Arrowsmith Water Service
Englishman River Water Intake Study
Phase 1 - Conceptual Planning

Groundwater Management
Discussion Paper 5-2 – Aquifer Storage Recovery

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1 Introduction

This discussion paper is the first step in determining the feasibility of Aquifer Storage Recovery (ASR) for enhancing water resource management in the Arrowsmith Water Service region. This preliminary feasibility assessment includes; identification and characterization of suitable ASR well sites, consideration of regulatory requirements, confirmation of the level of treatment for recharged water and discussion and analysis of all technical and non-technical issues relevant to successful ASR program implementation. A conceptual design is also developed including preliminary cost estimates for a field test program and the final ASR well field installation.

2 Methodology

Available data and information from various sources was compiled, analysed and summarized including:

- well records and aquifer mapping available from the BC Water Resources Atlas (Ministry of Environment, 2010 a);
- selected information from partners; Associated Engineering Group Ltd., Koers & Associates Engineering Ltd. and Kerr Wood Leidal Associates Ltd.
- the study outline follows guidelines set out in the book “Aquifer Storage Recovery” 2005, R. David G. Pyne.
- previous discussion papers, hydrogeology and engineering reports on local wells and in particular the Terracon Geotechnique Ltd. 1994 *Groundwater Computer Modeling Study of the Nanoose Peninsula.*
- discussions with the BC Ministry of Environment regarding regulatory requirements

3 Definitions

This report refers to a number of key hydrogeological terms and concepts that are defined herein as follows:

AQUIFER – An aquifer is a formation, group of formations or part of a formation containing enough saturated permeable material to produce significant amounts of water to wells and springs. (See also confined aquifers or artesian aquifers and unconfined aquifers.)

AQUIFER STORAGE AND RECOVERY (ASR) - involves injecting water into an aquifer through wells and then pumping it out when needed. The aquifer essentially functions as a water bank. Deposits are made in times of surplus, typically during the rainy season, and withdrawals occur when available water falls short of demand (Department of Ecology, 2009). ASR as referred to in this document refers exclusively to systems where the same wells are used for recharging water to and discharging water from the aquifer.

BEDROCK – Rock underlying soil and other unconsolidated material.

CONFINED AQUIFER – Confined is synonymous with artesian. A confined aquifer or an artesian aquifer is an aquifer bounded both below and above by beds of considerably lower permeability than that existing in the aquifer itself. The groundwater in a confined aquifer is under pressure that is significantly greater than that existing in the atmosphere.

CONFINING BED OR LAYER – A bed of impermeable material stratigraphically adjacent to one or more aquifers. Confining bed is now used to replace terms such as "aquiclude", "aquitard" and "aquifuge".

DRAWDOWN – The variation in the water level in a well prior to commencement of pumping compared to the water level in the well while pumping. In flowing wells drawdown can be expressed as the lowering of the pressure level due to the discharge of well water

FLUVIAL DEPOSITS – Deposits related to a river or stream.

FRACTURE – A break or crack in the bedrock.

FRESH WATER - SALT WATER TRANSITION ZONE – The interface zone occurring between fresh water and saltwater underlying marine islands and coastal areas with groundwater occurring below the surface of the ground in geologic formations under saturated conditions.

FLOWING ARTESIAN WELL – A well where the water level is above the ground surface.

GLACIO-FLUVIAL DEPOSITS – Deposits related to the joint action of glaciers and melt water streams.

GROUNDWATER – Water in the zone of saturation underground, that is under a pressure equal to or greater than atmospheric pressure.

GROUNDWATER TABLE – That surface below which rock, gravel, sand or other material is saturated. It is the surface of a body of unconfined groundwater at which the pressure is atmospheric.

HETEROGENEOUS DEPOSIT – Non-uniform structure and composition throughout the deposit.

HOMOGENEOUS DEPOSIT – Structure or composition of the deposit is uniform throughout.

HYDRAULIC CONDUCTIVITY – Hydraulic conductivity is a measure of the ability of a fluid to flow through a porous medium determined by the size and shape of the pore spaces in the medium and their degree of interconnection and also by the viscosity of the fluid. Hydraulic conductivity can be expressed as the volume of fluid that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

HYDRAULIC GRADIENT – The slope of the groundwater level or water table.

HYDRAULIC HEAD – The level to which water rises in a well with reference to a datum such as sea level.

HYDROGEOLOGY – Study of groundwater in its geological context.

ICE CONTACT DEPOSITS – Drift sediment deposited in contact with its supporting ice.

IGNEOUS ROCKS–Rocks that solidified from molten or partly molten material, that is from a magma or lava.

IMPERMEABLE – Impervious to flow of fluids.

INFILTRATION RATE – The rate at which water permeates the pores or interstices of the ground.

LEVEL OF GROUNDWATER DEVELOPMENT – The level of groundwater use of an aquifer relative to the aquifer's ability to replenish itself.

LITHOLOGY – All the physical properties, the visible characteristics of mineral composition, structure, grain size etc. which give individuality to a rock.

MARINE DEPOSITS – Mostly silt and clay materials deposited under a marine environment.

METAMORPHIC ROCKS – Any rock derived from pre-existing rocks by mineralogical, chemical, and/or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shearing stress, and chemical environment, generally at depth in the earth's crust.

OBSERVATION WELL – A well constructed for the objective of undertaking observations such as water levels, pressure readings and groundwater quality.

OUTWASH DEPOSITS – Stratified drift deposited by meltwater streams flowing away from melting ice.

OVERBURDEN – The layer of fragmental and unconsolidated material including loose soil, silt, sand and gravel overlying bedrock, which has been either transported from elsewhere or formed in place.

PERCHED WATER TABLE – A separate continuous body of groundwater lying (perched) above the main water table. Clay beds located within a sedimentary sequence, if of limited aerial extend, may have a shallow perched groundwater body overlying them.

PERMEABILITY – The property of a porous rock, sediment or soil for transmitting a fluid, it is a test of the relative ease of fluid flow in a porous medium.

PERMEABLE – The property of a porous medium to allow the easy passage of a fluid through it.

PIEZOMETER – Pressure reading and measuring instrument connected to a short sealed off length of a drill hole or hydrogeologic unit.

PIEZOMETRIC SURFACE – Imaginary surface defined by the elevation to which water will rise in wells penetrating confined aquifers.

PLEISTOCENE – The period following the Pliocene during which an ice sheet covered the greater part of North America. Named by Lyell in 1839.

POROSITY – The volume of openings in a rock, sediment or soil. Porosity can be expressed as the ratio of the volume of openings in the medium to the total volume.

POTENTIAL WELL YIELD – An estimate of well yield generally above the existing yield rate or test rate, but considered possible on the basis of available information, data and present well performance.

PUMPING INTERFERENCE – The condition occurring when a pumping well lowers the water level in a neighbouring well.

PUMPING TEST – A test conducted by pumping a well to determine aquifer or well characteristics.

QUATERNARY – The period of geologic time that follows the Tertiary. The Quaternary includes the Pleistocene and Recent Periods and is part of the Cenozoic Era.

RADIUS OF INFLUENCE – The radial distance from a pumping well to the point where there is no drawdown of the water table or piezometric surface. This point marks the edge of the cone of depression around the pumping well.

SALINE GROUNDWATER – Groundwater consisting of or containing salt.

SALT WATER INTRUSION – Movement of salty or brackish groundwater into wells and into aquifers previously occupied by fresh or less mineralized groundwater either through upconing or sea water encroachment.

SANDSTONE – A sedimentary rock composed of mostly sand sized particles.

SATURATED ZONE – The subsurface zone in which all voids are ideally filled with water under pressure greater than atmospheric.

SEA WATER ENCROACHMENT-Lateral landward movement of sea water into wells and freshwater aquifers.

SEDIMENTARY ROCKS–Rocks formed from consolidation of loose sediments such as clay, silt, sand, and gravel.

SHALE – A fine-grained sedimentary rock, formed by the consolidation of clay, silt, or mud. It is characterized by finely laminated structure and is sufficiently indurated so that it will not fall apart on wetting.

SPECIFIC CAPACITY – The rate of discharge of a water well per unit of drawdown. Specific capacity can be expressed as L/s/m of drawdown.

STATIC WATER LEVEL – The level of water in a well that is not being influenced by groundwater withdrawals. The distance to water in a well is measured with respect to some datum, usually the top of the well casing or ground level.

STORATIVITY, STORAGE FACTOR OR STORAGE COEFFICIENT – refers to the volume of water that is released from storage for a unit area of aquifer per unit decline in water level, it may be expressed as a percent. Unconfined sand and gravel aquifers, for example, may have relatively large storativity values in the range 10 to 25 percent while fractured aquifers have low storativity values, for example, <5 percent, depending upon bedrock type.

SURFICIAL DEPOSITS – Deposits overlying bedrock and consisting of soil, silt, sand, gravel and other unconsolidated materials.

SUSTAINED YIELD – Rate at which groundwater can be withdrawn from an aquifer without long-term depletion of the supply.

TILL – Till consists of a generally unconsolidated, unsorted, unstratified heterogeneous mixture of clay, silt, sand, gravel and boulders of different sizes and shapes. Till is deposited directly by and underneath glacial ice without subsequent reworking by meltwater.

TOPOGRAPHY – The configuration of a surface including its relief and the position of its natural features.

TOTAL DISSOLVED SOLIDS (TDS) – Concentration of total dissolved solids (TDS) in groundwater expressed in milligrams per litre (mg/L), is found by evaporating a measured volume of filtered sample to dryness and weighing this dry solid residue.

TRANSMISSIVITY – Rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Transmissivity values can be expressed as square metres per day (m^2/day), or as square metres per second (m^2).

UNCONFINED AQUIFER–An aquifer in which the water table is free to fluctuate under atmospheric pressure.

UNCONSOLIDATED DEPOSITS – Deposits overlying bedrock and consisting of soil, silt, sand, gravel and other material which have either been formed in place or have been transported in from elsewhere.

UPCONING – Upward movement of salty or brackish groundwater into wells and into aquifers previously occupied by fresh or less mineralized groundwater.

UNSATURATED ZONE – The zone between the land surface and the water table. The pore spaces, interstices, contain water at less than atmospheric pressure, and also air and other gases. Perched groundwater bodies (local saturated zones) may exist in the unsaturated zone.

WATERSHED – A catchment area for water that is bounded by the height of land and drains to a point on a stream or body of water, a watershed can be wholly contained within another watershed.

WATER TABLE – See Groundwater Table.

WELL DEVELOPMENT – This operation helps make water enter the well more easily and can make the difference between a satisfactory and an unsatisfactory well. Different techniques for well development can be used, the aim is to remove the smaller sized particles from the aquifer surrounding the well screen and to provide a coarser filter zone around the screen. The smaller sized particles are drawn into the well screen and can then be removed by bailing or pumping.

WELLHEAD PROTECTION – Protection of the recharge (or capture zone) area of a pumping well.

WELL INTERFERENCE – When the area of influence, or the cone of depression around a water well comes into contact with or overlaps that of a neighbouring well pumping from the same aquifer and thereby causes additional drawdown or drawdown interference in the wells.

WELL POINTS – Also referred to as sand points, gravel points, are used in shallow permeable unconfined (usually) aquifers generally less than 30 feet deep. Well points consist of a short length of screened pipe with a sharp point on the bottom end. As the pipe is driven into the ground, additional lengths of pipe are added to the top end. Sand points are also available with a check valve at the lower end to enable the pipe to be washed down in sand and fine gravel aquifers. Water can be pumped down the pipe and it passes out the check valve at the bottom and washes the sand up the hole to the ground surface.

WELL SCREEN – A cylindrical filter used to prevent sediment from entering a water well. There are several types of well screens, which can be ordered in various slot widths, selected on the basis of the grain size of the aquifer material where the well screen is to be located. In very fine grained aquifers, a zone of fine gravel or coarse sand may be required to act as a filter between the screen and the aquifer.

WELL YIELD – The volume of water discharged from a well in litres per minute (L/min), litres per second (L/s) or cubic metres per day (m^3/day).

4 ASR Program Feasibility Assessment

4.1 Recharge Objectives

The objective of the ASR program for the Arrowsmith Water Service is to provide seasonal storage and recovery of water to help satisfy peak demands. The ASR system will divert excess wet season flows in Englishman River to ASR wells via the Water Treatment Plant (WTP). In the summer high water demand season water will be withdrawn from the ASR wells and pumped to the distribution system after disinfection treatment only. In addition to helping meet peak demands the ASR program will reduce the required size (capacity) of the proposed treatment plant and reduce costs significantly.

4.2 Water Supply Variability

There is a large untapped flow in Englishman River in the fall, winter and spring each year. Water balance modeling by AE indicates treated surface water could flow to the ASR wells at rates up to 62 ML/week from winter to early spring. Water would be withdrawn from the ASR wells from early summer to early fall.

4.3 Recharge Water Quality and Variability

The recharge water from the WTP would meet all Canadian Drinking Water standards and would have a typical turbidity value of 0.1 NTU. From time to time the river experiences a spike in turbidity but these events are rare and short in duration. There would be only a few days each year when ASR well recharge would be prevented by poor raw water quality.

4.4 Water Demand and Variability

The water balance model by AE for the year 2050 population indicates ASR withdrawals ranging from 8.8 to 104.2 ML/week. Water will be withdrawn from the ASR wells at these rates from early summer to early fall. The combined daily yield for the ASR well field must then be 15 ML/d.

4.5 Storage Requirement

Based on the recharge objectives and variability in water supply and demand outlined above an annual volume of 1,000,000 m^3 (1000 ML) will be recovered from storage under design conditions.

Depending on the natural groundwater quality in the ASR wells a buffer zone of recharged water may be needed which will add to the "Target Storage Volume". A preliminary estimate of the buffer volume is 30 days of supply (average = 10 ML/d) or 30 x 10 = 300 ML. The water for the buffer zone is only recharged once so the first year of ASR recharge would entail a volume of 1,300 ML. This is the initial Target Storage Volume.

4.6 Hydrogeology

Careful evaluation of area hydrogeology will aid in the selection of suitable storage zones, recharge water treatment requirements and usually will affect the location and design of ASR facilities. The hydrogeologic characteristics of the AWS region are reasonably well known with 1500 well records available for review. However there are only nine observation wells that are concentrated in 3 aquifers in the Parksville – Qualicum area. There are thirteen mapped aquifers in the region. See Figure 1 for Aquifer locations. A detailed assessment of the area hydrogeology is provided in Discussion Paper 5-1, section 5.

Hydrogeology is not the only consideration in selecting a feasible ASR facility. Siting the ASR facility close to the water treatment plant and/or where there are existing, large diameter water pipelines is also important. It would also be advantageous if the ASR wells were located at the end(s) of the distribution system which would facilitate efficient distribution during peak demand periods. There is no single site available that could meet all the desired criteria. However we have undertaken a screening exercise on the 13 known aquifers to identify the most suitable aquifer for ASR development. Several criteria were evaluated to compare suitability among the 13 known aquifers. They are summarized as follows.

- **Confinement** – confined aquifers are most suitable for ASR, confinement of the ASR storage zone above and below by impermeable or semi-permeable layers is highly desirable to facilitate 100% recovery of recharged water.

- **Groundwater quality** – a low level of mineralization in the native groundwater decreases the threat of adverse geochemical reactions and reduces/eliminates the need for a treated water buffer zone.

- **Depth of storage zone** – deeper storage zones are advantageous especially if they are below the zone that is highly developed by domestic wells, potential conflicts are then avoided. Deep confined aquifers are also safe from contamination from surface sources.

- **Depth to water** – the depth of the natural groundwater level in the ASR zone is an important issue. If the water level is too high (water level in wells near ground surface) it will require high pressures to inject water into the storage zone. It is acceptable for ASR wells to become flowing artesian but pressures should not exceed 30 psi. Also nearby existing wells could become flowing artesian and if confinement is not complete springs may be created. This should be avoided.

- **Transmissivity** – water bearing zones with higher transmissivity allow for completion of higher yielding wells and therefore reduce the number of wells required. Locating the ASR wells in higher transmissivity zones (layers) is essential to economic feasibility of the ASR program.

- **Hydraulic gradient** – the groundwater level in any aquifer slopes down from the recharge area to the discharge area. The hydraulic gradient drives the flow in the aquifer. A low hydraulic gradient is desirable for ASR so that the recharged water will not move too quickly away from the ASR well.

- **Storage** – a large volume of water must be stored for large scale ASR programs. A large existing storage volume in the proposed ASR aquifer zone is desirable.

- **Multi-Layer** – the possibility for more than one storage zone at a single ASR well location is advantageous. More than one storage zone will mean more water stored in one well (and recovered) and hence less wells required to meet the required volume. Additionally in a multi-layer case there could be pairs of wells at individual sites. One well of the pair in the upper aquifer and one well in the lower aquifer. This may be necessary to avoid mixing of dissimilar water chemistry types within the aquifers. In some multi-layer situations water may also be recharged in one layer and extracted from the other layer. These situations are judged on a site-specific basis.

- **Distance to WTP** - an ASR well or well field closer to the proposed water treatment plant will reduce pipeline costs and be more convenient in the testing phase and for long term operation. Closer proximity to larger pipe sizes is also desirable.

- **End of System Location** – ASR wells located near the ends of the water distribution system would also be advantageous for water distribution especially at times of peak demand. Backfeeding the service area during peak demand will help maintain system pressures. Additionally distribution system retention times can be reduced during low demand periods thereby maintaining excellent water quality for the consumers.

- **Development** – the level of development in the proposed ASR aquifer zone must also be considered. The lower the number and density of existing wells the less chance for conflicts with existing users.

The thirteen mapped aquifers in the AWS region were graded with respect to the above eleven criteria. A simplified grading system was utilized assigning scores of 0, 5 and 10 points for poor or least favourable; fair or average; good or best of range, respectively. For example "confinement", an unconfined aquifer was assigned a score 0, a partially confined aquifer was assigned a score of 5 and a confined aquifer scored 10. In the case of "Development" the density of 11 – 14 wells per km^2 was assigned a score of 0, 7- 10 assigned a score of 5 and densities 2 – 6 scored 10. The results of this comparison of existing aquifers regarding suitability for ASR development is provided in Table 1 as follows:

The comparative analysis indicates that the Nanoose Creek Aquifer (Aquifer # 219) is by far the most suitable aquifer in the region for ASR development.

Table 1

Aquifer Number	Aquifer Location / Name	Confinement	Water Quality	Depth	Hydraulic Gradient	Depth to Water	Transmissivity	Storage	Multi-Layer	WTP * Large Pipes Distance	End of System Location	Development	Total Scores
664	Little Qualicum River	0	10	0	5	0	10	0	0	0	10	5	40
663	Upper Whiskey Creek	0	5	0	5	0	5	0	0	0	5	10	30
217	Qualicum	5	5	5	10	5	10	5	0	0	10	10	65
212	Parksville	10	10	5	5	5	0	0	0	5	0	5	45
216	Parksville	5	5	5	5	5	5	5	0	10	0	5	50
220	Errington	10	5	10	5	0	0	0	0	5	0	0	35
209	Errington	10	10	0	5	0	0	0	0	0	0	10	35
219	**Nanoose Creek**	**10**	**10**	**10**	**5**	**10**	**5**	**10**	**10**	**10**	**10**	**10**	**100**
221	Parksville	5	10	0	10	0	5	0	0	5	0	10	45
214	Madrona Point	5	5	5	10	0	0	0	0	10	5	10	50
218	Nanoose Hill	5	10	10	5	0	0	0	0	0	10	10	50
210	Nanoose Bay	5	10	10	5	0	0	0	0	0	10	0	40
213	Lantzville	5	0	10	0	5	0	5	0	0	10	10	45

* *WTP - Water Treatment Plant*

4.7 Selection of Recharge Process

Considering the water supply available from Englishman River and the water demand it is readily concluded that recharging an aquifer from the river is feasible. The screening exercise in 4.6 indicates the most suitable aquifer to be recharged is Aquifer 219.

An aquifer can be recharged from surface via infiltration basins or recharged by wells. Aquifer 219 is capped by a confining layer (two layers in some places) that is at or near ground level in most areas. Therefore recharge from surface is not an option.

Recharging the aquifer could be accomplished by single-purpose injection wells where the injected water would be recovered by single-purpose production wells offset from the injection wells. However single-purpose injection wells invariably become clogged and rehabilitation costs become prohibitive. Preferably ASR will be utilized whereby recharge and discharge are accomplished with dual purpose wells. Case studies since 1968 indicate ASR wells will be more likely to meet water management objectives. A Phase 2 testing program will be required to finalize the recharge-discharge process design.

4.8 Site Selection

It is evident that the ASR wells should be located in Aquifer 219. This aquifer is however 27 Km^2 and 13 km long stretching from Nanoose Harbour to Parksville Bay. Detailed hydrogeology characterization has been completed to aid in selecting specific sites for testing in Phase 2. The existing and proposed water treatment and distribution network have equally been considered to make preliminary site selections.

Three simplified hydrogeology cross-sections are provided in the attached Figures 3, 4 and 5. A location plan for the cross-sections is provided in Figure 2. All three cross-sections show an upper and lower (in elevation) permeable layer. The lower permeable layer is found at elevations ranging from 50 m. above to 30 m. below mean sea level. The lower unit is comprised of sand layers and sand and gravel layers usually with the sand and gravel at the bottom. This permeable layer is confined above and below by low permeability sediments or low permeability bedrock. This aquifer is often referred to as the lower Quadra Aquifer but this writer and others theorize that because the lower and upper sand layers are separated by glacial and marine sediments then the lower layer originated from an older deposit. The upper unit is Quadra sand.

4.8.1 Geological Interpretations

The vast majority of unconsolidated geologic materials (silt, sand, gravel, till, clay) on the East Coast of Vancouver Island were deposited during glacier advances and retreats. Sand and gravel layers deposited by these glacial events form the most productive known aquifers in the region. Climate changes over the last 3 million years have lead to many ice-ages with creation of continental ice sheets. Evidence on Vancouver Island indicates three glacial advances and retreats. The glacier advance moved southward from the Mainland, Coast Mountain Ranges, filling the Georgia Depression (Georgia Strait) with ice up to 2 km thick. The ice sheet covered the east coast of Vancouver Island up to an elevation of approximately 300 m. AMSL. The higher Mountain Ranges remained free of ice but local valley glaciers also formed. Also due to sea level fluctuation and the depression of the land surface, due to the weight of the ice, the ocean shoreline has moved dramatically. In the study area the highest ancient ocean shoreline is observed at the present day 200 m. AMSL elevation.

The main glacier retreated from South to North and therefore the northern most 5 km of the Englishman River Valley was blocked by ice for a considerable time. At this time the valley drained to Nanoose Harbour. Also flows in the valley were much greater because of glacial melt-water. As the valley drained to Nanoose Harbour vast quantities of sand and gravel were deposited in an alluvial-delta complex. This same scenario was true for the Nanaimo River which emptied into Ladysmith Harbour and formed the Cassidy Aquifer. Also this occurred at the Puntledge River in Courtenay.

There is also a bedrock channel trending SE-NW in the study area. An example transect cutting across the channel from Stewart Road (bedrock elevation – 120 m. AMSL), to Rocking Horse Subdivision (bedrock elevation – 20 m. below mean sea level) and up to Morello Road (bedrock elevation - 140 AMSL). This channel corresponds to the old Englishman River channel we have theorized.

The elevation of the lower permeable layer (shown in Figures 3, 4 and 5) also slopes down from Englishman River to Nanoose Bay. In cross-section C-C' (Figure 5) the layer is at approximately 15 m. AMSL and approaching the Bay (cross-section A-A', Figure 3) the elevation is 25 m. BMSL. This permeable layer is often comprised of an upper sand layer and lower sand and gravel layer but the latter is sometimes absent. The lower sand & gravel layer has wells with yields up to 1.6 ML/day (eg. Fairwinds Wells 1 to 3).

It can also be noted on Section C-C' that Englishman River appears to be an undersized stream. That is the valley is much larger than the present stream requires. This is because the valley was cut by the previous glacial meltwater flows that were much greater than present day flows.

Most unconsolidated aquifers in the AWS are underlain by Nanaimo Group sedimentary rocks. This rock unit is an aquifer in places but has low transmissivity and supports only lower yielding wells, 0.07 ML/d or less.

However the eastern end of Aquifer 219 is underlain by the Nanoose Complex bedrock type. See the bedrock map shown in Figure 6. This is a much older metamorphosed volcanic and limestone rock unit. These rocks are much older than the Nanaimo Group rocks and have been thrust up from great depth by tectonic forces. These forces are created by the collision of the Vancouver Island tectonic plate with the North American tectonic plate. Furthermore the Nanoose Complex Rock Unit has been intruded by a granitic magma (Island Plutonic Suite). This intrusion involves an upwelling of molten rock which forces itself upward through older rocks. Given these stresses that have been exerted on the Nanoose Rocks significant fracturing must have occurred. These fractured rock zones are saturated at depth and can be productive aquifers.

Furthermore the limestone layers within the Nanoose bedrock unit may have undergone solution weathering which creates large openings that can create productive aquifers.

4.8.2 Favourable Area and Potential Sites

Considering the geological and hydrogeological interpretations we have identified the most favourable area for ASR well exploration. The favourable area is shown in Figure 2. Preferred areas for exploration within the favourable area are also outlined. These areas are preferred primarily because more information was available to confirm suitability. Sites were not selected closer to the WTP because it is underlain at shallow depth by Nanaimo Group bedrock.

It should also be noted that we have allowed for deeper exploration drilling that could identify suitable zones for ASR development below the known and developed aquifers. Deeper aquifers can be more useful for ASR because of; greater confinement, lower groundwater flow velocity, higher yield and less interference with other wells. ASR wells are less susceptible to problems in deeper aquifers that usually have poor water quality and are not used for potable supplies.

The potential ASR well sites meet the following criteria:

- Located within 2 km or less of the 400 mm existing water main on Northwest Bay Road or the Water Treatment Plant
- Located near the end of the water distribution system (End at Nanoose Bay)
- At less than 100 m. geodetic for best energy efficiency
- At least 2,500,000 m^3 of storage volume per km^2 is available at each of the preferred areas
- Individual well capacities are likely to be sufficient to limit the required well field to 5-10 wells
- Offsets are possible to existing wells such that there should not be conflicts

4.9 Conceptual Design

The design concept is to construct nine wells in a grid pattern with 200 m. offsets. This requires an area of 400 m. x 400 m. Discharge pipes from the wells would be connected to a header which would lead to the nearest large water main or the WTP. A second smaller water line would be connected to each well and this would lead to a Rapid Infiltration Basin where back-wash water would be discharged. The wells would be equipped to enable backflushing independently while recharging the remaining wells. See Figure 7 for one possible layout.

The wells would be up to 125 m. deep and approximately 300 mm. diameter. The combined well yield would be adequate to meet the maximum ASR design flow of 104,233 m^3 week. We would recommend a 10% excess capacity to provide a safety factor to meet needs when a well is offline during peak demand. This leads to a design maximum flow from ASR wells of 114,400 m^3/wk or 16,350 m^3/day and 1,816 m^3/d per well on average (21 L/s). Aquifer characteristics are estimated as follows:

- Transmissivity – 150 m^2/d
- Storativity – 0.004
- Specific capacity – 0.125 L/s/m

- Porosity – 0.30
- Thickness – 12.0 m.
- Flow velocity – 0.29 to 0.38 m/d
- Hydraulic gradient – 0.007 to 0.009

4.10 Existing Wells

It is very unlikely that any existing well(s) will be available for ASR testing but we will investigate the possibility. All existing wells in the vicinity of a proposed ASR testing site will be investigated as some may be useful as monitoring wells.

4.11 Hydrogeologic Simulation Modelling

There was an aquifer computer model study completed for the RDN covering the Nanoose Peninsula in 1994. The model completed by Terracon Geotechnique Ltd. covers all of the area favourable for ASR wells. The modelling output is very useful and has been used in our analysis.

4.12 Target Storage Volume

Water balance modeling by AE indicates that ASR withdrawals will occur over a 14 week period with flows ranging from 8,800 m^3/wk to 104,200 m^3/wk. The total annual ASR withdrawal will be approximately 1,000,000 m^3. For the first year of operation we would aim to also recharge an additional 30 day supply of treated water to help ensure water quality will be maintained during the withdrawal period. Hence the first year Target Storage Volume would equal 1,000,000 + 300,000 = 1,300,000 m^3. The recharge volume of 1,000,000 m^3 should be adequate in the following years. Recharge will be possible over at last 26 weeks per year and therefore daily and weekly recharge volumes can be significantly smaller than withdrawal rates. An approximate 5,560 m^3/d or 39,000 m^3/wk recharge flow will be adequate.

4.13 ASR Test Program

Phase 2 of ASR development is a testing program to confirm feasibility. Firstly in this case we recommend drilling 6 test wells (200 or 250 mm. diam.) within the three preferred site areas. These wells would locate the best site for the ASR test well construction. The 6 test wells would also be used for sampling aquifer materials and groundwater. Some of these wells would be pumped to determinate aquifer hydraulic parameters. Test well depths could be 100 to 450 m.

Once the most promising ASR well site is located a full size ASR well would be constructed and equipped for cycle testing. The ASR test well would also be connected to the nearest watermain or the Englishman River Water Intake so that it can be recharged with river water. A basin for backwash water disposal would also be constructed near the ASR well. The need to treat the recharge water will be assessed as part of the Phase 2 program. It will be advantageous to do ASR testing before the water treatment plant is constructed. Therefore there will not be a source of filtered water for testing. As the river water is good quality this may not be an issue. A simple treatment system will be used if necessary. Water discharged from the ASR test well could be disposed in a local ditch or creek.

The test program will include a careful assessment of the many issues of concern. Well plugging is always a primary issue; however others of importance may include the following:

- geochemical effects such as cation exchange, precipitation, or dissolution and their effects upon well plugging, recovered water quality or changes in ambient water quality in the surrounding aquifer
- backflushing frequency required to maintain recharge capacity and to control well plugging
- mixing characteristics between stored and native water
- water quality changes for selected constituents of interest
- improvement of water quality with successive ASR cycles
- effect of storage time on water quality response
- recovery efficiency
- trickle injection flow rate during periods of no recharge or no recovery, required to maintain a disinfection residual in the well (this may also be required to maintain a target recovery volume in a highly brackish or seawater aquifer subject to density stratification losses)
- regional and local response of water levels to ASR operations (recharge, storage, recovery)

Other site-specific testing objectives may also occur. Depending upon the relative importance of each of these concerns, the test program design will typically adjust to meet site-specific needs.

Data collection will include:

- flow rate during recharge and recovery
- cumulative volume stored
- water level or pressure in ASR well
- water level response in observation wells
- elevation of measuring points
- water chemistry testing

ASR cycle (recharge – discharge) testing would begin with a short cycle, 1-2 days, followed by 200-300% recovery and water quality testing to confirm reactions. There would be a minimum of 3 cycles with the last cycle approaching operational range. The number of cycles can vary and up to 10 cycles may be undertaken. Storage time must also be allowed for potential chemical reactions (eg. Mn dissolution). If plugging is the main issue (anticipated) then fewer and longer cycles are recommended. The frequency of water sampling will depend on variability. Both river and aquifer water qualities are very good and water chemistry may not be an issue. It is anticipated that the testing program will last 6 to 18 months. After testing is complete a report will be prepared including a plan for field expansion.

4.14 Regulatory, Water Rights and Environmental Issues

Under the BC Water Act a water licence will be required to take water from Englishman River to recharge the ASR well(s). The BC Government is now considering modernizing the Water Act and a discussion paper has been developed to encourage a dialogue on modernization. Therefore the Act may be revised in the near future. Under the present Act there is no permit/license required to recharge an aquifer. BC does not have regulations specific to extraction/development of groundwater resources. There is groundwater protection legislation which deals mainly with protection of groundwater quality, well construction and closure specifications and drillers and pump installers registration.

Under the Environmental Assessment Act the ASR project may be reviewable. Any single well constructed that is proposed to produce a flow greater than 75 L/s is considered a reviewable project. If the ASR program involved several wells with flows <75L/s but combined to extract > 75 L/s the need for a review is unclear. In any case the monitoring, sampling, hydrogeology modeling and reporting required for the project would likely satisfy the review requirements if applicable.

Regarding ASR well testing and ASR well field development any permanent waterworks constructed would require a “Waterworks Construction Permit” from the Vancouver Island Health Authority (VIHA). Also any well(s) to be used for drinking water supply will require “Water Source Approval” from VIHA. Submissions to VIHA need to be made well in advance as the turnaround time is lengthy. Wells can be drilled and tested prior to the submission for a waterworks construction permit.

It is also recommended as a courtesy to apprise the Regional Environmental Protection Manager (MOE, Nanaimo) of any ASR well development.

From an environmental perspective ASR is generally considered a benefit as it makes more efficient use of water resources and minimizes negative impacts. For this particular project there may be three concerns; degradation of existing groundwater quality, impacts on surrounding wells and impact on Englishman River. The proposed ASR program involves recharge of treated river water that would meet all drinking water quality standards into an existing aquifer. The recharge water quality will be superior to the aquifer water quality and no negative impacts are anticipated. The ASR well field can be located distant enough from neighbouring wells to minimize impacts. Neighbouring wells may experience an increase in the water level or a positive impact. Withdrawals from Englishman River will be during high flow periods and will represent a very small portion of the flow.

For example the mean annual river discharge during a 100 year drought is 7.21 m^3/s. The proposed ASR withdrawal is a maximum of 0.1 m^3/s (62,000 m^3/wk during the high flow periods). When a river low flow of 1.44 m^3/s must be maintained there will be no ASR recharge withdrawal. Summer low flow in the river may be positively impacted if an ASR site near the river is selected. The ASR recharge will lead to higher aquifer water levels throughout most or all of the year. Groundwater discharge to the river will be increased if the native groundwater is at higher pressures because of a nearby ASR well field. Also aquifer geometry is such that the ASR wells cannot draw water from the river.

4.15 Institutional Constraints

Various institutional constraints may impede progress on an ASR program, some examples are as follows:

- lack of access to recharge water sources
- operational issues within the AWS that may impact integration of ASR
- higher priority water management programs that may inhibit progress on ASR despite its advantages

- outdated policies that are not amenable to ASR potential opportunities
- competing agendas, such as limiting growth or for promoting other high profile water management options
- the desire for a “monument” visually more impressive than an ASR well field. However typically an ASR publicity event for the first well is undertaken with the unveiling of a bronze plaque or similar marker.

None of the above constraints should impede progress on ASR development for the Arrowsmith Water Service.

4.16 Economic Considerations

In the vast majority of cases ASR can be used to meet water system expansion goals while achieving significant cost savings. There are three costs we will consider; the Phase 2 testing program, the full system capital costs and the ASR well field operation costs.

4.16.1 Phase 2 Testing Program

The testing program outlined in <u>section 4.13</u> is estimated to cost as follows:

- Assume drilling to 110 m. depth

1.	Geophysics and test well siting work	$60,000.00
2.	Test well drilling (6 wells)	$300,000.00
3.	Pumping tests on selected test wells (4 wells)	$45,000/00
4.	Water and soil sample collection & analysis	$10,000.00
5.	ASR Well construction (1-300 mm. well)	$80,000.00
6.	ASR Well initial pumping test	$25,000.00
7.	Temporary water connection for ASR Well (2 km)	$200,000.00
8.	RIB basin for backflushing discharge	$35,000.00
9.	Monitoring well loggers	$3,000.00
10.	Surveying	$25,000.00
11.	ASR Well cycle testing	$50,000.00
12.	ASR Well equipment/piping	$60,000.00
13.	ASR Well head power	$50,000.00
14.	Field supervision drilling & testing	$60,000.00
15.	Project Management/Engineering/Hydrogeology	$110,000.00
16.	Aquifer computer modelling	$50,000.00
17.	Contingency for deep well test*	$100,000.00
	Total cost	$1,263,000.00

** If a deep (up to 450 m. depth) drilling site was selected for ASR testing the well construction costs would increase however less wells would be required for the final installation. The deep well option would only be chosen if well yield could be significantly increased.*

4.16.2 ASR Well Field Capital Cost

Capital costs for ASR well fields are discussed in the text *Aquifer Storage Recovery, A Guide to Groundwater Recharge Through Wells,* R. D. G. Pyne, 2005 sec. 6.1. Here a

range of costs for many sites is provided. Up to date estimates of ASR Capital Costs are in the range of $140 - $570 CDN per m^3/d of recovery capacity.
For our proposed ASR well field the cost range would be:

Well field capacity -	15 ML/d or 15,000 m^3/d				
Least Cost:	15,000	x	140	=	$2,100,000.00
Maximum Cost:	15,000	x	570	=	$8,550,000.00

After reviewing the site specifics for the AWS region a first-cut estimate of capital cost is $330.CDN per m^3/d capacity or 15,000 x 330 = $4,950,000.
This cost estimate includes the ASR Test Program cost but does not include permanent pipeline connection cost or the cost of well field land.

ASR well field operating costs have also been estimated. Data on operating costs is sparse however a reasonable or typical cost is $4.25 CDN per m^3/d recovery capacity or 4.25 x 15,000 = $64,000.00/year in this case.

4.16.3 Cost Comparisons

With over 100 successful ASR projects completed in North America cost comparisons have been made for water system expansion with ASR versus expansion without ASR. The cost savings with ASR range from 57% to 90%.

5 Conclusions

1. Our preliminary feasibility assessment for an ASR program within the AWS indicates ASR is feasible.

2. As stated in Sec. 4.9 the proposed ASR well field could supply 16,350 m^3/day. This is the design flow rate that could be sustained for up to approximately 60 days. Additionally the peak day flow rate will be 30% higher or 21,255 m^3/day. This is because the standard well capacity calculation includes a 30% safety factor based on total annual production. On a short term basis (several days) this safety factor is redundant.

3. The ASR option for increased water supply capacity is superior with respect to cost, environmental concerns, supply security and it is scalable. With the immense volumes of excellent quality water presently untapped ASR offers a huge water management opportunity.

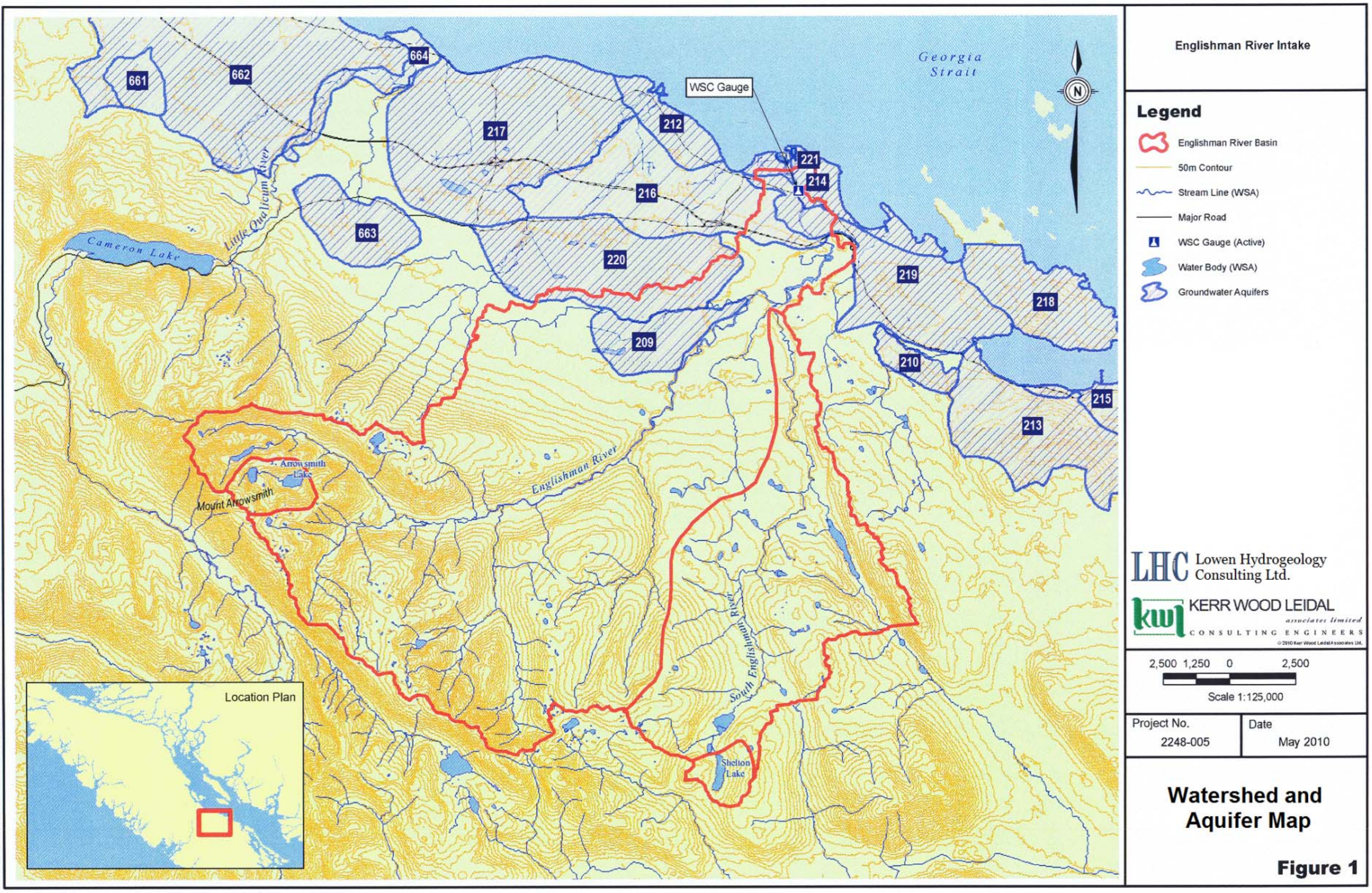
4. The total ASR capital cost is estimated at $ 5 million plus pipeline and land cost. This cost justifies proceeding with the ASR testing program.
5. There are many sites within the AWS region where ASR could be implemented.

6. A common problem with existing wells in the AWS region is long-term yield decline due to screen plugging by fine material. This issue should be greatly reduced/eliminated by ASR well design which allows for frequent back-flushing (weekly or monthly). Also flow in

ASR wells is reversed each year which also reduces the tendency of fines to collect around a well screen.

6 Recommendations

1. AWS should proceed with the Phase 2 ASR testing program as outlined.
2. Siting work for the ASR exploration wells should proceed soon to allow for completion in a timely manner.
3. We recommend progress reports be submitted after each major step in the ASR testing program.
4. The testing program budget should include a 20% contingency as flexibility is essential in groundwater exploration programs.


Georgia Strait
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Cameron Lake
Little Qualicum River
Arrowsmith Lake
Mount Arrowsmith
Englishman River
South Englishman River
Shelton Lake
Location Plan
N
Englishman River Intake
Legend
Englishman River Basin
50m Contour
Stream Line (WSA)
Major Road
WSC Gauge (Active)
Water Body (WSA)
Groundwater Aquifers
LHC Lowen Hydrogeology Consulting Ltd.
KERR WOOD LEIDAL associates limited CONSULTING ENGINEERS
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2248-005
Date
May 2010
Watershed and Aquifer Map
Figure 1

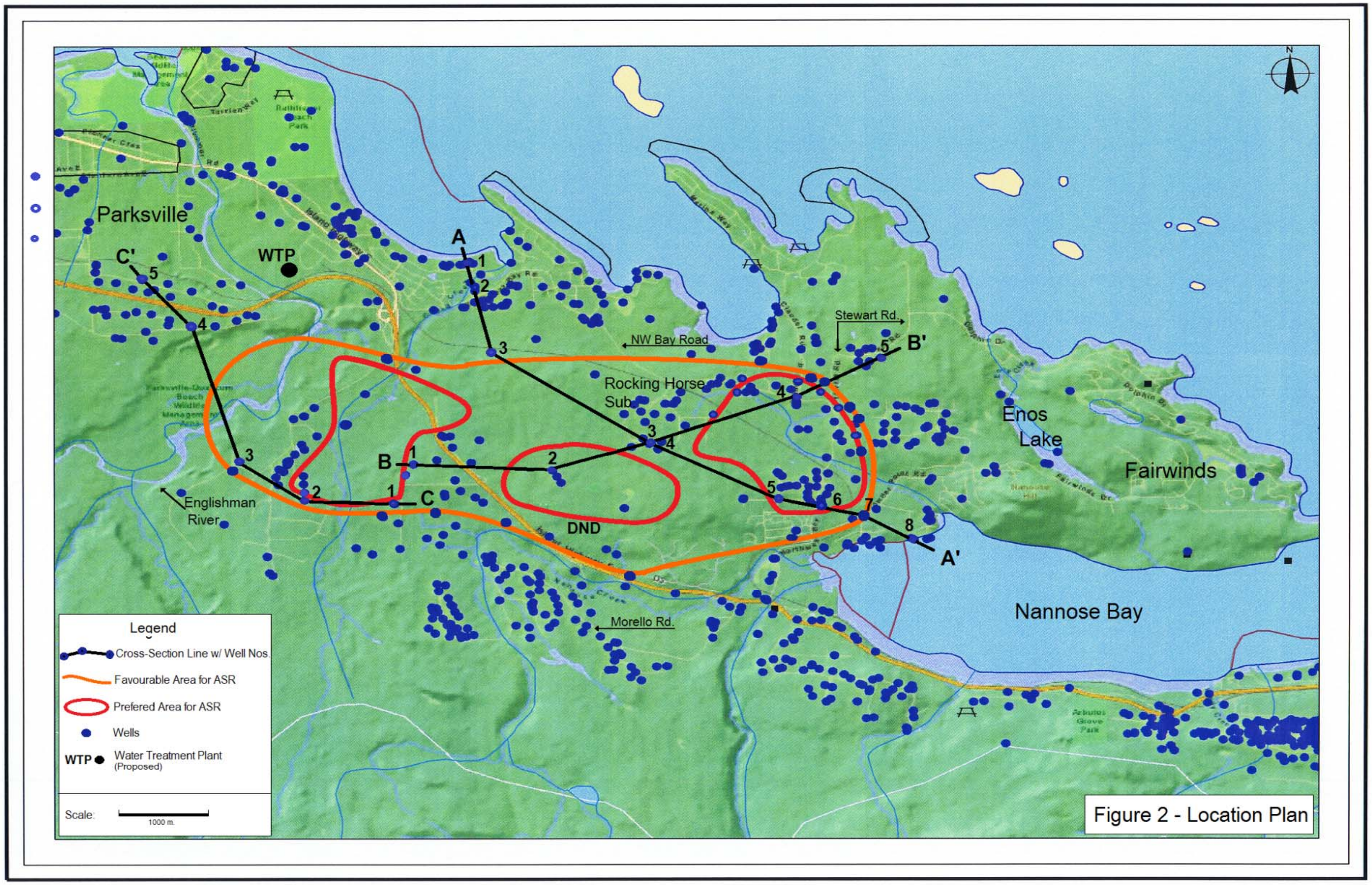

Figure 2 - Location Plan

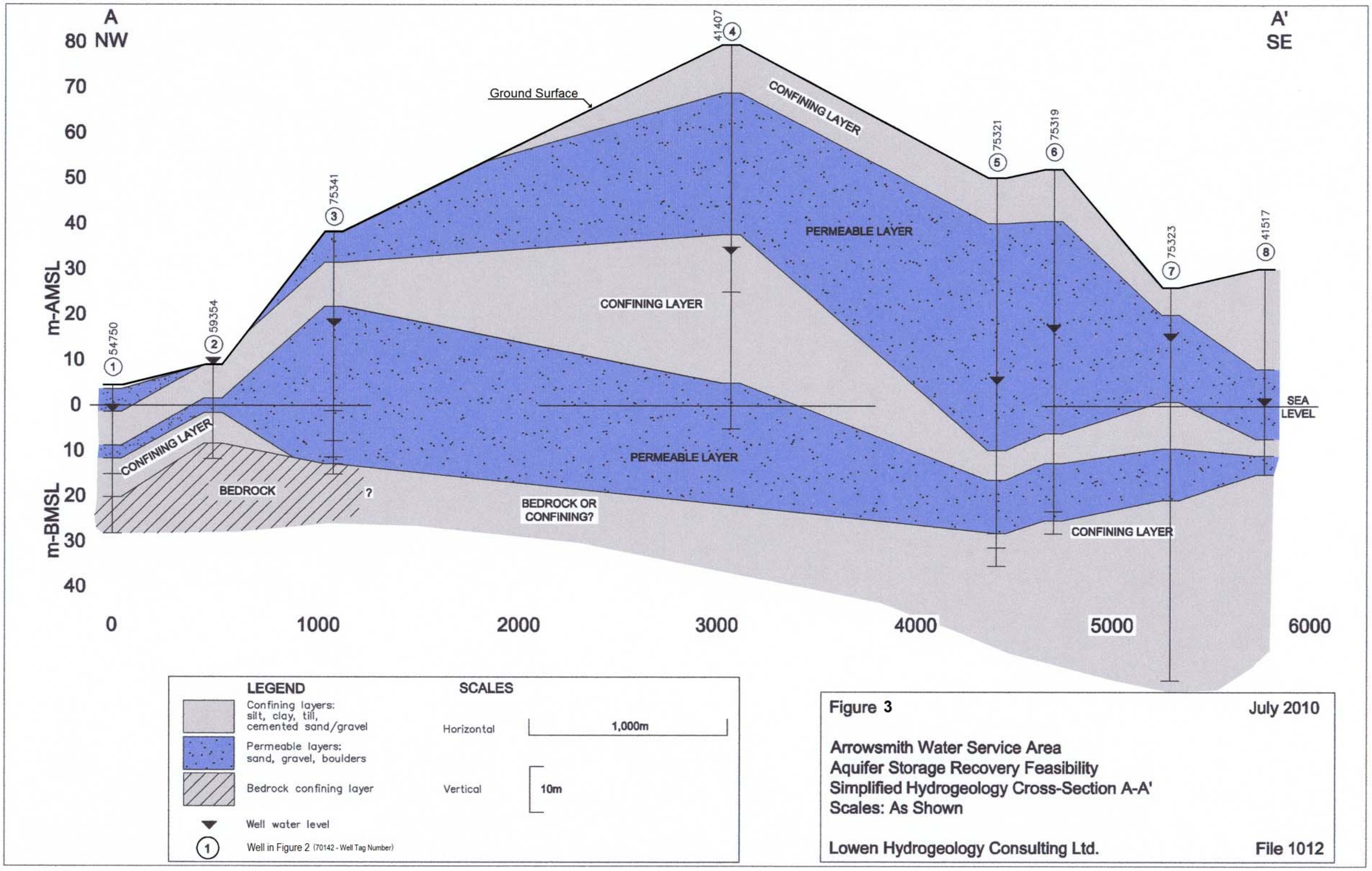

Figure 3 July 2010

Arrowsmith Water Service Area
Aquifer Storage Recovery Feasibility
Simplified Hydrogeology Cross-Section A-A'
Scales: As Shown

Lowen Hydrogeology Consulting Ltd. File 1012

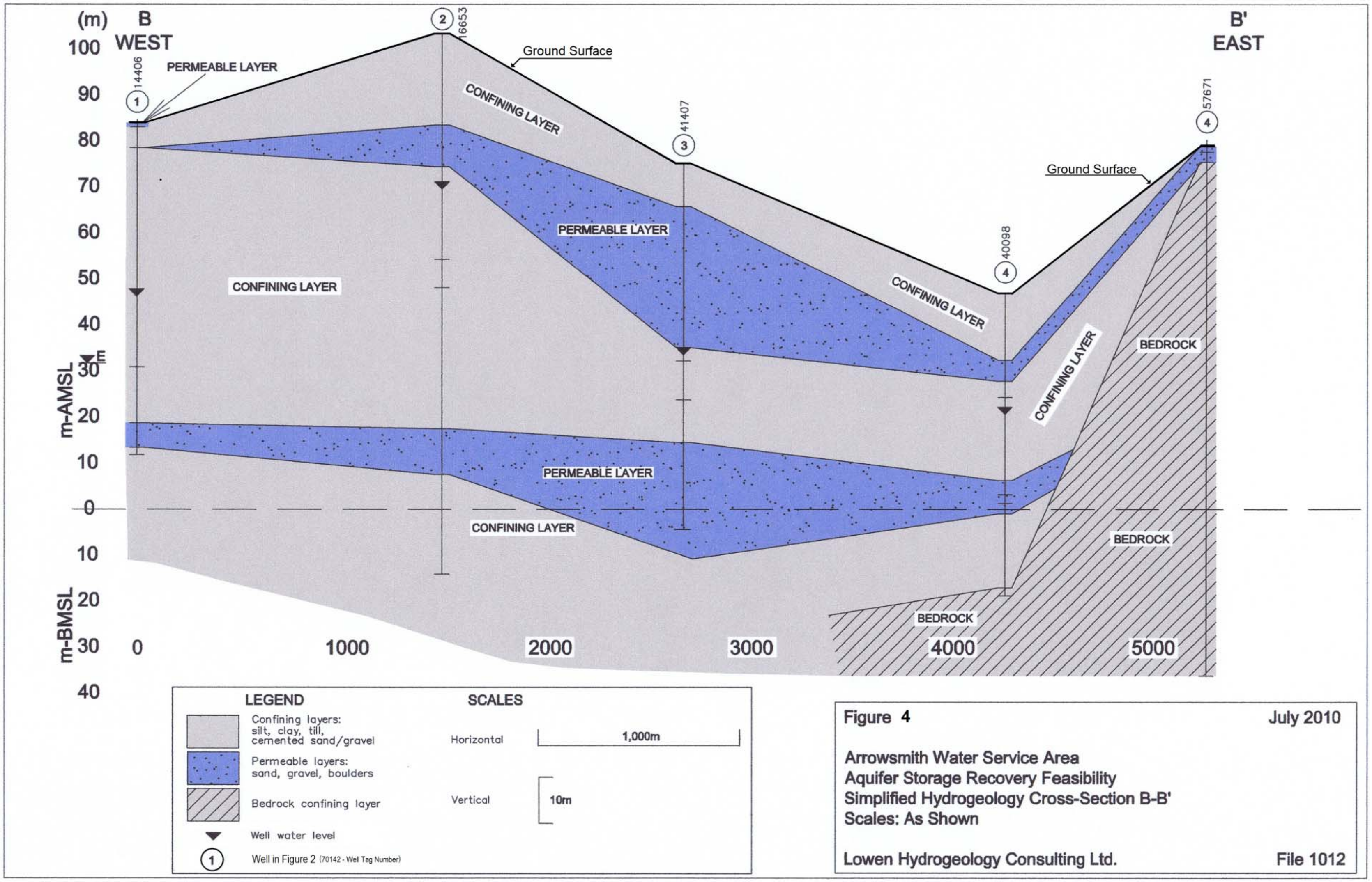

Figure 4 July 2010

Arrowsmith Water Service Area
Aquifer Storage Recovery Feasibility
Simplified Hydrogeology Cross-Section B-B'
Scales: As Shown

Lowen Hydrogeology Consulting Ltd. File 1012

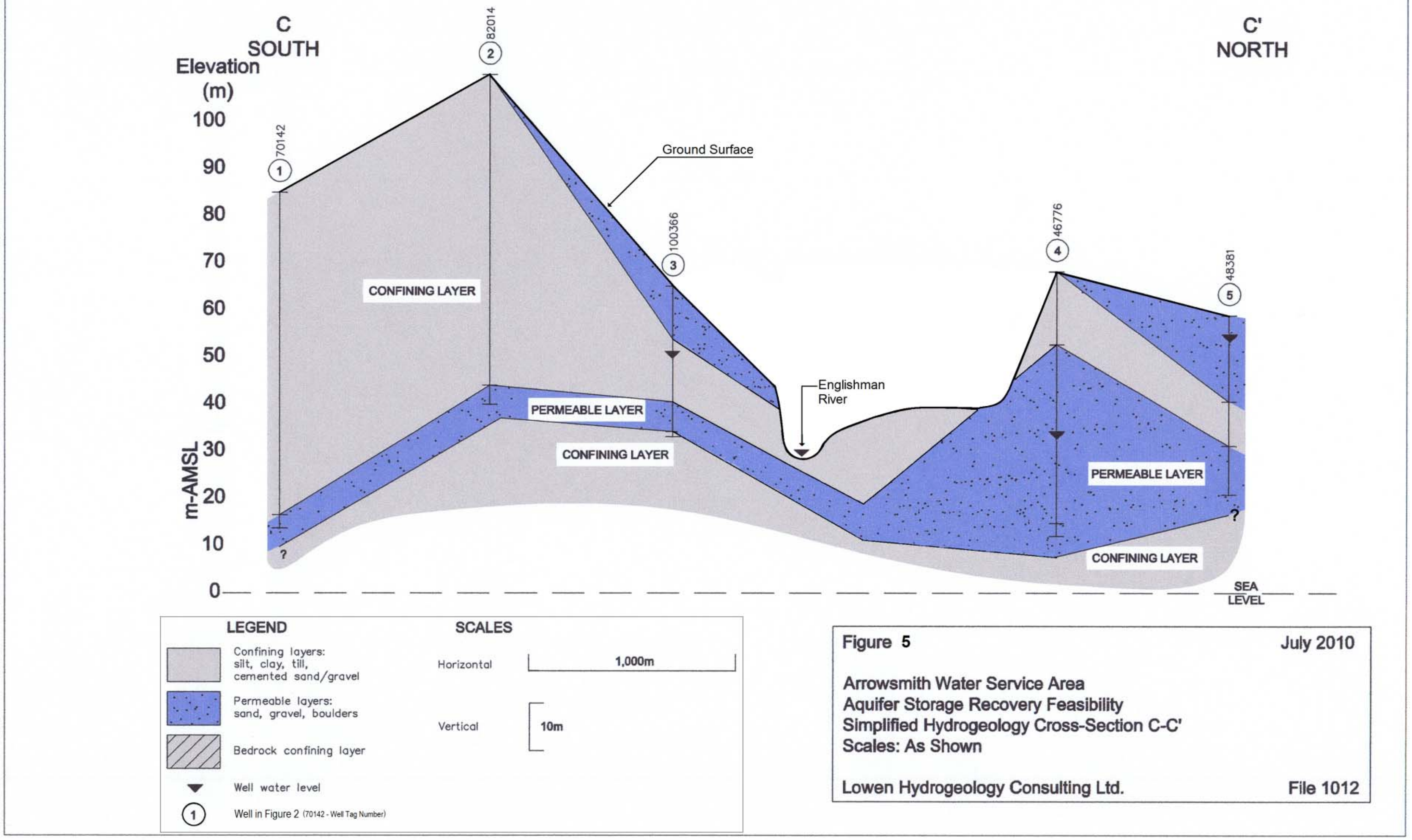

Figure 5 July 2010

Arrowsmith Water Service Area
Aquifer Storage Recovery Feasibility
Simplified Hydrogeology Cross-Section C-C'
Scales: As Shown

Lowen Hydrogeology Consulting Ltd. File 1012

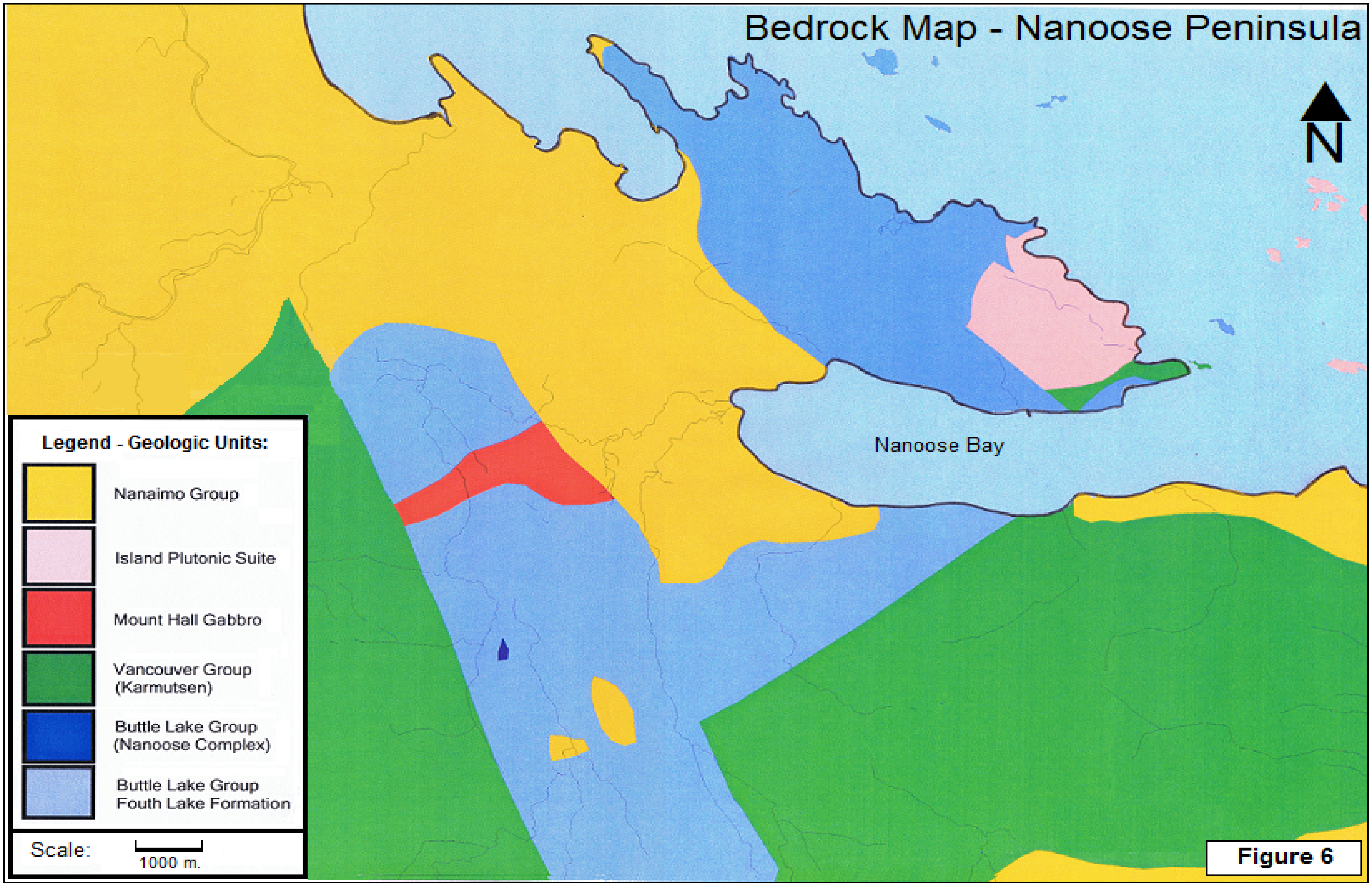
Bedrock Map - Nanoose Peninsula
N
Nanoose Bay
Legend - Geologic Units:
Nanaimo Group
Island Plutonic Suite
Mount Hall Gabbro
Vancouver Group (Karmutsen)
Buttle Lake Group (Nanoose Complex)
Buttle Lake Group Fouth Lake Formation
Scale:
1000 m.

Figure 6

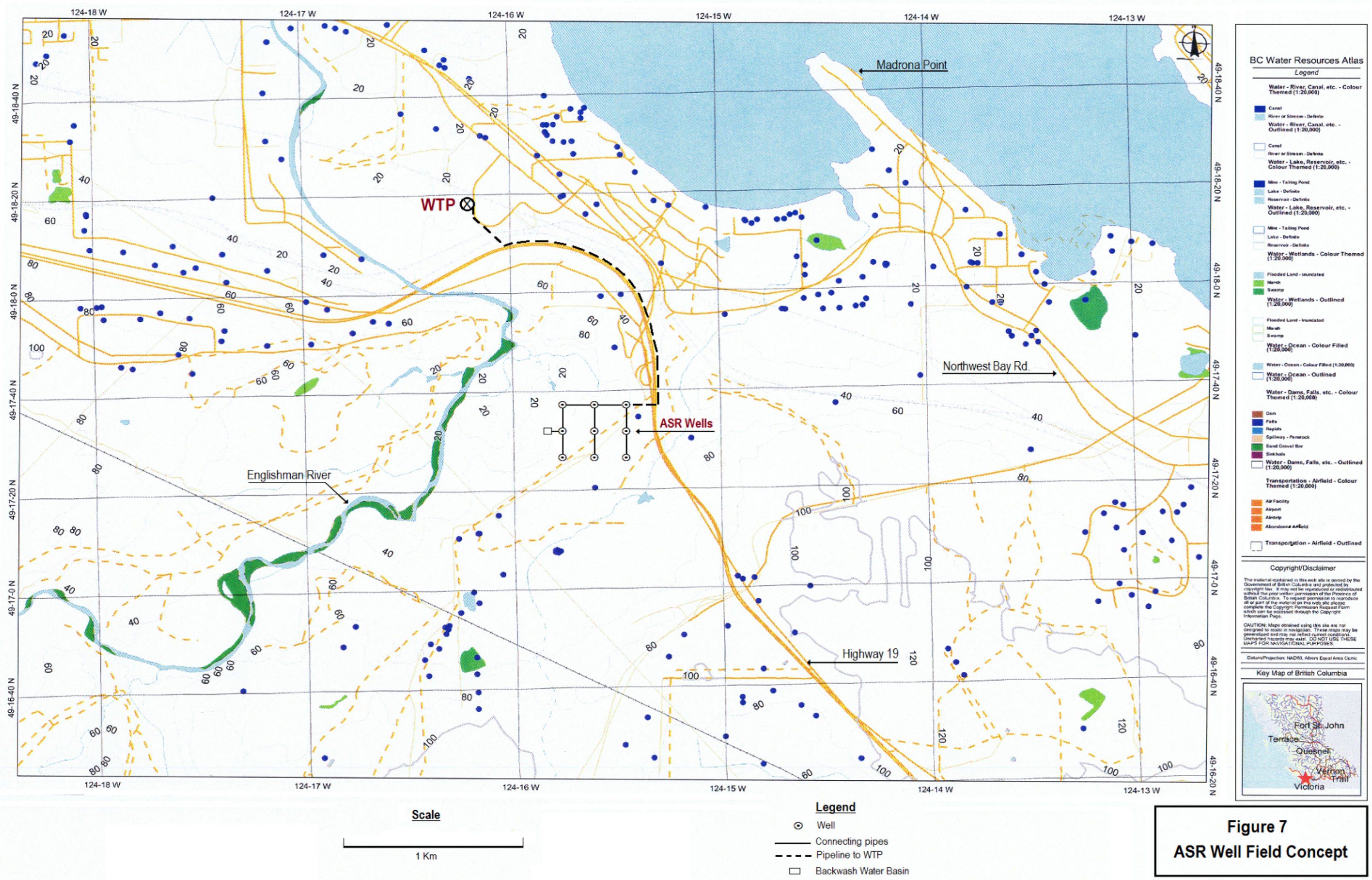

Figure 7
ASR Well Field Concept