths if known, and probable aquifer pumped. Early Warning and Contaminant Action Levels were established in 1996 for all of Thurston County by Thurston County Board of Health Resolution H-2-96. That same resolution:

- Establishes nitrate as the indicator of contamination of ground water due to human activities.
- Indicates that nitrate concentration levels below 2.0 mg/l are to be considered "background"
- Creates an Early Warning Level (EWL) when nitrate concentrations are between 2.0 and 3.9 mg/l.
- Establishes a Critical Action Level (CAL) for nitrate concentrations between 4.0 and 9.9 mg/l.
- Recognizes that 10.0 mg/l is the federal and state maximum contaminant level for nitrate.

Additionally, WAC 246-290-320 (3)(b) requires increased monitoring when testing shows water supplies exceed 50% of the maximum contaminant level (MCL), and references 40 C.F.R. 141.23(d)(2) which states that water systems must increase sampling frequency when they exceed the trigger level (5.0 mg/l for nitrate).

Results for Chemicals of Emerging Concern (CEC)

Groundwater samples from ten selected Tri Lakes area wells were analyzed for CECs (Chemicals of Emerging Concern) by the University of Washington (UW) Tacoma Center for Urban Waters. Chemicals of Emerging Concern are related to consumer usage; these are distinct from 'Residual Chemicals' described as present in post-treatment Reclaimed Water in studies conducted by LOTT Clean Water north of the Tri Lakes project area, for example (see Intertox [2022]).

Table 4 presents the distribution of the types of wells that were sampled:

Table 4 – Distribution of Wells Sampled for CEC Analyses

Group A	Group B	Domestic	Monitoring
2	2	5	1

Figures 5, 6, 7, 8, and 9 provide graphical presentations of instrument responses for substances tentatively identified using the UW Tacoma Center for Urban Waters methodology for CECs (James and Wark, 2023). Note that these are NOT groundwater concentrations, *per se*, but rather relative instrument responses. The analytical process used by the Center for Urban Waters (UW Tacoma) essentially *first* produces a "screening level" evaluation of chemicals that are present in a sample which can be compared with over 1000 chemical "standards" in a chemical signature "library"

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developed for the analytical process (Appendix C provides a summary review of this procedure). This results in a *tentative substance identification* that compares mass and retention time for the detected molecules to the known standards in the library. Phase I tentatively identified substances generally correlated with five chemical classes:

- Food additives: Six (6) substances
- Commercial chemicals: Twelve (12) substances
- Industrial chemicals: twenty-five (25) substances
- Pesticides and Herbicides: nine (9) substances
- Pharmaceuticals: Twelve (12) substances

Appendix B provides a screening list of tentatively identified compounds, while Figures 5 through 9 present a visual comparison of abundance for the same substances.

Figure 12 provides an overview of CEC detected in Puget/Salish waters, highlighting the ubiquity of these substances (Tian, et al, 2019).

Based on the Phase I findings, Phase II analysis was performed on ten selected groundwater samples using repeated quantification of replicates by Mass Spectrometry (MS/MS). See Appendix C for an overview of analysis procedures. The Phase II analysis process produced semi-quantitative concentrations for:

- **Caffeine** (a food additive)
- **2,6-Dichlorbenzamide (BAM)** (a breakdown product of the herbicide DCBN or dichlobenil – one trade name is "Casoron")
- **Sucralose** (a food additive)
- **Sulfamethoxazole** (an oral sulfonamide antibiotic)

Table 5 presents the approximate concentrations for these specific substances, and the substances themselves are tentatively identified.

Three other substances/classes were analyzed-for but were not detected: OPEO and NPEO (groups of chemicals widely used as surfactants or emulsifiers in detergents) and Methylprednisolone (a corticosteroid hormone pharmaceutical used to treat arthritis, blood disorders, severe allergies, etc.)

Note that the concentrations presented in Table 5 are semi-quantitative estimates, given in nanograms per liter of groundwater (ng/L) with a potential +/-50% variance. Estimated concentrations above 500 ng/L are above the upper limit of the original instrument calibration curve and can be treated as >500 ng/L; they are included for comparative purposes between sampling sites. Substances detected below the quantification limit are depicted with a less than (<) symbol. To protect owner/resident anonymity, well location alias names are used; other sensitive location information is excluded from Table 5. Please contact the Thurston County Health Department to request additional information.

The Center for Urban Waters analysis process tentatively identifies hundreds - or thousands - of substances and their concentrations using a large and powerful library of chemical properties. By providing tentative substance identifications and approximate concentrations, this 'screening' approach is very valuable for this first-of-its-kind assessment of groundwater in the Tri Lakes project area. However, this method alone cannot provide all the data needed for full substance confirmation and quantification. Additional sampling and analysis using agency-approved standard methods would be needed for assessments of human health risk.

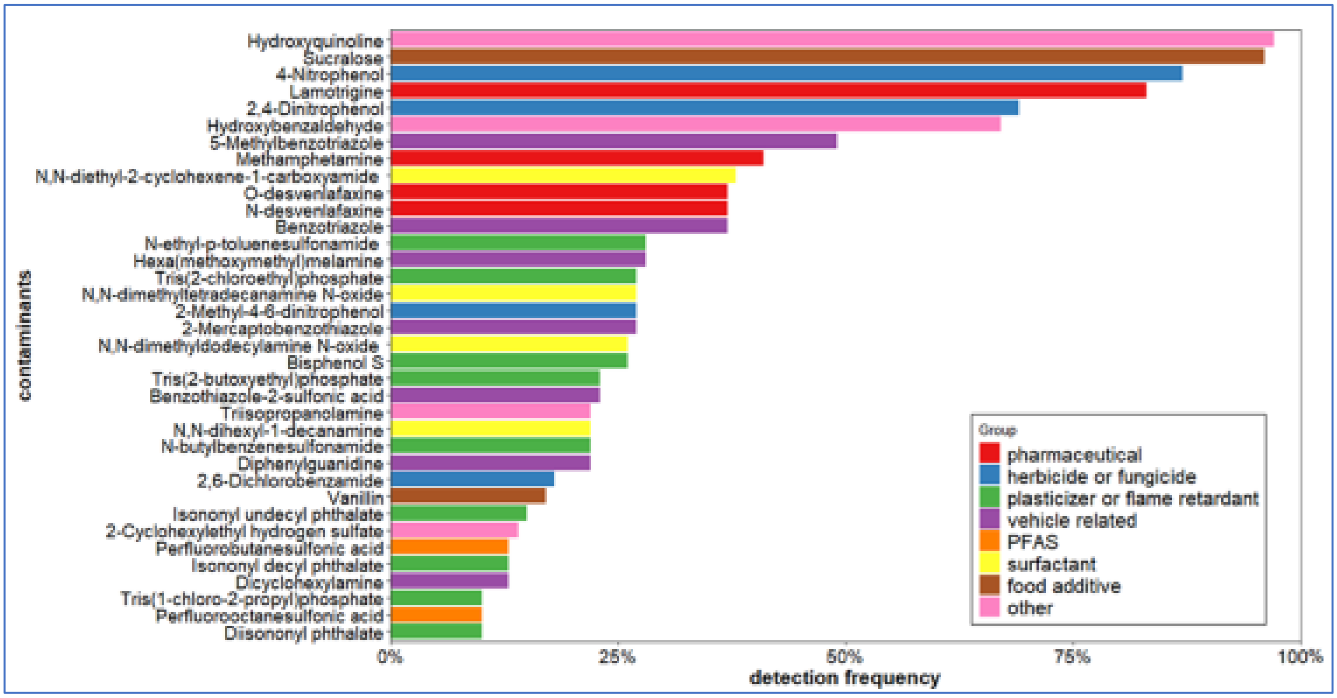

Figure 12. Detection frequency for Contaminants of Emergimg Concern (CECs) in Puget/Salish Sea waters (adapted from Tian, et al, 2019).

Results from Analysis of Surface Water Samples

Six surface water sites were sampled because preliminary observations and research suggested that they were each likely fed by groundwater. Provisionally, the surface water samples can be physically associated with groundwater sample analyses and modeling results (see Table 1). Total Coliform was elevated in all the surface water samples, while E. coli and Nitrate were present at relatively low concentrations. The significant differences between these six surface water samples and groundwater samples suggests different sources feeding these six surface waters. Although groundwater may contribute seepage to these water bodies, the contaminant profiles are dissimilar, suggesting a different conceptual model that cannot easily correlate with findings from the MODFLOW-NWT and MT3D-USGS simulations. Further surface water sample analysis and probably additional surface water sampling (for a broad range of CEC substances) would be required to evaluate the most important sources to surface water.

Comparison of Model Results with Groundwater Sample Analyses

The initial Tri Lakes project concept involved using the results of groundwater flow and solute transport modeling to guide the selection of the wells and surface water locations where risks to drinking water supplies and surface water were expected to be highest. One important purpose of sampling was to determine if the modeling could be used to forecast groundwater quality without the need for extensive corroborative field sampling. Overall, the modeling fulfilled those purposes. However, the comparison of modeled to actual/sampled concentrations yielded both important insights and cautionary notes, as follows:

- The groundwater flow field from MODFLOW-NWT flow model v253, in conjunction with steady-state MT3D-USGS solute transport model v23 provided a useful prediction of expected three-dimensional concentrations of a conservative (i.e., non-reactive) tracer across the entire study area, when compared with Nitrate (as N) concentrations at sampled wells.

- The modeled data with MODFLOW-NWT v253 and MT3D-USGS v23 generally underestimated actual Nitrate (as N) concentrations in groundwater.

- A best-fit of the modeled data to field data was achieved using a multiplier of 1.41 times all modeled concentrations.

- This aggregate multiplier produced the minimum RMS (root-mean squared) error between modeled and field data, after correction, of 3.06 mg/L.

- Location WEL51591, a domestic well, was a model outlier not included in the statistical analysis.

- Figure 11 provides a comparison between modeled and sampled concentration data versus depth, at locations where the depth of the sampled well was known (i.e., where the appropriate 3D modeled concentration could be chosen for each sampled well). Appendix E provides a tabular comparison of modeled and sampled data.

- Strong downward hydraulic gradients exist in most parts of the study area, increased in part by heavy deeper groundwater pumping. Downward gradients are an important reason why vertical movement is occurring despite low-conductivity layer properties such as high vertical anisotropy (i.e., Kv << Kh).

- Long-duration source persistence contributes to deeper contaminant concentrations. OSS systems have existed in-place in the study area, most of them for decades.

- The detailed vertical movement of contaminants was not evaluated. The model simulated average layer properties; however, study area is known to be very heterogeneous. For example, there are known 'windows' where confining layers are thin or absent. Some 'windows' were evaluated by the USGS (Drost et al, 1999) and are present in the MT3D modeling. Other 'windows' not in the numerical model were identified in studies reported by investigators knowledgeable in this area (personal communications).

The sampled well data were also compared with two major branches of the flow model. The MT3D-USGS transport model was run using both an earlier steady-state version of the MODFLOW-NWT flow model (v198) and the current transient version of the MODFLOW-NWT flow model (v253). The main differences between the flow fields and corresponding transport model results were as follows:

  - The earlier version of the MODFLOW-NWT flow model (v198) used higher recharge adapted from the method of the USGS in Bidlake and Payne (2001). Hydraulic conductivities calibrated using the MODFLOW-NWT v198 flow field were higher than hydraulic conductivities in later MODFLOW-NWT versions of the County model. The generalized effect of this was that solute transport distances were large, and simulated concentrations were lower near source areas, and lower at many model cells corresponding to sampled wells. This was interpreted to indicate that a higher dilution of OSS sources was simulated. In general, this "higher-recharge, faster-moving and more diluted septage plume" assumption proved to be a less-good match for actual field data.
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  - The current MODFLOW-NWT flow field (v253) used lower recharge (derived from a newer Soil-Water Balance [SWB]) simulation of Thurston County built by Keta Waters (see Massmann and Massmann, 2021). Hydraulic conductivities in the study area calibrated using the v253 flow field were

lower than hydraulic conductivities in earlier MODFLOW-NWT versions of the county model. The generalized effect of this was that solute transport distances were lower, and simulated concentrations were higher near source areas, at many model cells corresponding to sampled wells. This was interpreted to indicate that less dilution of OSS sources was simulated. In general, this “lower-recharge, slower-moving and more concentrated septage plume” assumption proved to be a better match for actual field data (albeit with a multiplier of 1.41 still required to best-fit actual groundwater sample data).

- The MT3D-USGS transport modeling assumed a single constant start date for all OSS loading. The groundwater sample data were compared with model results at a simulation time of 14,600 days (about 40 years’ simulated time, or a source start date of about 1983 from the present [April 2023]). That simulation start was chosen because the OSS buildout ages peaked in about 1980-1985 (see the histogram in Figure 10). Of the 11,577 OSS counted in the study area, initial buildout dates were approximated for 10,541 systems (about 91%). However, numerous systems were installed before and after this peak, and many systems were installed before modern permit requirements. Additionally, this method used tax record occupancy dates, that assume the septic system began operating immediately after the construction permit was issued. Thus, the timing of the peak concentration at each sampled well may vary considerably from the 40-year assumption. These uncertainties are additive to those introduced by numerous flow and transport model uncertainties for large areas such as the Tri Lakes study area.

- Numerous factors affect output concentrations of contaminants simulated by a numerical model. The proportions of contribution from any specific source type must be interpreted with caution. This study tested the effects of OSS/septic systems – one important class of sources. However, other sources exist that were not studied. Their contribution to actual detected concentrations is unknown. Additional work would be required to clarify the relative contributions of other possible source types.

Findings

1. The results of this project indicate the initial source delineations and modeling were largely correct: significant groundwater contamination does exist in the Tri Lakes area, and is likely related to OSS, but that other sources likely contribute to both modeled and sampled contaminants. However, modeling underestimated actual nitrate concentrations using best assumptions.

2. Twenty-eight of the fifty-nine sampled wells (47%) had nitrate-nitrogen results greater than or equal to the early warning level of 2.0 mg/L. This suggests and confirms that nitrate/nitrogen is a contaminant of concern in the Tri Lakes groundwater area.

3. Only one well (a monitoring well), exceeded the nitrate-nitrogen MCL. The area of that well is entirely served by OSS and this is thought to be the source. However, since the well is not being used for potable water, no investigation was conducted.

4. Nine wells exceeded the TRIGGER for additional monitoring. Since the TRIGGER only applies to public water supplies, only one Public B system was in exceedance. The project team notified the county’s drinking water program leader to inform her of this exceedance as Thurston County regulates Group B water systems.

5. Three wells exceeded the critical action level which generally triggers additional sampling and investigation of the scope of the problem and a corrective action plan. Initial owner/resident notifications were made.

6. Numerous CECs were detected in groundwater samples, suggesting the need for follow-up. Pesticides/herbicides, Industrial chemicals, Commercial chemicals, pharmaceuticals and Food additives were all detected, some in numerous wells.

7. One domestic well and three monitoring wells contained Total Coliform, but only one well was positive for E. coli (that owner was notified).

8. Groundwater flow and transport provided a useful prediction of expected three-dimensional concentrations of a conservative (i.e., non-reactive) tracer across the entire study area, when compared with Nitrate (as N) concentrations at sampled wells.

9. Sucralose emerged as a likely near-ubiquitous substance closely tied to OSS wastewater. Because of its ubiquity, sucralose may be a useful tracer and marker for human-derived wastewater loading.

10. Surface water samples' analysis result patterns were dissimilar from those of the groundwater samples, suggesting differing sources and dissimilar conceptual transport models.

11. This work helps fulfill the objectives of the 1990 Sewerage General Plan for follow-up analysis of the consequences of OSS wastewater loading densities that were in use at the time of that plan.

12. Modeling supports the hypothesis that reductions in allowable OSS wastewater loading densities implemented in the mid-1990s have improved groundwater quality when compared with those of the mid-1980s OSS construction peak.

13. Detections of nitrate and CECs below confining layers (typically either Vashon till or Kitsap Formation) indicate that these confining layers are allowing downward movement of contamination, over the timescale of decades. Model results confirm the predictable nature of contaminant movement deep in the aquifers, despite the presence of low-conductivity layers and strong vertical anisotropy identified in the flow model.

14. Strong downward hydraulic gradients exist in most parts of the study area, increased in part by heavy deeper groundwater pumping. Downward gradients are an important reason why vertical movement is occurring despite low-conductivity layer properties such as high vertical anisotropy (i.e., $K_v << K_h$).

15. Long-duration source persistence contributes to deeper contaminant concentrations. OSS systems have existed in-place in the study area, most of them for decades.

Assumptions, Limitations and Uncertainties

In addition to the uncertainties noted above:

1. To quantitively assess human health risk, additional analysis for CECs would be required using USEPA and DOE/DOH-approved methods, with full Quality Assurance and calibration standards.

2. Multiple assumptions, limitations and uncertainties exist; some of these – but not all - are noted in the text, figures, tables, and appendices referenced above.
3. The proportions of actual sources to the detected groundwater concentrations are unknown. This study focused on only one source type – but many other causes probably also affect the concentrations detected; their proportions are unknown and were not simulated herein.
4. Significant heterogeneity exists in the study area that was not evaluated.
5. Several outcomes of the regularization approach used in this study (the summation of recharge and mass by equally sized model cells) are important:
    a. Nitrate is assumed to be evenly mixed across the entire model cell.
    b. The scale of the model grid is useful for averaging location and concentration uncertainties, including the averaging of location errors, so that complete mixing is a useful simplifying assumption.
    c. At the site scale, the assumption of complete mixing often breaks down. Nitrate in seepage may reach much higher or lower concentrations than calculated by following preferential transport pathways.
    d. The initial concentrations calculated from wastewater loadings are almost always higher than actual groundwater sample concentrations - from either drinking water supply wells or monitoring wells. Groundwater advection alone mixes flowing groundwater with wastewater, causing substantial dilution. Recharge occurring along the contaminant travel path further dilutes concentrations. Diffusion compounds these differences.
2. Atmospheric nitrogen contributes a small amount to the total nitrogen analysis result (usually less than 0.7 mg/L).
3. Precise locations for wastewater loading were not always known – and documentation of many systems' installation details/locations is not easily obtainable. The aggregation by model cell (200x200feet) probably smooths some of this location uncertainty.
4. The default concentration of nitrate in wastewater reaching the groundwater surface (60 mg/L) is based on considerable research. However, by policy in Thurston County it is held as a constant - and was held constant in the MT3D-USGS solute transport modeling. The 40% average difference between modeled and sampled nitrate suggests that other sources may exist – or that source concentrations need further evaluation.
5. Work by the USGS (Rosen, et al, 2005) indicates that the nitrate concentrations from OSS built from the 1970s – early 1990s may be higher than this default value - and the range of concentrations may be large. Thurston County Health Department data suggest that OSS designed and installed after the 1995 Sanitary Code update are significantly more effective than older systems at nitrogen removal.
6. For this study, the Thurston County Environmental Health default-policy value of 60 mg/L was used; this concentration would benefit from further research.
7. Study findings are valuable for regional assessment, not site-specific evaluations.
8. Study findings are NOT appropriate for the enforcement of regulations.

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