STORMWATER INFILTRATION AND IMPACTS ON GROUNDWATER

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INTRODUCTION

Edgewood, Washington, contains six hydrologically isolated “potholes” that are prone to flooding during wet weather. As the soils in the contributing watershed become saturated, the water moves as surface and subsurface flow to the potholes, causing water levels to rise. During prolonged wet weather conditions, extensive flooding has occurred.

Out of a total city area of 8.4 square miles, almost 3 square miles are within the drainage area of the potholes, representing 35 percent of the area within the city limits of Edgewood (Kato & Warren et al. 1997). Approximately 0.28 square mile or 180 acres (3 to 4 percent of the city) become inundated during a major event, such as one that occurred during the winter of 2016--17. Flooding events have occurred with regular frequency in recent years, with at least three events over the past 10 years (J. Metzler, pers. comm.).

Infiltration or injection of treated stormwater into an aquifer is one possible method for controlling flooding. It has the added benefits of recharging the aquifer and not contributing to downstream erosion or flooding. However, because of the pollutants associated with stormwater, there are concerns with this method due to the potential for contamination of the groundwater if treated stormwater is allowed to bypass some of the natural filtration and attenuation provided by the upper aerobic units of soil.

Aquifers considered in this assessment include the near-surface aquifer (the aquifer closest to the ground surface) and deeper aquifers. The most recent geologic map of the area (Troost 1999), indicates the near-surface aquifer is buried below a layer of till that ranges from 50 to approximately 150 feet deep in the city of Edgewood. The Mountain View-Edgewood Water Company (Water Company) Wellhead Protection Plan ([WHPP] prepared by Robinson-Noble, 2005), identifies the Vashon advance aquifer as the primary source for water supply wells beneath the upland with lesser contributions from deeper (older) units. However, the 2005 WHPP plan used older geologic mapping as a basis for preparation of several of the figures presented in the WHPP resulting in uncertainty in subsurface correlation and the characterization of hydrostratigraphic units. For purposes of this report the near-surface aquifer is the aquifer to which stormwater would be discharged, i.e., the “receptor” aquifer. The relationship between the near-surface aquifer and the “Vashon advance aquifer” identified in the WHPP is uncertain and will require additional site-specific exploration borings to address these discrepancies if the City moves forward with evaluating the feasibility of a UIC wellfield approach. Deeper aquifers are also present and supply some of the drinking water source for the Water Company, an award-winning drinking water supply. Another concern is the potential for creating unstable slopes. If stormwater is discharged to the near-surface aquifer at a volume that exceeds the capacity of the aquifer, the excess water in the near-surface aquifer can result in surface seeps. If those surface seeps occur on the steep side slopes that exist in Edgewood, they can result in soil slumps or landslides.
The purpose of this paper is to:

- Describe the rules and regulations pertaining to infiltration of stormwater into an aquifer in Washington State.

- Describe local case studies of groundwater monitoring results where infiltration of stormwater into an aquifer has been used.

- Summarize findings from a literature review to assess potential groundwater contamination issues.

Appendix A also provides a summary of design and construction considerations related to use of deep infiltration for stormwater control.

In other activity related to considering the use of UIC wells for discharge of treated stormwater, the City is planning on completing a feasibility assessment and pilot project at the Edgewood Bowl site. The assessment will include evaluation of site-specific surface and subsurface conditions and characterization of flow control and treatment requirements as well as environmental benefits. The feasibility assessment will entail extensive monitoring, hydrologic modeling, exploratory borings, and local community and stakeholder involvement.

**Washington State Regulations**

Underground injection control (UIC) wells are regulated by the Washington State Department of Ecology (Ecology), as described in Ecology Publication 05-10-067, titled *Guidance Manual for UIC Wells that Manage Stormwater* (Ecology 2006). The following two basic requirements of the UIC program were taken directly from the Ecology UIC manual:

- **Register UICs with the Washington State Department of Ecology unless the wells are located on Tribal land.**

- **Make sure that current and future underground sources of ground water are not endangered by pollutants in the discharge (non-endangerment standard).**

UICs must either be rule-authorized or covered by a state waste discharge permit to operate. In Edgewood’s case, a UIC would be rule-authorized. A UIC is considered rule-authorized when it meets the criteria above and a registration form has been submitted to and accepted by Ecology.

The Ecology UIC Manual identifies two methods to meet the non-endangerment standard: a presumptive approach and a demonstrative approach. If all the requirements of Ecology’s manual are met and the well is rule-authorized, then the UIC well would be covered under the presumptive approach. The presumptive approach can be used when an Ecology-approved best management practice (BMP) for stormwater treatment identified in an Ecology approved...
stormwater management manual is used prior to conveyance into the UIC. The demonstrative approach is required if the proposed stormwater treatment utilizes technology or methods not currently included as a BMP by Ecology. In that case, the applicant must “demonstrate” the proposed treatment system will be protective of groundwater resources. Ecology would likely require long-term water quality monitoring to obtain system approval under the demonstrative approach.

**LOCAL CASE STUDIES**

**Issaquah Highlands**

Issaquah Highlands represents one of the most applicable local case studies for potential stormwater infiltration impact assessment. Issaquah Highlands is a large development in the city of Issaquah, starting in 1996. It includes approximately 700 acres of mixed-use residential and commercial on a 2,263-acre site on the Sammamish Plateau. One of the key concerns associated with the development was protecting groundwater recharge while also protecting groundwater quality because the lower aquifer is used as a drinking water supply. To protect groundwater recharge, stormwater infiltration was the selected stormwater management method used for most of the development and resulted in construction of five large stormwater infiltration facilities on the site. The development agreement with the City of Issaquah required extensive monitoring of groundwater elevations, groundwater quality, and stormwater to ensure that streams and wetlands associated with the site were not adversely affected during the construction and operations phases of the project.

To assess potential impacts on groundwater recharge, groundwater elevations were monitored in one shallow well and two deep wells on the project site, starting in 1997 and lasting until 2008; 2 years after the 75 percent buildout of the project (Herrera 2009). The shallow well reflects conditions in the receptor aquifer that first receives the stormwater, while the deeper wells reflect conditions in the aquifer that serves as a drinking water supply in the project area. The threshold criterion established for groundwater hydrology for the development states that there would be no decrease in the average annual groundwater level that cannot be explained by factors that are unrelated to the project when compared to predevelopment conditions. Monitoring indicated that there was a significant decrease in groundwater elevations in the two deep wells but no significant decrease in groundwater elevations in the shallow well in the receptor aquifer. Thus, the lower groundwater elevations in the deep wells were attributed to differences in precipitation as well as increased withdrawal of water from the lower aquifer, and the City of Issaquah determined that there was no impact from the development.

Groundwater quality was also monitored at the three well sites. Constituents monitored included conventional parameters such as turbidity and total suspended solids, metals, five organic contaminants (including benzene and endrin), and several other constituents important to groundwater quality.
Sample constituent concentrations from the three wells were compared to established threshold criteria. The threshold criteria for arsenic, iron, and manganese were frequently exceeded at the shallow monitoring well; however, they were also exceeded during baseline data collection. Groundwater standards were not exceeded for either arsenic or manganese. Concentrations of those metals are naturally high in many aquifers in Washington State, which is typically attributed to geology of the area, as evidenced by the high concentrations measured during baseline monitoring. That, coupled with the facts that arsenic and manganese are not typically associated with stormwater runoff and that the constituents that are typically associated with stormwater runoff (e.g., copper and zinc) were not elevated, indicates that the high concentrations are likely naturally occurring. No other constituents were measured at levels above the threshold criteria.

Issaquah Highlands is located on the Sammamish Plateau. A major slope failure occurred on the site in 2004. The primary cause for the slope failure was that an undocumented till layer functioned as an aquitard (i.e., a confining layer that impedes downward movement of water), resulting in accumulation of stormwater above the till layer. Thus, water did not flow vertically and directly into the underlying aquifer but instead followed “a circuitous path, much of it emerging as hillside seeps and springs” (Issaquah et al., 2004). Another contributing factor was that the five stormwater infiltration facilities were all clustered into the same part of the development (Area 4), which was very close to the steep valley side walls.

In a later phase of development of Issaquah Highlands another infiltration facility (the Lower Reid Infiltration Gallery or LRIG) was installed in the development and operated for about 6 years. This facility was located within 600 feet of a public water supply well. Elevated measurements of total coliform bacteria and temperature in the well raised concerns about potential contamination of groundwater by the stormwater facility. As a result of this and ensuing discussions and negotiations, the LRIG was decommissioned. However, there was follow-up monitoring of the stormwater that was bypassed around the facility for 2 years after it was decommissioned. This stormwater received basic treatment via a settling pond but not the additional treatment it would have received via infiltration. The monitoring results indicated that the concentrations of all of the regulated constituents monitored (i.e., arsenic, nitrates, copper, lead, and chlorine) were as low, or lower in the stormwater than in the groundwater (J. Shervey, Department of Ecology, personal communication). Coliform bacteria continued to be high in the stormwater, but this may well be a reflection of the settling pond and its attraction to waterfowl and other bacteria sources, since bacteria are not typically a concern associated with urban stormwater.

**Snoqualmie Ridge II**

The Snoqualmie Ridge II development encompasses a total of approximately 736 acres on the Lake Alice Plateau in the city of Snoqualmie, immediately adjacent to the existing Snoqualmie Ridge I development. The resource assessment for the Snoqualmie Ridge II development focused on assessing the potential impairment to water quality, hydrology, and other resources...
from the development. Similar to the Issaquah Highlands development and the conditions in the city of Edgewood, the Snoqualmie Ridge project site is on a plateau and the local aquifer (the Lake Alice aquifer) provides Group B and single-family domestic drinking water. Stormwater is managed through the use of detention and infiltration ponds. Water quality treatment occurs through either settling in the detention ponds or by use of presettling ponds in the case of two infiltration facilities using media backfilled UIC wells.

Monitoring requirements for the Snoqualmie Ridge II project included a preconstruction phase to establish baseline conditions, a construction phase (which lasted 10 years), and a post-construction phase. Groundwater samples were collected from two dedicated monitoring wells and four domestic wells within surrounding neighborhoods. One of the dedicated monitoring wells and two of the domestic wells are completed within the Lake Alice aquifer. The remaining wells (the second dedicated monitoring well and the remaining two domestic wells) are completed within the receptor aquifer for the infiltration facilities and are located in close proximity to the infiltration systems.

Monitoring parameters included physical parameters (color, specific conductivity, and total dissolved solids), primary contaminants, secondary contaminants, and volatile organic compounds (VOCs) as defined in WAC 246-290-310. Sampling results were compared to Washington State drinking water quality standards, and state and federal maximum contaminant levels (MCLs). Baseline and construction period measurements were compared to evaluate the potential adverse impacts on water quality that have resulted from construction activities and development on the project site.

As summarized in the most recent monitoring report (Herrera 2017), VOCs were detected at low concentrations in the dedicated monitoring wells during the baseline sampling phase and during the first 2 years of construction, but post-construction concentrations were below the detection limit. VOC concentrations never exceeded MCLs. Two secondary contaminants, iron and manganese, were detected above MCLs during baseline and construction phase sampling in the two dedicated monitoring wells and one of the domestic wells. Since concentrations were generally consistent between baseline and construction monitoring results, the high concentrations could not be attributed to the stormwater infiltration facility. As described above, the presence of iron and manganese in groundwater is likely due to natural leaching from host soil and rock formations, which is not uncommon in the Puget Sound area. The authors summarized, “...there are no trends in parameter concentrations that would suggest a substantial change or gradual impairment of groundwater quality based on a collective review of the data” from the baseline events and subsequent monitoring events. Overall, groundwater monitoring indicated that Snoqualmie Ridge II development and associated installation of a stormwater infiltration facility on the Lake Alice Plateau did not contribute to impaired groundwater quality.
City of Portland, Oregon

The City of Portland owns and operates an estimated 9,600 UICs, which include drywells, sumps, and trench drains that discharge stormwater to the subsurface. Most of Portland’s UICs are located in the rights-of-way of public roads and, therefore, can be expected to be discharging stormwater with high concentrations of heavy metals, petroleum hydrocarbons, and other pollutants associated with highway runoff.

Portland’s UICs are regulated under the Water Pollution Control Facility (WPCF) permit issued by the Oregon Department of Environmental Quality, requiring fairly extensive monitoring to evaluate impacts on groundwater to ensure protection of the aquifer that provides emergency and supplemental drinking water to local residents. The only treatment the UICs provide is through movement of the stormwater through the underlying soils. To ensure adequate treatment capacity, the WPCF permit requires separation from the seasonally high groundwater table of a minimum of 5 feet.

In total, approximately 44 storm event samples were collected at a minimum of 15 sites over a 10-year period, resulting in over 1,100 samples for some of the constituents of concern (Portland 2017). Samples were collected from the inlets to the UICs. Results were compared to the State of Oregon’s Maximum Allowable Discharge Limits (MADL), which are similar to the Maximum Contaminant Level (MCL) established by the US Environmental Protection Agency (US EPA) for primary drinking water standards. For the vast majority of the contaminants, none of the samples exceeded the MADL and average concentrations were well below MADL levels. Five contaminants (of more than 40 evaluated) occasionally exceeded the MADL standard; they were: pentachlorophenol (PCP), lead, Di (2-ethylhexyl) phthalate (DEHP), Benzo(a)pyrene, and arsenic. For the latter three contaminants, the exceedances were infrequent (less than 1 to 5 percent of samples), and calculated average concentrations were below detection. PCP and lead had more frequent exceedances (15.4 and 13.6 percent, respectively) of the MADL, but the average concentrations of those contaminants were still well below the MADL limits. PCP was found to pose the highest risk of adverse impact on groundwater because it was more frequently detected above the MCL and is more mobile than lead; however, it is still considered to have low mobility.

Due to the MCL exceedances for contaminants in stormwater entering UICs, additional monitoring of groundwater wells downgradient of UICs was performed but no contaminants were detected. In addition to sampling results, a conservative fate and transport model was used to evaluate the fate of pollutants once they enter the groundwater. Based on sample results and fate and transport modeling, the Oregon Department of Environmental Quality stated in its permit issuance letter, “The City’s UICs do not appear to endanger groundwater resources on the basis of existing groundwater quality data and the City’s pollutant fate and transport modeling.”
Spokane County

Spokane County contains more than 10,000 drywells, which discharge stormwater into the ground to reduce flooding and allow stormwater to be treated by natural processes. The Spokane Valley Rathdrum Prairie Aquifer is designated as a “Sole Source Aquifer” and provides drinking water to over 500,000 people. Monitoring in the 1970s and 1980s detected an increasing nitrate trend in groundwater that suggested septic systems were contaminating the aquifer. As a result, Spokane County implemented the Septic Tank Elimination Program (STEP) to convert septic tanks to sewer systems. The Spokane Aquifer Water Quality Management Plan was developed to monitor groundwater quality to assess the effectiveness of the STEP. While nitrate was associated with contamination from septic tanks, chloride was associated with storm runoff contamination (Spokane County 2009).

The current monitoring network includes 29 dedicated monitoring wells, 17 public supply wells, and 4 springs. Sampling is conducted quarterly. In addition to measuring parameters identified as primary and secondary contaminants in drinking water, additional tests are performed for conductivity, water level, pH, turbidity, and dissolved oxygen. MCLs for primary contaminants were not exceeded in 2007 or 2008. Secondary contaminants are not a threat to human health; rather, they may cause cosmetic or aesthetic effects in drinking water. Exceedances of the associated MCLs trigger requirements in Washington State for additional drinking water sampling by public water purveyors. Four analytes were found to exceed the MCLs for secondary contaminants during 2007 and 2008: iron, arsenic, manganese, and nitrate. None of those analytes are typically associated with stormwater runoff.

Literature Review

In addition to the local case studies, a literature review was conducted to search for additional studies for which subsurface soil or groundwater monitoring was performed explicitly to evaluate potential impacts on groundwater quality from stormwater infiltration.

Spatial Distribution of Pollution in an Urban Stormwater Infiltration Basin

Deschesne et al. (2004) implemented a study to evaluate dispersion of pollutants in the soils beneath a stormwater infiltration basin to examine the extent to which contaminants accumulate in the soil. The stormwater was generated by runoff from a truck parking lot with known high concentrations of heavy metals and hydrocarbons. Stormwater received pretreatment via a retention basin where larger particles were removed before entering the infiltration basin. The infiltration basin was built over highly permeable sediment and had been in operation for 14 years prior to the study, thus the results reflect conditions after many years of operation. The monitoring included 10 sampling locations within the infiltration basin. At each location, samples were collected from four different depths between the surface and a
depth of approximately 1 meter. The contaminants evaluated included nutrients, heavy metals, and hydrocarbons (total hydrocarbons and polycyclic aromatic hydrocarbons [PAHs]) and others. Contaminant concentrations were compared to “target” concentrations, which were defined as soil concentrations that represented fully functioning soil (similar to background concentrations), and “intervention” concentrations, which would represent contaminated soils.

Analysis of the samples revealed that, while there was an accumulation of contaminants in the uppermost layer of soil in the infiltration facility, all contaminants decreased rapidly between the surface and the next depth sample (i.e., 30 to 40 centimeters [cm] below the surface of the basin). Most metals were below target concentrations, even in the surface sample. Lead, cadmium, copper, and zinc—the metals most strongly associated with urban pollution—all exceeded target concentrations in the surface layer; zinc and copper exceeded the intervention concentration in the surface layer. The concentrations of those metals all decreased rapidly with depth; lead and copper achieved target concentrations by the second depth (30 to 40 cm), cadmium by the third depth (70 to 80 cm), and zinc largely achieved the target limit at the third depth, with a few exceptions. Hydrocarbon concentrations also exceeded the target level on the surface but rapidly decreased and were generally below the target limit by the second depth.

Another important finding of the study was the interdependency between stormwater inputs and continued contaminant retention. The surface soils of the facility changed characteristics as a result of the stormwater input. Cation exchange capacity (CEC), pH, and organic content all increased in the surface layer, while particle size decreased. Such physical and chemical changes contribute to improved pollutant removal over time. As stated by the authors, “The newly trapped pollutants therefore continuously improve efficiency of pollutant retention, whether mechanical or physico-chemical retention is considered.”

Overall, the study results indicate that, even after years of operation, stormwater contaminants are still effectively retained in the near-surface soils below infiltration facilities and do not appear to present a risk for movement to groundwater.

**Removal and Fate of PAHs in an Urban Stormwater Bioretention Facility**

Diblasi et al. (2009) conducted a study to assess PAH removal by a bioretention cell that received stormwater runoff from a parking lot and associated sidewalks at the University of Maryland. Both water quality and bioretention media were sampled. Although the study did not specifically include groundwater monitoring, it did address accumulation of pollutants in the soil/media in the facility. Flow-weighted composite samples of surface runoff at the influent and effluent were collected during five rainfall events. Bioretention media was sampled at two locations: one near the inlet and one near the midpoint of the linear cell. At both locations, core samples were collected to a depth of 40 to 50 cm below the surface and the cores were then separated into four to five 10-cm-deep sections.
PAH removal in the water samples ranged from 31 to 99 percent, with an average of 90 percent. As is often the case, the sampling events with lower removals were associated with much lower incoming influent concentrations. Effluent concentrations were fairly similar, no matter the influent concentration, and were typically below quantification limits.

The highest concentrations of PAHs were found in the upper layer(s) of the media core collected from near the inlet. Concentrations were a magnitude higher in the top 10 cm of the core than in the next depth. At the midpoint core, higher concentrations were actually measured lower in the core. Overall, however, the concentrations throughout the midpoint core were low (all at least a magnitude lower than the surface layer of the inlet core), and there was higher variability in the results. The great majority of the PAH accumulation appeared to be occurring in the upper few millimeters of the soil surface near the inlet. PAH removal was found to be positively correlated with removal of total suspended solids in the bioretention soil media.

**Assessing the Risks of Using Dry Wells for Stormwater Management and Groundwater Recharge: Results of the Elk Grove Dry Well Project**

The City of Elk Grove, California, performed a study to assess the feasibility of installing dry wells to manage stormwater runoff and promote aquifer recharge (Elk Grove and OEHHA 2017). Testing occurred at two locations: a residential neighborhood, and a city maintenance yard and bus parking lot (i.e., an industrial site). Each test location was designed as a treatment train with a vegetated pretreatment area (i.e., a grassy swale at the industrial site and vegetation in the water quality basin at the residential site), a sedimentation well, and then a dry well that conveyed the stormwater below the restricting soil layers. At each site, four monitoring wells were also constructed: a vadose zone well was constructed 15 feet downgradient of the dry well, two other downgradient wells were constructed approximately 100 feet from the dry well, and one well was constructed approximately 150 to 300 feet upgradient.

Stormwater and groundwater samples were collected for five storm events over 2 years, and groundwater was monitored prior to the drywell construction. In addition to testing effectiveness of the pretreatment facility through inlet and outlet monitoring, samples were also collected at the top and bottom of the vadose zone in the vadose zone well and in groundwater samples collected up- and downgradient of the wells.

Samples were analyzed for over 200 contaminants, including organics (i.e., VOCs, semi-volatile organic compounds, PAHs, pesticides, herbicides), metals, and bacteria. None of the organics were detected at quantifiable concentrations in groundwater. Outside of pesticides, only a few organic contaminants were detected in the stormwater, and only one (DEHP) was detected at the MCL for drinking water. Pyrethroid pesticides were consistently detected in untreated stormwater at both project sites but at much higher concentrations at the residential site. Bifenthrin, a pesticide widely used for insect control, was the main pesticide of concern.
Pretreatment greatly reduced concentrations of bifenthrin to below detection at the industrial site. At the residential site, it was still above detection levels as the runoff entered the drywell but below detection in the vadose well and downgradient wells. Fate and transport modeling for bifenthrin indicated that it did not pose a risk to groundwater quality due to its hydrophobic nature and high degradation rate in the subsurface. The authors summarized that “Pyrethroid data suggests that hydrophobic pesticides in general are highly unlikely to pose a risk to groundwater quality.”

Motor oil was one of the other organic contaminants regularly detected in stormwater from both sites, although concentrations were much higher at the industrial site. Median concentrations decreased threefold as runoff moved through the pretreatment systems. The motor oil was still above detection limits as the runoff entered the drywell, but none was detected in the vadose well or either downgradient well.

Acetone was also detected at elevated concentrations in the industrial site stormwater, but it decreased to below reporting limits after pretreatment. Based on the observed high concentrations of both motor oil and acetone at the industrial site, the authors recommended dry wells not be installed near vehicle maintenance facilities and similar industrial sites. (Note: Washington State does not permit dry wells in these locations.)

Metals were the primary class of contaminants detected in both stormwater and groundwater at both sites. However, only a small number were detected at quantifiable concentrations. The authors divided the metals into two groups: those that are naturally occurring, and those that are anthropogenic. The only anthropogenic metal detected at significant concentrations in the stormwater was aluminum. The concentrations exceeded the MCL at the industrial site but were well below the MCL at the residential site. Pretreatment through vegetation greatly reduced concentrations at both sites. Aluminum was detected at downgradient wells, occasionally at concentrations that exceeded the public health goal, but that also occurred at upgradient wells at both sites, indicating that the source of the aluminum was not stormwater infiltrated through the wells.

Total bacteria were measured at high concentrations at both sites in stormwater and groundwater. However, the elevated concentrations could not be clearly attributed to the dry well. Nitrate was measured at higher concentrations in groundwater than in the stormwater and was, therefore, attributed to historical agriculture.

The results of the study indicated that dry wells with pretreatment and appropriate separation between the bottom of the well and the top of the water table could be used to increase groundwater recharge with little risk of degrading groundwater. However, the authors’ recommendations about siting dry wells included avoiding sites where hazardous chemicals are used or soils are contaminated.
Impact of Stormwater Infiltration Practices on Groundwater Quality

Nieber, et al. (2014) quantified the potential for contaminants to reach groundwater under established infiltration facilities. The field study considered three sites with large infiltration facilities. The sites included bioinfiltration, an underground infiltration gallery, and an infiltration basin. Groundwater samples were extracted from the soil at various depths. Stormwater samples were collected during runoff events for 18 months, resulting in a total of 145 samples. Samples were analyzed for chloride, nitrate, phosphorous, heavy metals, and petroleum hydrocarbons.

Results suggested that nitrates were not a concern in urban runoff because concentrations in untreated stormwater are typically much lower than the US EPA primary drinking water standard. Chloride was found to be a more significant concern for both surface water and groundwater resources. However, the issue of chloride is related to the practice of salting roads in the Midwest; it would not be expected to be an issue in western Washington. With a few exceptions, there was no evidence of a difference in metal concentrations with depth. A closer examination of results for copper and zinc, the metals most closely associated with urban stormwater runoff, indicated no evidence of increasing concentration with depth in the soil at any site. While US EPA has not established drinking water standards for copper or zinc, there is an Action Level for copper of 1.3 milligrams per liter (mg/L). The concentration range of copper measured in the study was approximately 0.0001 to less than 0.01 mg/L. Zinc concentrations primarily were in the range of 0.010 to 0.100 mg/L, range. In comparison, Washington State has a secondary drinking water standard for zinc of 5.0 mg/L.

Total petroleum hydrocarbon samples were collected at only one of the three study sites. While there were occasions when subsurface concentrations were higher than surface concentrations, the data were insufficient to assess possible trends.

Summary of Related Literature Reviews

During the literature search, a number of other literature reviews for a similar topic were identified. Major findings are summarized below.

US EPA completed a literature review in 1999 entitled *Groundwater contamination potential from stormwater infiltration practices* (Pitt et al. 1999). The primary purpose of the study was to determine whether regulations in existence at the time were sufficient to mitigate risks to underground drinking water sources. Existing literature was reviewed, contaminant spills linked to dry wells were documented, and state practices were assessed.

In this review, groundwater contamination was found to be rare in residential areas; the most common pollutant found in groundwater in residential areas was chloride in areas where road salts are used. Groundwater contamination was found to be more common in commercial or industrial areas with subsurface infiltration. The authors identified a number of contaminants...
that would have moderate to high potential for contamination of groundwater if they were present in stormwater and if no pretreatment was provided. This included some pesticides (i.e., lindane and chlordane) and other organics (e.g., VOCs, 1,3-dichlorobenzene, pyrene, fluoranthene), and some pathogens. For all those contaminants, the potential for contamination of groundwater was considered to be low if pretreatment that included sedimentation was provided. Similarly, nutrients (as nitrate) and heavy metals were considered to have low to moderate potential for groundwater contamination if they were present in the stormwater at high concentrations; if pretreatment was provided, they would have low potential to contaminate groundwater. Salts were the one contaminant for which the potential for contamination was high and would remain high, regardless of pretreatment.

In 2008, the State of Minnesota funded a literature review entitled Contamination of Soil and Groundwater Due to Stormwater Infiltration Practices (Weiss et al. 2008). The following is excerpted directly from their executive summary:

> Heavy metals are often present at very low levels in urban stormwater. Fortunately, studies have demonstrated that metals are generally retained in the upper soil layers via adsorption to solid particles. However, eventual breakthrough can occur due to the finite sorption capacities of the soil media. Periodic replacement of the upper soil layer within infiltration systems has been suggested as a method of preventing possible groundwater contamination and maintaining low soil concentrations.

> Suspended solids are usually removed via straining by the soil. Because they pose little health risk, suspended solids are mainly a concern because they may clog the infiltration system. Phosphorus and nitrogen can also be removed within the soil media—phosphorus by precipitation or adsorption reaction, and nitrogen by bacterial denitrification. Nitrates present in drinking water supplies can pose a health concern to certain target groups. Most studies indicated that nitrate is poorly retained in infiltration devices due to high solubility. However, the low levels typically found in urban stormwater make nitrate pollution a low concern.

> Anthropogenic organic pollutants, such as petroleum hydrocarbon residues, are typically present at low levels in urban runoff. Only a few published studies have examined the fate of those compounds in stormwater, but the limited results appear promising. Many organic pollutants, such as oils and gasoline, have a high soil affinity and can also be biodegraded. Degradation rates and the contaminant capacity of the soil, however, have largely been unexplored. Some organic compounds are less likely to be retained by the soil, and certain practices (such as subsurface injection) have been documented to increase the risk of groundwater contamination. Subsurface injection provides a more direct conduit to groundwater and does not allow infiltration through the aerobic vadose zone where biodegradation is enhanced.
Few studies have examined the efficacy of infiltration practices for pathogenic organisms (e.g., fecal coliform, other bacteria, and viruses) removal. However, the outlook appears to be positive, in that pathogens can be physically strained by the soil in a manner similar to that of a sand filter at a drinking water treatment plant. However, documented cases of bacterial contamination of groundwater wells exist; certain practices (e.g., subsurface injection) may increase the risks. Pathogens may move vertically and/or horizontally with subsurface water flow and survive for days. Contamination of groundwater by pathogens has been documented and cannot be ignored.

Finally, it is known that soil media has no appreciable retention of salts. Thus, salts have a high potential for groundwater contamination, and documented cases of groundwater contamination by salts exist. Placement of the infiltration device largely dictates the influence of saline pollution.

A more recent review was completed in 2016 (Tedoldi et al. 2016) that evaluated studies that examined either: assessment and testing of contaminant accumulation in soil/filter media from “sustainable urban drainage systems,” or modeling efforts to predict fate and transport. The authors concluded that the soil/filter media acts as a physicochemical and mechanical filter for most of the urban source contaminants that are typically studied. As a consequence, significant accumulation of those contaminants occurs in the upper layers of the soil/filter media, but the accumulation usually is restricted to the upper 10 to 30 cm of soil. Vertical migration of metals outside of that zone was found to be related to the exhaustion of the soil’s sorption capacity, or by contaminants bypassing the soils sorbing phase through colloidal facilitated transport or through preferential flow pathways. The authors cautioned that, because the focus of the studies was soil/filter media contamination, little is known about the downward fluxes of pollutants that are not retained by the solid matrix and/or are hydrophilic in nature.

In terms of the overall findings of the many studies reviewed, Tedoldi et al. noted that the variety of sampling strategies, investigated contaminants, analytical methods, physical measurements etc., were detrimental to study comparisons. However, they concluded: “These methodological biases induced some uncertainties about the measured values in experimental studies, the observed tendencies can still be compared, leading to interesting and potentially generalizable conclusions which are consistent with the theoretical considerations.”

**OTHER CONSIDERATIONS**

**Slope Stability**

Steep slopes can be affected by groundwater daylighting on the slope and increasing landslide hazard potential. Potential adverse impacts on steep slopes can be avoided by: 1) evaluating groundwater mounding due to infiltration from UICs, and 2) determining the height of
groundwater mounds at distant slopes and their influence on slope stability from a deep infiltration system. Several deep UICs and pit drain systems have been located immediately adjacent to steep slopes, as described in Appendix A. Such systems have specifically included slope stability and mitigation elements to avoid adverse impacts on steep slopes and downgradient resources. Long-term water level and slope monitoring from multiple sites has demonstrated that groundwater mounding effects dissipate rapidly with distance from properly constructed UIC and pit drain infiltration systems; therefore, adverse slope impacts have been avoided.

**Facility Siting**

In addition to design considerations, such as subsurface conditions and vertical separation from groundwater, there are a number of other siting considerations, including: avoiding sites where there are hazardous materials or industrial/commercial land uses, avoiding contaminated soils, avoiding public water supply wells, and avoiding the area of influence from septic systems.

**Long-Term Performance and Maintenance**

As indicated by some of the studies described in this report, some contaminants accumulate on the surface of infiltration facilities. Although one study indicated that the soils’ capacity to remove pollutants may actually increase due to physical and chemical changes in the soil structure (Deschesne et al. (2004), it is still recommended that periodic removal and disposal of the surface sediments in infiltration facilities be a requirement for long-term maintenance. The frequency and nature of maintenance requirements for UIC systems is dependent on system design. Pretreatment facilities can simplify maintenance, such as sand filters placed over media-backfilled wells where sediment can be easily removed using hand equipment and that allow routine access to the UIC.

**Summary and Conclusions**

The primary goal of this report is to summarize the potential impact of UIC or injection wells on groundwater quality. Protection of groundwater quality is a major consideration in the design of UIC systems because UICs, by design, penetrate through some of the natural “protective” barrier provided by soils and, in many cases, through some of a restrictive till layer.

Based on local case studies and a review of relevant literature, there is little evidence of groundwater quality impacts from UICs, assuming the stormwater receives pretreatment before discharge. While contaminants were found to accumulate in the surface soils or media, in most cases, they were not detected or were not detected at levels of concern in vadose zone or groundwater samples. There are a few known exceptions; chloride, nitrates, and bacteria all have been shown to be mobile in soils and can move to groundwater, as documented by the many wells throughout the United States that have elevated concentrations of these contaminants.
None of these contaminants is strongly associated with urban stormwater runoff, but they provide evidence that not all contaminants are easily treated by movement through soil.

Although not documented in any of the studies reviewed, one study (Elk Grove and OEHHA 2017) suggested that concentrations of some naturally occurring metals that are not typically present in stormwater, such as arsenic and chromium, may increase nonetheless due to increased solubility caused by changes in redox reactions that result from stormwater influence.

The pesticides evaluated in the studies reviewed were removed through pretreatment, were quickly degraded, and/or were hydrophobic in nature. As recommended in the Elk Grove study (Elk Grove and OEHHA 2017), water-soluble pesticides, such as fipronil and imidacloprid, have not been adequately characterized, and further information on their concentrations and removal by pretreatment should be considered. Other authors, too, cautioned that the studies were largely limited to contaminants more strongly associated with urban runoff, implying that there could be contaminants in the runoff that are hydrophilic in nature but that exist at concentrations too low for detection in stormwater that could nonetheless accumulate in the groundwater over time. More research is needed on fate and transport of these types of contaminants.

While this literature review was constrained by resources, the similarity in findings across a variety of study types and locations and in more comprehensive literature reviews further strengthens the confidence in the study findings.

**Recommendations**

Siting of a UIC is critical to groundwater quality protection. UICs should be located well away from water supply wells—for example, outside of the 1-year time of travel. They should not be sited near septic systems or areas potentially affected by septic systems during flooding events, and they should not be sited near industrial or commercial areas.

As experienced with the Issaquah Highlands II development, if the capacity of the receptor aquifer is not properly characterized, infiltrated water can migrate laterally to surface seeps and contribute to slope failures if the seeps are located on steep slopes. Proper siting, understanding of the underlying geology, and a groundwater mounding analysis are necessary to address this concern.

Before the City of Edgewood adopts the use of deep infiltration to address flood control and groundwater recharge, a pilot project should be implemented to evaluate potential groundwater quality impacts as well as recharge potential. In selecting the site for the pilot project, distance to water supply wells, septic systems, and commercial or industrial land uses should be considered. Infiltration assessment and a groundwater mounding analysis should also be performed for the selected site. The pilot project should include rigorous monitoring to evaluate potential impacts on groundwater quality, including testing for water-soluble pesticides.
and evaluating the potential for desorption of arsenic or chromium, if they are found in high concentrations in the groundwater.

If this approach is adopted by the City of Edgewood, a long-term monitoring program is recommended to assess performance of the UIC and to provide early warning for any potential risks to groundwater quality or downgradient slopes. Monitoring should focus on stormwater and vadose zone sampling, as is done in Oregon, rather than groundwater monitoring, which is less likely to show impacts.

In addition, if the City of Edgewood adopts the use of UICs to control stormwater flooding, the City should expand its public education program to emphasize the importance of pollutant reduction for further protecting groundwater quality.

Although it was not the purpose of this report to evaluate recharge potential, it is one of the key benefits of using a deep well injection system. As fresh water has become scarcer, communities are taking a more integrated approach to managing their water supplies by considering the value of all potential water sources: precipitation, stormwater, groundwater, and surface water. In that way, the risk to groundwater quality can be weighed against the risks to groundwater supply and on surface water quality and supply.
References


Metzler, Jeremy, Senior Engineer, City of Edgewood. Personal communication: e-mail to Joy Michaud, Herrera Environmental Consultants, Inc. June 1, 2017.


APPENDIX A

Technical Memorandum re: Deep Infiltration
Technical Memorandum

Date: November 9, 2017
From: Sue Sweet, L.G.
Curtis J. Koger, L.G., L.E.G., L.Hg.

To: Herrera Environmental Consultants, Inc.
Project Manager: Curtis J. Koger, L.G., L.E.G., L.Hg.
1220 Fourth Avenue NE
Olympia, Washington 98506

Principal in Charge: Curtis J. Koger, L.G., L.E.G., L.Hg.

Project Name: City of Edgewood Stormwater Management Plan

Attn: Joy Michaud
Project No: 170304H001

Subject: Issue Paper on Deep Infiltration via Underground Injection Control Wells or Drains

1.0 BACKGROUND

The purpose of this Technical Memorandum (TM) is to describe some of the hydrogeologic, environmental, regulatory and design considerations/issues associated with the potential use of deep Underground Injection Control (UIC) wells by the City of Edgewood (City) for infiltration of treated stormwater runoff. AESI has design, construction and post-construction experience with over 30 deep UIC well and “pit drain” (excavated pits) systems designed to convey treated runoff deep into the subsurface below surficial low permeability units. This TM contains descriptions of two major types of deep UIC well systems termed media backfilled and screened wells, and includes a description of deep pit drains. Based on past experience the systems with lowest long term Operations and Maintenance concerns are media backfilled systems using either deep UIC wells or pit drains that are placed in an infiltration basin with a large footprint covered by a blanket of water quality sand media to protect the deep drilled or excavated intervals. Although the screened UIC wells are briefly described in this TM, the document is focused more comprehensively on media backfill design considerations.

1.1 Infiltrate Stormwater/Reduce Flooding

Surficial low-permeability lodgement till deposits in the City of Edgewood (City) area limit stormwater infiltration potential with shallow stormwater infrastructure methods. Areas of permeable recessional outwash deposits overlying the till are present in the City, but are localized and of limited aerial extent diminishing long-term infiltration potential. Conveyance of treated stormwater through the low-permeability surficial lodgement till deposits to underlying infiltration horizons with the use of Class V Underground Injection Control (UIC) wells has been successfully implemented by Associated Earth Sciences, Inc. (AEIS) on numerous projects with similar goals for reduction of stormwater runoff. AESI has monitored long-term infiltration performance of more than 10 deep UIC well and pit drain systems demonstrating system reliability. Water quality data has also been obtained from long-term monitoring of six deep UIC well and pit drain systems and demonstrate ground water quality standards are protected with proper system design. No adverse ground water quality impacts have been identified in monitored systems.
1.2 Geologic Considerations

Surface geologic mapping (Troost, 1999) and subsurface well data presented in the Mountain View-Edgewood Water Company (Water Company) Wellhead Protection Plan (WHPP) prepared by Robinson, Noble & Saltbush in 2005 indicate the upland areas of the City are primarily underlain by a sequence of Vashon lodgement till (Figure 1). The lodgement till was deposited at the base of the Vashon ice sheet during the last glaciation (termed Fraser Glaciation) of the Puget Lowland, and consists of a heterogeneous mixture of extremely compact clay, silt, sand, and gravel. The infiltration potential of the till is very low, typically in the range of about 1 to 2 inches per month. The low permeability of this near surface geologic unit limits the potential for infiltration through the till from shallow infiltration methods, such as pervious pavement systems, bioretention, rain gardens, and conventional shallow infiltration basins.

The surficial Vashon lodgement till is underlain by a thick sequence of unsaturated Vashon advance outwash based on available subsurface information. The Vashon advance outwash consists of interbedded sand and gravel deposited in meltwater streams during the advancing phase of the Fraser Glaciation. The Vashon advance outwash unit is a suitable receptor horizon for treated stormwater using deep UIC wells or shallower Pit Drains, where till is thinner than approximately 15 to 20 feet.

The 2005 WHPP used an older version of the geologic map of the Edgewood area. Figure 2 from the WHPP specifically references that the geologic information was modified from Water Supply Bulletin 29 (WSB 29). (Since WSB 29 is from Mason County, AESI assumes the correct reference was intended to be WSB 22 titled Ground Water Occurrence and Stratigraphy of Unconsolidated Deposits, Central Pierce County, Washington published by the United States Geological Survey (USGS) in 1968.) Page 7 of the WHPP identifies the Vashon Advance Aquifer System as “the primary source for all of the Company’s wells”. The only exception noted in the WHPP on page 7 was Well #5. Figure 1 included with this TM shows the locations and one year time of travel (TOT) radius of Group A wells provided by Tacoma-Pierce County Health Department. The 2005 WHPP prepared for the Water District includes 6 month, 1 year, 5 year, and 10 year TOT boundaries.

AESI used more recent geologic mapping of the Edgewood area (Troost, 1999) to evaluate the subsurface characterization presented in the WHPP. AESI reviewed descriptions provided on Water Company drillers logs with the updated geologic map and compared those with Figure 4 in the WHPP titled Hydrogeologic Cross Section A-A’. Based on the available data the nomenclature presented on Figure 4 of the WHPP is inconsistent with more recent geologic mapping. For discussion purposes the Water District wells identified in the WHPP can be grouped into two major categories including 1) Upland Wells, and 2) Slope Margin wells. The upland wells include #2, #3, #6 and #7. The slope wells include #1R, #5, #8 and #9.

Upland Wells

Log and construction details for Well # 2 (Leighton Site) show two screen intervals. The upper screen interval was from 272 to 279 feet, but was noted as “not successful” on the log. The final construction configuration indicates the well was screened from 382.3 feet to 397.3 feet. Notably the lithologic description from 222 feet to 271 feet states “cemented gravel and layers of till, red-brown, deeply weathered”. The deeply weathered condition of the samples observed during drilling is highly unusual for Vashon age deposits and strongly suggests older units were encountered for both the original shallower completion and the final deeper completion. Descriptions provided on logs for both wells #3 and #7 indicate fifteen feet of “till-like clay sand and gravel” beginning at a depth of 123 feet. The producing zone, identified approximately 224 feet below ground surface in Wells #3 and #7, may represent a pre-Vashon interval. Descriptions for Well #6 indicate 39 feet of hardpan beginning at a depth of 157 feet with silty clay identified at a depth of 130 feet. The screen zone is reportedly from 370 to 385 feet, and is highly likely to be completed in a pre-
Vashon age unit. The logs for wells #3, #6 and #7 all indicate sandy clay and till intervals, at similar elevations, beneath thick unsaturated sand sequences suggesting pre-Vashon age sediments would be present deeper in the subsurface at the completion zones.

Slope Margin
Wells #1R and #8 are completed near the base of the slope just above the broad Puyallup River valley. The Troost 1999 geologic map indicates the wells are located in a pre-Vashon geologic unit. Figure 2 in the WHPP also shows both wells #1R and #8 are completed below the base of the Vashon advance outwash contact near the base of the slope. Therefore, both the newer geologic map and the WHPP map confirm the wells must be completed in pre-Vashon age deposits. Well #5 is acknowledged as a pre-Vashon completion in the WHPP, and this interpretation is supported by lithologic descriptions presented on the log and geologic mapping. Well #9 is completed below sea level based on Figure 4 in the WHPP. This is inconsistent with the geologic map shown on Figure 2 in the WHPP which shows the base of the Vashon advance outwash near an elevation of 100 feet above sea level. In addition, the vertical stratigraphic sequence indicates a general fining upward pattern above the sands and gravels of the producing zone which is inconsistent with a prograding Vashon advance outwash sequence. Based on the available data it appears likely well #9 is also completed in a pre-Vashon unit.

Discussion

The available geologic and well log data suggests most if not all of the Water District wells described in the WHPP represent pre-Vashon age units. Although there is uncertainty regarding geologic units and nomenclature of the Water District producing intervals, the protection of ground water quality is central to any proposal that may incorporate the use of UIC wells. UIC wells must be protective of groundwater quality even in very shallow highly vulnerable aquifer systems. Additional subsurface investigation, testing and impacts analysis would be required prior to initiating any UIC project.

1.3 Deep Infiltration Systems

Deeper infiltration systems have consisted of both “Pit Drains” and UIC wells. Pit drains are typically designed to access receptor horizons located less than approximately 15 to 20 feet below ground surface (bgs) and are constructed using conventional excavation equipment. UIC wells are typically used to access deeper receptor horizons greater than about 20 feet, with most deep UIC’s ranging from about 40 to 150 feet bgs depending on site conditions. Drilling methods are required to construct UIC wells. Either infiltration system can significantly reduce the impact of surface stormwater runoff. Benefits of deep infiltration systems include increased aquifer recharge and maintenance of off-site instream baseflows, while avoiding direct discharge of excess stormwater runoff to surface water features to avoid erosion and flooding. An example drilled UIC well schematic is provided on Figure 2.

1.4 UIC Well Requirements

UIC wells are regulated by the Washington State Department of Ecology (Ecology), as described in Ecology Publication 05-10-067 titled Guidance Manual for UIC Wells that Manage Stormwater (Ecology UIC Manual, December 2006). The following two basic requirements of the UIC program were taken directly from Ecology’s UIC manual:

- Register UIC wells with the Washington State Department of Ecology unless the wells are located on Tribal land.
• Make sure that current and future underground sources of ground water are not endangered by pollutants in the discharge (non-endangerment standard).

The Ecology UIC Manual states “UIC wells must either be rule-authorized or covered by a state waste discharge permit to operate”. In the case of the City a UIC well would be rule-authorized. A UIC well is considered rule-authorized when it meets the following criteria:

• A registration form must be submitted to the Department of Ecology
• Discharge from the UIC must not contaminate ground water. This is the “non-endangerment performance standard”.

The Ecology UIC Manual identifies two methods to meet the non-endangerment standard.

• One way is to follow the requirements of this technical guidance. The Department of Ecology will presume that the UIC well meets the non-endangerment standard and the well will be rule-authorized. This is called the presumptive approach.
• The other way is for the registrant to demonstrate that the non-endangerment standard has been met in some other way. This is called the demonstrative approach.

The presumptive approach can be used when an Ecology approved Best Management Practice (BMP) for stormwater treatment identified in an Ecology approved stormwater management manual is used prior to conveyance into the UIC well. The demonstrative approach is required if the proposed stormwater treatment utilizes technology/methods not currently included as a BMP by Ecology. In this case the applicant must “demonstrate” the proposed treatment system will be protective of groundwater resources. Long term water quality monitoring may be required by Ecology to obtain system approval.

The City of Edgewood adopted the 2015 Pierce County Manual for surface water design and maintenance standards; which is an equivalent manual to the Department of Ecology (Ecology) 2012 Stormwater Management Manual for Western Washington, as Amended in 2014 (Ecology Manual). We anticipate any UIC well system constructed in the City would utilize Ecology approved BMP’s for water quality treatment prior to conveyance to a UIC well and would therefore be rule-authorized and meet the non-endangerment standard. However, the demonstrative approach has been used on previous UIC well projects and can also be considered if applicable.

2.0 UIC WELL CONSTRUCTION, DESIGN, AND TESTING

Well design depends on multiple factors including depth to the receptor horizon, physical properties of the receptor horizon, depth to ground water, proposed method of water quality treatment prior to conveyance to the UIC, space available for well construction, and long term O&M considerations. Other factors may also influence well design based on project specific requirements.

2.1 Depth to Receptor and Water Table

The depth to the receptor horizon and the thickness of the unsaturated zone above the water table influence UIC well construction and design. Drilled UIC wells are typically completed using either conventional air-rotary methods or solid stem auger techniques. The thickness of the unsaturated zone will influence the length of the completion zone and may affect the diameter of the well. Typically, the completion interval extends across 20 to 50+ feet of the receptor horizon, but must always maintain a minimum of 5 feet of
separation above the seasonal high water table. In this way, the UIC well is always dry except when receiving stormwater inflow, and will meet the minimum vertical separation requirement to the water table per the Ecology UIC Manual requirements.

2.2 Typical UIC Well Flow Rates

Individual UIC well flow rates are primarily controlled by: 1) physical properties of the receptor horizon, and 2) well design. The permeability of the receptor horizon combined with the available completion interval thickness will limit the maximum flow rate of the UIC well. Based on over 200 UIC well tests, the Vashon advance outwash typically has flow rates ranging from about 50 gallons per minute (gpm) to 300 gpm per well.

2.3 UIC Well Construction

Two major classes of UIC wells have been constructed in the Puget Sound region including 1) media backfilled, and 2) screened wells. Pit drains have also been constructed to convey treated stormwater runoff deep into the subsurface. The following summarizes some of the typical construction specifications for each, as well as information on construction of a wellfield.

2.3.1 Media Backfilled UIC Wells

Media backfilled wells are commonly drilled using solid-stem auger rigs. A typical construction method includes advancing a 36-inch-diameter casing about 5 feet past the base of the till, with the remaining interval drilled open hole in the advance outwash. Pea gravel or similar media extends the full length of the well and can be capped with a sand filter. The media backfilled well must be preceded by a water quality treatment BMP to prevent migration of particulates entrained in stormwater runoff from entering the well. The media backfilled wells should be backfilled with washed gravel meeting the specifications of Table 1.

Variations of the typical media backfilled well include:

1) A UIC wellfield may be used when sufficient land area is available and final sand filtration of the stormwater is desirable immediately prior to entry into the wells. No conveyance pipe would be needed for this configuration (Figure 2).

2) Installation of a minimum 4 to 6-inch diameter open PVC casing with screen in the center of the pea gravel for the entire depth of the well to avoid flow restriction due to the backfill media.

Flow restrictions due to the media backfill can be minimized through proper subgrade preparation and application of site specific media gradation design. With adequate water quality treatment, media backfilled wells have a long history of proven success. Two monitored systems have been operating for approximately 12 years without a reduction in water level drawdown response following storm events. Informal observations of unmonitored systems have indicated that they are operating as intended and have no standing water following storms.
2.3.2 Screened UIC Wells

Screened wells are typically drilled using conventional air-rotary equipment. These wells are usually completed with screened intervals ranging from 20 to 50+ feet long to maximize flow rate in a small (6- to 12-inch) diameter boring. The well may be completed with or without a sand pack using continuous wire-wrapped stainless steel well screen. Similar to the backfilled wells, the screened well must be preceded by a water quality treatment BMP to prevent migration of particulates entrained in stormwater runoff from entering the well. The sand pack may provide additional filter media to limit the migration of fine sand from the native formations into the drain.

2.3.3 Wellfield Backfill Media and Subgrade Preparation Specifications

The UIC wells should be backfilled with a washed, clean free draining media such as washed gravel as specified in Table 1. In wellfield applications, the infiltration area of a wellfield should be overexcavated to slope the subgrade to the UIC wells prior to installation of the filter sands. The subgrade slope should be a minimum gradient of 2 percent toward the UIC wells and may terminate at a “sump” excavation located at each UIC well. The overexcavated area should be backfilled with coarse washed sand media (such as specified in Table 2) that will underlie the sand filter media. This gradation of the filter media will prevent flow restriction due to presence of the overlying filter sand.

### Table 1

**Washed Gravel Backfill**

<table>
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<th>U.S. Sieve Number</th>
<th>Percent Passing</th>
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</thead>
<tbody>
<tr>
<td>1/2”</td>
<td>100</td>
</tr>
<tr>
<td>3/8”</td>
<td>80-100</td>
</tr>
<tr>
<td>#4</td>
<td>5-15</td>
</tr>
<tr>
<td>#8</td>
<td>0-10</td>
</tr>
<tr>
<td>#100</td>
<td>0-0.5</td>
</tr>
<tr>
<td>#200 (wet sieve)</td>
<td>0-0.5</td>
</tr>
</tbody>
</table>

Two successive layers of sand filter media should be placed over the top of the gravel backfill. The sand filter layers should consist of a minimum 12-inch layer of 4x8 coarse sand overlying the gravel backfill, and a minimum 24-inch layer of filter sand overlying the 4x8 sand. Inclusion of the sand filter layers will provide additional filtration of suspended particles that may remain in the stormwater.

The sand filter media should blanket the entire wellfield area to minimize potential migration of fines into the UIC well. Specifications for the 4x8 sand and filter sand are presented in Table 2 and Table 3:
Table 2
4 x 8 Sand Specification

<table>
<thead>
<tr>
<th>U.S. Sieve Number</th>
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</thead>
<tbody>
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<td>100</td>
</tr>
<tr>
<td>#4</td>
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<tr>
<td>#200 (wet sieve)</td>
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</tr>
</tbody>
</table>

Table 3
Filter Sand Specification

<table>
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<th>Percent Passing</th>
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</thead>
<tbody>
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</tr>
<tr>
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<td>&lt;1</td>
</tr>
</tbody>
</table>

2.3.4 Wellfield Construction Considerations

Water Quality Treatment

Pre-treatment of stormwater from pollution-generating sources is necessary prior to discharge into the wellfield area. While a permanent wet pond would provide the required water quality treatment, it is a recommended approach only in cases where there is sufficient land area to allow the water to spread across a large footprint in an infiltration basin. In AESI’s experience, permanent wet pond elements incorporated in the stormwater infiltration design can be sources of filter contamination by aquatic flora or fauna. Therefore, we recommend minimizing permanent wet facilities in the stormwater treatment/infiltration train if large land areas are not available.

Energy Dissipation

Energy dissipation elements must be provided to prevent the erosion of the filter sand in the wellfield area. Energy dissipation strategies may include walls, level spreaders, quarry spall blankets, or other means. Energy dissipation strategies must be sized to be effective for peak flow events. If spall blankets are selected, it is advisable to place the spall on filter fabric to prevent comingling of spall and the underlying sand.
2.3.5 Pit Drain Construction

Excavated Pit Drains are used to access shallow to intermediate depth receptor horizons, and are especially applicable in cases where low-permeability lodgement till mantles the site and the depth to the receptor horizon is less than about 15 to 20 feet. Pit Drain methods can also be used in shallower infiltration systems to penetrate through low-permeability interbeds in the receptor horizon, increase the overall effective infiltration rate, and if applicable, reduce the footprint of the facility.

2.4 Design-Rate Testing

2.4.1 Media Backfilled UIC Well Design-Rate Testing

Although a variety of drilling methods can be used, a common media backfilled UIC well design consists of a drilled boring which extends into the receptor horizon to create an “exposed” interval of 20 to 50+ feet. A 2-inch-diameter PVC monitoring port is commonly installed during backfill of the pea gravel for performance monitoring during the flow testing phase.

The UIC testing protocol generally consists of stepped-rate and constant-rate flow tests. Similar to shallow infiltration tests, inflows are monitored with an in-line digital flow meter providing both instantaneous and total flow volumes. A hydrant or portable water storage tanks are used to provide a continuous supply of water during the inflow portion of the test. The flow rate, total volume, and stage height/water levels are recorded, and the duration of the test must be sufficient to confirm stabilization of water level in the well at specific flow rates.

The determination of an appropriate design infiltration rate for UIC wells is different than infiltration pond or trench applications. Each UIC well is effectively a “stand-alone” infiltration facility, therefore, the field test method developed replicates full-scale performance. The design infiltration rate is typically about a factor of 0.5 to 0.8 of the tested rate, and is determined on a site-specific basis. Some factors influencing design rates include 1) native formation characteristics, 2) flow rates obtained during testing, 3) potential well spacing, and 4) anticipated wellfield flow volumes. Verification testing of infiltration rates is also completed for each well during construction to confirm that the anticipated flow rate is met.

2.4.2 Pit Drain Construction and Testing

Pit Drain testing is performed by excavating a pit through the overlying lodgement till, and extending several feet into the receptor sediments. A piezometer is installed into the pit, and the pit is backfilled with free-draining material, such as clean, washed, pea gravel. Similar to the UIC testing protocol, water is typically supplied from a hydrant or water truck, and water is conveyed into the drain at a known flow rate throughout the test period. Typically, the method incorporates a minimum 6-hour soaking period and will include a combination of low head and high head test phases to evaluate receptor horizon characteristics at varying head levels. This allows for the determination of the degree of heterogeneity in the receptor horizon and assists in the determination of final design parameters. Determination of the design flow rate of the Pit Drain can be provided for each drain when used as a “stand-alone” facility, or as a final design rate for a combined Infiltration/Pit Drain system.
2.5 Construction Erosion Hazard Best Management Practices

Care must be taken to ensure that gravel backfill media and sand products are clean and free of fines. Stockpiled backfill materials must be protected from site soils and run-on from silt-contaminated surfaces.

Care must be taken during construction not to contaminate the UIC wells, wellfields, or pit drains with stormwater and silt. All construction site stormwater should be directed to a suitable location as specified on the approved TESC plan. The infiltration system, including any UIC wells or pit drains, must remain off-line during construction to avoid siltation. Stormwater runoff must not be routed to the UIC wells, wellfields, or pit drains until the site is stabilized and runoff is clear.

3.0 UIC WELL CONSIDERATIONS: ENVIRONMENTAL CONSIDERATIONS AND MAINTENANCE

Key considerations in the design of deep UIC well systems include:

1) protection of ground water quality,

2) identification of downgradient impacts, if any, to slopes or water supply wells, and

3) long-term performance and maintenance.

3.1 Ground Water Quality Protection

Protection of ground water quality is a major consideration in the design of UIC well systems since the UIC wells penetrate through the natural “protective” barrier provided by the low permeability, fine grained lodgement till. Stormwater runoff derived from pollution generating surfaces must receive water quality treatment prior to conveyance into a deep UIC well (or pit drain). This can be achieved by use of an Ecology approved BMP for stormwater treatment prior to conveyance into the UIC well. Water quality treatment alternatives typically include routing flows through amended soil or sand filter media and through a sump system for additional fine sediment removal. Ecology evaluates emerging stormwater treatment technologies through their Technology Assessment Protocol - Ecology (TAPE). Approved stormwater treatment technologies for pollutants of concern are provided on the Ecology website.

Multi-year water quality results are available from AESI’s deep UIC well system located at Snoqualmie Ridge which includes two separate wellfields draining a combined area of over 45 acres. The wellfields are located in infiltration basins and have a layer of filter sand across the entire pond bottom area covering the UIC wells. The combined wellfields contain 59 UIC wells, and depths ranged from approximately 100 to 160 feet. The water quality data include baseline conditions established prior to construction of UIC wells and 10 years of on-line performance monitoring. Water quality samples have been obtained by a third party from a dedicated monitoring well located immediately downgradient of the UIC well field and an adjacent water supply well. The data show the MCLs for primary contaminants of concern are well below established thresholds, and that water quality from the aquifer interval receiving direct injection of infiltrated stormwater is very similar in quality to the water quality obtained from the water supply well where no infiltration is occurring. The data demonstrate there is no adverse impact to water quality resulting from infiltration of the treated stormwater runoff (Herrera, 2016).
3.2 Downgradient Impact Considerations – Water Users and Slope Stability

Potential adverse impacts to downgradient water users or sensitive areas, such as steep slopes, must be considered as part of the UIC well feasibility evaluation. Concerns are commonly expressed about potential impacts to water supply wells and landslide hazards. However, potential adverse water quality impacts can be avoided by 1) using Ecology approved water quality treatment BMPs prior to conveyance into UIC wells, and 2) locating UIC wells away from water supply wells. We anticipate any UIC well system constructed in the City would be outside of the 1-year TOT delineated on Figure 1 (or in the 1-year TOT in the 2005 WHPP) for Group A water supply wells in the City and vicinity.

Steep slopes can be impacted by groundwater daylighting on the slope and increasing landslide hazard potential. Potential adverse impacts to steep slopes can be avoided by 1) evaluating ground water mounding due to infiltration from UIC wells, and 2) determining the height of ground water mounds at distant slopes and influence on slope stability from a deep infiltration system. Several of the deep UIC well and Pit Drain systems designed by AESI have been located immediately adjacent to steep slopes. These systems have specifically included slope stability and mitigation elements to avoid adverse impacts to steep slopes and downgradient resources. Long-term water level and slope monitoring from multiple sites demonstrates ground water mounding effects dissipate rapidly with distance from properly constructed UIC well and Pit Drain infiltration systems and adverse slope impacts have been avoided.

3.3 Long-Term Performance and Maintenance

AESI has long-term performance monitoring data from UIC well and Pit Drain infiltration systems and has developed operation and maintenance programs for UIC well systems. Hydrographs from a 20-year period of record for a combined infiltration basin Pit Drain system at Redmond Ridge show baseline and on-line water level performance monitoring and rainfall. Infiltration rates determined from analysis of the water level and rainfall records demonstrate there has been no reduction in system effectiveness during the 18 years of on-line operation. Long-term monitoring results are also available from a 15-year period of record for a combination infiltration/UIC well system from Snoqualmie Ridge. The monitoring results include 3-years of baseline conditions and 12-years of on-line conditions, and demonstrate the deep UIC well system exceeds design rate flow criteria with no reduction in performance during almost 12 years of on-line operation.

The frequency and nature of maintenance requirements for UIC well systems is dependent on system design. Media backfilled UIC wells constructed in infiltration basins are protected from siltation by placement of a sand filter layer. This approach reduces UIC well maintenance requirements by limiting the introduction of silt or suspended particulates from entering the wells. Sand filters placed over media backfilled wells allow routine access for removal of accumulated sediment using hand equipment.

Screened well completion designs require final treatment prior to conveyance of stormwater into the well to avoid the accumulation of silt inside the well. Screened well design includes a sump to allow for long-term sediment accumulation which can be removed using vactor methods on a prescribed schedule. In some cases well rehabilitation may be needed requiring the use of surge and bail techniques to remove accumulated sediment.

The type and frequency of maintenance would be determined based on treatment methods and well system design.
Attachments: Figure 1: Geology and Wellhead Protection Map  
Figure 2: Media-Filled UIC Well Construction Detail  

4.0 REFERENCES  
Robinson, Noble & Saltbush, 2005, Mountain View-Edgewood Water Company Wellhead Protection Plan  
Troost, K.G., in review, (submitted 1/99), DRAFT Geologic map of the Puyallup 7.5-minute quadrangle,  

CARE MUST BE TAKEN TO ENSURE THE GRAVEL BACKFILL AND SAND PRODUCTS ARE CLEAN AND FREE OF FINES. STOCKPILED BACKFILL MATERIALS MUST BE PROTECTED FROM SITE SEDAM AND RUN-OFF FROM SLOTCONTAMINATED SURFACES. CONTAMINATED BACKFILL MATERIALS CANNOT BE USED IN THE UIC WELL OR POND AND WILL BE REJECTED.

**TABLE 1 - FILTER SAND SPECIFICATION**

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**TABLE 2 - 4X8 SAND SPECIFICATION**

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**TABLE 3 - GRAVEL BACKFILL FOR UIC WELL**

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