Groundwater for non-potable use in Vancouver, BC

A Literature Review

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August 2019

This report was produced as part of the Greenest City Scholars (GCS) Program, a partnership between the City of Vancouver and The University of British Columbia, in support of the Greenest City Action Plan.

This GCS project was conducted under the mentorship of City staff. The opinions and recommendations in this report, and any errors, are those of the author, and do not necessarily reflect the views of the City of Vancouver or The University of British Columbia.

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Acknowledgements

I would like to thank my mentor, Chris Despins, and co-mentor, Teri Lubianetzky for their contribution, guidance, and support throughout this project.

Contents

Introduction 1
Method 2
City of Vancouver Context 2
Non-potable Groundwater Regulation 5
Opportunities, Challenges and Gaps 7
Findings 7
San Francisco, California 10
Perth Metropolitan Region, Australia 21
Los Angeles, California 26
Summary 29
Recommendations 33
References 36
Appendix A Water Quality Parameters 43
Appendix B Data Collected 52

List of Figures

Figure 1. Water use in the CoV in 2014 (Source: City of Vancouver, 2015) 3
Figure 2. Map of aquifers and historic watercourses in Vancouver. The red rectangle shows the extent of the Cambie Corridor, the Broadway Area Plan in blue, and the SkyTrain lines in grey (Source: VanMaps, 2019). 4
Figure 3. San Francisco Groundwater Supply Project (extracted from San Francisco Planning Department, 2013). 12
Figure 4. On the left: San Francisco's natural creek systems. The pink area shows the old shoreline (Extracted from San Francisco Bay Area Planning and Urban Research Association, 2006). On the right: the subway system (Extracted from Google Maps, 2019 17

List of Tables

Table 1. Opportunities, challenges and gaps in implementing non-potable groundwater use at the City of Vancouver. 7
Table 2. Summary of the permitting process to install and operate non-potable water systems in San Francisco (SFPUC, 2019). 15
Table 3. Summary of the requirements for alternative water systems including foundation drainage (Adapted from Los Angeles County Department of Public Health,2016). 27

Table 4. Overview of the Top 3 cities: location, climate and drinking water sources. 29
Table 5. Overview of the Top 3 cities: groundwater uses and management. 30
Table 6. Overview of the Top 3 cities: non-potable groundwater systems. 31
Table 7. Water Quality Requirements for Foundation Drainage Treatment Systems (Extracted from SFPUC, 2017a) 43
Table 8. Volatile Organic Compound (VOC) Limits (Extracted from SFPUC, 2017a) 44
Table 9. Western Australia Non-Potable Groundwater Use limits (Extracted from Department of Environmental Regulation, 2014). 45

Introduction

In many urban settings like the City of Vancouver, the majority of the water demand is supplied by potable water. This practice has historically improved sanitation and reduced waterborne diseases. This approach, however, has resulted in water treated to drinking water standards being supplied for all domestic uses, including those that do not require water to be of drinking water quality, like toilet flushing. This and other demands could be supplied with non-potable water, which represents an alternative to drinking water consumption.

Non-potable water use comprises all applications that do not require meeting drinking water quality guidelines. Permitted uses for non-potable water vary by jurisdiction, but some typical uses include irrigation, toilet and urinal flushing, laundry, ice rinks, water features, street sweeping and cleaning, industrial uses, cooling and heating. Studies have observed non-potable water use representing up to 50% of multi-family household water use and almost 95% of office buildings water demand (WJW Foundation, 2018).

Sources of non-potable water can include rainwater, stormwater, greywater, blackwater, heat exchange condensate, groundwater and foundation drainage. In the City of Vancouver (CoV), the permitted sources of non-potable water are clear-water waste (condensate), and rooftop harvested rainwater. If a non-potable water system is installed in a new building they are required to supply non-potable water to all trap primers, toilets and urinals. Optional uses for non-potable water include irrigation of non-food purpose plants, and make-up water for boilers and cooling towers (City of Vancouver, 2019).

The CoV is currently investigating expanding the sources and uses of non-potable water systems permitted across the City. Two non-potable water sources of interest are groundwater and foundation drainage. This approach supports at least two Greenest City Action Plan Goals, which are:

- Clean Water: contributing to the goal of “33% reduction in the per capita water consumption from 2006 levels” (City of Vancouver, 2015), by substituting drinking water with groundwater or foundation drainage for non-potable uses; and
- Walking the talk: “to reduce water use in City operations by 33% from 2006 levels”, replacing drinking water with non-potable water for City operations such as cleaning streets, ice rinks, irrigation, toilet and urinal flushing.

Furthermore, non-potable water use contributes to one of the goals of the Metro Vancouver Integrated Liquid Waste and Resource Management Plan to “use liquid waste as a resource” (Metro Vancouver, 2010).

Foundation drainage consists of nuisance groundwater pumped to maintain the structural stability of underground infrastructures and avoid flooding. It can be extracted from the saturated zone, where the water table intercepts underground structures, or the vadose zone, due to rainwater infiltration. Currently, foundation drainage is treated as a form of waste or nuisance water that is discharged directly into the storm or combined sewer systems, which are not designed to receive this extra inflow. Non-wastewater discharges into the sewer reduce its capacity, increasing their susceptibility to surcharges and combined sewer overflows, requiring more investments to expand the system. The management of foundation drainage onsite through a non-potable water system is one option to reduce this extra inflow into the sewer.

From a broader perspective, the sustainable use of groundwater is essential for the City, which recognizes the need to have a strategy and a plan to manage this precious resource. Aquifers provide vital ecosystem services, including, but not limited to, water supply, water storage, preservation of surface water bodies, soil stability and natural water filtration. To enable the sustainable use of groundwater it is necessary to understand the aquifer to avoid jeopardizing the ecosystem services it provides. Potential issues associated with groundwater overexploitation include saltwater intrusion, subsidence, erosion, migration of contaminated plumes and the reduction of the aquifer's capacity. The CoV is currently exploring the development of a citywide groundwater management strategy to better understand and protect this resource.

The objective of this project is to undertake a literature review to understand how other municipalities worldwide have planned, implemented and regulated non-potable groundwater use, and to provide recommendations on approaches that could be applied at the City of Vancouver.

Method

The methodology adopted for this study included the collection and analysis of secondary data, including guidelines, standards, by-laws, reports, and research on various regulatory agencies' websites. The City of Vancouver's regulations were also examined to identify opportunities, challenges, and gaps in the implementation of non-potable groundwater use. Then, after a brief scan, ten cities worldwide that use or have used groundwater for potable or non-potable purposes were selected. The key information available regarding groundwater use, non-potable water systems, and water management strategies was tabulated, highlighting the similarities and differences between each of the ten cities relative to the City of Vancouver. The ten cities were ranked based on four categories: data availability, examples of non-potable groundwater use, and regulation and management plan. From this long list of ten cities, the top three cities (San Francisco, Perth, and Los Angeles) were selected based on their higher rankings and then studied in more detail. Appendix B lists the information included in the research, and this report presents a summary of the data collected.

A limitation of this study was the differences in nomenclature used by the municipalities, regulatory agencies and others worldwide. These differences in nomenclature made it difficult to identify policies and guidelines specific to the non-potable use of groundwater and foundation drainage as each jurisdiction, standard, guideline contained unique definitions of non-potable water sources. In some instances, foundation water was included as a sub-set of groundwater, alternatively it was included with stormwater or greywater. Another limitation of this project was the limited number of hours available to undertake the literature review. These challenges made it difficult to find many examples of jurisdictions using groundwater and foundation water for non-potable purposes. As such, other examples may exist, but were not identified through this study.

City of Vancouver Context

The CoV is experiencing rapid growth, with many existing single-family homes and commercial centres undergoing redevelopment to higher density multi-family, mixed use and commercial high-rise developments. These new developments are increasing water demand and wastewater generation, requiring the expansion of the potable water distribution and wastewater conveyance infrastructure.

Vancouver's drinking water source is the Capilano, Seymour and Coquitlam reservoirs (City of Vancouver, 2015). Currently, the largest water consumers are residences, followed by commercial, industrial and institutional buildings (Figure 1). In light of studies that estimate approximately 50% of water demand in multi-family homes can be offset by non-potable water, with this figure rising to 95% for office buildings (WJW Foundation, 2018), the CoV has the potential to reduce drinking water consumption by more than 33% through non-potable water use, helping the city to achieve the Clean Water Greenest City Action Plan goal.

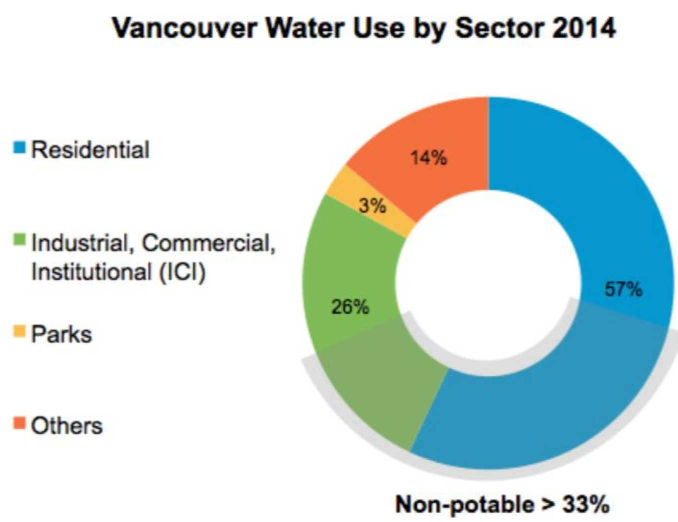

Figure 1. Water use in the CoV in 2014 (Source: City of Vancouver, 2015)

There are examples of non-potable water systems in Vancouver, but only a few use groundwater and/or foundation drainage as one of the sources. Typical non-potable groundwater applications in Vancouver include geo-exchange systems and irrigation of golf courses. The Hillcrest Community Centre is one example of an onsite non-potable system utilizing groundwater (City of Vancouver, 2012) for both indoor and outdoor use. The Centre collects and stores rainwater from the Aquatic Centre roof as well as a groundwater sump system, using the non-potable water for toilet flushing and landscape irrigation.

Although the extent of groundwater and foundation drainage pumping throughout the CoV is not yet fully understood, there are a number of areas where groundwater pumping is likely greater. Potential areas for further investigation for implementing non-potable groundwater systems is sub-surface infrastructure located in areas adjacent to historical watercourses, as these locations may serve as preferential flow paths for groundwater. Figure 2 shows a map of the approximate location of historic watercourses, the aquifers that underlie the City, as well as major redevelopment areas. As shown in Figure 3, both Cambie Corridor and the Broadway Area Plan have historic watercourses that cross their boundaries. Another factor to consider is the depth of sub-surface excavation (basements or sub-surface parkades) associated with the development. Depending on the depth of the existing and future underground structures, there is the possibility to intercept the water table, which in turn may result in a high quantity of foundation drainage that needs to be pumped temporarily or in perpetuity.

Underground subway stations located near historic watercourses or areas where the water table is elevated is one example of sub-surface infrastructure that may intercept the water table and require a system that manages foundation drainage to keep the infrastructure dry. One example where foundation drainage from an underground transit station has been used beneficially as part of a groundwater non-potable water system is in San Francisco, where foundation drainage is pumped from the Powell Street Bay Area Rapid Transit station and used for a district energy (please refer to the Non-potable Groundwater Case Studies section for further details). In Vancouver, there are some SkyTrain stations located near historic watercourses or in high water table regions where a similar system could be implemented to provide beneficial non-potable water.

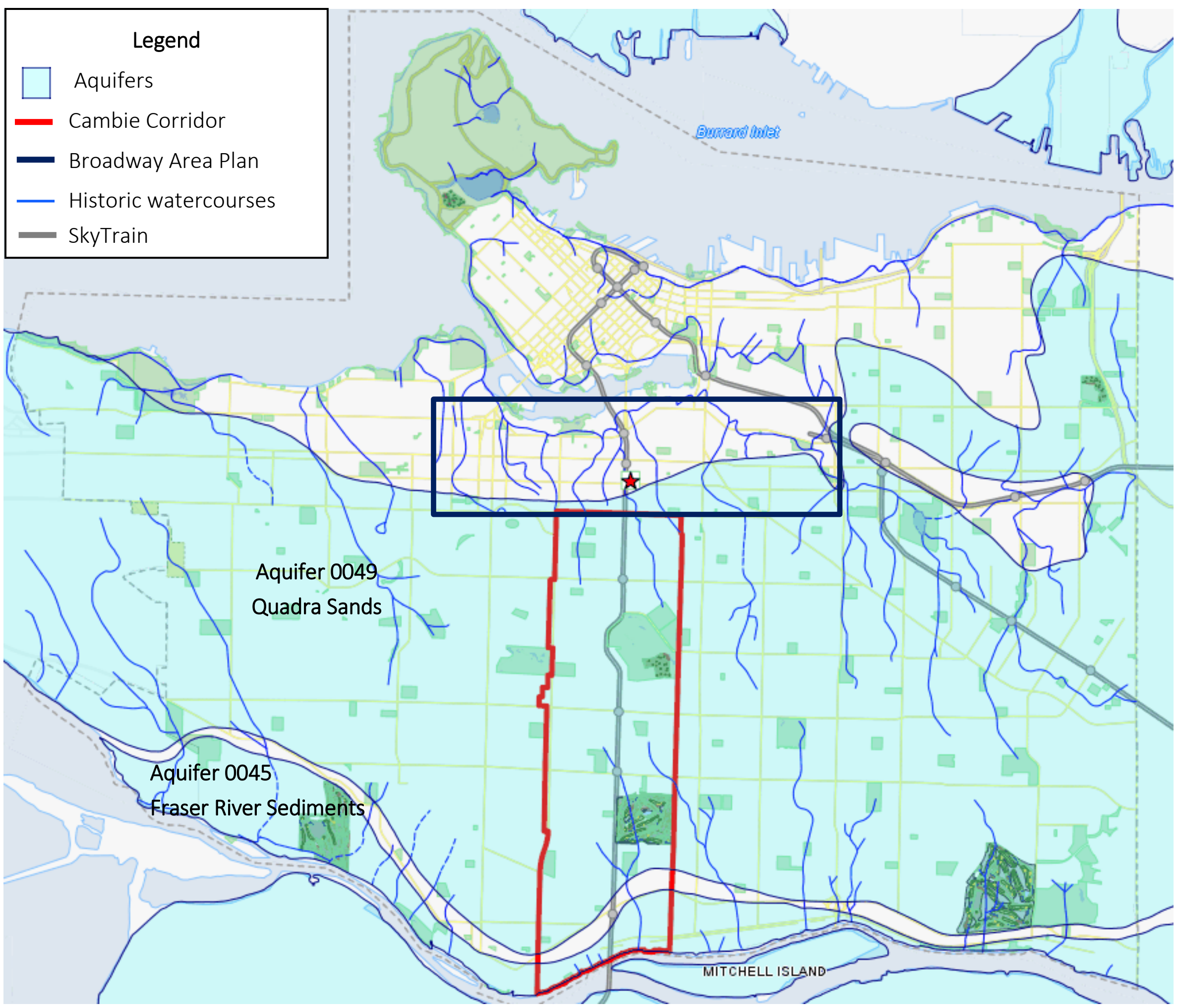

Figure 2. Map of aquifers and historic watercourses in Vancouver. The red rectangle shows the extent of the Cambie Corridor, the Broadway Area Plan in blue, and the SkyTrain lines in grey (Source: VanMaps, 2019).

Non-potable Groundwater Regulation

Groundwater Extraction

In British Columbia (BC), groundwater use is regulated by the Water Sustainable Act (2014), under the jurisdiction of the BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development (BC FLNRORD). The construction of wells, extraction and use of groundwater require licences issued by the BC FLNRORD. Exceptions are applied to domestic users, who are encouraged to register their wells to guarantee water allocation. Currently, there are 115 groundwater wells in Vancouver registered at the BC FLNRORD database. Only one well is licensed (BC, 2019), and there is limited groundwater level or quality monitoring at the City.

At the municipal level, the Zoning By-law may require applicants to present a hydrogeological study and an impact assessment as a condition to the approval of the permit, in order to avoid issues to the environment, the sewer and the drainage infrastructure. The developer must demonstrate that "there will be no significant negative impacts, including, but not limited to: anticipated flow rates; soil subsidence; impact to nearby wells; evaluation of potential effects on known contamination; and water quality" (City of Vancouver, 2018a).

Groundwater Discharge

The discharge of groundwater into the sewer is regulated by the CoV and Metro Vancouver. Currently, 54% of the City's sewer system is comprised of separated storm and sanitary pipes, and 46% of combined pipes. According to the Groundwater Management Bulletin, groundwater that is not contaminated is not permitted to discharge to sewer post-construction (City of Vancouver, 2019), requiring an alternative solution. The City does not specify a preferred solution. Some options could include waterproofing (tanking foundations to reduce or eliminate pumping), reinjection and non-potable reuse.

Non-potable Water Systems

The City of Vancouver regulates the implementation of alternate (non-potable) water systems through the Vancouver Building By-Law (amendment 12346) (City of Vancouver, 2019). Currently, the use of perimeter drainage water and groundwater for non-potable purposes is not permitted by the By-law. However, the City can evaluate applications on a case-by-case basis. To implement a non-potable water system using alternative sources like groundwater, the proponent can apply for a non-potable alternative solution. The CoV's Development, Buildings and Licensing department is responsible for evaluating and issuing the permit. Additionally, non-domestic users have to apply for a licence from the BC FLNRORD for the extraction and use of groundwater, as discussed in the Groundwater Extraction section.

Water quality targets are specified in the Building By-law for non-potable water systems for rainwater and clear-water waste, including Escherichia Coli, Turbidity and Temperature (City of Vancouver, 2019). There are a few other standards and guidance documents in Canada, including the Canadian Guidelines for Domestic Reclaimed Water for Use in Toilet and Urinal Flushing (2010), which define limits for BOD5, Total Suspended Solids, Turbidity, Escherichia Coli, Thermotolerant Coliforms, and Total Chlorine Residual

(Health Canada, 2010). However, none of them includes other contaminants that can be found in contaminated groundwater like metals and organic carbons.

The Province of British Columbia published a draft “Guidance for using Non-Potable Ambient Water for Domestic Purposes in British Columbia” (BC, 2016), which recognizes surface water and groundwater as non-potable water sources. Similar to other guidelines, this document does not define limits for non-microbiological parameters. According to the provincial guideline, the design, manufacture and installation of non-potable water systems shall follow CAN/CSA-B128.1 "Design and Installation of Non-Potable Water Systems,” and B128.2-06 – “Maintenance and Field Testing of Non-Potable Water Systems” (Canadian Standards Association, 2011). Neither of these standards have specific requirements for groundwater systems.

Opportunities, Challenges and Gaps

Table 1 summarizes opportunities, challenges and gaps in implementing non-potable groundwater use at the City of Vancouver identified through a review of the City's regulations and discussions with City staff.

Table 1. Opportunities, challenges and gaps in implementing non-potable groundwater use at the City of Vancouver.

Opportunities
▪ Reduce drinking water consumption through the implementation of non-potable groundwater use. ▪ Provide a beneficial use for foundation drainage, reducing the waste of this resource. ▪ Reduce the inflow of groundwater into the combined sewer system, reducing the volume of combined sewer overflows. ▪ Use existing and new groundwater wells for potable and non-potable water to the community in case of emergencies. ▪ Increase the application of groundwater for irrigation, which represents 3% (308,831 m^3 per day) of the total annual water consumption of the CoV (City of Vancouver, 2015 and Metro Vancouver, 2015).
Challenges
▪ Implement a feasible approach to assess human health risks associated with groundwater quality and potential long-term contamination risks. ▪ Integrate and engage stakeholders from different jurisdictions and municipalities to regulate non-potable groundwater use. ▪ Encourage users to adopt non-potable water systems, given the low metered rates for water and wastewater services in the city. ▪ Understand the aquifer characteristics and limitations and how this could impact the sustainable use of groundwater resources. ▪ Control and mitigate environmental risks associated with urban groundwater extraction like contamination, plume migration, saltwater intrusion, ground subsidence and erosion.
Gaps
▪ Strategy/Plan: there is no Groundwater Management Strategy and/or Integrated Urban Water Management Plan, defining a clear strategy for groundwater management and use at the City. ▪ Data: limited information about groundwater wells, withdrawals and discharge of groundwater into the stormwater/combined sewer pipes. Furthermore, there is no computational model, or water budget of the Quadra Sands, the aquifer that underlies most of the City of Vancouver (BC, 2019a). ▪ Regulation: non-potable groundwater use is not permitted by the January 1, 2019 version of the Plumbing By-law (City of Vancouver, 2019).

Findings

Ten cities that use or have used groundwater for potable or non-potable purposes were identified as part of this study: Amsterdam, Berlin, Los Angeles, Orange County, Paris, Perth, San Francisco, Seattle, Sydney, and Tokyo. The key aspects of non-potable groundwater use are summarized in this section.

In the United States, the William J. Worthen Foundation published in 2018 the Onsite Non-potable Water Reuse Guide (WJW Foundation, 2018). The report was created for designers and provides information about how to incorporate non-potable water into design, operation and maintenance of projects. This guideline covers a wide range of non-potable water sources, including foundation drainage.

Another US institution, the National Blue Ribbon Commission (NBRC) developed a number of guidelines to support public agencies on the regulation of onsite non-potable systems (NBRC, 2019). The guidelines provide a good framework and are intended to be used as a national reference for onsite non-potable water systems since there is not a federal regulation in the US yet. Although the NBRC's guidelines do not include foundation drainage or groundwater as a non-potable water source, their guidelines can be applied to any type of non-potable water system.

The most recent NBRC report highlights a number of US states that have been developing regulations for onsite non-potable use, including Alaska, California, Colorado, Hawaii, Minnesota, Oregon, Texas and Washington. However, of these states only California has passed a state law regulating onsite treated non-potable water systems. The Senate Bill 966, from September 2018, requires the adoption of "risk-based water quality standards for the onsite treatment and reuse of non-potable water for non-potable end uses in multifamily residential, commercial, and mixed-use buildings". Jurisdictions have until December 2022 to adopt the non-potable water policy (California, 2018).

San Francisco, California, is one of the leading US cities in implementing and regulating non-potable water systems. The City has implemented several non-potable water projects, at least four of which incorporate foundation drainage (SFPUC, 2019). In Los Angeles (LA), the largest Californian municipality, groundwater is an important drinking water source, and problems with contamination represent a challenge. For non-potable water, LA County adopted a different framework than San Francisco, relying upon a tiered approach that specifies different requirements based upon the non-potable water source.

Seattle, due to its similar climate to Vancouver and its high precipitation rates, was one of the targets of this review. There are some examples of non-potable water systems using rainwater and greywater implemented in Seattle. However, no significant information about non-potable groundwater use was identified through the course of this jurisdiction scan. King County, where Seattle is located, has an infiltration and inflow program to reduce the quantity of non-wastewater inflow into the combined sewer systems, but it does not include non-potable groundwater applications (King County, 2019).

Australia has a strong focus on integrated water management. Over the last decades, water scarcity has been a key challenge for Australians. In Perth, groundwater is a source of both potable and non-potable water, including examples of district-scale non-potable groundwater systems for irrigation.

Considering the focus on non-potable groundwater use, the three cities selected for in-depth research and comparison with Vancouver were:

1. San Francisco, California;
2. Perth, Western Australia; and
3. Los Angeles, California.

A review of non-potable groundwater use in other cities was undertaken but limited or no relevant examples of non-potable groundwater systems were found, or limited regulations in English were available. As such, these cities were not examined in depth.

The following sections include a literature review of each city, and a summary of the data, comparing the key aspects of Vancouver and the three cities.

San Francisco, California

General Aspects

Located on the West Coast of the United States, San Francisco has a Mediterranean climate, characterized by cool dry summers and mild wet winters (SFPUC, 2019h). The total annual precipitation is around 537 millimetres, and median temperatures vary from 7^{o} to 22^{o} Celsius throughout the year (NOAA, 2019). The City, as well as the whole state of California, has been facing severe droughts and floods over the last decades (USGS, 2019), and due to climate change, it is expected that these events become more frequent and severe, increasing the pressure on the City's water, drainage and sewer systems.

San Francisco's primary drinking water source is the Hetch Hetchy Regional Water System, a complex of eleven reservoirs located between the mountains on the Yosemite Park and the City of San Francisco. Around 85% of the water consumed is imported from the eastern regional watersheds (San Francisco Planning Department, 2013). The dependence on surface water increases the vulnerability of the system not only from stresses like climate change but from shocks like earthquakes. San Francisco, like Vancouver, is located in an area susceptible to earthquakes. The pipes and tunnels that transport water from the reservoirs to City cross three major geological faults (SFPUC, 2019e).

To address the challenges associated with climate change, water scarcity, and possible emergencies, San Francisco has been investing in a more reliable water system through initiatives such as the Local Water Program. The Program supports the implementation of conservative water actions and alternative water sources, including recycled and non-potable water uses, as well as the construction of local groundwater facilities for both drinking water and emergency purposes (SFPUC, 2019). The Local Water Program is part of the OneWaterSF approach, adopted by the City to create a more resilient and sustainable water system (SFWPS, 2017).

The Public Utility responsible for managing drinking water, stormwater and wastewater is the San Francisco Public Utilities Commission (SFPUC), a department of the City of San Francisco. SFPUC is the owner and the operator Regional Water System, including the reservoirs, pipelines, tunnels, treatment facilities and the local water distribution system that supplies the City of San Francisco and other municipalities as well. Currently, 90% of the City of San Francisco is served by a combined sewer system, and just a few areas along the shore have separated systems (SFPUC, 2019).

Groundwater Uses and Licencing

Uses

Groundwater in San Francisco is currently a source of water for drinking, non-potable and emergency purposes.

Until the 1930s, groundwater was a local potable water source for San Franciscans. After the construction of the Hetch Hetchy system, the City started to rely primarily on surface water, with a few wells dedicated to irrigation. In the 2000s, SFPUC's started planning to reintroduce groundwater as an additional potable, non-potable and emergency water source (San Francisco Planning Department, 2013), and three major projects were developed to improve groundwater management and increase beneficial uses, which are:

1. The San Francisco Groundwater Supply Project;
2. The Regional Groundwater Storage and Recovery Project; and
3. The Non-potable Water Program, discussed in more details in section Non-potable Water Initiatives.

The San Francisco Groundwater Supply Project adds groundwater to the drinking water system and provides an emergency source of water. The project comprises six production facilities (including four new and two upgraded existing irrigation wells), where groundwater is extracted, disinfected with chlorine, and pumped to be blended with surface water in two of the City's drinking water reservoirs (Figure 11). One of the wells, the West Sunset, is linked to a generator for onsite disinfection and connected to a hydrant to fill water trucks, serving as an emergency potable water source in case of an earthquake. In 2017, the four proposed new groundwater wells started operation. The project began in August 2014, and it is expected to finish in the fall of 2019, providing an average of 15,000 m^3 (4 million gallons) of water per day. The total project cost is $ 85,800,000 CAD (66 Million US dollars) (SFPUC, 2019c).

Other current groundwater uses include lake filling and irrigation of parks, golf clubs, cemeteries and the San Francisco Zoo (SFPUC, 2019h). The wells are operated by the San Francisco Recreation and Park Department, and according to the San Francisco Urban Water Management Plan, groundwater will be replaced by recycled water over the next years in most of these sites (SFPUC, 2016).

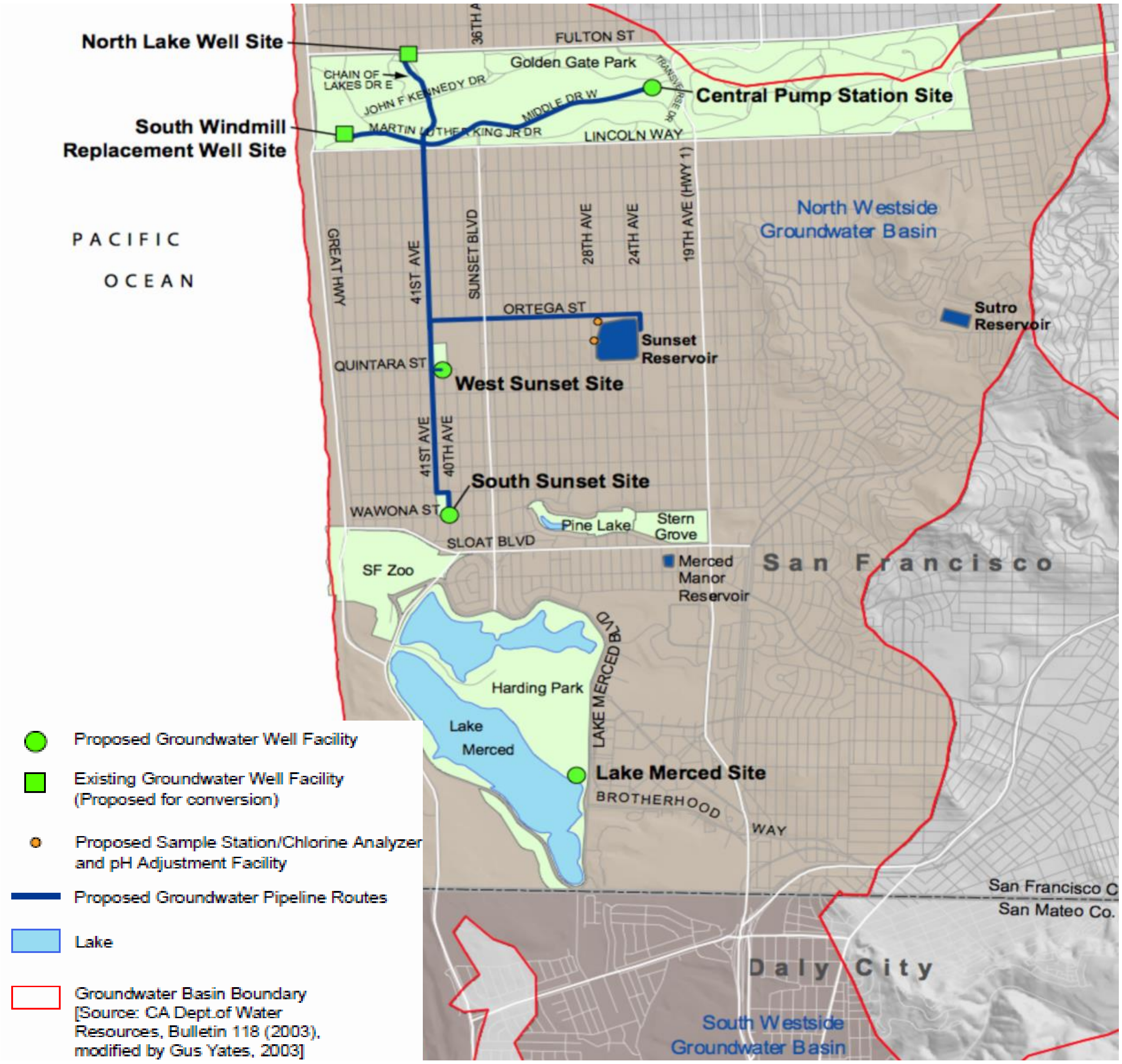

Figure 3. San Francisco Groundwater Supply Project (extracted from San Francisco Planning Department[1], 2013).

The Regional Groundwater Storage and Recovery Project is a collaborative plan developed by San Francisco, and its neighbouring municipalities that share the same aquifer for drinking water purposes, including Dalas City, San Bruno and South San Francisco. The project will optimize the surface and groundwater withdrawals according to climate variability to promote the sustainable use of water resources. During normal or wet years, SFPUC will increase surface water supply, and reduce groundwater extraction, prioritizing natural aquifer recharge. During dry seasons, when surface water is scarce,

[1] http://sfmea.sfplanning.org/2008.1122E_DEIR1.pdf

municipalities will increase groundwater extraction, since the level of the aquifer would be higher. This project includes the construction of sixteen new wells (Kennedy/Jenks Consultants, 2012), and the estimated cost is $148,200,000 CAD (114 Million US dollars). Construction started in April 2015 and is expected to finish in the winter of 2021 (SFPUC, 2019g).

Licencing

In San Francisco, beneficial and non-potable groundwater uses are regulated by different by-laws. Beneficial groundwater uses are irrigation of parks, landscaping and maintaining natural water features, emergencies, industrial uses, and water supply by the City (San Francisco Health Code, 2015a). Non-potable use of foundation drainage[2] is not considered a beneficial use. It is recognized as non-potable water use and is regulated by Article 12C (discussed further in Non-potable Water Initiatives section) (San Francisco Health Code, 2019).

The extraction of groundwater for beneficial uses is regulated by the Article 12B of Municipal Health Code (San Francisco Health Code, 2015a). According to this Article, the construction, operation and demolition of wells require approval from three City Departments, the Planning Department, the SFPUC and the Department of Public Health (SFDPH). The steps to be followed to construct and operate a new extraction well are listed below (SFPUC, 2019f):

1. Submit an Environmental Evaluation Application to the Planning Department for an environmental determination;
2. Obtain approval from SFPUC through an application for the use of water well;
3. Obtain a licence from the SFDPH to the construction of new wells and
4. After the construction and prior to starting the operation, obtain an operational permit with SFDPH.

Existing wells also need a permit to operate. Both the application and the operation processes are charged. During the operation phase, there is a fixed annual fee per well (SFDPH, 2018). Currently, new wells are allowed only for industrial or irrigation uses (SFWPS, 2018).

The discharge of uncontaminated groundwater is allowed either into the combined or separated sewer systems, under the requirement of a permit issued by SFPUC (San Francisco Department of Building Inspection (2016) and SFPUC (2017a)). For temporary discharges such as dewatering of construction sites, a Batch Wastewater Discharge Permit may be obtained (SFPUC, 2018a).

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[2] *"Foundation Drainage: nuisance groundwater that is extracted to maintain a building's of facility's structural integrity and would otherwise be discharged to the City's sewer system. Foundation drainage does not include non-potable groundwater extracted for a beneficial use that is subjected to City groundwater well regulations" (San Francisco Health Code, 2019, p.2).*

Non-potable Water Initiatives

Since 2012, San Francisco permits onsite non-potable water systems for commercial, multi-family and mixed-use developments, but in 2015, it became mandatory for some developers (SFPUC, 2019). According to the Article 12C, all new developments above 250,000 square feet, which haven't received a permit prior to November 1, 2016, shall "install and operate an onsite non-potable water system to treat and reuse available graywater, rainwater, and foundation drainage for toilet and urinal flushing and irrigation" (San Francisco Health Code, 2015). For projects of 40,000 square feet or more, it is required to "prepare water budget calculations assessing the amount of available rainwater, graywater, and foundation drainage, and the demands for toilet and urinal flushing and irrigation" (San Francisco Health Code, 2015).

The non-potable water sources permitted are rainwater, stormwater, graywater, blackwater and foundation drainage. End uses approved are divided into indoors (toilet and urinal flushing, clothes washing and priming drain traps) and outdoors (irrigation, decorative fountains and impoundments, cooling, and street cleaning) (SFPUC, 2019). Other sources and uses can be requested and will be analyzed case-by-case (San Francisco Department of Public Health, 2017).

Three Departments of the City are in charge of the onsite non-potable water program, the SFPUC, the San Francisco Department of Public Health - Environmental Health Branch (SFDPH-EH), and the San Francisco Department of Building Inspection Plumbing - Inspection Division (SFDBI-PID). SPFPUC is responsible for reviewing onsite non-potable water budget applications, managing the cross-connection control program, undertaking cross-connection inspections, providing technical and financial support to the developers and managing the whole program. SFDPH defines water quality requirements, reviews and approves engineering reports to allow construction, issues operational licences and reviews water quality reports during the operation. SFDBI-PDI conducts the plumbing plan check, issues the plumbing permit, and inspects and approves the systems (San Francisco Department of Public Health, 2017).

To support and encourage the developers to implement alternative water sources systems and offset potable water, SFPUC has the San Francisco Non-potable Grant Program. The Program offers financial support from $100,000 US dollars (for projects that offset at least 450,000 gallons of potable water per year) to $500,000 US dollars (3,000,000 gallons or more of potable water saved per year) (SFPUC, 2019a). Grants are not applicable to projects under mandatory requirements described above.

Since 2012, when onsite non-potable water systems were permitted in San Francisco, at least 17 projects have been implemented at the City, and another 18 applications have been submitted to SFPUC. The majority of these projects used rainwater, greywater, condensate, or a combination of these sources. Four projects included foundation drainage (SFPUC, 2018 and SFPUC, 2014). Three of these projects are described in the Non-potable Groundwater Case Studies section.

Permitting

The steps of the permitting process are summarized below for single-buildings (SFPUC, 2019). The City provides examples of documents and instructions online, which can be accessed through the links provided below.

Table 2. Summary of the permitting process to install and operate non-potable water systems in San Francisco (SFPUC, 2019).

PERMITTING PROCESS
Before the Construction
Step 1. Submit a water budget application to the SFPUC Water Resources Division, listing and quantifying the non-potable water sources, the proposed uses and the make-up water required to meet non-potable demands. There is an online excel file to help to calculate the water demands. After reviewing the application, SFPUC will distribute it to SFDPH-EH and SFDBI-PDI. **Step 2.** Submit an engineering report, developed by a Registered Professional, to the San Francisco Department of Public Health Environmental Health Branch (SFDPH-EH). The Report must include information about the design of the system, the treatment method adopted, the monitoring plan, and the controlling strategies to meet the water quality requirements. After the approval of the Report, SFDPH-EH will send a letter of approval to SFDBI-PID. **Step 3.** Submit plumbing plans and obtain building permits from the SFDBI-PID. For district-scale projects, it necessary to submit a Non-potable Implementation Plan to SFPUC. For foundation drainage systems applied only for subsurface irrigation, the engineering report and a permit from SFDPH are not required.
After the construction and prior the operation
Step 4. Book a cross-connection test with a certified specialist and submit with a construction certification letter to SFDPH-EH, informing that the system was built according to the approved engineering report or informing any changes. After approving the letter, SFDPH-EH will issue the construction certification letter. **Step 5.** Obtain a permit to operate by the SFDPH-EH. To obtain a permit to operate the developer shall submit, among other documents, an operation and maintenance manual, a proof of a contract with a certified laboratory to monitor the water quality during the operation, and assign a qualified treatment system manager that will operate and maintain the system. SFDPH-EH will first issue a temporary licence. After the conditional period, if there was no bypass to the sewer and the system operates correctly, it is issued a permanent operational licence.
During the operation
Step 6. Conduct the monitoring and submit periodic reports. The permit must be renewed annually by paying an annual license fee. For foundation drainage, during the conditional operation, a monthly discharge should be submitted monthly and, during the permanent operation, it can be annually. Backflow prevention also shall be retested in an annual base.

Water Quality Requirements

Onsite non-potable water systems that use foundation drainage must meet the water quality requirements for control of pathogenic microorganisms and Volatile Organic Carbon (VOC) (SFPUC, 2017a). Parameters are included in Appendix A. Article 12C does not specify distinct water quality requirements based upon the end use of the water, its requirements are specified based on the non-potable water source. One potential gap identified with San Francisco's approach is that many other contaminants can be present in groundwater in urban areas, like metals, nitrates, and semi-volatile organic carbons, but they were not included in the list.

Design, Operation and Maintenance Requirements

All non-potable water systems must have:

- Separated non-potable water, in purple, identified in accordance with the different sources, according to the Californian Plumbing Code (SFWPS, 2018);
- Make-up water connection to the drinking water system;
- Backflow preventer between the municipal and the non-potable pipes;
- Overflow connection to the sewer system equipped with a backflow prevention device; and
- Flow meters to on the non-potable system and on the drinking make-up pipe (San Francisco Department of Public Health, 2017).

All the devices must be tested and approved. A list of approved backflow prevention assemblies and manufacturers is provided by the University of South California to help the developers (USC, 2019).

To obtain the operational permit, the owners shall contract a treatment system manager qualified to operate and maintain the system according to the regulation and the O&M Plan. They must be certified as a Grade II Wastewater Treatment Plant Operator and sign an affidavit attesting their ability and commitment (SFPUC, 2017a). A list of non-potable water system companies which provide design, manufacture, installation, operational and maintenance is available for developers online.

Non-potable Groundwater Case Studies

Currently, foundation drainage from most of the buildings is discharged into the stormwater and combined sewer systems. The amount of foundation drainage discharged is not monitored (SFPUC, 2019f), but it is a known issue, since a number of neighbourhoods and underground utilities (including the subway line) have been constructed in historically wet areas (Figure 4). On the left of Figure 4, there is a pre-development map of the City and its natural creek systems and, on the right, part of the Bay Area Rapid Transit (BART) line (San Francisco Bay Area Planning and Urban Research Association, 2006).

The three case studies of sites using foundation drainage for non-potable use presented below were located in this historically wet areas, between the Embarcadero Station and the 16th St Mission Station.

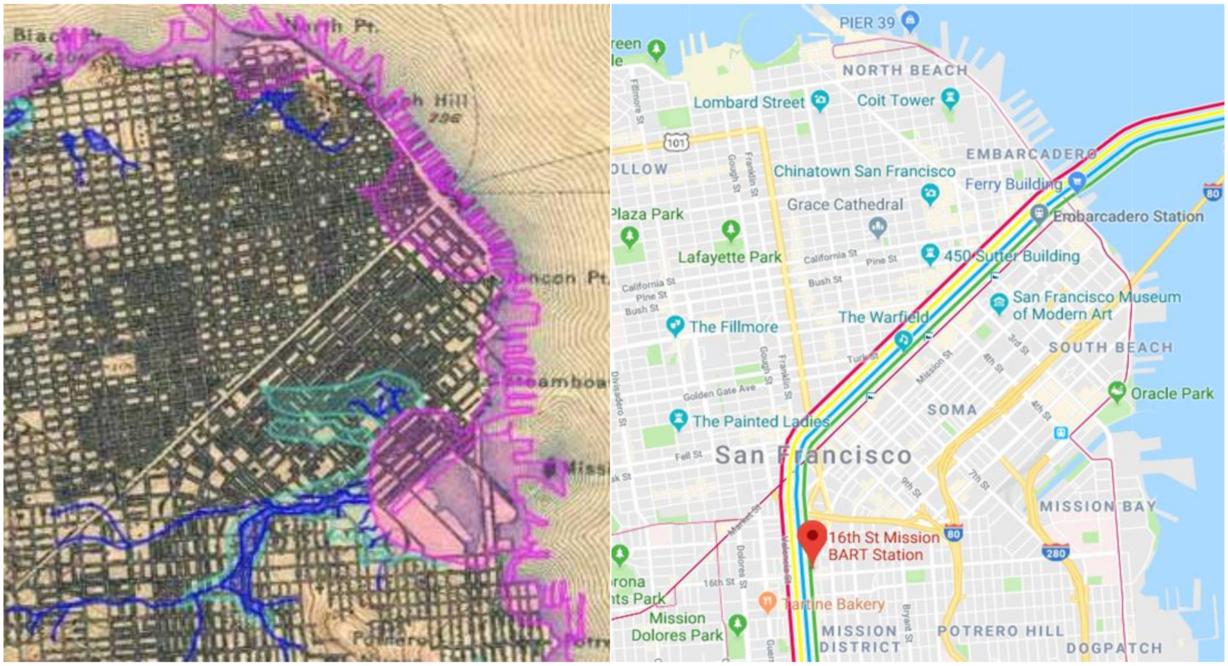

Figure 4. On the left: San Francisco's natural creek systems. The pink area shows the old shoreline (Extracted from San Francisco Bay Area Planning and Urban Research Association[3], 2006). On the right: the subway system (Extracted from Google Maps, 2019

[3] https://www.spur.org/publications/spur-report/2006-11-07/integrated-stormwater-management

Downtown Steam Loop - NRG Energy Centre, San Francisco, California

Project: NRG is an energy company responsible for providing heating, domestic hot water, air conditioning and industrial process water to more than 170 buildings in downtown San Francisco. The district heating system comprises 16km of pipes and two stations, with a total of nine boilers, all fueled by natural gas (Clearway energy, 2019). The boilers consume a large quantity of water resulting in high operating costs to NRG. From 2003 to 2005, even with the reduction of water use, the costs significantly increased due to increases in San Francisco's metered water rates. In close proximity to the District Heating System, the Bay Area Rapid Transit (BART) pumps millions of litres of foundation drainage to keep the water table low and avoid flooding the Powell Street subway station (Judd and Chiovoloni, 2018). Powell Street is one of the stations built in a formerly wet area, and since the construction in 1973, foundation drainage has been pumped and discharged into the sewers (Philips et al., 1993). Recently, a partnership among the City of San Francisco, BART and NRG was established to implement a non-potable groundwater system, offsetting potable water consumed by the District System by groundwater. Foundation drainage recovery rate is estimated at 170,000 m^3 (45 million gallons) per year, which combined with groundwater from a new well, will meet 100% of the District's water demand (Judd and Chiovoloni, 2018).

Non-potable Water Sources:
- Foundation drainage
- Groundwater
- Steam condensate

→

Non-potable Water Uses:
- District Heating

System: The system includes the installation of new groundwater pumps, foundation drainage, condensate return pipes, new groundwater wells, and the improvement of the water treatment plant including microfiltration and reverse osmosis.

Motivation: Reduce potable water use and reduce operating costs associated with water and sewer rates.

Ownership and Operation: The system is partially owned by BART (old foundation drainage pumps) and NGR Energy (non-potable water system and new groundwater well).

Timeline: The project started in 2018 and the planned completion date is 2028.

Costs: The estimated capital cost is $ 4,550,000 CAD (US$ 3.5 million), whereas the annual savings is $ 1,690,000 CAD (US$ 1.3 million). The payback is estimated to take 2.8 years.

Funding: The project will receive a $650,000 CAD (US$ 500,000) grant under the San Francisco Non-potable Grant Program.

References: Judd and Chiovoloni (2018) and Clearway Energy (2019).

Moscone Convention Centre - 747 Howard Street, San Francisco, California

Project: The Moscone Convention Centre is the major exhibition centre in San Francisco. It has three main buildings and a 46,000 m^2 underground exhibition hall. The expansion of 2018 included the connection of two buildings via an underground hall under Howard Street.

Non-potable Water Sources:

- Foundation drainage
- Rainwater
- Steam condensate

→

Non-potable Water Uses:

- Toilet and urinal flushing
- Irrigation
- Street cleaning

System: The district-scale onsite water system is comprised of a storage tank of 265 m^3 (70,000 gallons), a multi-step filtration and an ultra-violet disinfection unit. Non-potable water produced will be used both on-site, for toilet flushing and irrigation, and off-site, for irrigation of the Yerba Buena Gardens and to fill trucks to clean the streets of the City. The annual potable water savings estimated is around 57,000 m^3 (15 million gallons), meeting 100% of the non-potable water building demand as well as some external uses.

Motivation: Reduce potable water consumption, LEED certification and meet the San Francisco's Stormwater Management Ordinance to reduce the stormwater runoff rate and volume by 25%.

Ownership: The building is a City asset, and the San Francisco Conventions Facilities Department is responsible for the operation and maintenance of the non-potable water system.

Timeline: This was a four-year construction project, completed in December 2018.

Costs: The non-potable water system cost was estimated at $ 3,250,000 CAD (2.5 million US dollars), representing 0.5% of the total project cost. The operation and maintenance costs were not available.

Funding: The project received $650,000 CAD (500,000 US dollars) funding under the San Francisco Non-potable Grant Program.

References: SFPUC (2018) and Moscone (2019).

UN Plaza - Market Street between 7th and 8th Streets, San Francisco, California

Project: This project will restore and recommission an old non-potable groundwater system, last used approximately 30 years ago. This system used foundation drainage to fill trucks for street sweeping. Currently, foundation drainage is discharged into the combined sewers. When the restored system is operational again, the potable water offset will be around 20,000 m^3 (5 million gallons) per year.

Non-potable Water Sources:
- Foundation drainage

→

Non-potable Water Uses:
- Irrigation
- Fountain make-up water
- Street cleaning

System: The treatment system includes ultra-filtration (reducing the concentration of iron and manganese), and disinfection with chlorine. Clean groundwater will be stored in a 57 m^3 tank (15,000-gallon) and continuously monitored for chlorine and turbidity to ensure compliance with regulations.

Motivation: Reduce drinking water use and provide beneficial use for foundation drainage.

Ownership and Operation: San Francisco Public Works is the owner and will operate and maintain the system.

Timeline: Construction started in July 2019 and is expected to finish in September 2019.

Costs: The system's cost estimate is $ 3,900,000 CAD (3 million US dollars). Operation and maintenance cost estimates were not available.

Funding: The project will receive a $650,000 CAD (500,000 US dollars) grant under the San Francisco Non-potable Grant Program.

References: SFPUC (2018) and San Francisco Public Works (2019).

Perth Metropolitan Region, Australia

General Aspects

The Perth Metropolitan Region (PMR) is an administrative area of Western Australia, comprised of 30 local government areas, including the City of Perth, the capital of the Western Australia state. The population of the metropolitan region is 2,059,484. Perth itself is quite small and has only 27,762 habitants (Australian Bureau of Statistics, 2019).

Located on the southwest coast of Australia, PMR's climate has hot dry summers and wet winters. The total annual precipitation is 765 millimetres, and median temperatures vary from 8^{o} to 31^{o} Celsius (Australia Bureau of Meteorology, 2019). Over the last decades, climate change effects have been severely affecting Western Australia's rainfall and streamflow rates. To meet the rising drinking water demand, the government has been investing in two water sources less impacted by climate change: desalination and indirect potable water reuse (groundwater from aquifers replenished with recycled wastewater) (Water Corporation, 2009).

PMR's drinking water supply comprises four water sources, 48% of desalination, 40% of groundwater, 10% of surface water from reservoirs and 2% indirect potable water reuse. The percentage of each source varies according to climate conditions. Future plans to meet the growing water demand include expanding desalination, increasing recycled water production to replenish the aquifers, and expanding a deep aquifer network (Water Corporation, 2019a).

Drinking water, stormwater drainage and wastewater services are provided by the Water Corporation, a state company (Water Corporation, 2019b). In PMR, fees are applied for the use of these three services. Drinking water is metered, whereas stormwater drainage and wastewater are charged based on the rental value of the property (Water Corporation, 2019c).

Groundwater Uses and Licencing

Uses

Besides drinking water, groundwater in PMR is used for irrigation through community and domestic bores. A community bore is a well or group of wells used to provide non-potable water to multiple users for irrigation of public and private areas. In urban areas where there is a community bore, domestic bores are not allowed or need to be replaced by community bores (Josh Byrne & Associates, 2018).

According to the Department of Water (2019), there are approximately 190,000 garden bores in PMR, withdrawing almost 82,000,000 m^3 of groundwater from shallow aquifers per year. Urban irrigation consumes a high quantity of water, accounting for 50% of the total domestic use (Water Corporation, 2019e).

Licencing

In Western Australia, groundwater use is regulated by the state through its various agencies. The Department of Water (DoW) is accountable for allocating, regulating, and licencing groundwater use. To support the decision-making process, DoW developed allocation plans assessing the quantity of groundwater that can be extracted from aquifers to guarantee a sustainable water use and protect the water-dependent ecosystems (Department of Water, 2019a). Regions with quantity or quality limitations are classified as proclaimed areas, and DoW restricts groundwater use of in those regions (Department of Water, 2019b).

The construction of groundwater wells and the withdrawal of groundwater require the following licences, issued by the DoW. Exemptions include domestic garden bores that do not withdraw from artesian aquifers or irrigate areas larger than 2,000 m^2 (Department of Water, 2019).

1. Licence 26D: Applied for construction of wells.

   When analyzing the request for the construction of a new well, the DoW will evaluate whether water is available at the location for the intended use, according to the allocation plan (Department of Water, 2019c).
2. Licence 5C: Applied for groundwater extraction.

   This licence is required to extract water from an artesian well or other activities that use groundwater in a proclaimed area (Department of Water, 2019d). A Hydrogeological Report is mandatory and, during the operation, monitoring reports can be required (Department of Water, 2009).

Community bores that serve a group of users shall have one party responsible for operating, maintaining, and meeting the regulatory requirements. An operator of a multiple-use community bore is recognized as a water service provider, and may need an additional licence for water services operating. Operators can be a private user, the local government or the water service company (Department of Water, 2013).

Non-potable Water Initiatives

The Western Australia Department of Water recognizes rainwater, stormwater, greywater, wastewater and groundwater[4] as non-potable water sources. End uses are not restricted. It is proposed by the developer and must be approved by proper regulatory agencies (Department of water, 2013).

For district scale systems, the Western Australia government developed a Guideline for the approval of non-drinking water systems, describing the process and requirements to implement those systems. The

[4] Groundwater is water located below the surface of the ground and resides in aquifers (superficial or confined). It includes surface expressions of groundwater such as lakes and wetlands. (Department of water, 2013, p. 27)

assessment of non-drinking water systems involves a four-stage process: option evaluation and concept design; preliminary design; detailed design; and implementation.

Regulators recommend the discussion of the project proposal with the approving agencies in early stages to certify that all the requirements are met. On the first two stages (concept and preliminary design), the Western Australia Department of Water (Water Recycling and Efficiency) coordinates feedback on the design with all the regulatory agencies, consolidating the response to the developer. On the detailed design step, the developer is ready to apply for the licences.

Individual groundwater wells for irrigation or single-home non-potable water systems are not covered by the guideline, and users shall apply for the groundwater withdrawal licences with the DoW (Department of Water, 2013).

The regulatory agencies involved in the assessment of non-potable water systems are the (Department of water, 2013):

- Department of Health - Regulates health standards for non-potable water and sewer systems design and operational requirements;
- Department of Environment Regulation – Issues annual operational licences;
- Department of Water - issues licences for construction and withdrawals of groundwater wells, and assesses water management reports;
- Local City Building Department – issue building permit;
- Office of the Environmental Protection Authority - Evaluate proposals of relevant environmental impact;
- Western Australian Planning Commission and Department of Planning - Coordinate, assess and approve regional land use planning and development.

Water Quality Requirements

For chemical contaminants, the Department of Environmental Regulation (DER) and the Department of Health (DoH) of Western Australia defined water quality assessment levels for non-potable groundwater uses at the Contaminated Sites Guidelines (Department of Health, 2014). These limits are based on the Guidelines for Managing Risks in Recreational Water (NHMRC 2008), and are applied to recreational waters as well. The non-potable water uses considered are, but are not limited to: irrigation of gardens and parks, laundry, toilet flushing, car washing and growing vegetables.

Since the guideline was developed for contaminated sites management, concentration limits are applicable to groundwater sampled at the monitoring well, before extraction. If the concentration exceeds the limits at the point of use, actions to mitigate risks must be taken.

According to the DoH (2014), the values are generally ten times higher than the drinking water health standards, or the aesthetic value, for parameters without health limits. The list of all parameters and limits are presented at Appendix A.

Microbiological contaminants are not included in this guideline (Department of Environmental Regulation, 2014). For pathogen control, the Department of Health (2009) developed the Draft Alternate Water Supply Guidelines – Stormwater and Rainwater. Although it does not include groundwater or foundation drainage, the guideline adopted a risk assessment approach based on the level of exposure of the user to the water. Both guidelines are good references for the City of Vancouver to develop its own regulation.

Design, Operational and Maintenance Requirements

All non-potable water systems, including the community bores, require a separated pipe network, purple and identified by a distinct label (Department of Water, 2013). The examples identified are independent systems, without connection with the drinking water supply, meaning that they do not require cross-connection control. Systems must be periodically monitored according to the water quality requirements.

Non-potable Groundwater Case Studies

The main example of non-potable groundwater system in PMR are the community bores. The White Gum Valley, described below, shows a case study of a new development adopting this system.

White Gum Valley, Western Australia

Project: The White Gum Valley is a new residential development on 2.29 ha with 80 residential units, located in the City of Freemantle, Greater Perth Region. Efficient water use is one of the project's goals, which adopted a community bore, water-wise irrigation systems, rainwater reuse, and metering with real-time monitoring for drinking water and groundwater.

Non-potable Water Sources:
- Groundwater
- Rainwater

Non-potable Water Uses:
- Irrigation (Community Bore)
- Toilet flushing
- Laundry

System: The system is separated by source. Each source has its own pipes, storage tank, and treatment unit. Groundwater from community bores will irrigate public and private gardens, and rainwater will be used for toilets and washing clothes in each building or house. The project estimates more than 60% reduction in drinking water use in comparison with the average Perth domestic consumption. Groundwater will be metered at each property, but residents will be charged flat rates.

Motivation: Reduce drinking water consumption and optimize water use.

Ownership: the City of Freemantle owns, operates, and maintains the community bore. LandCorp, the Western Australia Land Development Agency, is the administrator of the project.

Timeline: Project planning started in 2003. The first lots were released for sale in 2015.

Costs: Not available.

Funding: Not available.

Reference: Cooperative Research Centre for Water Sensitive Cities (2017), and Josh Byrne & Associates (2018).

Los Angeles, California

General Aspects

On the southwest coast of the United States, Los Angeles (LA) is the second most populated North American city, with 3,990,456 habitants in 2018 (United States Census Bureau, 2018). LA's climate is characterized by an annual precipitation rate of 765 millimetres and median temperatures from 8^{o} to 31^{o} Celsius (NOAA, 2019).

Los Angeles has long been dependent on water imported from other Californian watersheds. The primary supply source is water imported from Eastern Sierra Nevada Mountains, Sacramento-San Joaquin Bay Delta and the Colorado River watersheds, supplemented by local groundwater and recycled water (Los Angeles Department of Water and Power, 2015). Due to environmental, legal, and regulatory limitations, the availability of imported water was reduced. As part of the One Water LA program, the City has been investing in recycled water projects and groundwater aquifer recharge to increase local water supply (Los Angeles Department of Water and Power, 2019).

In LA, drinking water is supplied by the municipal Department of Water and Power (Los Angeles Department of Water and Power, 2019), whereas wastewater and stormwater drainage by the Environment LA Sanitation (LA Sanitation, 2019).

Groundwater Uses and Licencing

Currently, 10 to 15% of the Los Angeles drinking water supply is groundwater. Approximately 80% of the groundwater comes from the San Fernando Groundwater Basin, located on the Upper Los Angeles River Area of the Los Angeles County, and the rest 20% from Sylmar, Central and other minor basins. Although the LA's Integrated Urban Water Management Plan (IUWMP) aims to increase local water sources, the local aquifers face major quality and quantity challenges (Los Angeles Department of Water and Power, 2015).

The San Fernando Basin had more than 80 of its 115 groundwater wells removed from service or restricted in use, mostly due to contamination issues associated with volatile organic compounds. The same situation occurred in the Sylmar Basin and the Central Basin. To address this problem, the Los Angeles Department of Water and Power (2015) has been conducting remediation actions.

Due to high consumption over decades, and to increase aquifer capacity to supply the growing demand, the IUWMP includes projects to replenish groundwater basins, capturing and injecting stormwater and recycled water (Los Angeles Department of Water and Power, 2015).

The use of groundwater in the City of Los Angeles is regulated by Los Angeles County. The Department of Public Health issues the licences for the construction of wells and groundwater extraction.

Non-potable Water Initiatives

In Los Angeles County, the Department of Health - Environmental Health Division (DPH EH) published a Guideline for Alternate Water Sources: Indoor and Outdoor Non-Potable Uses. Sources for onsite non-potable water systems "include, but are not limited to, rainwater, graywater stormwater, recycled water, reclaimed water, cooling tower blow-down water, condensate, and foundation drainage" (Los Angeles County Department of Public Health,2016).

The guideline adopts a tiered approach, classifying non-potable water sources in four tiers: Tier 1 Rainwater, Tier 2 Greywater, Tier 3 Stormwater and Tier 4 Blackwater. Foundation drainage is recognized as Tier 2 – Greywater (Los Angeles County Department of Public Health,2016). The requirements for greywater systems defined by LA County are described in Table 3.

Table 3. Summary of the requirements for alternative water systems including foundation drainage (Adapted from Los Angeles County Department of Public Health,2016).

REQUIREMENTS FOR ALTERNATIVE WATER SYSTEMS INCLUDING FOUNDATION DRAINAGE
Users
Single-family homes, multi-family buildings, hotels, commercial, institutional, and municipal facilities
End Uses
▪ Indoor: Toilet and urinal flushing, laundry, trap primers, and cooling ▪ Outdoor treated water: Spray and drip irrigation, car-washing and non-interactive water feature[5] ▪ Outdoor non-treated water: Mulch basin and subsurface irrigation
Permitting
The permitting process to approve non-potable water systems in Los Angeles involves at least two regulatory agencies: City of Los Angeles Department of Building and Safety (LADBS) and the Los Angeles County Department of Public Health - Environmental Health Division (DPH EH). The licences and approvals required are: ▪ Plumbing Permit, issued by City of Los Angeles Department of Building and Safety (LADBS, 2017); ▪ Department of Public Health of the Los Angeles County system review, approval and cross-connection test; and If a groundwater well is required, it is also necessary to obtain a licence with the DPH EH.
Water Quality Requirements
NSF 350 with disinfection or California Code Regulation Title 22 Recycled Water Quality Equivalence at the point of use or other standard matching or exceeding accepted standards.

[5] "Non-interactive water feature: Fountains, waterfalls, or other features not intended to act as play zones for children" (Los Angeles County Department of Public Health,2016).

REQUIREMENTS FOR ALTERNATIVE WATER SYSTEMS INCLUDING FOUNDATION DRAINAGE
Design, Operation and Maintenance
Alternate water systems including foundation drainage shall have (Los Angeles County Department of Public Health,2016): ▪ Separated plumbing; ▪ Screen or other protection to vector intrusion; ▪ Overflow to an approved drainage system (stormwater, combined or sewer system); ▪ Make-up connection to a potable water source; ▪ Backflow preventer; ▪ Failsafe sensing and signalling equipment according to NSF 350; ▪ Online monitoring of turbidity, pH, and Total Suspended Solids (TSS); and ▪ An Operation and Maintenance Manual, developed by the designer including online water quality monitoring requirements, water quality standards, sampling frequency, and procedures for response to system failures

The guideline recommends systems be certified to NSF/ANSI 350 or other applicable standard certified by an external tester approved by the DPH EH. All systems must be tested for cross-connections by the DPH EH Greywater (Los Angeles County Department of Public Health,2016).

Users must undertake water quality monitoring and present reports. For Owner-Occupied single-family homes, this should occur upon installation, and whenever ownership changes. For other users, it can be annually, or quarterly, if used for laundry washing.

Non-potable Groundwater Case Studies

No examples of non-potable water systems utilizing groundwater were identified in the City of Los Angeles.

Summary

The tables below provide a summary of the key aspects compiled from the literature review for Vancouver and the three cities selected. Table 4 shows location, climate, temperature, annual precipitation, drinking water sources and key drivers to implement non-potable groundwater use. Table 5 summarizes information on groundwater use and management, and Table 6 presents non-potable groundwater system aspects.

Table 4. Overview of the Top 3 cities: location, climate and drinking water sources.

	Vancouver	San Francisco	Perth Metropolitan Region	Los Angeles
Location	Southwest coast of Canada	West coast of the US	Southwest coast of Australia	Southwest coast of the US
Average Temperature	1º C - 22º C [1]	10º C - 22º C [4]	8º C - 31º C [7]	13º C - 23º C [4]
Annual precipitation	1456 mm [1]	524 mm [4]	765 mm [7]	325 mm [4]
Population (2018)	672,963 people [2]	883,305 people [5]	2,059,484 people in 2018 [8]	3,990,456 people [5]
Drinking water source	Reservoirs [3]	Reservoirs and groundwater [6]	Reservoirs, groundwater, desalination plants and indirect potable reuse [9]	Imported water from distant watersheds (reservoirs), and local groundwater [10]
Key drivers to implement non-potable water use	Reduce foundation drainage discharge into the combined sewers systems; reduce potable water consumption	Severe drought events; reduce reliance on distant reservoirs due to possible disconnection in case of an earthquake	Water scarcity; severe drought events; reduce drinking water consumption	Severe drought events; reduce the dependence on imported water

[1] Environnent Canada (2019)
[2] BC Stats (2019)
[3] Metro Vancouver (2014)
[4] NOAA (2019)
[5] United States Census Bureau (2018)
[6] San Francisco Planning Department (2013) and SFPUC(2019c)
[7] Australia Bureau of Meteorology (2019)
[8] Australia Bureau of Statistics (2019)
[9] Water Corporation (2019)
[10] Los Angeles Department of Water and Power (2019)

Table 5. Overview of the Top 3 cities: groundwater uses and management.

	Vancouver	San Francisco	Perth Metropolitan Region	Los Angeles
Current GW uses	Irrigation of parks and golf clubs; cooling.	Irrigation; drinking water; and non-potable water program	Irrigation and drinking water	Irrigation and drinking water
GW* Management Plan or IUWMP**	No. There is a Rainwater Management Plan and an Integrated Liquid Waste Management Plan. They do not include groundwater.	Yes, IUWMP	Yes, IUWMP	Yes, IUWMP
Aquifer Monitoring	Yes, but just a few wells annually.	Yes	Yes	Yes
GW Model	No	Yes	Yes	Yes
Requires licence to use GW	Yes	Yes	Yes	Yes

GW = groundwater
IUWMP = Integrated Urban Water Management Plan

Table 6. Overview of the Top 3 cities: non-potable groundwater systems.

	Vancouver	San Francisco	Perth Metropolitan Region	Los Angeles
Permitted sources	Rainwater from roof surfaces, or similar areas without the passage of vehicles, without storage of hydrocarbons, hazardous materials or fertilizers; clean-water waste[1]	Rainwater, Stormwater, Greywater, Blackwater and Foundation Drainage [2]	Rainwater, Stormwater, Greywater, Blackwater and Groundwater [5]	Rainwater, Greywater Stormwater, and Blackwater. Foundation Drainage is considered greywater [7]
Permitted End Uses	Toilet flushing, trap primers, irrigation of non-food purpose plants, make-up water for boilers and cooling towers [1]	Indoor: Toilet flushing, laundry and priming drain traps Outdoor: irrigation, decorative fountains, cooling and street cleaning [2]	Includes, but not limited to: Irrigating of parks, public, and private gardens, growing vegetables, laundry, washing vehicles, toilet flushing and aquifer recharge. [5] and [6]	Indoor: Toilet flushing, laundry, priming drain traps, and cooling Outdoor (treated): Spray and drip irrigation, non-interactive outdoor water feature, and vehicle washing. Non-treated: subsurface irrigation [7]
Water Quality Requirements for GW* systems	Groundwater is not permitted as a source. Quality requirements is not defined for GW [1]	Virus, protozoa and bacteria Log Reduction Targets; Turbidity and VOC maximum concentrations; minimum chlorine residual [3]	Associated to contaminated sites assessment. Apply to water sampled on the monitoring well. Extended list of chemicals + microbiological parameters adopted by the recycled water guideline + Methyl Tertiary Butyl Ether + Fertilizers [6]	Follow NSF/ANSI 350 with disinfection or Title 22 Recycled Water Quality Equivalence [7]

Key Design Requirements	Not defined for GW [1]	Dual pipe system (purple for non-potable), make-up water connection, backflow preventer between the potable and non-potable pipes, overflow connection, flow meters on the non-potable and make-up drinking water pipes [4]	Defined case-by-case	Meet the NSF ANSI 350 requirements; vector intrusion; dual pipe system, make-up water connection, backflow preventer between the potable and non-potable pipes, overflow connection to drainage/sewer system [7];
Key Operation and Maintenance (O&M) Requirements	Not defined for GW [1]	Hire a certified professional for O&M and an accredited laboratory for monitoring; Develop an O&M Plan [3]	Defined case-by-case	Online monitoring of turbidity, pH, and total suspended solids; have an O&M manual developed by the designer including, water quality standards, sampling frequency, and procedures in case of failures [7]
Jurisdictions involved in the permitting process	City of Vancouver (Departments: Green Infrastructure, Utilities Modeling & Data Management, and Development, Buildings & Licensing), BC MOE, BC FLNRORD and Vancouver Coastal Health	Public Utilities Commission, Department of Public Health, and Building Inspection Division, all San Francisco's departments [4]	Department of Health, Department of Environment Regulation, Department of Water, Western Australian Planning Commission [5]	LA County Department of Public Health and City of LA Department of Building and Safety [7]
Funding Program	No	Yes, for non-mandatory projects.	No one identified	No one identified
Case Study using GW*	Hillcrest Centre	Four cases including irrigation, toilet flushing, fountain make-up, heating, and street cleaning	Community bores for irrigation	No one identified
* GW = groundwater	[1] City of Vancouver, 2019	[2] SFPUC (2019) [3] SFPUC (2017a) [4] San Francisco Department of Public Health (2017)	[5] Department of water (2013) [6] Department of Environmental Regulation (2014)	[7] Los Angeles County Department of Public Health (2016)

Recommendations

The objective of this project was to undertake a literature review to understand how other municipalities worldwide have planned, implemented and regulated non-potable groundwater use, as well as to provide recommendations on approaches that could be applied at the City of Vancouver. This review identified three cities that are using groundwater for non-potable use: San Francisco, Perth Metropolitan Region and Los Angeles, each with their own regulatory framework on sourcing, treating and making use of the non-potable water.

Throughout the course of the literature review, a common theme that was observed across the cities was that the regulation and implementation of non-potable water systems was often undertaken in response to water scarcity issues. The City of Vancouver is not currently experiencing the same severity of water scarcity issues that many of the cities studied were encountering, but it (and the Metro Vancouver region) is experiencing challenges associated with a significant rise in population and a reduction in the seasonal supply of water to its reservoirs due to climate change. As such, the City of Vancouver has the opportunity to be a leader in adopting non-potable water systems ahead of these issues, becoming more severe and costly to manage later. Furthermore, gaining a greater understanding of the city's groundwater resources is only starting to be explored by the City of Vancouver, which means that non-potable use of groundwater can be explored more fully as part of a Groundwater Management Strategy for the city.

From the review of how the use of groundwater and foundation drainage was implemented in San Francisco, Perth and Los Angeles, the following approaches and best practices are recommended for consideration by the City of Vancouver as part of developing its own approach to non-potable groundwater use:

1. Groundwater Management Strategy and Integrated Urban Water Management Plan

The development of strategies and plans for the management of groundwater, as well as an integrated plan for all types of water managed within the city, is critical to developing a long-term vision for how the city protects, manages and uses water, as well as prioritize investments in its infrastructure. An integrated urban water management plan provides a broader view and understanding of the interconnections, limitations and opportunities among all the water systems, providing a foundation to develop the regulation and support the decision-making process.

2. Development of a regulatory framework

The creation of policies, guidelines and tools are needed to support the implementation of a non-potable water program. A municipality that provides a best practice example of this approach is San Francisco, which has very clear policies on non-potable water use backed by a suite of guidance documents and tools to support the development community. Currently, in Vancouver the authorities that would be involved in the development of policies, guidelines and tools include, but are not limited to: City of Vancouver (Development, Buildings and Licencing Department, Waterworks Design, Green Infrastructure

Branch, and Utilities Modeling & Data Management), BC FLNRORD, BC MoE, and Vancouver Coastal Health.

3. Collaborative Approach to Aquifer Management

The jurisdictions of Vancouver, Burnaby, New Westminster, Coquitlam, Port Moody and the University Endowment Lands share the same aquifer, the Quadra Sands. Since ecosystems do not follow political boundaries, actions in any of the cities can affect groundwater across other jurisdictions. As implemented by San Francisco and its neighbouring municipalities, a collaborative approach to aquifer management can be beneficial to all the cities involved, helping to preserve the ecosystem health, avoiding future issues due to contamination and overexploitation. Of the cities whose jurisdictions reside over the Quadra Sands aquifer, none are known to rely upon on the aquifer as a significant potable or non-potable water source. As such, now is an excellent time to start discussions between these parties to develop a joint approach to sustainably managing their shared aquifer.

4. Monitoring and Modeling

Understanding the quality issues and quantity limits of the aquifer is essential to evaluate the potential use of groundwater in Vancouver. Since groundwater is managed by the province, the development of a strategy in collaboration with the BC MoE and the BC FLNRORD is important to increase knowledge on contaminated sites and quantity constraints at the City. Monitoring and modelling may clarify the necessity of monitoring additional contaminants by the non-potable groundwater users and identify potential areas for groundwater use. Furthermore, the implementation of a groundwater monitoring plan and a groundwater model, either by the City or the province, can support the evaluation of groundwater quantity and quality, to define groundwater allocation and contaminant transport.

5. Defining Water Quality Requirements for Non-Potable Groundwater Use

Protecting human health is a critical aspect when developing water quality requirements for non-potable water uses. The methodology applied when undertaking risk assessments to define remediation targets for contaminated sites can serve as an example for non-pathogen contaminants. A best practice that could be referred to by the City of Vancouver is the water quality assessment levels for non-potable groundwater uses specified by the DER in Western Australia. The values specified by DER could be evaluated by the city as well as Vancouver Coastal Health as reference values for non-potable groundwater quality requirements in the City of Vancouver.

For the permitting process, a groundwater investigation should be part of the documents required. If no previous information of groundwater is available, or there is no preliminary/detailed site investigation, or monitoring of the area, then a monitoring program including a wide range of parameters should be performed. Monitoring must be part of the reports required for the permitting process to approve the construction and during the system operation.

6. Implement Non-potable Water Systems Alongside Water Conservation & Efficiency

The implementation of non-potable use including groundwater and foundation drainage use has the potential to reduce drinking water consumption across the city, but it also carries the risk of using water inefficiently or for uses that should be restricted or banned. Many of the other cities studied employed a number of policies and practices to reduce potable water use beyond non-potable water systems, including requiring metering and charging significantly higher metered rates for water and wastewater services. To ensure that non-potable water sources are used to provide the greatest benefit it is important that they be implemented alongside other water conservation and efficiency measures.

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Appendix A Water Quality Parameters

San Francisco Water Quality Parameters

Table 7. Water Quality Requirements for Foundation Drainage Treatment Systems (Extracted from SFPUC, 2017a)

Parameter	Water Quality Limit	Monitoring Frequency
Virus	Treatment must achieve at least: • 3.5-log reduction in enteric virus for indoor reuse OR • 3.0-log reduction in enteric virus for outdoor reuse.	Continuously (via surrogate parameter(s))
Protozoa	Treatment must achieve at least: • 3.5-log reduction in parasitic protozoa for indoor reuse OR • 2.5-log reduction in parasitic protozoa for outdoor reuse.	Continuously (via surrogate parameter(s))
Bacteria*	Treatment must achieve at least: • 3.0-log reduction in enteric bacteria for indoor reuse OR • 2.0-log reduction in enteric bacteria for outdoor reuse AND/OR meet the Total Coliform requirements listed below: • No sample shall exceed an MPN of 2.2 /100 ml at any time or additional sampling will be required	Continuously (via surrogate parameter(s)) Weekly, Other*
Turbidity	For media filter: • The median concentration shall not exceed 2 NTU within a 24-hour period; • The maximum shall not exceed 5 NTU more than 5 percent of the time within a 24-hour period; and • No sample shall exceed 10 NTU at any time. For membrane filter: • The maximum shall not exceed 0.2 NTU more than 5 percent of the time within a 24-hour period; and • No sample shall exceed 0.5 NTU at any time.	Continuously
Chlorine Residual	Over any 24-hour period, the average chlorine residual shall be within the range 0.5 – 2.5 mg/L.	Continuously
Odor	The system shall not emit offensive odors.	n/a
Flow	At least one flow meter must be installed.	Continuously
Volatile Organic Carbon	See Table 9	Quarterly

Notes:

* Pathogenic microorganism control for bacteria is achieved by complying with water quality limits for total coliform. Total coliform sampling shall be conducted weekly during the Conditional Startup Mode. Based on the results, the Director may reduce the frequency of total coliform sampling during Final Use Mode or may allow surrogate parameter monitoring for systems that can meet the specified log reduction targets as described in Section 11 of these Rules and Regulations.

Table 8. Volatile Organic Compound (VOC) Limits (Extracted from SFPUC, 2017a)

Volatile Organic Carbon	Unacceptable Concentration (mg/L)
Benzene	0.1
Carbon Tetrachloride	0.5
1,2-Dichlorobenzene	5.4
1,4-Dichlorobenzene	5.4
1,1-Dichloroethane	14.4
1,2-Dichloroethane	0.1
1,1-Dichloroethylene	0.1
cis-1,2-Dichloroethylene	28.4
trans-1,2-Dichloroethylene	28.4
Dichloromethane	3.1
1,2-Dichloropropane	12.6
1,3-Dichloropropene	0.2
Ethylbenzene	15.6
Methyl-tert-butyl ether	5.2
Monochlorobenzene	1.7
Styrene	7.7
1,1,2,2-Tetrachloroethane	0.3
Tetrachloroethylene	6.1
Toluene	6.8
1,2,4-Trichlorobenzene	1.4
1,1,1-Trichloroethane	68.2
1,1,2-Trichloroethane	1.6
Trichloroethylene	4.8
Trichlorofluoromethane	201.1
1,1,2-Trichloro-1,2,2-Trifluoroethane	272.9
Vinyl Chloride	0.1
Xylenes	15.6

Western Australia Water Quality Parameters

Table 9. Western Australia Non-Potable Groundwater Use limits (Extracted from Department of Environmental Regulation, 2014).

Parameters	Non-Potable Groundwater Use (NPUG) (mg/l)
Metals/Metalloids	
Aluminium, Al	0.2
Antimony, At	0.03
Arsenic, As	0.1
Barium, Ba	20
Beryllium, Be	0.6
Boron, B	40
Cadmium, Cd	0.02
Chromium, (unspeciated), Cr	-
Chromium, Cr(III)	-
Chromium, Cr(VI)	0.5
Cobalt, Co	-
Copper, Cu	20
Iron, (Total) Fe	0.3
Lead, Pb	0.1
Lithium, Li	-
Manganese, Mn	5
Mercury (Total), Hg	0.01
Molybdenum, Mo	0.5
Nickel, Ni	0.2
Selenium (Total), Se	0.1
Silver, Ag	1
Tributyl tin (as Sn)	-
Tributyl tin oxide	0.01
Uranium, U	0.17
Vanadium, V	-
Zinc, Zn	3
Ammonia as NH3	0.5
Bromate, BrO3	0.2
Chloride, Cl-	250
Cyanide (as un-ionised Cn)	0.8
Fluoride, F-	15

Hydrogen sulfide	0.05
Iodide, I-	5
Nitrate (as NO3)9	500
Nitrite (as NO2)9	30
Nitrogen, N9	-
Total nitrogen, N14	-
Total phosphorus, P14	-
Phosporus (as P)9	-
Sulfate (as SO4)	100015
Organic Compounds	
Ethanol	-
Ethylenediamine tetraacetic acid (EDTA)	2.5
Formaldehyde	5
Nitrilotriacetic acid	2
Methyl tertiary butyl ether (MTBE)	0.023
Anilines	
Aniline	-
2,4-Dichloroaniline	-
3,4-Dichloroaniline	-
Chlorinated Alkanes	
Dichloromethane (DCM) (methylene chloride)	0.04
Trihalomethanes (total, including chloroform)	2.5
Tetrachloromethane (carbon tetrachloride)	0.03
1,2-dichloroethane	0.03
1,1,2-Trichloroethane (TCE)	-
Hexachloroethane	-
Chlorinated Alkenes	
Chloroethene (vinyl chloride)	0.003
1,1-Dichloroethene	0.3
1,2-Dichoroethene	0.6
Perchloroethylene (PCE) also known as tetrachloroethene	0.5
Chlorinated Benzenes	
Chlorobenzene	0.01
1,2- Dichlorobenzene	0.001
1,3- Dichlorobenzene	0.02
1,4- Dichlorobenzene	0.0003
1,2,3- Trichlorobenzene	0.005
1,2,4- Trichlorobenzene	Adopt individual or total trichlorobenzenes
1,3,5-Trichlorobenzene	For individual or total trichlorobenzenes
Polychlorinated Biphenyls (PCBs)	

Aroclor 1242	-
Aroclor 1254	-
Other Chlorinated Compounds	
Epichlorohydrin	1
Hexachlorobutadiene	0.007
Monochloramine	0.5
Monocyclic Aromatic Hydrocarbons	
Benzene	0.01
Toluene	0.025
Ethylbenzene	0.003
Xylenes	0.02
Styrene	0.004
Polycyclic Aromatic Hydrocarbons (PAHs)	
Naphthalene	-
Benzo[a]pyrene	0.0001
Phenols	
Phenol	-
2-Chlorophenol	3
4-Chlorophenol	-
2,4-Dichlorophenol	2
2,4,6-Trichlorophenol	0.2
2,3,4,6-Tetrachlorophenol	-
Pentachorophenol	-
2,4-Dinitrophenol	-
Phthalates	
Dimethylphthalate	-
Diethylphthalate	-
Dibutylphthalate	-
Di(2-ethylhexyl) phthalate	0.1
Pesticides and herbicides	
Acephate	0.08
Acrolein	-
Aldicarb	0.04
Aldrin plus Dieldrin	0.003
Ametryn	0.7
Amitraz	0.09
Amitrole	0.009
Asulam	0.7
Atrazine	0.2
Azinphos-methyl	0.3
Benomyl	0.9
Bentazone	4

Bifenthrin	0.35
Bioresmethrin	1
Bromacil	4
Bromoxynil	0.1
Captan	4
Carbaryl	0.3
Carbendazim (Thiophanate-methyl)	0.9
Carbofuran	0.1
Carboxin	3
Carfentrazone-ethyl	1
Chlorantraniliprole	60
Chlordane	0.02
Chlorfenvinphos	0.02
Chlorothalonil	0.5
Chlorpyrifos	0.1
Chlorsulfuron	2
Clopyralid	20
Cyfluthrin, Beta-cyfluthrin	0.5
Cypermethrin isomers	2
Cyprodinil	0.9
1,3-Dichloropropene	1
2,2-DPA	5
2,4-D [2,4- dichlorophenoxy acetic acid]	0.3
DDT	0.09
Deltramethrin	0.4
Diazinon	0.04
Dicamba	1
Dichlobenil	-
Dichloroprop	1
Dichlorvos	0.05
Diclofop-methyl	0.05
Dicofol	0.04
Dieldrin plus Aldrin	0.003
Diflubenzuron	0.7
Dimethoate	0.07
Diquat	0.07
Disulfoton	0.04
Diuron	0.2
Endosulfan	0.2
Endothal	1
Endrin	-
EPTC	3
Esfenvalerate	0.3

Ethion	0.04
Ethoprophos	0.01
Etridiazole	1
Fenamiphos	0.005
Fenarimol	0.4
Fenitrothion	0.07
Fenthion	0.07
Fenvalerate	0.6
Fipronil	0.007
Flamprop-methyl	0.04
Fluazifop-p-butyl	0.1
Flumetsulum	0.035
Fluometuron	0.7
Fluproponate	0.09
Flutriafol3	0.33
Glyphosate	10
Haloxyfop	0.01
Heptachlor	-
Heptachlor (including its Epoxide)	0.003
Hexazinone	4
Imazapyr	90
Iprodione	1
Lindane (γ-HCH)	0.1
Malathion	0.7
Mancozeb (as ETU, ethylene thiourea)	0.09
MCPA	0.4
Metaldehyde	0.2
Metham (as methylisothiocyanate, MITC)	0.01
Methidathion	0.06
Methiocarb	0.07
Methomyl	0.2
Methyl bromide	0.01
Metiram (as ETU, ethylene thiourea)	0.09
Metolachlor/s–Metolachlor	3
Metribuzin	0.7
Metsulfuron-methyl	0.4
Mevinphos	0.06
Molinate	0.04
Napropamide	4
Nicarbazin	10
Norflurazon	0.5
Omethoate	0.01
Oryzalin	4

Oxamyl	0.07
Paraquat	0.2
Parathion	0.2
Parathion methyl	0.007
Pebulate	0.3
Pendimethalin	4
Pentachlorophenol	0.1
Permethrin	2
Picloram	3
Piperonyl butoxide	6
Pirimicarb	0.07
Pirimiphos methyl	0.9
Polihexanide	7
Profenofos	0.003
Propachlor	0.7
Propanil	7
Propargite	0.07
Proparzine	0.5
Propiconazole	1
Propyzamide	0.7
Pyrasulfatole	0.4
Pyrazophos	0.2
Pyroxsulam	40
Quintozene	0.3
Quizalofop-p-ethyl	0.4
Simazine	0.2
Spirotetramat	2
Sulprofos	0.1
2,4,5-T	1
TCA (Trichloroacetic acid)	-
Tebuconazole	1
Tebuthiuron	-
Temephos	4
Terbacil	2
Terbufos	0.009
Terbuthylazine	0.1
Terbutryn	4
Thiobencarb	0.4
Thiometon	0.04
Thiram	0.07
Toltrazuril	0.04
Toxafene	-
Triadimefon	0.9

Triadimenol	2
Trichlorfon	0.07
Triclopyr	0.2
Trifluralin	0.9
Vernolate	0.4
Other parameters	
Methyl Tertiary Butyl Ether	0.02

Appendix B Data Collected

General Aspects

1. Location, climate and population
2. Primary water sources

Groundwater Uses and Permitting

3. How has groundwater been used to date
4. Authorities responsible for regulating groundwater use
5. Regulations applicable to groundwater use (extraction and discharge)

Non-potable Water Use

6. Regulations applicable to non-potable water use
7. Authorities responsible for regulating non-potable water use
8. Non-potable water sources permitted
9. Non-potable water uses permitted
10. Water quality requirements for non-potable water use
11. Operation and maintenance requirements
12. Case studies including non-potable groundwater use