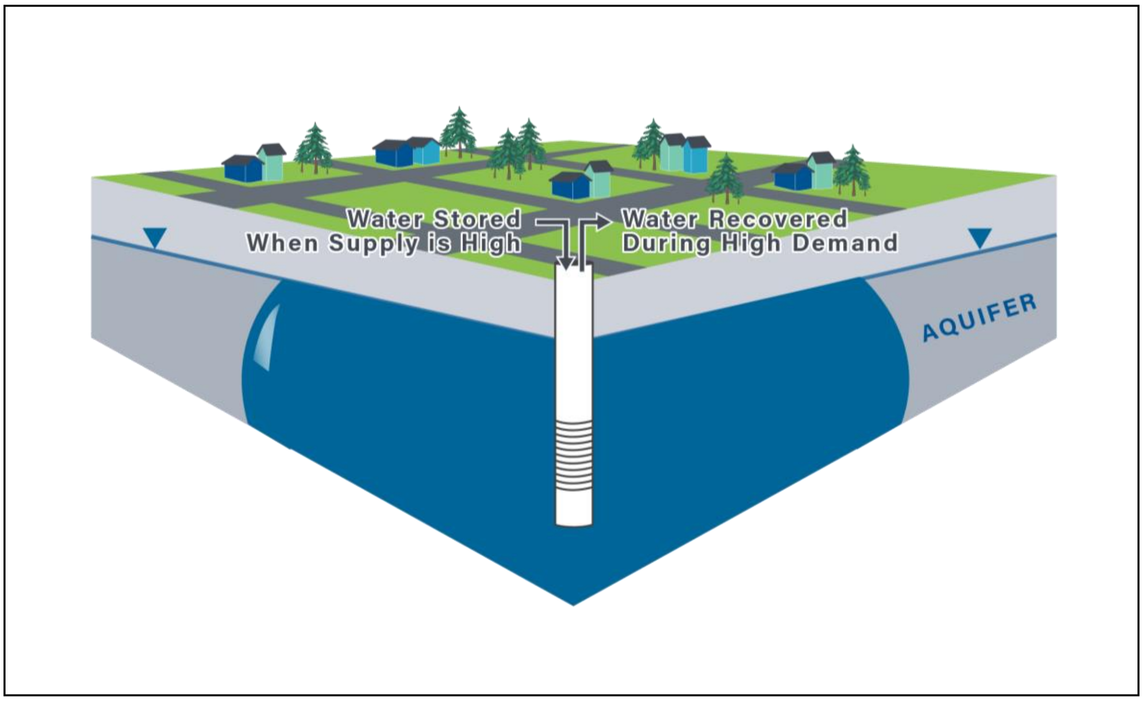
WATER SCIENCE SERIES

Assessment of Managed Aquifer Recharge (MAR) and Aquifer Storage and Recovery (ASR) Potential in British Columbia: Regional Opportunities and Regulatory Approaches



April 2021

No. 2021-05

The **Water Science Series** are scientific technical reports relating to the understanding and management of B.C.'s water resources. The series communicates scientific knowledge gained through water science programs across B.C. government, as well as scientific partners working in collaboration with provincial staff. For additional information visit: http://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-science-data/water-science-series.

ISBN: 978-0-7726-7923-9

Citation:

Ministry of Environment and Climate Change Strategy, 2021. Assessment of Managed Aquifer Recharge (MAR) and Aquifer Storage and Recovery (ASR) Potential in British Columbia: Regional Opportunities and Regulatory Approaches. Water Science Series WSS2021-05, Province of British Columbia, Victoria.

Cover Graphic: GSI Water Solutions Inc.

Acknowledgements

Douglas Geller, M.Sc., P.Geo. (B.C.) of Western Water Associates Ltd. and Walter Burt, M.Sc., R.G. (Oregon) of GSI Water Solutions, Inc. prepared the original project report under contract to the Government of British Columbia. This report is an edited version of the original project report by Western Water Associates Ltd. and GSI Water Solutions prepared by the Ministry of Environment and Climate Change Strategy. Funding for this project was provided by the Ministry of Environment and Climate Change Strategy through the Groundwater Science Program.

EXECUTIVE SUMMARY

This project assessed the potential opportunities for managed aquifer recharge (MAR) and aquifer storage and recovery (ASR) in British Columbia with a focus on regional water stresses and perceived priorities for water management. MAR/ASR are established practices that may be considered by water management staff as one potential option for addressing water supply issues in the province. This study was intended to improve knowledge of potential MAR/ASR practices in British Columbia through:

- Identifying potential ways in which MAR and ASR can be applied to solve water shortages in a sustainable manner while protecting water quality and the environment;
- Increasing the understanding of MAR and ASR implementation constraints from a technical and regulatory standpoint;
- Suggesting potential strategies and approaches that could address policy and regulatory gaps to support proponents considering or investigating the potential use of ASR/MAR; and,
- Identifying areas for further review of ASR and MAR potential in the Province of British Columbia.

The study was initiated as a preliminary review of MAR/ASR potential in B.C. and was limited to desktop analyses and feedback from government staff; the study did not seek input from First Nations or local municipalities.

Suggested terminology to describe ASR and MAR is as follows:

- MAR is the intentional recharge of water to suitable aquifers for subsequent recovery (use) and/or to achieve environmental benefits (e.g., augment streamflow, restore aquifer levels). The managed aspect is intended to ensure adequate environmental and human health protection. Methods to achieve recharge and recovery may vary and involve surface infiltration facilities and wells.
- ASR is a specific type of MAR technology that is most commonly used to capture excess seasonal water supply and store it underground for use when the capacity of water supply sources is inadequate to meet water needs. Most practitioners refer to ASR when the same well is used for recharge and recovery, though there are many variations.

MAR and ASR projects are often developed in phases that typically involve: 1) identifying a water shortage; 2) conducting a feasibility analysis; 3) field-based pilot testing; and finally, 4) MAR/ASR system expansion. Future development of regulations, policies and guidelines may find efficiencies in following this stepwise progression.

Review of Existing Regulations and Policies

Literature reviewed provided broad information on ASR and MAR applications as well as a focussed review of existing regulations in Oregon and Washington states. The review was conducted through a ‘B.C. application’ lens focussed on current water regulation, particularly, the *Water Sustainability Act (WSA)* and its implementing regulations as well as the B.C. Drinking Water Protection Regulation. This review indicates existing legislation and associated regulations are sufficiently broad and flexible to administer the authorization and licensing of MAR/ASR projects. However, there are potential policy issues and uncertainties that may require further analysis and resolution in order to align existing policy and regulation with MAR/ASR processes. Topics that could be considered include: guidance on the procedures for authorizing and licensing MAR/ASR systems; guidance or regulation development on the allowable changes in groundwater quality resulting from MAR/ASR storage and recovery; and, the amount of water from artificial recharge that may be recovered from aquifer storage. The latter topic is

typically determined on a project-specific basis but could also be considered in regulation or policy, or otherwise addressed at the time of licensing. The review also identified the need for establishing or defining water use purposes that would support the use of artificial recharge (MAR) for the purpose of conveying water to an aquifer in order to restore groundwater levels or to enhance groundwater baseflow discharge to streams (i.e., groundwater conservation).

Policy and Regulatory Recommendations

An objective of this work was to provide a jurisdictional scan of current MAR/ASR best practises and overview of recent case studies to inform future discussions regarding B.C. policy on MAR/ASR. Success in another jurisdiction has been achieved through the use of a single, coordinating agency that is tasked with guiding ASR and MAR project development and also providing the regulatory oversight. In B.C., it is expected that the main approver of water diversion and storage projects is the Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD), who would likely assume the responsibility of coordinating approvals and permits from other ministries depending on the scope and location of the MAR/ASR project. The eventual approval process could also benefit from a step-wise approach similar to large surface storage projects where conditional interim approvals are authorized and permitted to allow diversion and storage of water for pilot testing, followed by successive authorizations for system expansion and full-scale operation.

Potential Project Areas for Further Work

The project has identified four potential areas that could be considered for further investigation of ASR and MAR. The areas identified exhibit a combination of factors including water shortages that could potentially benefit from new solutions, potential availability of surface water sources on a seasonal basis, and suitable aquifers and hydrogeological conditions. The areas and project concepts recommended for further investigation are:

- Township of Langley: Treated drinking water could potentially be used to recharge local aquifers to offset groundwater level declines, and potentially provide storage and streamflow augmentation (MAR or ASR).
- South Okanagan: Surface infiltration of Okanagan River canal water could potentially augment recharge to Aquifers 254 and 255 to support use for agricultural water support and to support groundwater baseflow to streams, particularly during critical low flow periods (MAR).
- Merritt / Nicola Valley: Divert surplus surface water in the non-irrigation periods (winter season) for artificial recharge and to store for later agricultural water use, and possibly support baseflow augmentation during critical low-flow periods (MAR).
- Parksville area: Revisit the concept of diverting treated Englishman River water through the combined municipal system to recharge suitable aquifers via wells for later seasonal or emergency use (ASR).

Additional suggested measures for consideration fall broadly into the area of building support over a period of time for the eventual development of ASR and MAR in British Columbia. Further efforts to examine specific projects including, but not limited to, the ones identified in this study are suggested to help raise awareness of how MAR or ASR might help solve water shortage issues and support resource management. A near-term opportunity is to expand existing guidance for groundwater technical assessments in support of water licence applications (Todd et al., 2020) to include and define the potential assessment and monitoring requirements for artificial recharge projects.

CONTENTS

LIST OF FIGURES (WITHIN TEXT)

TABLES (WITHIN TEXT)

LIST OF MAPS (FOLLOWING TEXT Appendix A)

ACRONYMS/ABBREVIATIONS

AKART	All Known and Reasonably Available Technologies
ASR	Aquifer Storage and Recovery
AR	Artificial Recharge
DWPR	Drinking Water Protection Regulation
EA	Environmental Assessment
EAO	Environmental Assessment Office
EMA	*Environmental Management Act*
ENV	Ministry of Environment and Climate Change Strategy
FLNRORD	Ministry of Forests, Lands, Natural Resource Operations and Rural Development
GSI	GSI Water Solutions, Inc.
GWPR	Groundwater Protection Regulation
MAR	Managed Aquifer Recharge
OCPI	Overriding Consideration of Public Interest
POD	Point of Diversion
SDM	Statutory Decision Maker
SOLID	South Okanagan Lands Improvement District
USACE	U.S. Army Corps of Engineers
WQ	Water Quality
WSA	*Water Sustainability Act*
WSP	Water Sustainability Plan
WSR	Water Sustainability Regulation
WWAL	Western Water Associates Ltd.

1. BACKGROUND AND OBJECTIVES

Excluding ice in mountain and arctic regions that contain about 77% of the world's fresh water, less than 2% of the world's freshwater supply is found on the earth's surface in the form of streams and lakes (Kasenow, 2010). Groundwater thus forms a large percentage (~98%) of the earth's available freshwater supplies (Kasenow, 2010). Moreover, surface water bodies are commonly replenished in part by groundwater released from aquifers. Thus, groundwater and aquifer systems are arguably one the most important parts of the water cycle while remaining one of the least understood of the earth's freshwater systems.

Large-scale diversion and storage of surface water for agricultural, commercial, industrial and drinking water purposes has been undertaken in North America including British Columbia since the 1900s. Propelled by population growth and supporting industries, water management in the 20th century was an era of extensive dam building in North America ("big dam era") with many of the larger projects built before the 1960s (Water Encyclopedia, 2021a). However, beginning in the 1960's there was an evolving recognition of the economic and environmental costs associated with large-scale storage projects, which prompted the search for alternative water sourcing and water management strategies (Water Encyclopedia, 2021b). At the same time, the advent of high-lift turbine well pumps in the 1960s led to widespread drilling of groundwater wells that "radically escalated groundwater withdrawal from aquifers and quickly reduced groundwater in storage" in North America and globally (Dillon, 2019). In many locations, including B.C., the development and exploitation of groundwater resources proceeded with minimal government oversight or regulation.

Starting about 1990, as options to manipulate or develop water became either too expensive or unsustainable (or both), water managers began to search for new and innovative ways to divert and store water at a lower cost and with fewer environmental impacts. Out of this need for innovation came the idea to use artificial means (including wells) to recharge groundwater; in some cases, the very wells that had been over-pumped and subsequently depleted were considered. In 1995, R. David Pyne published Groundwater Recharge and Wells and this text remains a key reference source on the subject of Aquifer Storage and Recovery (ASR), with a 2nd edition that was published in 2005. Since the 1990s, there has been steady growth in interest in groundwater recharge applications (Burt and Barry, 2011), particularly in North America and specifically in the western U.S. The last two decades of growth of ASR in the states of Washington and Oregon are of particular relevance to B.C. as these states share some of the same geographies, climate and economies with some regions in British Columbia

Much of B.C.'s population is concentrated in three main regions: the Southern Interior region including the Okanagan-Shuswap area; the Fraser Lowland / South Coast region including Vancouver; and southeast Vancouver Island. These regions are likely to see continued increasing demands on water supplies for the foreseeable future with the two main intersecting drivers being: 1) population growth and its attendant intensifying impact on land uses; and, 2) climate change. Although forecasted climate change impacts vary regionally, most areas of B.C. can expect to have warmer winters, wetter spring and fall seasons, hotter and drier summers, and longer growing seasons (Pinna Sustainability 2020; Hamm and Hopkins 2016). It is expected that northeast regions of the province will see more precipitation across all seasons (Government of British Columbia, 2020). There is a high risk that climate change will result in summer water shortages in two or more regions of the province (e.g., West Coast, South Coast, Southern Interior), which can cause environmental damages, particularly for temperature-sensitive aquatic species such as salmon, as well as damaging wetlands and forest ecosystems (B.C. Ministry of Environment and Climate Change Strategy, 2019). Reduced low flows in streams and associated impacts to aquatic ecosystems is exacerbated in areas where groundwater use pressures affect the baseflow replenishment of streams, which can occur in both summer and winter low flow periods (Douglas, 2006). Douglas (2006) also discusses the use of artificial groundwater recharge as a potential tool to restore groundwater levels and support the protection of aquatic ecosystems.

The Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD) and the Ministry of Environment and Climate Change Strategy (ENV) initiated this project to explore potential ASR and MAR opportunities and constraints in B.C. The study objectives were:

1) provide an overview assessment of the broader topic of managed aquifer recharge (MAR) as well as ASR
2) investigate and identify the key issues and constraints for the siting, design, and operation of MAR/ASR systems in B.C.
3) investigate potential policy approaches that could support the implementation of MAR/ASR systems in B.C., and
4) identify potential areas/sites for study of MAR/ASR systems.

The study was initiated as a preliminary review of MAR/ASR potential in B.C. and was limited to desktop analyses and feedback from government staff. This work is not an exhaustive review of the topic and the study did not seek input from First Nations or local municipalities. The study was completed by Western Water Associates Ltd. (WWAL) and GSI Water Solutions, Inc. (GSI) under government contract. This report is an edited version of the final project report submitted by the WWAL/GSI team. Staff from ENV edited the WWAL/GSI report to make it available to a broader audience of government staff and the general public. The contents of this report are based the work of consultant team and should not be interpretated as government policy.

2. ARTIFICAL GROUNDWATER RECHARGE

2.1 Overview of AR, MAR, ASR Terminology

The following subsections introduce key terms related to artificial groundwater recharge, managed aquifer recharge, and aquifer storage and recovery. These terms are broadly used throughout the world, though there are many different variations and practitioner preferences. As such, the following should not be considered strict definitions, but rather a guide to understanding key concepts presented in this report.

2.1.1 Artificial Groundwater (Aquifer) Recharge (AR)

Artificial recharge (AR) is defined as the intentional (managed) or incidental (unmanaged) augmentation of the natural processes of groundwater recharge. The typical natural processes by which water enters an aquifer system include infiltration of rainwater and snowmelt, stream losses, discharge from other aquifers, and seepage from wetlands, ponds and lakes. Some of the more common types of "incidental" aquifer recharge are seepage losses from dams and reservoirs, stormwater recharge, irrigation return flow, losses from irrigation ditches and canals, and wastewater disposal to ground. Intentional aquifer recharge is commonly described as managed aquifer recharge (MAR), described in the next section. To some practitioners, AR is an older term, and there have been perceived problems with use of the word 'artificial', which has led many proponents and practitioners to prefer the term of MAR.

2.1.2 Managed Aquifer Recharge (MAR)

Managed aquifer recharge is the intentional recharge of water to suitable aquifers for subsequent recovery (use) and/or to achieve environmental benefits. Within the definition the managed aspect is intended to assure adequate protection of human health and the environment. Some practitioners define AR and MAR interchangeably, while others distinguish the two by defining MAR as having a "later use" (recovery) component. Dillon et al. (2019) succinctly defines MAR as a recharge project that is not only intentional in terms of supply (quantity) but is also designed to maintain water quality and is environmentally sustainable.

There are a number of methods used to recharge aquifers including injection wells (including ASR wells, see 2.1.3 below) or infiltration structures such as ponds, basins, galleries and trenches, which help to reduce transport and storage costs and water loss through evaporation. Water from a variety of sources can be used in the recharge process. These may include municipal water from a water distribution system, water diverted from watercourses, water from above-ground reservoirs, stormwater and treated wastewater. Figure 1 provides a schematic diagram of a typical MAR system using an infiltration structure or injection well.

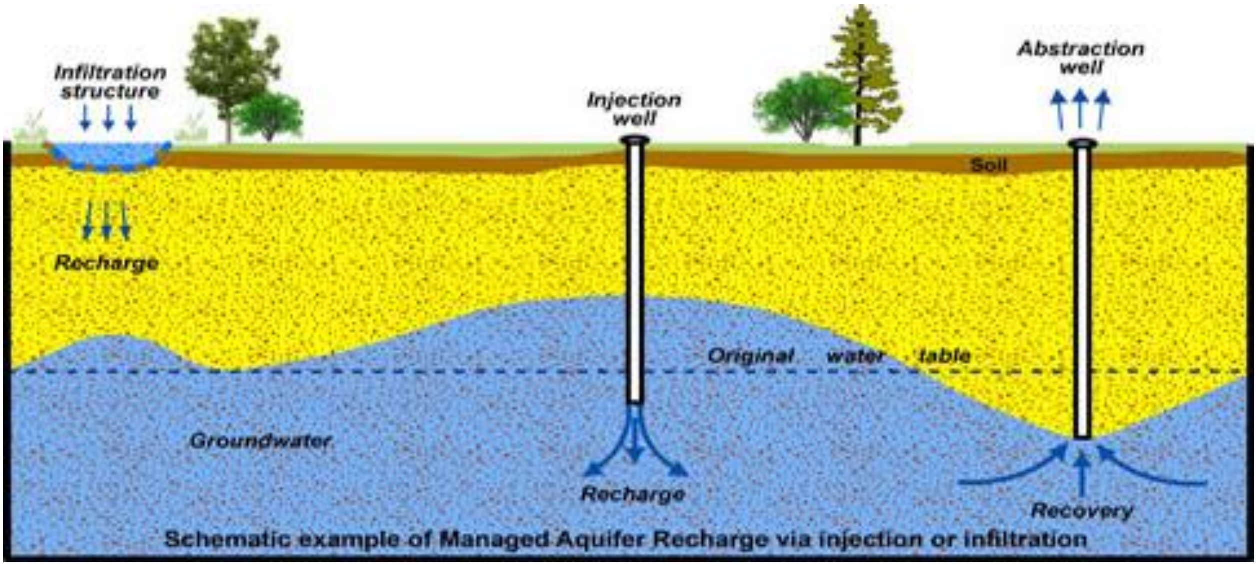


Figure 1: Example MAR schematic demonstrating intentional groundwater recharge through use of an infiltration basin or an injection well. Source: Government of Western Australia (2021).

2.1.3 Aquifer Storage and Recovery (ASR)

ASR is a specific type of MAR technology most commonly used to capture surplus seasonal water supply capacity and store it underground for use when the capacity of water supply sources is inadequate to meet water needs (Figure 2). Most practitioners refer to ASR when the project involves diverting/withdrawing surface water during times of high flow, treating it to drinking water standards, injecting it through a well into an aquifer with sufficient storage capacity, and recovering the water from the same well when needed. ASR has seen numerous applications worldwide including extensive investigation, testing and operations in North America (Burt and Barry, 2011; Dillon et al., 2019). ASR provides a way to store large volumes of water where the stored water is pumped out (recovered) typically from the same well(s) used for recharge and added to the distribution system.

2.1.4 Summary Recommended Terminology for British Columbia

For the purpose of this study and developing recommendations, ASR is defined as indicated in Section 2.1.3 above and includes a specific recovery component. MAR has a broader context referring to all "intentional" artificial recharge projects, including those without a specific recovery component (e.g., recharge projects directed toward environmental benefits). Thus, MAR encompasses ASR projects, which therefore form a specific type of MAR project category where wells are used for injection (recharge) and withdrawal (recovery). When wells are used only for recharge, then this would not be an ASR project as there is no “R” (recovery) component; hence the term MAR. When wells are used only for recovery following surface recharge, this would also be a MAR project.

2.2 Typical Applications of MAR/ASR

Western North America experiences a pronounced seasonality in precipitation, streamflow and water demand profiles, with higher precipitation paired with lower demands in the winter and spring months, followed by high demands and low precipitation in the summer and fall months. Trends towards lower winter snowpack accumulation and earlier melt have been contributing to this imbalance in snowpack-dominated watersheds (Environmental Reporting BC, 2021). While MAR techniques are used as management tools to address a relatively wide range of water supply challenges, the most common uses involve storing water in the subsurface during periods of availability for later use during periods of seasonal or longer-term scarcities, most commonly, though not exclusively for municipal supply systems. Many ASR systems have been developed with the primary purpose of addressing this seasonal variability between supply and demand. MAR (infiltration basins and ASR) also is being used by water agencies on larger scales to bank water for municipal, industrial and agricultural uses as a hedge against longer-term scarcities caused by climatic variability and drought.

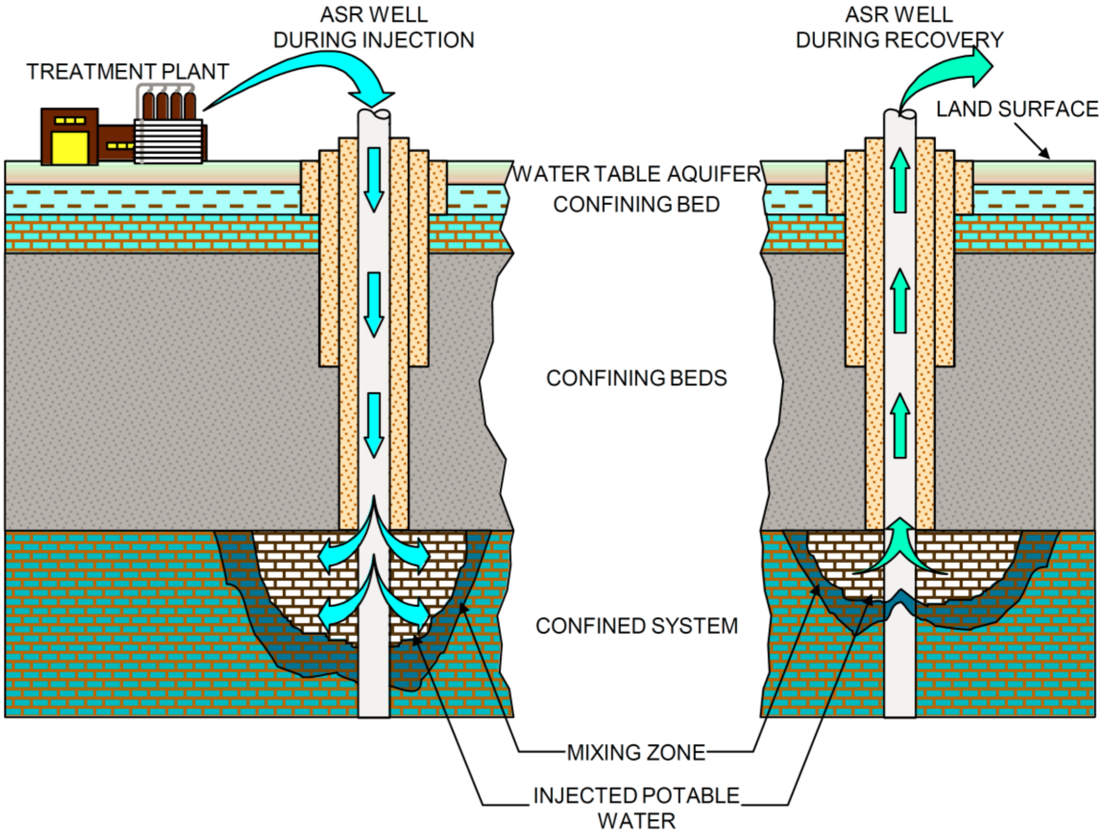


Figure 2: Schematic of a typical ASR system showing use of an injection well to artificially recharge surplus water supply into a confined aquifer system (left) and subsequent recovery of stored water using the same well during periods of high water demand Source: Bloetscher et al. (2014).

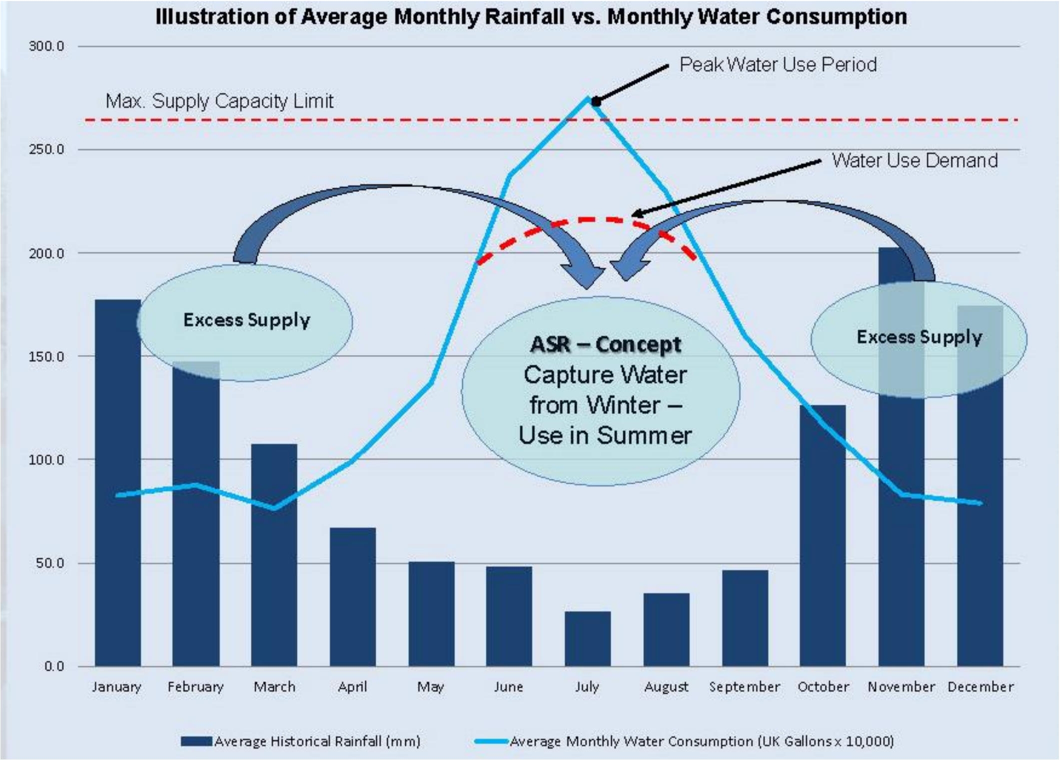


Figure 3: Example water supply-demand hydrograph illustrating how ASR/MAR can help meet peak demands in coastal B.C. (Parksville). Source: Squire (2012).

Over the past 25 years, a variety of MAR technologies have become increasingly used in industrial, agricultural and environmental applications. Several of the more typical applications of MAR and the basic methods employed in these applications are listed below. It is important to note that many systems are developed to meet more than one objective for a particular application. The reader is referred to Shrier (2004), the National Research Council (2008) and Pyne's books (1995; 2005) for detailed discussions of different applications of MAR systems, and in particular ASR, around North America and on other continents. The following provides a brief overview of the more important applications.

2.2.1 Municipal Supply

Municipal water supply is one of the earliest and most common MAR applications in North America. The Mannheim ASR project in Waterloo, Ontario stores treated Grand River surface water in a semi-confined glacial drift aquifer using several wells as part of this region's peaking summer supply (Wootton et al., 1997). In the US Pacific Northwest states, ASR is typically developed to meet seasonal supply deficits, whereas in the arid southwest states, ASR and infiltration basins are being used by municipalities to "bank" large volumes of water as a hedge against longer-term climatic cycles. Figure 3 is a concept developed by the City of Parksville, B.C. (Squire, 2012) to illustrate how ASR can help meet peak season demand along with primary water sources and treatment infrastructure.

2.2.2 Storage to Address Seasonal Supply Limitations

Municipal water systems in western North America typically have an existing source of high-quality source water with surplus diversion and treatment capacity during seasonal low demand periods, a circumstance that is well suited for use of ASR to address supply limitations during periods of high demand. ASR is commonly used to shift infrastructure capacity to non-peak times to avoid developing new source capacity, reduce the size of the new source or treatment plant capacity infrastructure, and/or to provide a supply "bridge" over the period between when peak demands begin to exceed water system capacities and when the next capacity increase can be developed. This is a primary reason for the rapid growth in ASR systems in western Oregon including projects developed by the cities of Beaverton, Tigard and Tualatin, the Tualatin Valley Water District, and the Joint Water Commission. Many of these cities have reduced or deferred considerable infrastructure costs by implementing ASR over other supply and storage options (Shrier, 2004; Eaton et al., 2009; Burt and Barry, 2011).

2.2.3 Water Quality Improvement

Municipal water systems also use MAR/ASR to improve or reduce variability of the quality of water delivered to their customers by displacing natural groundwater of less desirable quality with water from a higher quality source and/or conditioning the aquifer to reduce concentrations of redox-sensitive minerals such as manganese. In several instances, a high-quality groundwater source is being used instead of a surface source to displace or condition lower quality groundwater quality in a different aquifer. The term "condition" refers to the process of repeating several cycles of recharge, storage and pumping (recovery) aimed at ultimately displacing poorer quality groundwater and in some cases, to allow for mixing or reaction effects to run their course prior to scale-up of the operation. Early development of ASR in Florida focused on displacing brackish groundwater with higher quality drinking water to create storage zones in the Floridan aquifer (Pyne, 2005; National Research Council, 2008).

2.2.4 Multiyear Water Banking to Mitigate Drought Cycles

While many municipal systems utilize ASR to address the annual seasonal variability of supply and demand, some municipalities and water agencies that represent several municipal systems and are using MAR to "bank" large volumes of water to increase resiliency during extended drought cycles (Shrier, 2004). In such applications, withdrawals are made from the "bank" as triggered by droughts or supply shortages that may not occur every year. Water banking projects have been developed in Arizona, starting with the formation of the Arizona Water Banking Authority in the 1990s (Jacobs, 1997). Water banking not only increases resiliency during drought; it has been used extensively to transition water suppliers from unsustainable groundwater use of the allocated banked water. Larger scale water banking is an extremely complex undertaking involving construction of pipelines and usually, multiple recharge facilities.

2.2.5 Emergency Supply

Water suppliers commonly seek to find ways to secure sufficient system redundancy so that if a water source is lost due to unforeseen circumstances, system demands can still be met from other sources. Several ASR systems have been developed in Pacific Northwest states in part to provide a reliable emergency source of good quality water in the event the primary supply is interrupted. Water is injected and stored in confined aquifers for later use. These systems typically will recover a portion of the stored water to meet summer demands during low flow periods but have the dual purpose of providing a reliable source of water in the event the primary surface supply is interrupted. A primary motivation for the cities of Baker City (Oregon) and Walla Walla (Washington) to develop their ASR systems is recognition of the potential for a wildfire in their watershed sources to cause extended supply interruptions (Burt and Barry, 2011).

2.2.6 Agriculture

Irrigated agriculture in the U.S. has started to turn to MAR systems to increase the reliability of existing water sources, or where new sources of surface or groundwater are not available. Several large-scale water banks in California use infiltration basins and wells to replenish depleted aquifers, and to store water for use during future droughts. Two large-scale farming operations in eastern Oregon also have developed ASR systems in a confined basalt aquifer system to enable them to keep 1,100 acres in cultivation because extensive regional pumping has resulted in groundwater level declines of up to 150 metres, leading to regulation of pumping by the state. The farming operations divert spring surface flows using bed filtration through horizontal infiltration galleries in an unconfined alluvial aquifer and store water in the confined basalt aquifer for irrigation season (Eaton et al., 2009; Burt and Barry, 2011).

2.2.7 Industrial

ASR is currently being used at the Micron Technology industrial facility in Boise, Idaho to increase the sustainability of existing groundwater sources and provide a more consistent water quality and temperature than surface water sources (National Research Council, 2008). ASR also has been explored by other industrial facilities as a way to store water for industrial cooling (summer) and heating (winter).

2.2.8 Groundwater Resource Management

MAR systems have been used for several decades for resource management by water agencies to replenish water removed by pumping, and counter resulting intrusion or upwelling of saltwater, or mitigate against pumping-induced subsidence. These applications utilize wells (ASR) or infiltration basins. The Orange County Replenishment District in Southern California, Equus Beds project in Kansas and the Comprehensive Everglades Restoration Program in Florida are examples of large-scale MAR projects designed to manage the effects of aquifer withdrawals and achieve sustainability of the water supply for communities (National Research Council, 2008; Pyne, 2005).

MAR methods also are being used to mitigate for municipal pumping of aquifers hydraulically connected to surface water. The state of Idaho has initiated a project to infiltrate surplus winter and spring surface flows through canal systems and infiltration basins into the Eastern Snake Plain Aquifer system in southern Idaho to mitigate withdrawals by down-gradient municipal groundwater users (Idaho Water Resources Board, 2019). Communities in the south Puget Sound region of Washington State are recharging the shallow glacial sedimentary aquifer with treated wastewater in infiltration basins to mitigate for potential effects on stream flows from municipal pumping by the communities (LOTT Clean Water Alliance, 2020).

2.2.9 Ecological Mitigation and Restoration

Several projects are using MAR techniques to capture and store cold surface water diverted during winter and spring runoff to augment stream flows and improve temperature conditions for salmonid-bearing streams during the summer and fall months. For example, the Walla Walla Basin Watershed Council is diverting water in the winter and spring in existing irrigation canal systems to augment the natural recharge of the shallow alluvial aquifer system with the purpose of restoring or mitigating for lost floodplain function and increase return flow to streams during the summer and fall. Other projects in Oregon are currently evaluating the feasibility of diverting and cost-effectively treating cold surplus winter/spring flows, storing the water in a confined aquifer and returning the cool water during hot and/or low flow periods in the summer months to improve migratory conditions and provide thermal refugia in salmonid streams (Burt and Barry, 2011; Burt and Melady, 2013).

2.3 Phases of MAR/ASR Project Development

Pyne (2005) and the National Research Council (2008) outline similar approaches in the development of a MAR project. Aspects of the approach and each phase may vary, as dictated by objectives, the availability of hydrogeological information, funding, and regulatory requirements. However, the general approach typically includes four-phases spanning feasibility assessment and conceptual design, pilot testing, system expansion, and full-scale operations and maintenance.

2.3.1 Phase 1 - Feasibility Assessment and Conceptual Design

Depending on the level of understanding and degree of characterization of potential storage aquifers, this phase may consist of two separate stages. The first stage is an initial pre-feasibility screening that commonly involves a desktop study using available information to assess the need for ASR or MAR, the potential benefits and fatal flaws, and to identify key uncertainties, data needs and a high-level estimate of project costs. Where little information is available about the target storage aquifer, the first step is sometimes followed by a second, proof-of-concept step, involving drilling and testing of a test well(s) to define target storage volumes and recovery rates, and refine project costs. This two-step process appears to have been used in the 2012-2014 Parksville ASR project discussed elsewhere in this report (Squire, 2012).

2.3.2 Phase 2 - Pilot Test Program

The second phase consists of a pilot project designed to verify the results from Phase 1 under a field application. This involves an assessment of well or recharge facility performance, aquifer response, and the identification of full-scale operational features, such as target injection and recovery rates and back flushing frequency. Commonly, the pilot test phase also entails permitting and constructing an operational MAR system along with supporting infrastructure where (for ASR) either an existing well is retrofitted, or a new well is drilled and tested. After one or more pilot testing cycles of injection, storage, and recovery to verify system performance and that water quality meet regulatory and operational requirements, the system may become fully operational with the recovered water put to the intended use during pilot testing cycles. Many papers and reports describe the kinds of issues to be addressed during a pilot test program. A pilot program would typically address the following design factors and potential operational issues (Wootton et al., 1997):

- impacts of changes in quality of recharge water on ASR well operation
- impacts of injection rates and durations on well efficiency
- geochemical sensitivity of the aquifer to the chemistry and oxidative state of the recharge water
- well clogging rates and processes, and well back-flushing frequency during operations
- recovery efficiency (i.e., how much stored water can be recovered)
- water quality changes between recharge, storage, and recovery
- hydraulic response in the aquifer as measured in nearby monitoring wells during recharge, storage and recovery
- movement of stored water in the subsurface based on monitoring and sampling
- when recharge water is chlorinated, fate of disinfection by-products during storage and recovery
- potential long-term recharge rates and volumes

The pilot test phase is considered the most crucial period in project development. This stage addresses not only most technical and cost questions but also ensures community and stakeholder contact be built into the project approval process at the earliest stage. It is not unusual for there to be intense local interest in water projects potentially having a high price tag such as treatment plants, large pipelines and in some instances larger recharge programs.

The pilot test phase will provide an initial measure of the portion of the stored water the proponent can recover for use. Some portion of the stored water is normally assumed to be lost but the proportion varies by project.

2.3.3 Phase 3 - MAR or ASR System Expansion

Phase 3 is an expansion phase where new sites are identified and developed based on the results of the pilot testing and full system buildout capacity objectives. Commonly, wells (or infiltration facilities) are added incrementally and each piloted for a period to refine the understanding of storage aquifer characteristics and system performance at each new site, before adding the next increment of storage to the system.

2.3.4 Phase 4 - Full-Scale Operations and Maintenance

The last phase entails full-scale operations at the design scale, monitoring, and refinement of maintenance schedules for backflushing or (as needed) periodic well reconditioning to maintain system performance. Where applicable, regulatory agencies will issue final approvals at this phase either as a permit or licence that authorizes operation at full scale rates and volumes determined during pilot testing and expansion.

The photos below (Figure 4) show examples of typical MAR recharge basins, and a municipal ASR well. The recharge basins shown are in Arizona and are of the "off-channel" variety where water from the Central Arizona Project is piped to recharge the local groundwater resource. The City of Beaverton ASR well in Figure 5 illustrates the typically complex-appearing wellhead piping arrangement. This is due to the bi-directional flow into the well and back out again, with flow into the well from the treated supply under pressure and the supply line back to the system; along with drain-to-waste lines to facilitate well back-flushing events during injection operations.

Figure 4: Oblique aerial view of MAR recharge basins (Superstition Mountains) Arizona (USA). Source: Central Arizona Project https://www.cap-az.com.

Figure 5: Pump house interior view of ASR wellhead – Beaverton, Oregon (USA). Source: GSI Water Solutions.

3. MAR/ASR LITERATURE

WWAL and GSI assembled a focused literature search relevant to ASR from a number of sources including textbooks, manuals, conference proceedings and journal articles. References listed at the end of this report were assembled and reviewed for this project. It is important to note this is small sample of literature relevant to MAR, ASR and hydrogeological/groundwater conditions that are relevant to B.C.

Literature related to MAR and ASR has proliferated since 2000 corresponding with the rapid expansion in the use of MAR/ASR globally. This section highlights a few significant publications on MAR and ASR as a starting point for interested readers.

3.1 Textbooks and Practical Manuals

David Pyne of ASR Systems LLC authored the first textbook on ASR titled: *Groundwater Storage and Wells: A Guide to Aquifer Storage Recovery*. First published in 1995, Pyne subsequently updated the publication in 2005, summarizing the advances in applications and understanding of the technology since the first edition (Pyne, 2005). This comprehensive work is likely the most-cited reference on the topic and summarizes the history, applications, approach to project development, and technical aspects to feasibility assessment, system development, operations and maintenance and case studies. Missimer and Maliva (2010) published another comprehensive ASR-focused text and reference book in 2010. This reference includes several case studies organized by aquifer type to help the reader focus on studies relevant to their situation.

Rapid growth in applications of ASR and other MAR techniques in North America and throughout the world since 2000 have spurred regulatory agencies, and groundwater and engineering professional associations to develop manuals to document and disseminate best practices for design, operation and maintenance of MAR facilities. For ASR-focused practices, the reader is referred to the South Australia code of practice (Government of South Australia, 2004), the National Ground Water Association suggested best practices manual (NGWA, 2014), and the AWWA Manual M63 (American Water Works Association 2015). Other design guidelines and standards for ASR and MAR applications have been developed by the American Water Works Association Research Foundation (Bouwer et al., 2008), and by the American Society for Civil Engineers in 2001 and recently updated in 2020 (ASCE, 2001, 2020).

The U.S. National Research Council (2008) report summarizes the state of knowledge, research and education needs, and priorities for MAR projects, and is a good reference for trends in the practice.

3.2 ASR Surveys and Suitability Assessments

Several of the references above include survey information on ASR systems, including Missimer and Maliva (2010), Pyne (2005) and the National Research Council (2008). Recently the U.S. Army Corps of Engineers (USACE) published a review of how MAR has been and is being used in conjunction with USACE civil works and provides recommendations for steps the USACE might take to facilitate MAR applications (Logan, 2020). Additional surveys such as one by the Shrier (2002) that summarizes ASR systems and their associated regulatory programs in the United States, are also available.

Pyne (2005, chapter 2) and the National Research Council (2008, chapters 2 and 6) summarize general elements of ASR projects and steps for assessing feasibility, which were reviewed in Section 2.3. Several researchers have developed specific decision methodologies for determining ASR feasibility in regions and specific sites. Brown et al. (2005) developed a site selection index for ASR sites for the Everglades areas in Florida. Perhaps of more relevance to coastal B.C. is a subsequent publication by Brown et al. (2016) summarizing a site selection index for ASR in brackish water aquifers. Rahman et al. (2012) have developed a site selection decision support tool for MAR sites. In closer proximity to B.C., the states of Oregon and Washington have funded studies to develop criteria for evaluating ASR potential across each respective state. Woody (2007) developed a metric for evaluating the potential feasibility of ASR across the State of Oregon. The State of Washington subsequently funded a desktop suitability assessment of ASR potential by Gibson and Campana (2014). Each of these studies define certain metrics that make ASR more or less favourable and apply them to different regions of each state. These types of surveys provide blueprints for initially assessing potential feasibility of ASR or other MAR technologies (Gibson et al., 2018), but do not replace a location-specific evaluation because objectives and criteria that define feasibility may vary greatly depending on circumstances.

Finally, the survey by the Shrier (2002) of ASR systems and regulatory programs in the United States provides a good inventory of active ASR projects as of the time of the survey, and perhaps more valuable, a compendium of regulatory frameworks under which these systems have been developed. A more recent assessment of regulations was prepared by Yuan et al. (2016).

3.3 Technical Studies

As with any other aspect of water supply and water management, MAR and ASR literature includes hundreds of peer-reviewed and consultant-led scientific investigations and studies on technical issues such as well performance, mobilization of redox-sensitive metals and other reactions in the aquifer, well clogging, and storage zone dynamics and recovery volumes. Many references for specific technical issues and case studies are available in several of the publications listed above, including Pyne (2005), National Research Council (2008), and Missimer and Maliva (2010). Two issues that many ASR systems grapple with include clogging and the fate of disinfection by-products (DBPs) in the storage aquifer from injection of chlorinated source water. A monograph edited by Martin (2013) provides a compilation of papers on clogging issues with MAR systems from the Commission on Managed Recharge in Australia. Papers by Izbicki et al. (2010) and Fram et al. (2002) provide a starting point and additional references for understanding potential issues with DBP formation and fate associated with MAR projects.

3.4 Typical ASR Technical Issues and the Need for Technology Experts

It is beyond the scope of this project to delve into the details of technical issues encountered in artificial recharge projects. We briefly note here that as MAR and ASR projects proceed through feasibility to field testing and implementation, there are several common technical issues that projects could typically encounter, including:

- clogging from the buildup of sediment (fines) at the base of surface infiltration facilities
- clogging of injection wells due to biofouling, entrained air, or sediment buildup
- recovery of stored water (recovery efficiency)
- treatment of recharge (source) water and of recovered water
- chemical reactions between recharge water and natural groundwater including but not limited to mobilization of metals, disinfection by-product formation
- well interference, and
- design of recharge facilities including specialised aspects of ASR well design

To explore any of these subjects further, the reader is referred to the ASR / MAR literature. Specific to ASR wells, both editions of the Pyne textbook (1995; 2005) go into considerable detail.

4. REGIONAL WORKSHOPS AND ASSESSMENT OF REGIONAL PRIORITY AREAS

4.1 Regional Staff Workshops

A major part of this project involved organizing, facilitating and documenting a series of regional Ministry staff workshops that took place in the late fall of 2019. Members of the WWAL project team met with Ministry staff in four regional offices (Nanaimo, Surrey, Vernon and Prince George). The format of these workshops was as follows:

- Short presentation as an introduction to ASR by WWAL;
- Roundtable discussion for staff input on regional water stresses; and
- Continuing discussion for staff input on potential ASR applications in their region.

All the workshops were held in November 2019, with nearly 50 total attendees with a combination of in-person attendance, and online/teleconference participation. Each meeting was 3 to 4 hours long and based out of the four regional offices depicted on Figure 6.

Figure 6: Natural resource regions in B.C. and workshop locations (starred).

A few weeks before the workshops, WWAL developed and circulated a backgrounder document and several ASR related documents or reports for additional pre-workshop reading. WWAL also prepared a PowerPoint presentation for use at the meetings that gave a brief background on ASR and prompted discussion of potential ASR applications, the region's water-related stresses, and regulatory issues. The intent of the workshops was to share information with regional staff about ASR and its potential applications, provide examples of ASR projects and assessments, answer questions from staff, and to seek information and input from staff. As such, the meetings were interactive and informative.

Previous assessment of potential ASR/MAR projects in B.C. were discussed across the four workshops. Table 1 summarizes three documented projects that have been previously considered, of which only one project advanced to the pilot testing phase. Other instances of intentional aquifer recharge, such as farmers diverting creek water to ditches or wells to recharge an aquifer were noted by some regional staff as historically occurring but outside the realm of being licensed. However, there is no available documentation that would indicate such works or operations have been authorized to date.

Table 1: Previous local assessments of potential MAR/ASR applications in B.C.

Location /Proponent	Project Concept	Outcomes
Parksville (Vancouver Island) Englishman River Water Service	Use treated Englishman River water to recharge Aquifer 219 using wells. ASR is a component in a larger water project to build a new intake and treatment plant by Englishman River Water Service.	A pilot ASR well was constructed and tested for two cycles of injection, storage and recovery in 2013. Arsenic mobilized from the aquifer matrix during these early cycle tests. Arsenic concentrations exceeded Drinking Water Guidelines. A cost assessment of treatment for recovered water indicated ASR was not practical in Phase 1 of treatment plant project.
District of Lillooet Southwest B.C. Coastal Mountains	Use treated surface water from Town Creek to recharge Aquifer 324 using two existing deep wells. Existing wells produced water with arsenic levels above Drinking Water Guidelines. Concept was to "condition" aquifer through repeated recharge cycles to produce stored water with lower arsenic and similar water quality as the surface source.	Pre-feasibility assessment only conducted as part of a water system plan (Summit Environmental Consultants, 2010). Ultimately, the District pursued development of other water sources including two shallow wells and a new river intake and treatment plant.
District of 100 Mile House Cariboo Region of Interior B.C.	Use treated (filtered) surface water from Bridge Creek to recharge basalt Aquifer No. 124 using deep wells. Concept was to store high quality surface water at times of surplus and acceptable water quality and displace poorer quality water present in the productive basalt aquifer. The basalt aquifer was thought to have similar favourable features as the Columbia Basalts extensively used in Washington and Oregon for ASR projects.	Pre-feasibility assessment only, conducted as part of a larger water system planning project. Ultimately, the District chose to increase its reliance on groundwater, decrease use of surface water due to supply constraints and treatment costs, and built treatment works to address the aesthetic water quality issues in the groundwater source.

4.2 Summary of Parksville ASR Project

Lessons from the Parksville ASR project included both technical and non-technical project obstacles:

1) Early cycle testing results indicated a technical issue (arsenic mobilization), which could have eventually been addressed through further pilot testing and monitoring, but a decision needed to be made based upon infrastructure grant funding deadlines., Therefore, ASR was not pursued because of insufficient time in the larger project schedule to complete the pilot testing program.
2) There was reportedly some local resident push-back on the ASR project, with individuals citing opposition to the location of production wells within neighborhoods.

However, there was apparently a future phase of water treatment plant expansion envisioned as of 2014 and there is another ASR site that was identified in the study that could be investigated. This site may have more favourable hydrogeology but could be further from the water source. See discussion in Section 4.5 on the potential for ASR in the Parksville area.

Figure 7 shows the water supply rationale for pursuing ASR as a component of the larger Englishman River water project.

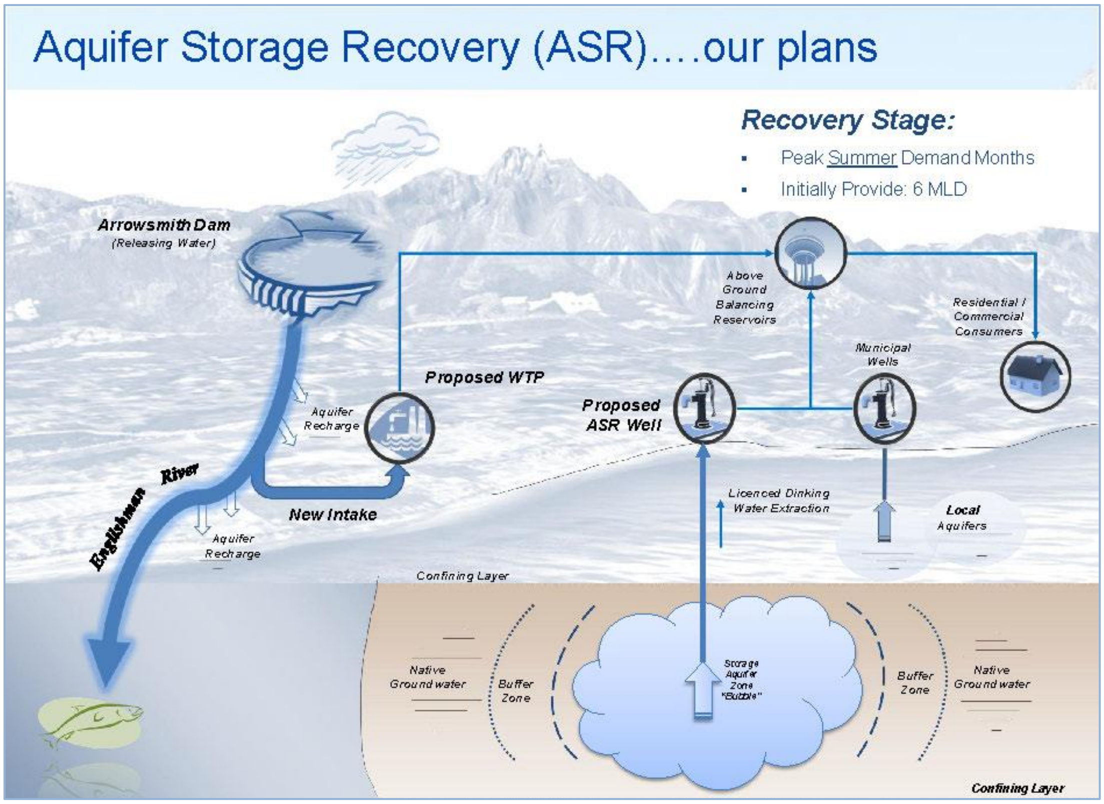


Figure 7: Parksville/Englishman River Water Service ASR Concept (2013). Source: Squire (2012).

4.3 Regional Water Stresses Identified in Workshops

A number of common themes and shared understandings around water-related stresses and potential uses of ASR/MAR systems in B.C. emerged from the four workshops. For this report, we have expanded on these topics, as presented below. The following information therefore is based on the interpretation of discussions with regional staff at the workshops and does not necessarily represent the input, opinions or official government policy direction.

- In general, **B.C. surface water resources appear to be more stressed than groundwater resources**. This was a common theme throughout the discussions and could be attributed, in part, to the longer history of surface water licensing in B.C. There are numerous streams throughout the province that have allocation restrictions (e.g., fully recorded, possible water shortage, refused no water, or other restricted status), whereas B.C. is in the early stages of licensing groundwater.
- Extraction of groundwater from some aquifer systems is seen as a contributing factor to some streams experiencing prolonged periods of low flow or water temperatures that can act as a stressor on fish and other species.
- From the above, it can be inferred that **groundwater is more likely to be stressed in the same areas where surface water is already stressed,** with the highest stresses likely in heavily developed aquifers with strong hydraulic connectivity to surface water.
- Outside of B.C., and particularly in the U.S. West, confined aquifers that are susceptible to depletion have been over-allocated leading to very large magnitude groundwater level declines. While there have been no such large declines in B.C., it is well known that confined aquifers are more prone to depletion effects than unconfined aquifers. The search for groundwater sources that are not hydraulically connected to fully recorded surface waters in B.C. could lead to increased targeting of confined aquifer systems, which could potentially increase stresses on these systems.
- While stresses on surface waters tend to occur on a watershed or regional scale, **groundwater stresses tend to be more localized than surface water stresses**. For example, there are a number of observation wells that show long-term water level declines (B.C. Environmental Reporting, 2020) but such declines, in general, have not been accompanied by reported problems of groundwater shortages (although drillers have reported well deepening is needed in some areas).
- **Unauthorized water use** was also discussed as an issue of concern in most areas. Ongoing efforts to license existing groundwater use and improve public awareness about licensing requirements will help to reduce unauthorized water use.
- **Climate change** and the resulting longer dry season and earlier spring runoff has long been identified as a high-risk contributor to water shortages during critical low flow periods in certain regions.
- Aquifers in coastal regions are vulnerable to seawater intrusion. To date this issue has been mainly addressed through regional compliance and enforcement, while more regional solutions using artificial recharge have not been considered.
- Some deeper, confined aquifers have known naturally occurring water quality issues (e.g., arsenic and manganese). Shallow unconfined aquifers are potentially vulnerable to water quality impacts from nitrates originating from agriculture and other land uses.
- The **existing *Water Sustainability Act* (*WSA)* legislation is sufficiently flexible and broad enough to potentially cover ASR/MAR projects.** Some additional effort and planning would be needed on integrating ASR/MAR systems into the regulatory structure in order to clarify a path to licensing and the technical expertise and information requirements.
- There were two potential approaches for licensing of ASR/MAR systems discussed based on established water licensing precedence: 1) a short-term use approval for pilot testing followed with formal licensing, if feasible; and 2) a licensing process similar to dams, which would typically mean a multi-year licensing effort with step-wise authorizations given ("leaves" to construct, for example) as more information is gathered during feasibility assessments and pilot

tests. Regardless, given the data-intensive nature of ASR/MAR investigation and testing, licensing would likely require years.

- **Technical guidelines** and possibly **new regulations** governing ASR/MAR could be beneficial to assist both proponents and regulators. However, because current demand for ASR/MAR is low, there is likely low justification for putting significant resources toward the development of detailed regulations and guidelines until such demand is warranted.
- There was broad interest in a range of potential ASR/MAR opportunities, from the traditional municipal or regional drinking water sector to applications such as agricultural ASR and ASR/MAR applications to address specific water quality or quantity concerns. The Western Water team's presentation touched upon the scalability of ASR/MAR and how sometimes even a very small project can be viable when the benefits are great enough and there are few if any other options available to address the water quality or quantity issues.

Although ASR/MAR systems are not a comprehensive solution for all water stresses and there are limitations in applying these systems, MAR and/or ASR could be one component to consider in addressing water shortages as well as other issues such as poor water quality or declining aquifer levels. Taken in this context, ASR and MAR are best viewed as potential strategies that could be considered as part of a larger overall effort to address water management challenges resulting from changing climate, population growth and other factors.

4.4 Assessment of Regional Priority Areas

For the purposes of this study, "regional priority areas" were considered to be regions or watersheds where there may be a combination of water stresses, potential seasonal water availability and suitable aquifer systems to receive recharge for beneficial purposes. The regional workshops informed the development of potential regional MAR/ASR priority areas, which was then developed and assessed further by the WWAL-GSI team. This task included broadly assessing the hydrologic and hydrogeological conditions in each of the four regional priority areas, based on a high-level review of existing information (e.g., aquifer mapping and characterization, water allocation status of surface water resources, available information on environmental flows, location of water supply systems, climate change projections) and other regional water supply and demand patterns.

To arrive at regional priority areas for consideration of potential recharge projects, the project team used information obtained during the regional staff workshops as well as WWAL-GSI professional knowledge of areas where there are known or potential water shortages, combined with known stresses on surface water and/or groundwater resources. The regional priority areas identified in the assessment are described in the following sections. For the purposes of this study, WWAL-GSI defined a "regional priority area" as encompassing a large area, to include one or more major watersheds or a series of smaller but related watersheds. Note that these regional priority areas were identified on the basis of limited staff input and should be viewed as preliminary in nature. Discussion of these areas does not imply that ASR/MAR projects are applicable or even feasible in these areas, nor does it take into consideration the full suite of alternative water management options. There could be several or no possible ASR/MAR projects within a proposed priority area.

This project identified three regional priority areas including southern Vancouver Island, the Southern Interior and the Fraser Lowland as summarized below. Conditions in the northern region of B.C. that were discussed did not lead to identifying it as a priority area for exploring ASR or MAR opportunities at this time (but this does not preclude identification in the future).

4.4.1 Southern Vancouver Island

Southern (more precisely, Southeast) Vancouver Island, approximately from Comox southwards emerged as a regional priority area for several reasons, including:

- Parksville area was the location of the ASR project that advanced to a pilot test stage
- Growing population and seasonal population growth (e.g., tourism in coastal areas)
- Bi-modal climate with distinct wet and dry seasons with greatest water demand in the dry season
- Surplus water for recharge may be available seasonally in winter, in some areas
- Many streams are flow sensitive with designated water allocation restrictions
- Seasonal curtailment of water uses was implemented in the Koksilah Watershed in 2019 (Section 88 order)
- Potential for a Water Sustainability Plan (WSP) under the *WSA* for the Koksilah Watershed; interim letter of agreement between government and Cowichan Tribes; MAR potential could be explored in conjunction with the planning process of the WSP
- Groundwater forms an important source of water to Indigenous communities and is highly valued by community members
- Known stresses on groundwater sources are groundwater level declines in some provincial observation wells, and restrictions/conditions or refusals of some groundwater licences due to potential impacts on surface waters or existing users, or limited availability, and
- Potential exists for ASR applications using wells for drinking water storage and recovery, as well as MAR for streamflow enhancement during summer low flow periods.

Of relevance to water supply management, the following are some of the more significant studies that have been undertaken on southern Vancouver Island:

- Englishman River Water Service, ASR feasibility and pilot testing (Pyne, 2012; Lowen Hydrogeology, 2014; Associated Engineering, 2014)
- Groundwater Budgets in the Cobble Hill/Mill Bay area (Harris and Usher, 2017).
- Koksilah River Watershed Preliminary Assessment of Hydraulic Connection (Sivak and Wei, 2019).
- Regional District of Nanaimo Water Budget Study (RDN, 2021).

Map 1 provides an overview map of the Parksville area where ASR has been investigated previously. This project is identified as a potential pilot project area for further investigation (see Section 4.5). There may be other potential managed recharge projects that will emerge on Southern Vancouver Island, and owing to the relatively rapid pace of development and limited groundwater resources, this could be a region where smaller-scale ASR and recharge projects are considered as potential alternatives to other more expensive or environmentally unsustainable water supply alternatives. Map 1 includes selected observation well hydrographs in this area. Observation well #304 shows a long period of water level decline while another well (#395) shows declining seasonal lows in recent years, which suggest potential areas of groundwater stress. Groundwater is heavily used in this area along with surface water.

4.4.2 Southern Interior

The dry southern Interior, particularly the Okanagan valley but also other areas such as around Merritt have known water stresses. Climate variability is high in this region, where surface runoff from one year to the next can range from very low to extremely high. Agricultural and other outdoor water uses (e.g., golf courses, lawn watering) represent upwards of 84% of total water use in the Okanagan valley

(Okanagan Basin Water Board, 2020), and comprises a significant percentage of water use elsewhere in the southern Interior, typically for propagation of forage crops as well as fruits, grapes, and other products. The southern Interior is included as a regional priority for the following reasons:

- The region is characterized by long and relatively hot summers.
- Many streams have experienced low-flows, elevated water temperature, or have designated water allocation restrictions. Licensing of groundwater in hydraulically connected aquifers may not be feasible as demonstrated by groundwater allocation restrictions placed on some aquifers.
- While streamflow is usually low in winter (approaching baseflow), this is also a time of low water demand and so there may be water available seasonally for artificial recharge.
- While the larger municipalities such as Penticton, Kelowna, Vernon and Kamloops use surface water as the main water source, groundwater is moderately to heavily used in many areas with use ranging from municipal to agricultural to industrial.
- Groundwater-surface water interaction is a concern in some areas where groundwater extraction can impact environmental flows.
- There are potential opportunities for ASR using wells and MAR using more passive forms of recharge without recovery for streamflow enhancement and/or maintenance of groundwater levels.

A number of water-related plans and studies have been undertaken in this region to address water concerns. A few examples are listed below:

- Okanagan Basin Water Supply and Demand Project (Okanagan Basin Water Board, 2021)
- Nicola Watershed Community Roundtable studies, 2007-2010 (Nicola Watershed Community Roundtable, 2021)
- Monthly Water Budgets for Aquifers 254, 255 and 256 in the Oliver Area (Geller and Manwell, 2016).

Maps 2-**5** provide a few overview maps of some possible areas of interest, including the Semlin Valley near Cache Creek, the 100 Mile area, the Nicola Valley near Merritt, and the South Okanagan north of Oliver. These and other areas within the southern Interior could see increased interest in the scoping of recharge projects in future. The paragraphs below give brief backgrounds on each of these areas of interest, while the discussion in Section 4.5 identifies potential MAR applications that could be considered for initial feasibility assessment.

The Nicola Valley including the City of Merritt (**Map 2**) and surrounding rural areas are dependent on groundwater, as well as surface water; and the area has been noted as being water stressed for many years. The City derives all of its water supply from a series of wells, most of which are located in and around downtown and draw from the shallow, unconfined aquifer (No. 74). The City also maintains one deep well (Kengard well) that reportedly flows under artesian pressure and completed in confined Aquifer No. 1167.

Two aquifers are located immediately downgradient of the Nicola Dam. Aquifer No. 79 is the Lower Clapperton creek unconfined sand and gravel aquifer and the deeper, confined aquifer is No. 80. These aquifers provide a source of irrigation water supply for ranches and rural residences. Aquifers associated with the Coldwater River, which joins the Nicola River at Merritt include No. 75 (Joeyaska deep), and the shallow Joeyaska No. 1169. Between Merritt and Spences Bridge there are additional layered aquifer systems. Throughout this valley, the Lower and the Upper Nicola Indian Bands as well as the Coldwater First Nation rely on groundwater wells for on-reserve supplies.

The Nicola watershed has been the focus of a number of water–related plans and studies for approximately the past 12 to 15 years. In the late 2000s, the Nicola Community Roundtable commissioned surface water and groundwater studies (e.g., Water Management Consultants, 2008). Some of the previous studies focused on identifying additional surface storage options to address seasonal shortages. Mention was made of the potential of ASR at that time, but to date there have been no assessments of MAR or ASR potential. In 2018, the Government of B.C. and the valley's Indigenous communities signed a Watershed Pilot Memo of Understanding to foster progress in shared governance toward sustainable water management (Government of British Columbia, 2021). This structure holds considerable potential for collaborative efforts to address water sustainability over the long term. Although water is in high demand and at times scarce in the Nicola Valley, observation well data indicate relatively stable groundwater levels.

The Semlin Valley (**Map 3**) is a relatively small valley located just east of the Village of Cache Creek. Ranchers in the area developed wells in the 1970s and some of the early wells were noted to flow under artesian pressure. As groundwater continued to be extracted for irrigation, groundwater levels declined in the aquifer. The largest surface water licences in this area appear to be located on Cache Creek toward the west end of the Semlin Valley for irrigation and support of ranching operations. A potential recharge project for this area could entail use of existing wells to recharge the aquifer with surface water during times of high runoff. Augmenting groundwater would be intended to reverse groundwater levels declines and potentially enhance groundwater levels in order to support ongoing groundwater use for irrigation supply and baseflow discharge during critical low flow periods.

The Okanagan River Valley between Vaseux Lake and the Town of Oliver in the South Okanagan (**Map 4**) is another area of potential interest. There are three mapped aquifers in the valley, as described in some detail in the 2016 Water Science Series report (Geller and Manwell, 2016). Water usage in the Oliver area includes irrigation of croplands, fruit trees, and wine grapes. Water is delivered to rural agricultural properties by the Town of Oliver and in some locations, there are also private irrigation wells. The Town of Oliver operates the former South Okanagan Lands Improvement District (SOLID) water system that was originally built by the Province of B.C. The SOLID canal system derives its water from the Okanagan River at McIntyre Dam a short distance south of Vaseux Lake. Oliver also operates a series of groundwater supply wells, most of which are used to supply drinking water to area residents. Three wells are used principally for irrigation in various parts of the system where connections to the SOLID canal either do not exist or lack adequate capacity. The monthly water budget study by Western Water Associates Ltd. noted that water availability in Aquifer 255 north of Oliver could be limited during the peak summer irrigation season. One observation well (#332) in Oliver showed a decline for several years that has since stabilized while the other (#405 in Aquifer 255) appears to be influenced by pumping of nearby wells. Water quality in the shallow aquifer system, on a broad scale, shows evidence of anthropogenic impacts including nitrates. Some wells also have naturally occurring uranium above Health Canada Drinking Water Guidelines. Groundwater quality tends to be better north of Oliver than to the south. This is believed to be due to the recharge effect of Vaseux Creek, which forms a major Okanagan River tributary in this area. Consideration of a recharge project in this area could include assessing the availability of Vaseux Creek and/or Okanagan River water in the non-irrigation season, recharging Aquifer 255 during the winter and spring sufficiently to promote or enhance discharge of cool water to the downstream river reaches in summer, while also maintaining water levels and potentially improving water quality in the aquifer. Groundwater levels are relatively stable though one well (#332) showed a period of decline that appears to have ceased, the reasons for which are thought to be changes in the location of groundwater pumping by the Town of Oliver (Geller and Manwell, 2016).

The southern Cariboo municipality and area surrounding 100 Mile House forms another area of potential interest for application of MAR/ASR (**Map 5**). This area as a potential ASR site could have a relatively high ASR metric rating due to the productivity of the plateau basalt aquifer and relatively deep static water level at 100 Mile (i.e., > 25 m below ground) (Western Water Associates, 2014). Should the region increase withdrawals from the basalt aquifer, the current availability of source water from Bridge Creek (or other suitable sources of recharge water), and the presence of the basalt aquifer system would suggest this area has potential for a future feasibility assessment. However, at this time the region appears to lack the water shortages necessary to elevate investigation of MAR solutions. Observation well #81, located south of the 100 Mile area shows a long period of record of relatively stable groundwater levels with no discernable trend in the last two decades. Groundwater use in this area is thought to be quite low.

4.4.3 Fraser Lowland

The Fraser Lowland extending from approximately Hope in the east to Metro Vancouver in the west is identified as a regional priority area due to the following characteristics:

- Indicators of water stresses include critically low flows in streams, fully recorded streams, declining groundwater levels, water quality concerns and intensive land development and population growth.
- Climate is similar to the southern Vancouver Island, with long and relatively warm summers.
- Outside of the western areas served by Metro Vancouver regional surface water supplies, the region is highly dependent on groundwater.
- Like other regions, Indigenous communities value water resources for multiple reasons and often community water systems are dependent on groundwater wells.
- Areas closer to the Metro Vancouver service area are experiencing increasing water demand (e.g., Abbotsford, Langley).
- There is a potential at varying scales for possible drinking water and agricultural ASR using wells, as well as more passive forms of MAR used for aquifer replenishment and/or streamflow enhancement.
- Areas further from Metro Vancouver are seeing considerable population growth and could potentially experience increasing water stresses in the future.

Owing to the large population and heavy water use in the area, there have been numerous water-related plans and studies in this region including:

- Township of Langley, Water Management Plan (2009)
- Monthly Water Budget for the Hopington Aquifer, Salmon River Area, B.C. (Golder Associates, 2016)
- Assessment of Aquifer-Stream Connection Related to Groundwater Abstraction in the Lower Fraser Valley (Middleton and Allen, 2017)

Map 6 shows an overview map of the Township of Langley / Hopington area of interest. This area is identified for further consideration as a potential area that could be considered for initial feasibility assessments. The map illustrates the density of groundwater wells in this area and groundwater level hydrographs measured in provincial observation wells that show groundwater declines that may be attributable to over-use of the groundwater resource. Middleton and Allen (2017) also identified the Salmon River as highly vulnerable to potential impacts from groundwater pumping. Historical observation well data plotted on Map 6 illustrate an extended period of groundwater decline in Hopington area, despite the aquifer setting and the relatively wet climate of the region.

A main challenge for implementing MAR or ASR in this area is the availability of recharge water for a drinking water ASR program and suitable recharge water for an aquifer replenishment type of scheme (MAR). At this time, it appears the nearest water supply from the Greater Vancouver regional water system are at least 2 km away from the Hopington area (see inset on **Map 6** for GVRD supply pipeline locations near Langley).

4.5 Potential MAR/ASR Project Opportunities

Locations for possible investigation of MAR and ASR potential are identified in Table 2 and are briefly discussed below. Note, this is an initial list of potential project opportunities for discussion and consideration only and should not be interpreted as an endorsement of specific MAR/ASR projects by the WWAL-GSI team or the Government of B.C. Moreover, none of these potential project opportunities have been coordinated or reviewed by government staff nor have they been informed by local communities, municipalities, and First Nations. Also, the project list in Table 2 is incomplete; there are likely many other potential opportunities to explore MAR and ASR in the province and at varying scales in terms of water volume and cost.

Table 2: Initial list of potential MAR/ASR projects in B.C.

Potential Project Type	Location	Potential Source Waters	Target Aquifer(s)	Recharge Methods	Potential uses (see notes)
MAR or ASR	Township of Langley	GVRD treated drinking water	Hopington A/B	ASR well(s) Surface infiltration	Offset declining groundwater levels. Streamflow augmentation (Salmon River and other streams). Local storage for drinking water supply.
MAR	South Okanagan	Vaseux Creek and/or SOLID canal (Town of Oliver)	Aquifers 255, 254	Surface infiltration	Agricultural water, river flow/temperature augmentation.
MAR	Merritt/Nicola	Shallow groundwater, river water	Several possible candidate aquifers	Surface infiltration	Irrigation supply. Streamflow augmentation.
ASR	Parksville Area	Englishman River (treated drinking water)	Aquifer 219	ASR well(s)	Storage for drinking water supply.

A key consideration in identifying the potential projects is their location in areas where there has been previously or there is currently a process underway to address current and future water supply issues. It is also important to note that any managed recharge project would ultimately need to be weighed against (and sometimes as an integral part of) water supply strategies such as demand management (conservation) and other forms of supply and storage augmentation (e.g., surface storage, regional transmission pipelines, regional water system connections, etc.). As discussed in Section 2.3, pre-feasibility and feasibility studies typically includes a broad review of supply and storage alternatives as part of the assessment of MAR/ASR projects.

In terms of the project team's understanding of the urgency for water supply and storage solutions, from the above list, both the Langley area and the Nicola watershed are clearly in need of some new approaches to address ongoing water shortages and concerns about low streamflow during critical periods. Parksville would be an ideal location to revisit ASR pilot studies as part of the next increment of that water system's overall system expansion. Although, ASR was not able to be "proven out" in time for Phase 1 of Parksville's Englishman River water treatment project, there could be opportunity to revisit ASR potential when Phase 2 is needed (in the next few years), particularly for helping to address that area's water supply needs in terms of addressing seasonal peak demand.

The area north of Oliver possesses some of the qualities needed for a feasible MAR project, including existing water diversion infrastructure (SOLID canal) that overlies an unconfined aquifer that is heavily used and impacted by land use (Aquifer 255, which flows south to Aquifer 254, both of which are Type IA aquifers) that is also strongly connected to the Okanagan River. In summary, each one of these areas has enough potential for MAR or ASR that it would be worthwhile to undertake more detailed feasibility assessments.

5. REGULATION AND POLICY REVIEW

WWAL and GSI conducted a limited review of ASR/MAR regulatory models that are in place in other jurisdictions. This information was subsequently related to B.C. legislation and regulations for the purpose of identifying potential regulatory gaps and potential considerations for Government.

5.1 Existing Regulatory Models and Attendant Issues

Permitting MAR/ASR systems can be complex, involving multiple sets of regulations regarding water quality and water authorizations, sometimes involving several regulatory agencies at different levels of government. Some states in the U.S. have developed specific MAR/ASR regulations that identify a single agency with primacy over permitting, and that define and integrate the permitting process in a way that increases clarity and reduces uncertainty.

MAR/ASR projects typically involve several activities with attendant issues that may be regulated by several laws or regulations and requiring several permits or authorizations. These can loosely be grouped (per the National Research Council, 2008) as water quantity and water quality related activities and issues. Some of these are summarized below to provide context for subsequent review of existing regulatory frameworks and a possible framework for B.C.

5.1.1 Water Quantity Related Issues

Water quantity related activities and issues are those that pertain to how the quantities of water to be diverted, stored, recovered and used would be authorized and accounted for within existing regulations, and/or whether new rules are needed to facilitate assessment and implementation of MAR projects. These attendant issues include:

- Authorization to divert and store water for MAR activities: Public water systems in the U.S. and Canada commonly hold an authorization granted by the state or province for a water source and specifies the type of uses allowed for the recovered water. This authorization may or may not allow interim storage in lieu of directly using the diverted water. Under some regulatory systems that address MAR, a separate permit is necessary to divert water for "storage" uses, and a separate permit is required for recovery and use of the water. For example, the State of Washington requires separate permits to divert the recharge source water and to store the recharge water in geologic setting.

- Authorization to recover and use water: Under some regulatory systems, authorization to recover and use the stored water is intrinsic to the underlying permit or authorization for diverting source water. Other regulatory systems treat these authorizations differently; some require a separate authorization ("secondary" permit) to recover and use the water, e.g. the State of Washington.
- Ownership (or access to) and use of stored water: Questions of ownership and precedence of rights under a storage and recovery authorization are important to identify to provide clarity and certainty about rights to access and use stored water.
- Recovery Percentage: Recovery percentage is the percentage of the volume of water stored that is allowed to be recovered and used, commonly accounted for on an annual basis. Some regulatory bodies require a percentage of the stored water to be left in the aquifer to account for uncertainties regarding the processes and water loss from the system, or to provide a net benefit to the storage aquifer and downstream receptors. Some regulatory structures specify a maximum recovery percentage and utilize a simple water balance accounting approach. Others determine the allowable percentage based on pilot testing and consideration of water quality, potential leakage and/or storage zone migration under natural gradients. For example, the State of Oregon limits recovery of AR to 85% during the initial 5-year testing period.

5.1.2 Water Quality Related Issues

Water quality related activities and issues are those that pertain to which, and how, existing or new standards are applied to source water and recovered water qualities, and/or water quality related authorizations needed for assessment and implementation of MAR/ASR projects. These attendant issues include:

- Standards and requirements for source water quality: Potable standards are a common benchmark for ASR source water quality to protect the naturally occurring groundwater quality. However, some states in the U.S. use anti-degradation as a standard; i.e., the potential to degrade the natural groundwater quality. Applied in its strictest sense, differences in quality between source water and groundwater may be considered a form of degradation of groundwater, regardless of whether the qualities of both meet potable standards and no adverse water quality effects from geochemical reactions occur; i.e., artificial recharge cannot increase levels of water quality parameters in groundwater, regardless of whether they meet water quality standards.
- Differences and compatibility between source water and naturally occurring groundwater qualities: Regulations for MAR projects commonly include a requirement to identify differences between source water and natural occurring groundwater quality, assess whether differences are significant in relation to water quality standards, such as anti-degradation or specific numerical standards, and also to evaluate the potential for adverse chemical reactions between the waters and aquifer matrix that might affect the aquifer (e.g., mineral precipitation) or recovered water quality.
- Standards and requirements for quality of recovered water: Standards for the quality of the recovered water are generally based solely on the end use. Water quality monitoring for municipal ASR projects in the states generally includes regular sampling for the list of constituents typically analyzed for drinking water systems.

5.2 Review of Selected Regulatory Systems for MAR/ASR

Following below is a limited survey of North American regulatory models and systems where there are operating MAR/ASR projects, focusing the review on the Province of Ontario (where there is one ASR system), the State of Washington (where there are several ASR projects), and the State of Oregon (where there are also a number of ASR projects).

5.2.1 Ontario and Canada's Approach to ASR/MAR Regulations

In Ontario, the Region of Waterloo has operated an ASR well field adjacent to its Mannheim Water Treatment Plant for more than 15 years. The first test well of the system was constructed in 1996, but the construction and detailed design of the expanded ASR system didn't occur until 2003, with the full system of four ASR wells commissioned in 2005 (Camilleri, 2019). The Province of Ontario has not enacted ASR-specific legislation and rules. Rather, the ASR system in Waterloo is operated under the regional municipality's existing Permits to Take Water (PTTW) for each water source and other Ontario based permits to operate a regional water system, which include a Municipal Drinking Water Licence (MDWL) and a Drinking Water Works Permit (DWWP) (Region of Waterloo, 2020).

To date, no other ASR projects have been successfully developed in Ontario or Canada, and there are very few existing MAR projects in Canada (Camilleri, 2019). The main reason is the lack of need due to the relative abundance of surface water. However, there is growing interest in the use of MAR/ASR in portions of Canada where there are increasing constraints on water supply, particularly Southern Ontario and Alberta (Camilleri, 2019). There is also interest in B.C. as demonstrated by the ASR pilot study in Parksville. Camilleri (2019) further notes that in Canada, the lack of clear regulatory guidelines for ASR projects creates some uncertainty about how onerous the approval process would be on a project.

In contrast to the lack of ASR/MAR specific regulations in Ontario, and more generally in Canada as a whole, the U.S. Pacific Northwest states of Oregon and Washington responded to demand from water suppliers to develop specific ASR regulations. However, the resulting regulatory systems are quite distinct from each other despite the apparent similarity in the title of the governing regulations.

5.2.2 Oregon AR and ASR Regulations

The U.S. Pacific Northwest State of Oregon had originally developed regulations governing Artificial Recharge (AR) of groundwater in 1961, with a primary focus on agricultural applications. These regulations as amended remain in use (Table 3). Oregon passed regulations governing ASR in 1995 in response to requests from drinking water providers for rules specific to drinking water systems that would provide clarity in the process and reduce uncertainty. Oregon's AR and ASR regulations are found in Division 350 of Oregon Administrative Rules (OAR), Chapter 690 (State of Oregon, 2021). There is some overlap between AR and ASR rules in Oregon, but also some distinct differences, which are compared in Table 3. Because of these overlapping regulations, in Oregon it is possible to use either infiltration facilities or wells for AR, whereas the ASR rules specifically apply only to wells.

Depending on the intended use, different standards are applied to the source water and to the quality of the resulting water once recharged into an aquifer. Source water for ASR must meet drinking water standards, and in certain cases, must have concentrations less than 50% of drinking water standards, and the standards are applied at the injection wellhead. Oregon AR projects (of which there are few) are held to an anti-degradation standard, which may be applied at the injection point or an alternative point of compliance, such as a downgradient well. Oregon has set clear standards in the regulations in terms of water quality, as opposed to leaving this up to regulatory decision makers to resolve on a case-by-case basis. This standards-based approach is believed to be one of the key factors contributing to the popularity of ASR in Oregon since the development of the ASR rules in the 1990s.

Table 3: Comparison of Oregon AR and ASR approaches and regulatory requirements.

Topic	Artificial Recharge [AR]	Aquifer Storage and Recovery [ASR]
Water Quality	Recharge must not impair or degrade water quality (anti-degradation standard).	Recharge water quality standards are based on one-half the drinking water standard.
Water Rights	Separate permits to source water for recharge and to recover the water.	Can use existing rights to store and recover water (one permit); recovered water must be used for the same purposes as the underlying authorization to divert recharge source water.
Primary Applications	Irrigation, stream enhancement, groundwater management (mitigation).	Drinking water with a few irrigation applications.
Typical Methods	Spreading basins for recharge; wells may be used if there is recovery permit.	Strictly with wells for injection and recovery.

Information sources: Nazy and Woody (2017) and Oregon Administrative Rules OAR, pgs. 690-350.

The conditions for a water right authorization to divert injection source water under each rule set are different (i.e., AR versus ASR in Table 3) and could dictate the regulatory framework for a project. For example, the use of stored water under the ASR rules must be the same as the authorization under which water is diverted for ASR, which is usually municipal, although two agricultural [irrigation use] projects exist. Under the AR rules, the authorization to divert water for storage must specify storage as the use. Recovery of stored water that is conducted per AR rules requires a separate authorization that specifies the end use of the water.

All ASR projects have as their ultimate objective the recovery of a large percentage of the stored water. An ASR limited licence typically allows recovery of up to 95% of the volume of stored water on an annual basis. If testing indicates that a higher percentage of stored water can be recovered without loss, the Oregon Water Resources Department can allow up to 100% of stored water to be recovered. ASR projects may have secondary objectives in addition to recovery for drinking water use. These objectives are stated in the project descriptions and may be conditioned on receipt of a limited licence or permit.

An AR project may have a large recovery component or may simply be a recharge project to achieve other objectives. AR recovery percentages are limited to 85% of the recharge volume for a minimum 5-year period. The recovery percentage can be adjusted on request if loss estimates based on monitoring data justify a higher percentage.

The “single permit” and single managing agency aspect of the Oregon ASR and AR regulatory system is probably the most distinct aspect of aquifer recharge regulation in that state. The ASR limited licence (testing) and ASR Permit (full-scale permanent operations) authorizations are issued and managed by the Oregon Water Resources Department. Conditions on each permit and limited licence, however, are established through a referral process that typically involves the Health Division of Oregon, the Oregon Department of Environmental Quality, and the Oregon Fish and Wildlife Department. These ASR permits are issued to regulated drinking water providers primarily, although there is an example of two agricultural ASR projects in eastern Oregon (the Madison Ranches and McCarty Farms projects) that operate according to strict water quality limits imposed on the recharge operation (summarized in Burt and Barry, 2011).

ASR pilot testing is conducted under a limited licence, which is valid for 5 years and can be renewed indefinitely (i.e., the City of Beaverton, Oregon is conducting operational pilot testing and expansion of its ASR system under the fifth renewal of its limited licence). Upon completion of full buildout and testing, a water system may apply for a final permit, which secures its authorization to operate the ASR system permanently. There are also federal permits required, but not reviewed here.

The technical requirements for ASR applications in Oregon include the following:

- pilot test work plan
- limited licence application
- water rights information (and application if new rights are needed)
- engineering drawings and designs
- hydrogeological assessment and ASR monitoring plan
- ASR pilot test reporting
- ASR expansion application (to transition from pilot to permanent operations)

Recharge projects for purposes other than drinking water use would typically proceed under the older AR regulation system in Oregon. As discussed above, a key difference between AR and ASR in Oregon is that the former need not have a recovery component. If so, only the permit to recharge is required, which in turn would require the availability of water rights on the recharge water source. The second permit, if needed, to recover any recharged water would be based on the use purpose and the conditions on such permit in terms of timing, location and volume of recovery. A new water right for AR is a storage right, for which water availability is evaluated based on 50% exceedance flows, whereas a new water right for ASR, which lists the use as the final intended use (not storage) uses the 80% exceedance flow to assess water availability. Generally, there is a lot more water available for a storage right if one needs a new water right, and therefore AR rules are attractive when a new right might be needed.

5.2.3 State of Washington ASR and MAR Regulations

Gibson and Campana (2014) provide a thorough overview of all the applicable regulations governing ASR in the State of Washington, which are summarized here. Washington State administers water recharge projects in a similar way to Oregon, classifying them as ASR projects if the water is recovered for later use and MAR projects if there is no recovery (note: this definition is not the same as we suggest for consideration in B.C.). Recharge projects are regulated under Washington state's Artificial Recharge and Recovery Regulations, with the application and approval process described in Washington's Administrative Code (State of Washington, 2021). Washington state also included a specific definition in its Revised *Water Pollution Control Act* (90.03.370) to include an aquifer used for storage as one type of "reservoir" as comprising "any naturally occurring underground geological formation where water is collected and stored for subsequent use as part of an underground artificial storage and recovery project" (State of Washington, 2021d).

Washington state developed its ASR regulations a few years after Oregon's were finalized and in so doing, it considered Washington's situation in terms of how to manage water quality. Like many jurisdictions, Washington makes environmental and natural resource decisions based on what is called an Overriding Consideration of Public Interest (OCPI), which applies to ASR and many other natural resource projects. Thus, should a project not meet specified criteria in regulation, a decision-maker can still approve the project, but only if the project still meets the OCPI test. Since about 1990, Washington has followed a strict groundwater quality anti-degradation policy (State of Washington, 2021b). Water thus stored in an aquifer as part of an ASR project must meet quality standards for groundwaters in the State of Washington as well as drinking water quality standards, and the two sets of standards are not identical. In effect, this policy makes it problematic for a recharge project to potentially even alter groundwater quality, even temporarily unless it can be demonstrated that all known and reasonably available technologies (AKART) to prevent the degradation have been considered, in which case a project may meet the OCPI criteria. The AKART requirement and the uncertainties on how the antidegradation policy would be applied to recharge projects potentially incumber ASR/MAR projects.

The technical ASR/MAR requirements for applications are fairly similar to Oregon's approach. These include:

- hydrogeological conceptual model (report)
- project operational plan
- legal framework
- environmental assessment
- project mitigation plan
- project monitoring plan (may include a pilot test phase)

To date, most of the focus on the application of AKART has been centered on concerns about the fate of disinfection by-products associated with the injection of chlorinated drinking water into aquifers and the potential mobilization of metal species such as arsenic. To help proponents address the AKART uncertainties, a guidance document was recently published (Shaleen-Hansen, 2017). The guidance document includes three case studies of how the public interest determination was made and supported by the AKART assessments.

At least two, and sometimes three, ASR permits are required in Washington state: i) a water right permit to divert the recharge source water; ii) a reservoir permit to store the water; and, iii) if the use on recovery is different, a third permit allowing for the uses of the recovered water.

ASR pilot testing in Washington state is conducted under a temporary permit that is issued under the reservoir permit application for the project. A recovery percentage is not explicitly stated in the temporary permit, contrary to specifications of injection and recovery volumes and rates. In the case of the City of Kennewick, Washington, the volumes equate to a recovery percentage of 95 percent under the temporary permit (Golder Associates, 2012). However, the recovery percentage stated in the final permits may differ from that during pilot testing, depending on monitoring results. Similar to the Oregon ASR limited licence process, the ASR temporary permit allows water recovered during pilot testing to be delivered to the distribution system and put to use if it meets drinking water quality standards.

In contrast to ASR projects, Washington state MAR projects are intended to supplement the natural pattern of recharging groundwater to help add to water discharging to streams, wetlands, and springs or to use as a tool to stabilize or reverse declining groundwater levels (State of Washington, 2021c). MAR may also be used as mitigation for other water withdrawals including withdrawals in another location. MAR projects typically involve recharge using surface infiltration facilities. As there is no intentional withdrawal of stored water, a reservoir permit is not required in Washington state for these types of MAR installations.

In summary, compared to Oregon, Washington has a slightly more complex ASR permitting system, not only in regard to multiple permits, but also owing to attendant greater uncertainty due to the AKART demonstration requirement for water quality, as opposed to the standards-based approach of Oregon. Table 4 summarizes the State of Washington regulations for underground injection and surface recharge.

Table 4: Comparison of State Washington regulatory requirements for AR and ASR.

Topic	Surface Recharge (i.e., AR)	Underground Injection (i.e., ASR)
Water Quality	Recharge must not impair or degrade water quality	Must meet drinking water standards or demonstrate AKART
Water Rights	Water Right Permit	Water Right Permit, Reservoir Permit, US federal UIC Permit
Primary Applications	Irrigation, stream enhancement, groundwater management (mitigation)	Drinking water
Typical Methods	Most commonly, spreading basins for recharge; if there is recovery permit, wells are used	Strictly with wells for injection and recovery

5.3 Potential Regulatory Model for MAR/ASR in B.C. under the *WSA*

This section discusses a potential framework for authorizing and supporting MAR/ASR project in B.C. under the *WSA*. This framework is primarily based on existing legislation, regulations and licensing in B.C., but also incorporates information from other regulatory models reviewed in the previous section. This framework was developed by the WWAL-GSI consultant team under government contract and should not be interpreted as government policy. It is intended as a possible approach for authorizing and supporting MAR/ASR in B.C.

5.3.1 Introductory Remarks

The *WSA* governs the use of water in B.C. and applies to most all water uses and sources. There is no minimum flow or volume threshold under the *WSA* that cannot be regulated; i.e., any structure that allows water to be diverted, stored or used is required to have a water licence, with the exception of individual domestic use of groundwater (i.e., individual groundwater wells). From this, the WWAL-GSI team concluded that an aquifer used as the structure for storing water would require an authorization (licence) regardless of whether a proponent already holds authorizations to divert and store water using other (conventional) means such as surface diversions, surface reservoirs, and wells.

During the regional staff workshops there was a general consensus that an ASR (or by extension, and MAR) project could conceivably be licensed under the *WSA*. However, the specific details of what this licencing process would entail is uncertain and would require further analysis. This reflects back to the foregoing discussion in Sections 5.1.1 and 5.1.2 on water quantity and water quality related issues, as well as the source of recharge water, the method(s) of conveying it to subsurface storage and the end use.

5.3.2 The Case for a Lead Coordinating Government Organization

Although MAR and ASR are established practices that are successfully used throughout the world, there are currently no operating or planned MAR/ASR systems in B.C. and only one ASR project has been previously tested (Parksville) prior to passage of the *WSA* in 2016. Therefore, MAR/ASR systems are essentially new and untested water management tools in the province. The planning and development of any MAR/ASR project would likely require a high level of technical expertise, and a similar level expertise by government in the review and licensing of such projects. In addition, initial projects could potentially raise new and unique questions and issues regarding the authorization process and regulatory oversight, which would likely require coordination between multiple ministries (e.g., EAO, ENV, FLNRORD, HLTH). For example, it is unclear which legislation and ministry should have the lead responsibility for establishing and regulating groundwater quality in an ASR system. Based on the WWAL-GSI team's experience in Washington and Oregon, the implementation of MAR/ASR as a new or novel water management tool is more likely to be successful when there is a “champion” or lead government organization (e.g., FrontCounterBC, FLNRORD) identified who can coordinate the MAR/ASR program and establish a clear licensing process.

5.3.3 Potential B.C. Approvals and Permits for ASR and MAR Projects

Regardless of whether a lead agency model is adopted for MAR/ASR projects, based on the existing licensing system, it is expected that the main approver of water diversion and storage is FLNRORD. In addition, an ASR or MAR project could potentially require approvals and permits from other ministries depending on the scope and location of the MAR/ASR project. While the specific approval process and required permits is unknown, some of the possible provincial approvals & permits are summarized in Table 5 and discussed below. Here we distinguish between possible approvals and permits required for ASR projects with a drinking water use component and those required for MAR projects for non-drinking water applications. Within this second category different types of MAR projects may further shape the approval process, for example, projects that include active groundwater recovery for irrigation or other uses versus MAR projects with no groundwater recovery that are intended for mitigation of groundwater levels or to support baseflow into groundwater dependent ecosystems.

The discussion below does not address permits that could be required by local governments or by the federal government if the recharge project occurs on federal lands or there are other federal interests. However, any local or federal permitting requirements would depend on the specific project location or project features and therefore were not considered in this review. Also note that in the discussion below the words “approval” and “authorization” are taken to have the same meaning.

FLNRORD: A water licence is required for any surface water diversion or groundwater recovery in MAR/ASR projects and consequently FLNRORD is expected to be the main approver of these projects. Two separate water licences could potentially be required from FLNRORD:

(i) A water licence is required for the diversion of surface water for use as recharge source water in an ASR system or MAR project, and to authorize use of source water for artificial recharge through injection wells or by infiltration in surface facilities such as spreading basins. The water licence could either be a new licence (i.e., authorization to construct new facilities for surface water diversion) or an amendment of an existing surface water licence (i.e., adaption of existing diversion facilities). For example, existing diversion facilities that are licensed for irrigation purposes could potentially be used to divert surface water outside the normal irrigation season for the purpose of storage or replenishing an aquifer. In adjudicating the water licence application or licence amendment, FLNRORD could assess the surface water availability and the potential impacts of diversions to other water users and environmental ecosystems, establish the timing and quantity of allowable diversions, establish and assess the allowable use of surface water diversions for artificial recharge and the associated works for recharge, and could require a monitoring plan to assess impacts, as well as other licence conditions.

(ii) A groundwater licence is required for storage and withdrawal of groundwater in an ASR system or a MAR project with a groundwater recovery component. The groundwater licence application could either be a new licence application (i.e., authorization to construct a new well or convert an existing unlicensed well), or the amendment of an existing groundwater licence (i.e., authorization to convert an existing licenced well for use as an injection and/or recovery well in the ASR or MAR project). In adjudicating the water licence application or licence amendment, FLNRORD could establish the allowable works (well standards) for injection and/or recovery, the stored water approvals. FLNRORD would also establish the allowable groundwater withdrawals rates and timing and could potentially limit groundwater withdrawals to a specific volume of the water recharged into the aquifer. Additionally, FLNRORD would likely assess the potential impacts of groundwater injection and/or withdrawal on existing users and any connected surface waters and could establish groundwater monitoring requirements, as well as other licence conditions.

Table 5: Possible B.C. permits and approvals needed for ASR and MAR projects.

Agency	**ASR System for Drinking Water Use**	**MAR Projects for non-Drinking Water Use**
FLNRORD	Water licences: 1. A water licence for diversion of surface water to use as source water for groundwater injection in an ASR well. 2. A water licence for withdrawal of groundwater through ASR wells for drinking water use.	Water licences: 1. A water licence for diversion of surface water for use as source water for artificial recharge of groundwater. Recharge can be by various methods (e.g. injection through wells, infiltration through surface facilities such as spreading basins). 2. A water licence for withdrawal of groundwater through wells if the project includes a groundwater recovery component (e.g., groundwater use for irrigation supply or other uses).
Health Authority	Up to three required permits/approvals: 1. Drinking water source approval 2. Construction permit 3. Permit to operate	No permits required, but the Health Authority should be consulted if there are regulated drinking water sources in the vicinity of the proposed recharge project.
ENV	ENV would likely be involved in establishing water quality standards for groundwater resulting from ASR system operation (e.g., WQ of recharge source water, allowable WQ changes in the aquifer). Specific requirements or applicable regulations are unknown, but options could include: 1. Site specific water quality objectives for groundwater; 2. Development of water objectives under Section 43 of the *WSA*; or 3. EMA waste discharge authorizations.	Similar to requirements for ASR projects, ENV could use different approaches for regulating and managing allowable changes to groundwater quality resulting from the MAR project.
EAO	Requirements are based on groundwater withdrawal rates: 1. A project notification to the EAO is required for design pumping rates greater than 63.25 L/s; 2. The project would require either an Environmental Assessment (EA) certificate or EA exemption for design pumping rates greater than 75 L/s.	Similar to requirements for ASR projects if the project includes a groundwater recovery component.

Health Authority: For ASR projects with a drinking water use purpose, there could be up to three permits required by the local Health Authority: i) a Drinking Water Source Approval, ii) a Construction Permit, and iii) a Permit to Operate (or amendment to existing permits). The basic process of approving an ASR project with a drinking water use purpose would probably not be much different than existing water projects, except for the technical water quality monitoring elements that would likely be defined as an outcome of pilot testing. The monitoring requirements could apply to the recharge water as well as water recovered for drinking water use.

For MAR projects without a drinking water use purpose, the local Health Authority may still need to be consulted with during the application process if there are regulated drinking water sources in the vicinity of the proposed recharge project.

Environmental Assessment Office: An Environmental Assessment (EA) certificate or EA exemption would be required for projects large enough to trigger the Reviewable Projects Regulation. The flow rate during aquifer recharge component of an ASR or MAR project would not trigger a review by the EOA. But if the withdrawal rate during the recovery component of an ASR system or MAR project is large enough, then the project could trigger a project notification requirement to the EAO for design withdrawals rates greater than 63.25 L/s, and would require either an EA certificate or EA exemption for systems designed to pump at greater than 75 L/s.

For "passive" MAR projects that do not include groundwater recovery, there may still need to be consultation with the EAO if the purpose is to enhance streamflow.

ENV: Groundwater quality targets are key criteria for ASR system design, testing, and operation. Currently ENV develops water quality objectives for surface water and groundwater bodies throughout the province. Potentially, ENV could be involved in defining water quality objectives for ASR projects as a way to address the goal of limiting significant adverse effects on water quality as a result of the project. However, ENV water quality objectives are specific to ENV and are not enforceable. Other potential options for regulating groundwater quality that could be enforceable are: 1) include conditions on groundwater quality and monitoring in FLNRORD water licences; 2) develop water objectives under Section 43 of the *WSA*; or 3) issuing *Environmental Management Act* (*EMA*) waste discharge authorizations. As noted later in this report, groundwater quality associated with ASR operations is potentially a significant policy issue that government could consider applying different regulatory tools to resolve.

5.3.4 Potential Decision Making Framework

In terms of the regulatory framework for specific projects, discussions during this project suggested that ASR and MAR project submission processes could be approached from the perspective of the following elements:

a) the source of the water to be recharged;
b) the method(s) and works used to recharge the aquifer; and,
c) the end use(s) of the stored/recharged water.

Considering the particulars of each project, which vary from one to another, the following are the main aspects of ASR/MAR projects to consider in developing a decision making framework:

- diversion of the source water, either a new approval or amending an existing approval
- recharge of the aquifer
- storage in the aquifer
- recovery of stored water (if any) and allowed uses and purposes
- review of other allowed uses if no recovery (e.g., maintain water levels, augment stream flow)
- monitoring and reporting for each step in the process

To inform the discussion of ASR/MAR regulatory options for B.C., there are several potential regulatory and/or policy uncertainties (i.e., areas to examine and or develop) that could be addressed in the consideration of a licencing / permitting structure for MAR and ASR applications. The next section identifies these potential areas to further focus potential policy discussions. Some of these policy uncertainties are minor and could simply result from the lack of formal definitions; for example, MAR/ASR terminology within existing legislation and regulations. Other policy uncertainties could potentially require more significant policy review to accommodate recharge projects in its systems of water regulation.

5.4 Potential ASR/MAR Policy Uncertainties in B.C.

5.4.1 Scope of Policy Review

The information in this section is based on the WWAL-GSI team's understanding of existing water regulations and policies and discussions with ENV staff. The WWAL-GSI team emphasize here that this is a complicated topic that merits a lot of future discussion and analysis. The information in this section is not a comprehensive review or critique of B.C.'s water management policy. Rather, the WWAL-GSI team has attempted to identify and highlight key issues and uncertainties for the authorization of ASR/MAR projects with the intent of providing a starting point for further evaluation of these topics.

The legislation and regulations focused on in this review are the *WSA*, the Water Sustainability Regulation (WSR), the Drinking Water Protection Regulation (DWPR) and the Groundwater Protection Regulation (GWPR). This is an incomplete list as there are other B.C. legislation and associated rules that could be relevant to ASR/MAR systems (e.g., *Environmental Assessment Act, Environmental Management Act*). A comprehensive review of all water related legislation and regulations was not in the scope of this study.

5.4.2 Potential Policy Uncertainties

Table 6 summarizes potential MAR/ASR related regulatory and policy uncertainties to identify as areas for further focus on the ASR/MAR discussion. Table 6 also presents possible approaches to consider in addressing these issues. Additional policy uncertainties could emerge from a detailed examination of a regulatory system for managed recharge depending on the level of detail and requirements associated with the authorization and licensing of an ASR or an MAR project in British Columbia.

Although not a policy or regulatory issue, the WWAL-GSI team notes that the current online water licence interface accessed via FrontCounterBC does not have support applications for an ASR/MAR recharge project. Aspects of a recharge project could probably fall under a "new works" application. However, since MAR and ASR are highly technical projects, a more specific application process could further assist proponents in the licensing of MAR/ASR. Depending on the nature of the source water (licensed or needs a new licence or amendment) and the proposed uses/purposes of the stored water, it is possible that more than one type of application may be needed.

Table 6: Summary of potential MAR/ASR related regulatory and policy issues and uncertainties in B.C.

Possible Policy or Regulatory Uncertainty relating to MAR/ASR	Relevant Legislation or Regulation and/or Possible Implications	Considerations*
The ***WSA*** does not provide specific guidance on ASR water quality, i.e., within what limits can ASR temporarily or permanently alter water quality in the storage aquifer?	***WSA* s.46:** Determination of a "significant adverse impact" to groundwater quality associated with ASR/MAR projects is the responsibility of the statutory decision-maker (SDM). A lack of clarity regarding groundwater quality requirements could increase uncertainty in the planning, feasibility assessment, design, or pilot testing of ASR/MAR projects.	• For ASR applications with a drinking water use purpose, investigate use of the Drinking Water Protection Act/Regulation to guide/regulate groundwater quality. • Consider a province-wide standards-based approach similar to the Oregon model. • Provide guidance for project-specific water quality requirements to address local conditions and constraints; e.g., to meet applicable guidelines as defined in a permit or authorization, or meet certain water quality guidelines at a specified compliance point.
The ***WSA*** defines groundwater as "water **naturally** occurring below the surface of the ground;" it does not specifically address water that is **artificially recharged** into an aquifer (see also "Storage" discussed below).	***WSA* s.1** There is uncertainty as to whether water that is artificially recharged into an aquifer is defined as groundwater or water storage (i.e., retention for water for subsequent use). This potentially increases uncertainty in the licensing and authorization process.	• Clarify or add ASR/MAR definitions and/or water use purposes to the *WSA* or regulations • Provide guidance to proponents.
The **GWPR** does not specifically define ASR wells, which can be more complex than traditional water wells. Construction standards for water wells in the GWPR may not be sufficient for some ASR wells.	**GWPR Part 1** "Recharge" and "injection" wells are defined, but largely within context of conveying urban stormwater runoff to the subsurface, which typically occurs by gravity. Some ASR wells must be carefully designed to inject water under high pressure. The well construction standards in the GWPR do not address these design conditions.	• Develop and include definitions and minimum construction standards to the GWPR for ASR wells. • Expand the definition/description of injection and recharge wells in the GWPR to include other uses beyond the conveyance of urban runoff into the subsurface. Specifically include the use of injection/recharge wells for ASR and MAR applications.
ASR/MAR systems potentially influence water quality in aquifers due to water quality differences between recharge source water and natural groundwater. The ***WSA*** does not address changes in groundwater quality resulting from ASR/MAR activities.	***WSA* s.58** states that wells must not be operated in a manner "that causes or is likely to cause a significant adverse impact on water quality in the aquifer or existing uses"	• Consider designating ASR/MAR systems as a "prescribed activity." • Consider use of EMA waste discharge authorizations to address changes in groundwater quality from ASR/MAR projects.

Possible Policy or Regulatory Uncertainty relating to MAR/ASR	**Relevant Legislation or Regulation and/or Possible Implications**	**Considerations***
Underground storage of water in an aquifer is not defined in the ***WSA***, nor are the "works" associated with such storage clearly defined.	***WSA* s.1** There is uncertainty as to how water that is artificially recharged should be classified (i.e., as stored water, as source water, groundwater or water held in trust).	Consider developing guidance on how to define or classify underground storage of water in an aquifer resulting from artificial recharge strategies.
The ***WSA*** definition of storage may not extend to aquifers where water is artificially recharged and indefinitely retained to mitigate seawater intrusion, to replenish or maintain groundwater levels, or to augment baseflows to groundwater dependent ecosystems.	***WSA* s.1** There is uncertainty whether designated water uses can encompass water that is artificially recharged and retained in an aquifer for the purpose of maintaining or increasing groundwater levels.	Consider expanding the definition of existing water use purposes or developing new water use purposes that would permit a 'groundwater conservation use' using artificial recharge to an aquifer for the purposes a) retention in the aquifer to sustain groundwater levels and b) increase groundwater levels in order to augment baseflow to streams.
It is uncertain how water rights will be accounted for under the ***WSA*** when there is a surface water diversion licence used for recharge water and the recharge occurs through a well associated with a separate licence.	Neither the *WSA* or WSR address water rights associated with surface water that is artificially recharged to an aquifer for storage and recovery.	Consider developing guidance or policy that addresses the authorizations and associated water rights of an ASR well (the works) used for: 1) the injection, storage, and later recovery of surface water; and, 2) the extraction of naturally occurring groundwater.
It is uncertain whether the ***WSA*** authorized water allocation and licensing procedures administered through regional FLNRORD offices can accommodate an ASR or MAR application.	There is lack of clarity about the procedural steps for application and approval of ASR or MAR projects, and whether an application would be an amendment to existing licences or require a new licence.	• Consider developing guidance for water allocation staff on the procedural steps for authorizing and licensing ASR/MAR projects. • Consider accommodations for ASR/MAR projects in the FrontCounterBC applications utility.
The ***WSA*** support document *Guidance* for *Groundwater Technical Assessments* (Todd et al., 2020) provides a good overview of typical hydrogeology studies for water supply, but does not address key ASR/MAR technical issues	There is uncertainty for proponents and authorization staff on how much information is needed to support an application and approval for ASR/MAR projects.	Consider developing a companion guideline document for ASR/MAR projects that builds on the existing GW Technical Guidance.

*These are possible areas of focus. They are initial concepts that have been developed by the WWAL/GSI team based on review of existing legislation, regulations, and policies, and have not been informed by First Nations or stakeholders. These considerations are intended to inform future discussions and are not comprehensive; other measure/strategies are likely be developed or considered by Government.

5.4.3 Discussion

It is admittedly difficult at this early stage to clearly identify the actual steps that would be required for projects to be authorized as this report provides a starting point for further evaluation of regulatory processes and policy alignments needed to support ASR/MAR projects. As noted in Table 6, there is likely some uncertainty in several areas; for example, regarding the status of whether water that is stored in an aquifer is defined as stored water or groundwater. The strict interpretation of the groundwater definition would be that the water in the aquifer must occur naturally. This would apparently exclude water that enters an aquifer through stormwater infiltration, wastewater disposal, and artificial recharge associated with ASR/MAR systems. However, the clarifying definition provided in the GWPR suggests that water in an aquifer that is not within a pipe or other underground structure is indeed groundwater.

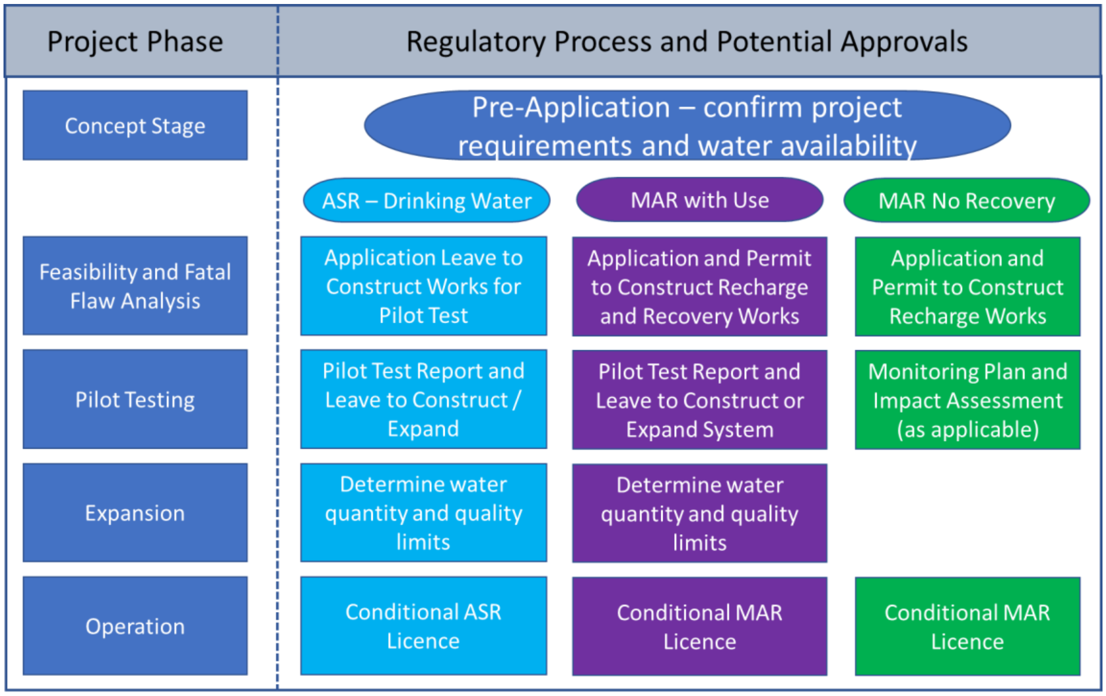
Works are typically taken to mean infrastructure that are purposely-built, such as a well, a pump station, a pipeline, reservoir or diversion structure. Forms of water storage appear to be broadly defined under "works" and could presumably include an aquifer, but additional clarity is needed regarding how storage of water in an aquifer could be quantified as part of a works associated with a MAR or ASR project. There does not appear to be an applicable definition for water that is intentionally recharged into an aquifer and left there (not withdrawn) to either sustain water levels or augment streamflow that would fit into one or more of the water use purposes established in the existing legislation. For MAR, and certain other projects that may be designed to have multiple benefits, water use purposes could be developed for groundwater level or streamflow augmentation (i.e., groundwater conservation) where the main purpose is to return water to the hydrologic cycle for non-consumptive (i.e., conservation, water quality) benefits.

Figure 8 illustrates one possible set of approaches for authorizing and managing recharge projects depending on the intended water use (i.e., drinking water, no drinking water, no recovery of water). This example is provided as a potential starting point for policy discussions. The WWAL-GSI team recommend areas for future work to include addressing the key aspects of recharge projects including: clarity on applicable water quality criteria, permits required, pilot testing requirements, monitoring and reporting procedures, how to account for water stored in the aquifer, and the allowable quantity and purpose of stored water is use.

Each of the three scenarios in Figure 8 require an application or authorization to divert water for the purpose of storage in an aquifer and would be associated with the application to authorize the construction of works (both pilot and full – scale). In addition, the SDM could choose to include licence conditions for the development and implementation of water quantity and water quality monitoring programs during pilot testing and to continuing into ASR/MAR expansion (full-scale operations).

The rationale for a pre-application step in Figure 8 is simple. ASR/MAR are complex projects and understanding the application requirements and the expectations in advance of capital investment in recharge programs is necessary. Ministries already employ pre-application steps in many processes. For example, the B.C. Municipal Wastewater Regulation uses this approach, as does the B.C. Environmental Assessment Regulation. Pre-application consultation with regional staff is also consistent with recommended guidance in the Groundwater Technical Assessment Guideline (Todd et al., 2020) for the application of a groundwater licence.

Figure 8: Potential processes for authorizing ASR and MAR Projects in B.C.



Project Phase	Regulatory Process and Potential Approvals		
Concept Stage	Pre-Application – confirm project requirements and water availability		
	ASR – Drinking Water	MAR with Use	MAR No Recovery
Feasibility and Fatal Flaw Analysis	Application Leave to Construct Works for Pilot Test	Application and Permit to Construct Recharge and Recovery Works	Application and Permit to Construct Recharge Works
Pilot Testing	Pilot Test Report and Leave to Construct / Expand	Pilot Test Report and Leave to Construct or Expand System	Monitoring Plan and Impact Assessment (as applicable)
Expansion	Determine water quantity and quality limits	Determine water quantity and quality limits	
Operation	Conditional ASR Licence	Conditional MAR Licence	Conditional MAR Licence

6. RECOMMENDATIONS

This section provides recommendations based on the results of this project including recommendations for MAR/ASR guidance and policy initiatives, recommendations on potential locations for further MAR/ASR assessments, and additional considerations to build on this study's initial findings.

6.1 Potential MAR/ASR Guidance and Policy Initiatives

Initiatives to develop guidance and policy strategies is an area that could greatly support the implementation of MAR/ASR in British Columbia. While the *WSA* and current water regulations can support an ASR or MAR project, the authorization process is uncertain and could benefit from the clarification of legal definitions pertaining to MAR/ASR processes, intra-ministry coordination to increase clarity and help reduce uncertainty about the project submission process, and guidance development for conditions of project approvals (e.g., recharge, stored and recovered water quality criteria). The WWAL-SGI team recommends the following options for consideration, as a starting point for discussion in supporting MAR/ASR projects.

1. Develop and evaluate approaches to define and manage water diverted from a stream and intentionally recharged/stored in an aquifer. This could include confirmation that aquifer storage is defined and managed similarly to groundwater, and that its use would be subject to the conditions of the licence granted for the recharge project. Specifically, review the definitions of a stream and groundwater under the *WSA* and consider whether these definitions should be broadened to specifically address and encompass MAR and ASR practices.
2. Confirm whether one or two water licences are required for ASR projects where there would be artificial recharge, aquifer storage, and recovery for later beneficial use. For example, does FLNRORD require a licence for the original surface water diversion and artificial recharge, and

potentially a separate licence for subsequent pumping and use of the stored water. Similarly, confirm whether one or two water licences would be required for MAR applications where the stored water is not directly recovered (e.g., artificial recharge projects to enhance environmental flows or to sustain groundwater levels). This is not a major issue but is a detail that should be made clear in the application process.

3. A potentially significant impediment in the licensing and adjudication of ASR/MAR is uncertainty and lack of precedence regarding the legislation and regulations that apply to groundwater quality aspects of both MAR and ASR. There is a need to clarify water quality requirements and guidelines for drinking water ASR and non-potable MAR projects (e.g., applicable water quality requirements, and how potential changes in groundwater quality during pilot tests are managed). This could include initiatives to develop or align policy and regulations to encompass the water quality aspects of MAR/ASR projects. Such an initiative could improve clarity for both proponents and staff and could help to support the use of MAR/ASR as a water management tool.
4. Government and proponents could benefit from a framework to guide MAR and ASR projects from application through to authorization, including application procedures via FrontCounterBC. Given the complexity of such projects, proponents could be provided opportunities for a pre-application meeting with SDMs or regional hydrogeologists at which concept-level project descriptions may be provided for input. This is consistent with current guidance on technical assessment requirements for groundwater licence applications, which encourages prospective applicants to complete pre-application research and seek input from provincial water staff. To further support pre-application information sharing, there could be technical and legal information requirements developed for supporting MAR/ASR licence applications (similar to the technical assessment requirements for groundwater licence applications, Todd et al., 2020) and provide these to proponents either as guidelines or in the form of Application Information Requirements (AIRs) and technical requirements, summarized following the pre-application meetings.
5. Confirm that licensing of MAR and ASR projects can be approved in steps or stages (such as “leaves” for major surface water storage projects) that follow the logical sequence of project development that has occurred in locations outside of B.C. (described in Section 2.3). A stepwise licensing structure could include the use of a conditional licence to commence pilot testing, and subsequent licence amendments for system expansion and construction of additional works.

6.2 Additional Considerations in Support of MAR/ASR

The following are suggested measures to support the consideration and use of MAR/ASR systems in groundwater resource planning and management initiatives.

1. Building support for alternative water supply and storage solutions will require communication on the benefits, the limitations and the need for careful assessment and monitoring of results. Although this report has touched upon a few example projects, further information regarding the potential uses and benefits of MAR and ASR are suggested. The funding and support for this study and report is an example of such information sharing. Future work can potentially build on this effort through meetings and presentations about the study with government staff and local partners.
2. To support and inform the development and refinement of policy and regulations, desktop assessments of one or two projects involving different types of MAR applications could be one

approach. The technical, economic, and regulatory analyses required in these desktop assessments would provide insights into the strengths and weaknesses of the existing approach to licensing. This would be a way to test the existing system (i.e., the legislation, regulations, policies, guidelines and approval mechanisms) in a quasireal-world situation.

3. Development of comprehensive ASR/MAR technical guidance covering the spectrum of topics from initial assessment to detailed design and operations, while useful, would be premature at this point. Such guidance would be needed after there is an increased demand for ASR and MAR projects and after the policy and regulatory pieces have been reviewed. As a first step, consideration could be given to adapting the existing Guidance for Groundwater Technical Assessment (Todd et al., 2020) to include ASR and MAR projects as part of the desktop assessments discussed in (2) above.
4. Begin the steps toward developing a B.C. ASR/MAR "community of practice" around ASR and MAR in B.C. by convening or hosting a conference or workshop focused on groundwater resource management issues to include managed aquifer recharge, ASR, and other forms of conjunctive surface water and groundwater use. Further to the community of practice concept, government could reach out to specific user groups and professional and trade associations in an effort to build understanding and support for alternative water management strategies such as ASR and MAR. Such outreach might include diverse groups as Environmental NGOs, First Nations, agriculture (e.g. Dairy Association, Cattlemen's Association), the B.C. Groundwater Association, B.C. Water and Waste Association, and Ministries with an interest in ASR and MAR (Ministry of Agriculture, Ministry of Health).

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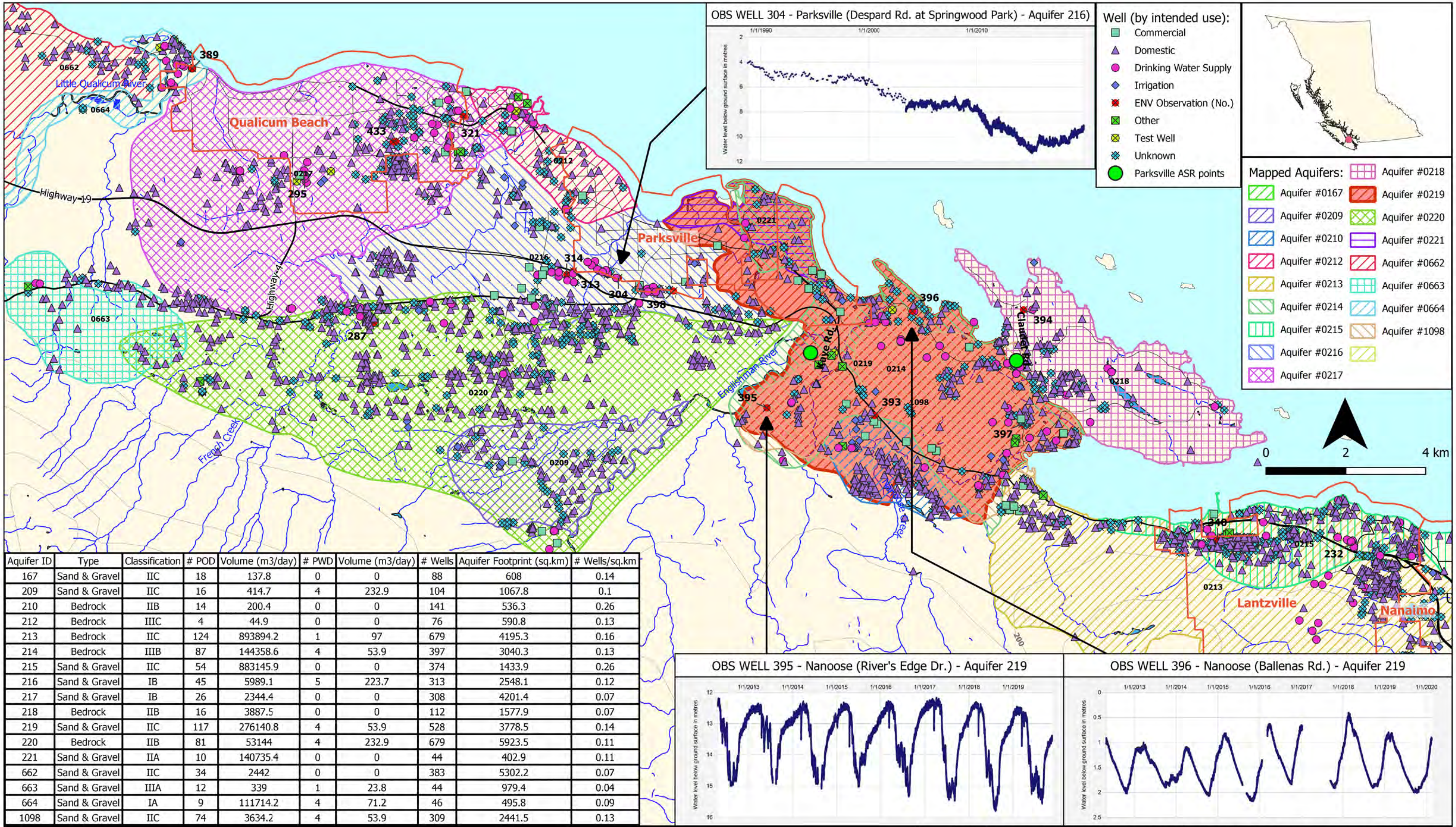
APPENDIX A: MAPS 1-6

Each of the maps 1 through 6 depict similar information, which is intended to show what kinds of data would be reviewed in the assessment of ASR or MAR feasibility, including:

- mapped aquifer extents;
- mapped aquifer classification, licensed point of diversion (POD) data summary including other well data (licensed volumes and well density) (table);
- registered wells by reported use purpose (table);
- hydrographs of area observation wells;
- identified ASR pilot sites (Map 1, Parksville only);
- locations of licensed points of diversion (surface water); and,
- rivers and streams (named).

Note for locations with multiple layered aquifers, the well data are based on map area and not assigned to a specific aquifer. Similarly, licensed PODs are assigned to the corresponding aquifer or nearest adjacent aquifer. In a relative sense, the maps show how well density can be loosely correlated with potential stress to local aquifers as well as reliance on groundwater by individual well users (as opposed to community systems). The Hopington area, for example, has well densities on the order of 10 to 40 wells/km^2, whereas the Parksville area (much of which is served with municipal water) has less than 1 well per km^2.



Aquifer ID	Type	Classification	# POD	Volume (m3/day)	# PWD	Volume (m3/day)	# Wells	Aquifer Footprint (sq.km)	# Wells/sq.km
167	Sand & Gravel	IIC	18	137.8	0	0	88	608	0.14
209	Sand & Gravel	IIC	16	414.7	4	232.9	104	1067.8	0.1
210	Bedrock	IIB	14	200.4	0	0	141	536.3	0.26
212	Bedrock	IIIC	4	44.9	0	0	76	590.8	0.13
213	Bedrock	IIC	124	893894.2	1	97	679	4195.3	0.16
214	Bedrock	IIIB	87	144358.6	4	53.9	397	3040.3	0.13
215	Sand & Gravel	IIC	54	883145.9	0	0	374	1433.9	0.26
216	Sand & Gravel	IB	45	5989.1	5	223.7	313	2548.1	0.12
217	Sand & Gravel	IB	26	2344.4	0	0	308	4201.4	0.07
218	Bedrock	IIB	16	3887.5	0	0	112	1577.9	0.07
219	Sand & Gravel	IIC	117	276140.8	4	53.9	528	3778.5	0.14
220	Bedrock	IIB	81	53144	4	232.9	679	5923.5	0.11
221	Sand & Gravel	IIA	10	140735.4	0	0	44	402.9	0.11
662	Sand & Gravel	IIC	34	2442	0	0	383	5302.2	0.07
663	Sand & Gravel	IIIA	12	339	1	23.8	44	979.4	0.04
664	Sand & Gravel	IA	9	111714.2	4	71.2	46	495.8	0.09
1098	Sand & Gravel	IIC	74	3634.2	4	53.9	309	2441.5	0.13

Assessment of ASR Systems

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TITLE **Map 1** Qualicum-French Creek-Parksville Area

DRAWN Tim Sivak

REVIEWED

DATE March 10, 2020

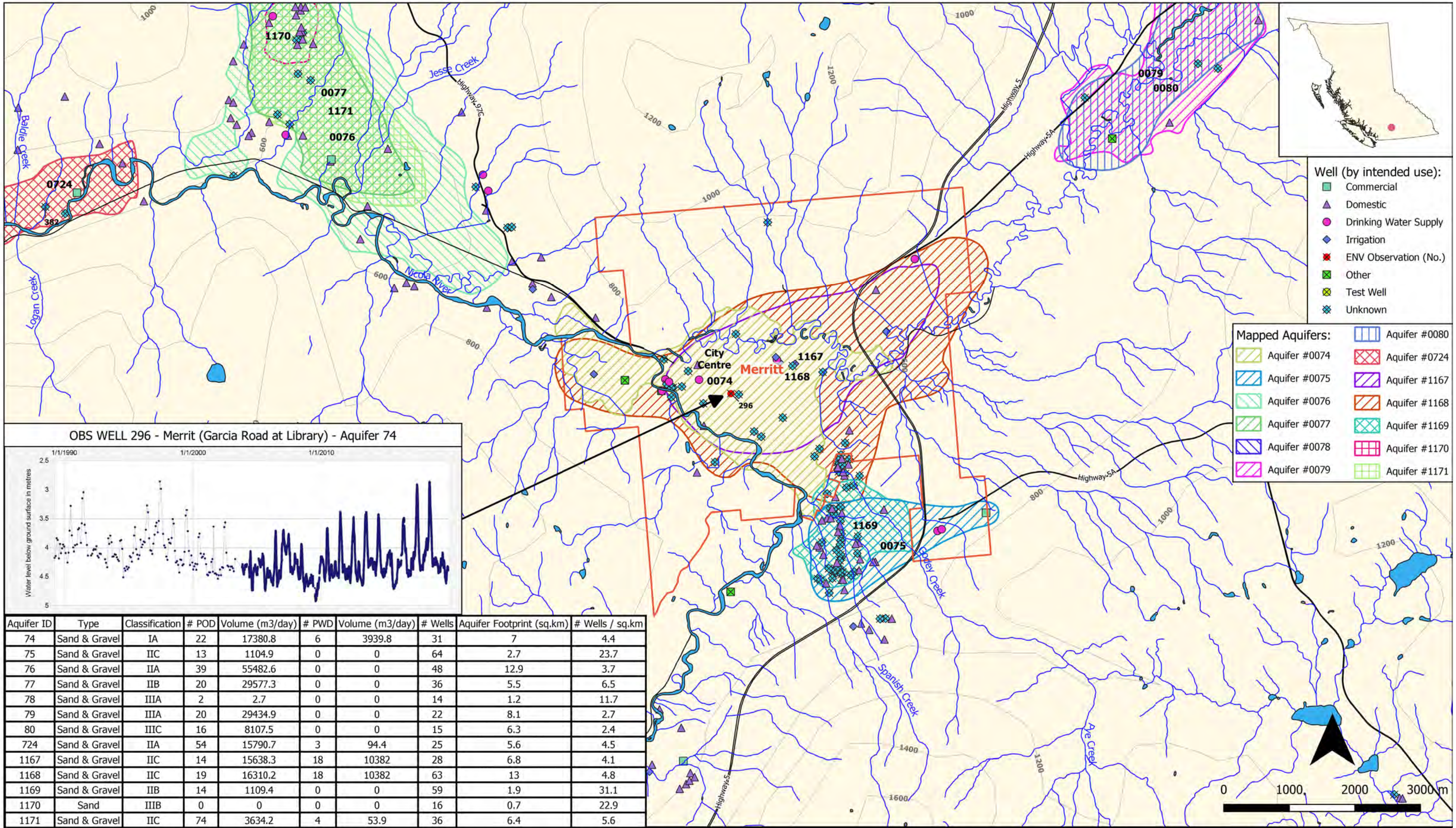
PROJECT NO. 19-099-01VR

CLIENT Ministry of Environment and Climate Change Strategy (ENV)

REVISION NO. E

Data Sources: Base plan from Google, DataBC, ENV. Data retrieved December 2019.

Contour interval: 200 m
Map Projection: NAD83 BC Albers
Other notes: POD is Point of Diversion. PWD is Point of Well Diversion. Pilot ASR site locations are approximate. Wells and water rights not shown on figure.



Aquifer ID	Type	Classification	# POD	Volume (m3/day)	# PWD	Volume (m3/day)	# Wells	Aquifer Footprint (sq.km)	# Wells / sq.km
74	Sand & Gravel	IA	22	17380.8	6	3939.8	31	7	4.4
75	Sand & Gravel	IIC	13	1104.9	0	0	64	2.7	23.7
76	Sand & Gravel	IIA	39	55482.6	0	0	48	12.9	3.7
77	Sand & Gravel	IIB	20	29577.3	0	0	36	5.5	6.5
78	Sand & Gravel	IIIA	2	2.7	0	0	14	1.2	11.7
79	Sand & Gravel	IIIA	20	29434.9	0	0	22	8.1	2.7
80	Sand & Gravel	IIIC	16	8107.5	0	0	15	6.3	2.4
724	Sand & Gravel	IIA	54	15790.7	3	94.4	25	5.6	4.5
1167	Sand & Gravel	IIC	14	15638.3	18	10382	28	6.8	4.1
1168	Sand & Gravel	IIC	19	16310.2	18	10382	63	13	4.8
1169	Sand & Gravel	IIB	14	1109.4	0	0	59	1.9	31.1
1170	Sand	IIIB	0	0	0	0	16	0.7	22.9
1171	Sand & Gravel	IIC	74	3634.2	4	53.9	36	6.4	5.6

Assessment of ASR Systems

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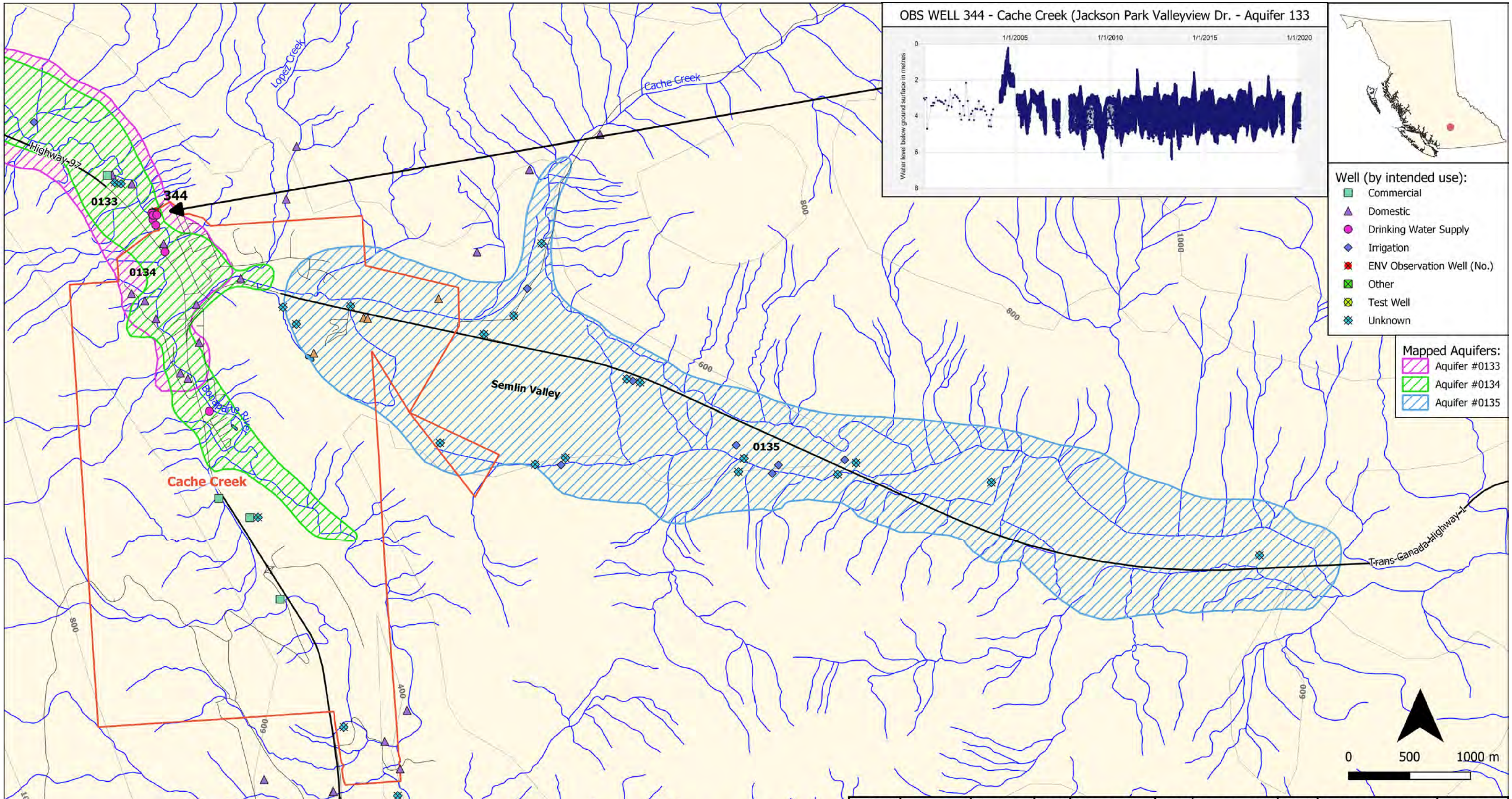
TITLE
Map 2: Merritt-Nicola Valley Area

DRAWN Tim Sivak
DATE March 10, 2020
CLIENT Ministry of Environment and Climate Change Strategy (ENV)
REVIEWED
PROJECT NO. 19-099-01VR
REVISION NO. E

Data Sources: Base plan from Google, DataBC, ENV. Geogratis. Data retrieved December 2019.
Contour interval: 200 m
Map Projection: NAD83 BC Albers
Other notes: POD is Point of Diversion. PWD is Point of Well Diversion. Wells and water rights not shown on figure.



Aquifer ID	Type	Classification	# POD	Volume (m3/day)	# PWD	Volume (m3/day)	# Wells	Aquifer Footprint (sq.km)	# Wells/sq.km
133	Sand & Gravel	IC	65	27905.4	1	1351.8	104	16.5	6.3
134	Sand & Gravel	IA	82	30689	2	1352.3	87	15.2	5.72
135	Sand & Gravel	IC	28	14864.7	0	0	27	10	2.7

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TITLE **Map 3:** Semlin Valley - Cache Creek Area

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DATE March 10, 2020

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PROJECT NO. 19-099-01VR

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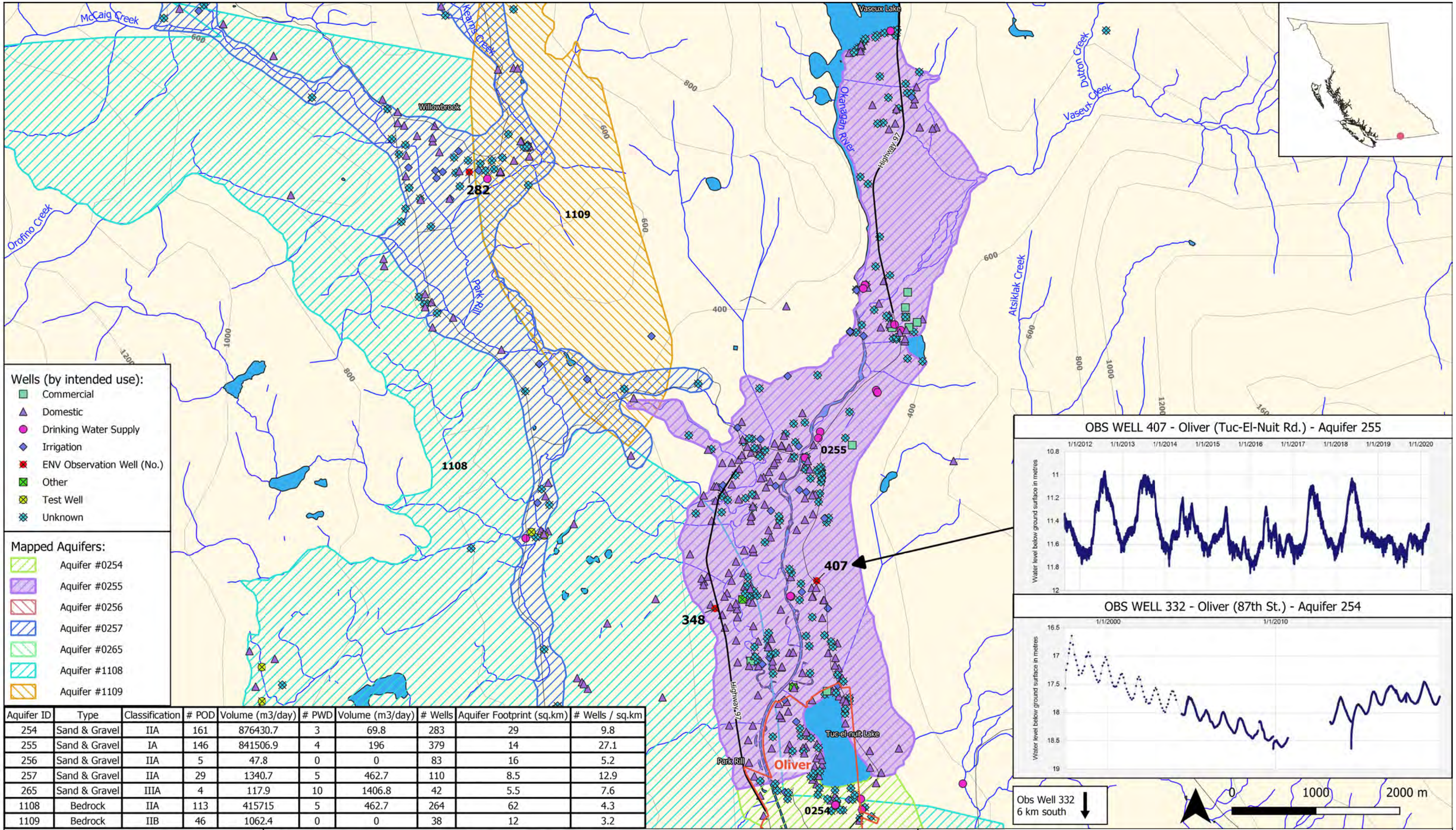
Data Sources: Base plan from Google, DataBC, ENV. Geogratis. Data retrieved December 2019.
Contour interval: 200 m
Map Projection: NAD83 BC Albers
Other notes: POD is Point of Diversion. Water rights not shown on figure.



Aquifer ID	Type	Classification	# POD	Volume (m3/day)	# PWD	Volume (m3/day)	# Wells	Aquifer Footprint (sq.km)	# Wells / sq.km
254	Sand & Gravel	IIA	161	876430.7	3	69.8	283	29	9.8
255	Sand & Gravel	IA	146	841506.9	4	196	379	14	27.1
256	Sand & Gravel	IIA	5	47.8	0	0	83	16	5.2
257	Sand & Gravel	IIA	29	1340.7	5	462.7	110	8.5	12.9
265	Sand & Gravel	IIIA	4	117.9	10	1406.8	42	5.5	7.6
1108	Bedrock	IIA	113	415715	5	462.7	264	62	4.3
1109	Bedrock	IIB	46	1062.4	0	0	38	12	3.2

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TITLE **Map 4:** Vaseux Lake-North Oliver Area

DRAWN Tim Sivak

DATE March 10, 2020

CLIENT Ministry of Environment and Climate Change Strategy (ENV)

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PROJECT NO. 19-099-01VR

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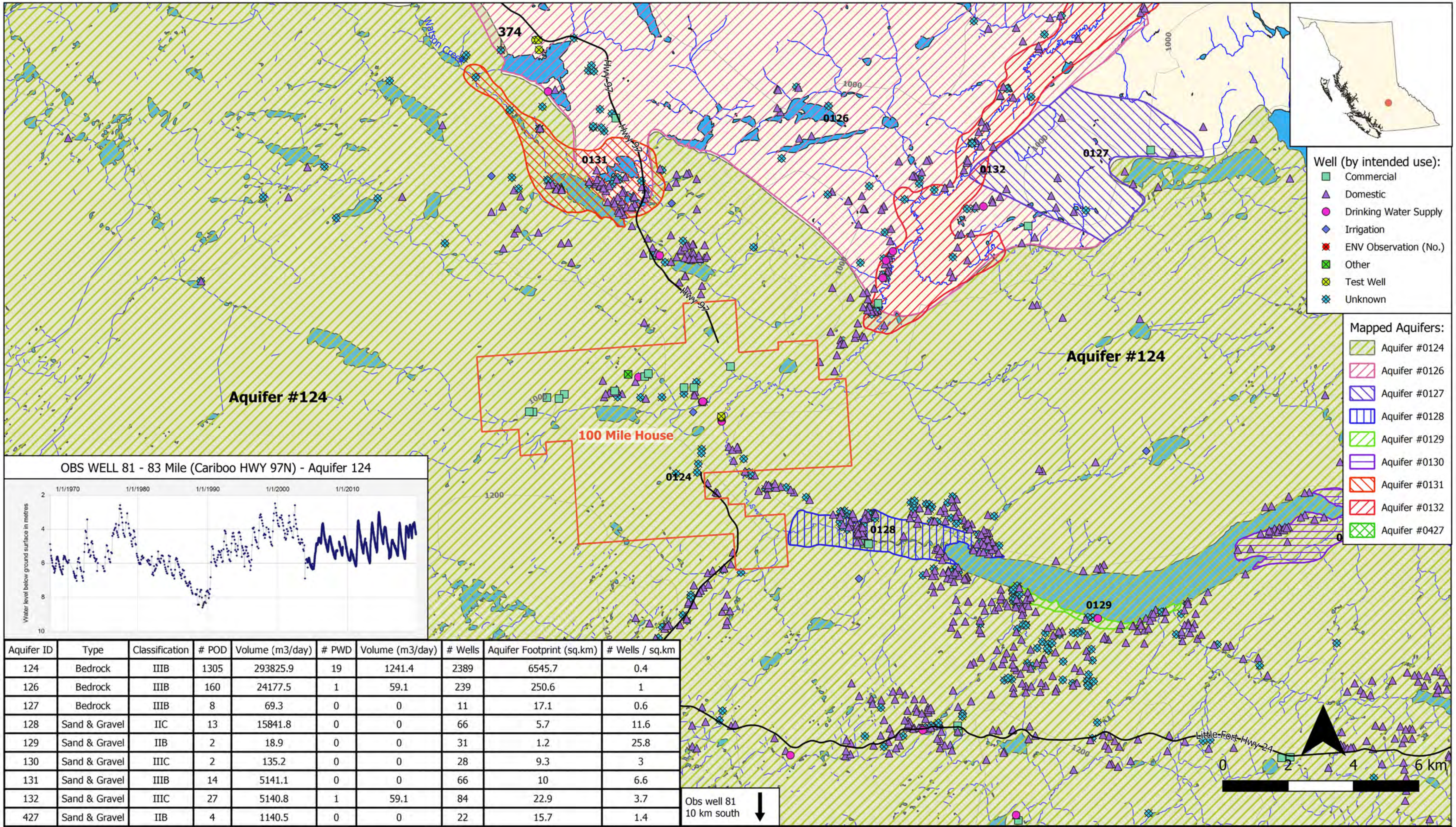
Data Sources: Base plan from Google, DataBC, ENV. Geogratis. Data retrieved December 2019.
Contour interval: 200 m
Map Projection: NAD83 BC Albers
Other notes: POD is Point of Diversion. PWD is Point of Well Diversion. Water rights not shown on figure.



Aquifer ID	Type	Classification	# POD	Volume (m3/day)	# PWD	Volume (m3/day)	# Wells	Aquifer Footprint (sq.km)	# Wells / sq.km
124	Bedrock	IIIB	1305	293825.9	19	1241.4	2389	6545.7	0.4
126	Bedrock	IIIB	160	24177.5	1	59.1	239	250.6	1
127	Bedrock	IIIB	8	69.3	0	0	11	17.1	0.6
128	Sand & Gravel	IIC	13	15841.8	0	0	66	5.7	11.6
129	Sand & Gravel	IIB	2	18.9	0	0	31	1.2	25.8
130	Sand & Gravel	IIIC	2	135.2	0	0	28	9.3	3
131	Sand & Gravel	IIIB	14	5141.1	0	0	66	10	6.6
132	Sand & Gravel	IIIC	27	5140.8	1	59.1	84	22.9	3.7
427	Sand & Gravel	IIB	4	1140.5	0	0	22	15.7	1.4

Obs well 81 ↓
10 km south

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TITLE **Map 5:** 100 Mile Area

DRAWN Tim Sivak

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DATE March 10, 2020

PROJECT NO. 19-099-01VR

CLIENT Ministry of Environment and Climate Change Strategy (ENV)

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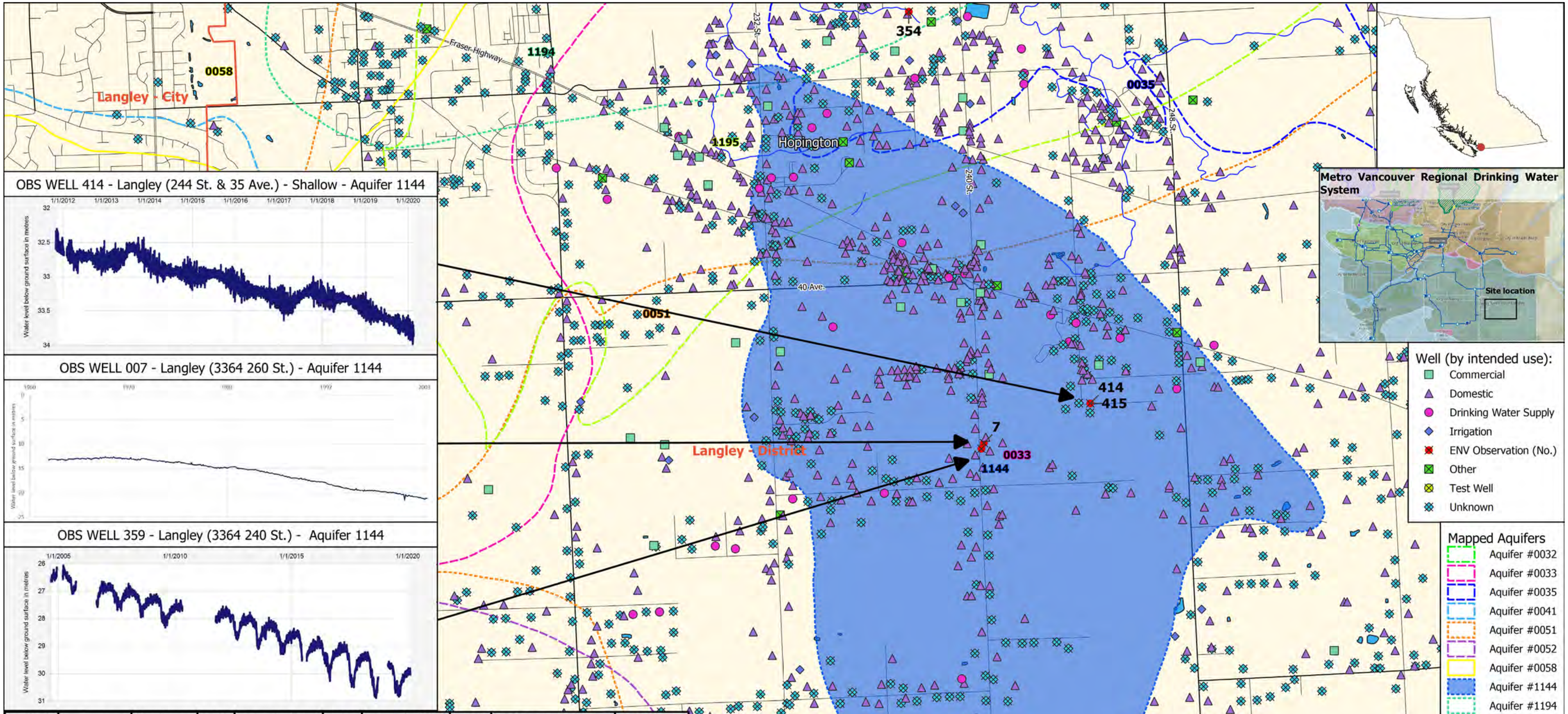
Data Sources: Base plan from Google, DataBC, ENV. Data retrieved December 2019.

Contour interval: 200 m
Map Projection: NAD83 BC Albers
Other notes: POD is Point of Diversion. PWD is Point of Well Diversion. Wells and water rights not shown on figure.



Aquifer ID	Type	Classification	# POD	Volume (m3/day)	# PWD	Volume (m3/day)	# Wells	Aquifer Footprint (sq.km)	# Wells/sq.km
32	Sand & Gravel	IIC	70	7198.9	8	797.1	1220	50	24.4
33	Sand & Gravel	IIC	122	11176.4	8	307.5	2346	73	32.1
35	Sand & Gravel	IA	42	3109.9	9	783.6	878	23.9	36.7
41	Sand & Gravel	IA	27	1336.3	0	0	862	32	26.9
51	Sand & Gravel	IIIC	120	16726	2	31.5	2196	73.5	29.9
52	Sand & Gravel	IIIC	38	2554.8	2	25	1080	42.3	25.5
58	Sand & Gravel	IIC	412	103520.6	5	161.8	2578	216	11.9
1144	Sand & Gravel	IB	19	444.6	4	19.8	713	16.5	43.2
1194	Sand & Gravel	IIIC	98	15954.9	8	797.1	1210	44	27.5
1195	Sand & Gravel	IIIC	49	5801.7	1	6	954	22.9	41.7

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TITLE **Map 6:** Langley-Hopington Area

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PROJECT NO. 19-099-01VR

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Data Sources: Base plan from Google, DataBC, ENV. Geogratis. Data retrieved December 2019.
Contour interval: 200 m
Map Projection: NAD83 BC Albers
Other notes: POD is Point of Diversion. PWD is Point of Well Diversion. Water rights not shown.

Assessment of ASR Systems	TITLE **Map 7:** Overview Map of B.C. Depicting Potential MAR/ASR Sites Identified in this Study		
western water ASSOCIATES LTD	DRAWN Tim Sivak	DATE March 8, 2020	CLIENT Ministry of Environment and Climate Change Strategy (ENV)
	REVIEWED	PROJECT NO. 19-099-01VR	REVISION NO. A