Arrowsmith Water Service
Englishman River Water Intake Study
Groundwater Management

Discussion Paper 5-1

Existing Groundwater Supply Evaluation and Aquifer Yield Assessment

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1.0 INTRODUCTION

Lowen Hydrogeology Consulting Ltd. was retained in June 2009 by Kerr Wood Leidal to conduct an overview assessment of the groundwater resources in the Arrowsmith Water Service (AWS) Region. The following assessment has been completed by reviewing existing information sources available from published reports and the local and provincial governments. Additional information was supplied by Tony Koers of Koers & Associates Engineering Ltd. This discussion paper covers work tasks 5-1 and 5-2 from our work program with Associated Engineering.

2.0 SCOPE

Work was focused on the examination of aquifer characteristics and geometry augmented by interpretation of well production data and observation well hydrographs. Tasks included:

(a) developing conceptual models of the hydrogeology with geologic information and aquifer mapping;
(b) assessing water production data from pumping wells;
(c) estimating inflow to aquifers utilizing aquifer mapping, surficial geology and precipitation data, and;
(d) assessing the potential impacts of climate change on groundwater supplies considering aquifer characteristics and climate models.

3.0 METHODOLOGY

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

- well records and aquifer mapping available from the *BC Water Resources Atlas* (Ministry of Environment, 2009a);
- observation well hydrograph records and related information available from Ministry of Environment websites and office files (Ministry of Environment, 2009b and 2009c);
- climate and streamflow data from Environment Canada websites (Environment Canada, 2009a and 2009b);
- published reports, and;
- pumping records from community water systems.

4.0 DEFINITIONS

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

aquifer storage and recovery (ASR), involves injecting water into an aquifer through wells or by surface spreading and infiltration 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)

demand versus storage ratio, is the ratio of the amount of water being extracted from an aquifer on an annual basis versus the amount of water that is stored in the aquifer, the ratio may be expressed as a percent

demand versus recharge ratio, is the ratio of the amount of water being extracted from an aquifer on an annual basis versus the amount that naturally replenishes an aquifer each year from precipitation and lateral groundwater flow from upslope regions, the ratio may be expressed as a percent. Natural recharge can also be augmented by artificial recharge through aquifer storage and recovery (ASR)

storativity, storage factor or storage coefficient, refer 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 bedrock aquifers have low storativity values, for example, < 5 percent, depending upon bedrock type.

5.0 HYDROGEOLOGY

5.1 Aquifers

The Ministry of Environment (2009a) has identified and classified thirteen (13) aquifers in the AWS area utilizing the *BC Aquifer Classification System* (BCACS). These include seven (7) unconsolidated, sand and gravel aquifers, and six (6) bedrock aquifers as listed in Table 1 in order of size from largest to smallest. Aquifer locations are shown in Figure 1. Some aquifers outside the boundaries of the AWS area are also shown in Figure 1 and have not been labeled. Most of the aquifers were classified by W.S. Hodge in 1995-96.

The *BC Aquifer Classification System* classifies aquifers on the basis of the degree of development and the intrinsic vulnerability to contamination from potential sources of contaminants at the land surface. Shallow unconsolidated sand and gravel aquifers, for example, are regarded as highly vulnerable to contamination as opposed to deep sand and gravel deposits that may be confined by low permeability clay deposits and considered to have a low vulnerability to contamination. A detailed description of the BCACS is provided by Berardinucci and Ronneseth (2002).

Wei et al (in press) have categorized six general types of aquifers found in British Columbia based on their origin and geologic/hydrologic properties. Four main types of unconsolidated sand and gravel aquifers and two types of bedrock aquifers are recognized. In the AWS area, unconsolidated aquifers include;

(a) Type 1, unconfined fluvial or glaciofluvial aquifers along river/stream valleys;
(b) Type 2, unconfined deltaic aquifers, and;
(c) Type 4a, unconfined glaciofluvial outwash or ice contact deposits and Type 4b, confined aquifers of glacial or pre-glacial origin.

Bedrock aquifers include:

(a) Type 5a, fractured sedimentary bedrock, and;
(b) Type 6b, crystalline granitic, metamorphic, meta-sedimentary, meta-volcanic and volcanic rock aquifers.

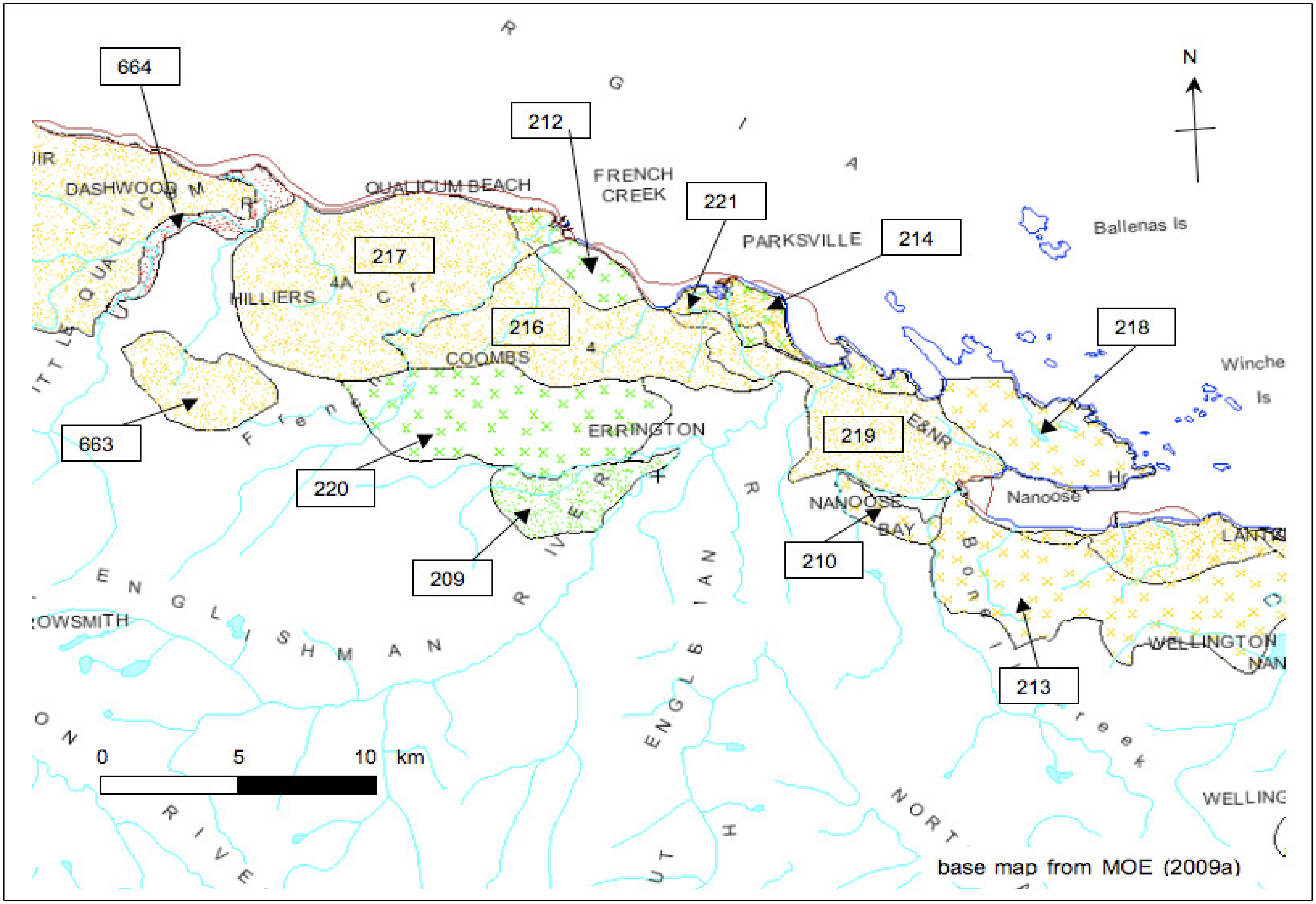


Figure 1. Classified aquifers in the AWS area.

Table 1. Classified aquifers in the Arrowsmith Water Service area.

Item	Aquifer Number	Aquifer Type	Location Description	Level of Development	Intrinsic Vulnerability	Ranking Value	Area km^2	Type of Water Use	Year Mapped
1	213	Bdrk	Lantzville	II	C	11	42	Domestic	1995
2	217	Uncon	Qualicum	I	B	14	42	Multiple	1996
3	219	Uncon	Nanoose Creek	II	C	10	27.4	Domestic	1996
4	220	Bdrk	Errington	II	B	10	26.6	Domestic	1996
5	216	Uncon	Parksville	I	B	13	24.9	Multiple	1996
6	218	Bdrk	Nanoose Hill	II	B	9	13.6	Domestic	1995
7	663	Uncon	Upper reaches of Whiskey Creek	III	A	13	9.6	Multiple	2004
8	209	Uncon	Errington	III	C	8	8.5	Domestic	1996
9	212	Bdrk	Parksville	III	C	6	5.9	Domestic	1996
10	214	Bdrk	Madrona Point/Parksville	III	B	10	5.6	Domestic	1996
11	664	Uncon	Little Qualicum River valley and delta	I	A	13	5	Multiple	2004
12	221	Uncon	Parksville	II	A	11	4	Domestic	1996
13	210	Bdrk	Nanoose Bay	II	C	7	3.4	Domestic	1996

Data from Ministry of Environment (2009a)

A brief description of each of the classified aquifers is provided below based on information available when the aquifers were originally identified and classified by MOE and from the *BC Water Resources Atlas*, Ministry of Environment (2009a):

Aquifer 213: Lantzville

- classified as moderately developed with low vulnerability to pollution from surface sources
- approximately 42 km^2 in area
- fractured bedrock aquifer comprised of rocks of the Vancouver Group, Buttle Lake Group and Nanaimo Group
- no reported quantity concerns
- isolated reports of hydrogen sulphide odour, elevated iron levels and salty water, possible sea water intrusion locally
- reported well depths range from 3 to 146 m (9 to 480 feet)
- depth to water ranges from flowing to 76 m (flowing to 250 feet)
- classified as moderately productive, reported well yields 0.005 L/s to 14.6 L/s (0.07 to 193 USgpm)
- principally domestic drinking water
- 129 reported drilled wells

Aquifer 217: Qualicum

- classified as highly developed with moderate vulnerability to pollution from surface sources
- approximately 42 km^2 in area
- confined, unconsolidated sand and minor gravel, Quadra Sand
- quantity concerns include water level declines noted in Observation wells
- localized quality concerns with regard to elevated levels of iron, manganese and isolated reports of elevated turbidity levels
- reported well depths range from 9.5 to 94.5 m (31 to 310 feet)
- depth to water ranges from 0.6 to 52 m (2 to 170 feet)
- classified as moderately productive, reported well yields 0.08 L/s to 31.2 L/s (1 to 412 USgpm)
- multiple use including domestic drinking water use and community water system production wells
- 120 reported drilled wells

Aquifer 219: Nanoose Creek

- classified as moderately developed with low vulnerability to pollution from surface sources
- approximately 27 km^2 in area
- confined, unconsolidated sand and minor gravel, Quadra Sand
- no reported quantity or quality concerns
- reported well depths range from 8 to 125 m (26 to 411 feet)
- depth to water ranges from 0.6 to 63 m (2 to 206 feet)
- classified as moderately productive, reported well yields 0.11 L/s to 15.5 L/s (1.5 to 205 USgpm)
- principally domestic drinking water use and community water systems

Aquifer 220: Errington

- classified as moderately developed with moderate vulnerability to pollution from surface sources
- approximately 27 km^2 in area
- fractured bedrock aquifer comprised of rocks of the Nanaimo Group
- no reported quantity concerns
- localized quality concerns including elevated fluoride and hydrogen sulphide
- reported well depths range from 2.4 to 130 m (8 to 425 feet)
- depth to water ranges from flowing to 60 m (flowing to 200 feet)
- productivity classified as low, reported well yields 0.04 L/s to 3.0 L/s (0.5 to 40 USgpm)
- principally domestic drinking water use
- 145 reported drilled wells

Aquifer 216: Parksville

- classified as highly developed with moderate vulnerability to pollution from surface sources
- approximately 25 km^2 in area
- confined and unconfined, unconsolidated sand and minor gravel, Quadra Sand
- quantity concerns include water level declines noted in Observation wells
- localized quality concerns with regard to elevated levels of iron, manganese and isolated reports of elevated turbidity levels
- reported well depths range from 6 to 122 m (20 to 400 feet)
- depth to water ranges from flowing to 58 m (flowing to 190 feet)
- classified as moderately productive, reported well yields 0.04 L/s to 6.4 L/s (0.5 to 84 USgpm)
- multiple use including domestic drinking water use and community water system production wells
- 125 reported drilled wells

Aquifer 218: Nanoose Hill

- classified as moderately developed with moderate vulnerability to pollution from surface sources
- approximately 14 km^2 in area
- fractured bedrock aquifer in Nanaimo Group, Buttle Lake Group and Island Plutonic Suite
- no reported quantity concerns
- quality concerns include isolated report of elevated manganese
- reported well depths range from 14 to 186 m (45 to 610 feet)
- depth to water ranges from flowing to 37 m (flowing to 120 feet)
- productivity classified as low, reported well yields 0.007 L/s to 3.4 L/s (0.1 to 45 USgpm)
- principally domestic drinking water use
- 52 reported drilled wells

Aquifer 663: Upper reaches of Whiskey Creek

- classified as lightly developed with high vulnerability to pollution from surface sources
- approximately 10 km^2 in area
- unconfined unconsolidated kame terrace and kame delta, sand and gravel deposits
- no reported quantity concerns
- quality concerns include elevated iron and manganese
- reported well depths range from 7.9 to 29 m (26 to 95 feet)
- depth to water ranges from 2.3 to 18.9 m (7.5 to 62 feet)
- classified as moderately productive, reported well yields up to 3.8 L/s (60 USgpm)
- transmissivity value reported at 240 to 480 m^2/day (19,325 to 38,650 USgpd/ft)
- domestic drinking water and community water supply system
- small number of reported wells (14)

Aquifer 209: Errington

- classified as lightly developed with low vulnerability to pollution from surface sources
- approximately 9 km^2 in area
- confined, unconsolidated sand and minor gravel, Quadra Sand
- no reported quantity or quality concerns
- depth to water ranges from 1.8 to 12.5 m (6 to 41 feet)
- classified as moderately productive, reported well yields range from 0.19 to 2.3 L/s (2.5 to 30 USgpm)
- domestic drinking water use

Aquifer 212: Parksville

- classified as lightly developed with low vulnerability to pollution from surface sources
- approximately 6 km^2 in area
- fractured bedrock aquifer in Nanaimo Group
- no reported quantity or quality concerns
- depth to water ranges from 5 to 28 m (17 to 92 feet)
- productivity classified as low, reported well yields range from 0.02 to 0.53 L/s (0.3 to 7 USgpm)
- principally domestic drinking water use
- small number of reported drilled wells (16)

Aquifer 214: Madrona Point/Parksville

- classified as lightly developed with moderate vulnerability to pollution from surface sources
- approximately 6 km^2 in area
- fractured bedrock aquifer in Nanaimo Group
- quantity concerns include “dry” wells
- quality concerns include elevated manganese and iron
- reported well depths range from 7 to 157 m (22 to 515 feet)
- depth to water ranges from 1.5 to 34 m (5 to 110 feet)
- productivity classified as low, reported well yields 0.02 L/s to 3.0 L/s (0.25 to 10 USgpm)
- principally domestic drinking water use, small number of reported drilled wells (28)

Aquifer 664: Little Qualicum River valley and delta

- classified as highly developed with high vulnerability to pollution from surface sources
- approximately 5 km^2 in area
- unconfined, unconsolidated sand and minor gravel, Salish Sediments
- no reported quantity or quality concerns
- reported well depths range from 3.1 to 29.6 m (10 to 97 feet)
- depth to water ranges from 1.1 to 4.9 m (3.5 to 16 feet)
- productivity classified as high, reported well yields up to 75.7 L/s (1200 USgpm)
- transmissivity values reported ranging from 372 to 7961 m^2/day
- domestic drinking water use and community water supply, 47 reported drilled wells

Aquifer 221: Parksville

- classified as moderately developed with high vulnerability to pollution from surface sources
- approximately 4 km^2 in area
- unconfined, unconsolidated sand and minor gravel, Salish Sediments
- no reported quantity or quality concerns
- reported well depths range from 3.6 to 30 m (12 to 100 feet)
- depth to water is shallow
- productivity classified as high, reported well yields 0.23 L/s to 25 L/s (3 to 330 USgpm)
- principally domestic drinking water use
- small number of reported wells (10)

Aquifer 210: Nanoose Bay

- classified as moderately developed with low vulnerability to pollution from surface sources
- approximately 3 km^2 in area
- fractured bedrock aquifer in Buttle Lake Group and Mount Hall Gabbro
- no reported quantity or quality concerns
- reported well depths range from 25 to 183 m (83 to 600 feet)
- depth to water ranges from flowing to 30 m (flowing to 100 feet)
- productivity classified as low, reported well yields 0.015 L/s to 4.5 L/s (0.2 to 60 USgpm)
- principally domestic drinking water use

Wendling (2009) has identified an upper (partially confined) and lower confined aquifer along the east side of the Englishman River near Craig Bay. These aquifers possibly represent an extension of Aquifer 219 Nanoose Creek.

5.2 Existing Observation Wells

The Ministry of Environment currently maintains six (6) active observation wells in the Arrowsmith Water Service (AWS) area as part of the provincial Observation Well Network (Ministry of Environment, 2009b). Locations of these wells are shown in Figure 2. Groundwater levels and water quality in these wells are monitored on a regular basis to provide data on developed aquifers to assist in management of groundwater. Historic records are also available for three (3) inactive observation wells. Table 2 summarizes available information on all of these observation well sites. Other private observation wells may also exist in the AWS but were not researched for this study.

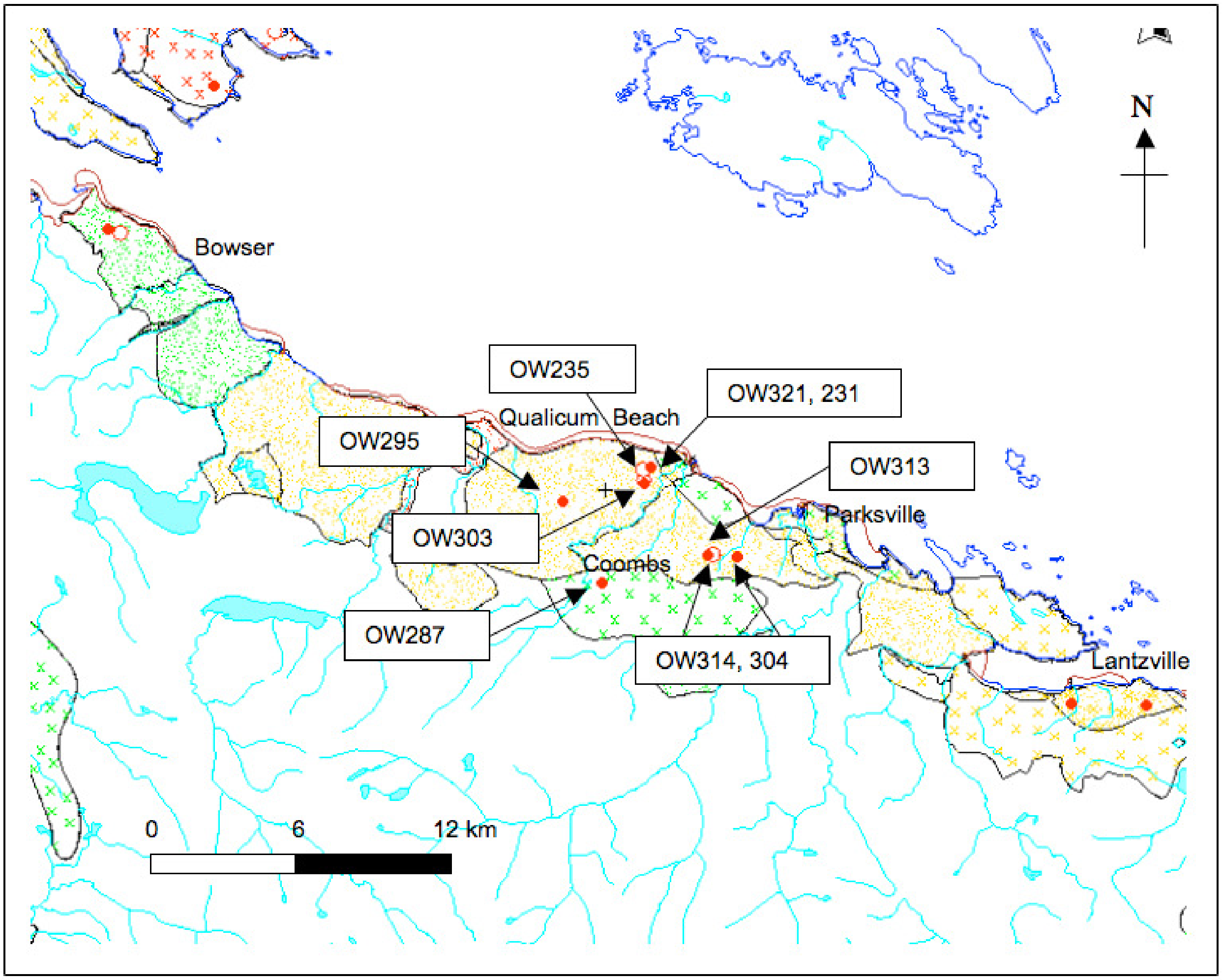


Figure 2. Location of MOE Observation Wells in the AWS area (from Ministry of Environment, 2009a).

Table 2. List of Ministry of Environment observation wells in the Arrowsmith Water Service area.

Item No.	MOE Obs. Well No.	Well Tag No.	BCGS No.	Well No.	Aquifer No.	Aquifer Class & Ranking	Aquifer Type	Location	UTM Northing Nad 27	UTM Easting Nad 27	Start Date	Well Depth (ft.) *	Well Dia. (In.)	Initial Objective of Observation Well	Recorder Type	Owner of Well	Period of Record
Active Wells																	
1	**287**	53360	092F.038.2.2.2	13	220	IIB(10)	Bedrock	Coombs	5461759	397226	1984	303	6.0	To monitor developed aquifers	Thal.	MOE	1984 - 2009
2	**295**	13653	092F.038.2.4.1	5	217	IB (14)	Surficial	Qualicum	5465300	395500	1986	91	10.0	To monitor developed aquifers	Thal.	TOQ	1986 - 2009
3	**303**	43750	092F.039.1.3.3	13	217	IB(14)	Surficial	Qualicum	5466250	399300	1988	175	8.0	To monitor developed aquifers	Diver	MOE	1988 - 2009
4	**304**	58215	092F.039.1.2.1	26	216	IB(13)	Surficial	Parksville	5462550	403500	1988	73	6.0	To monitor developed aquifers	Thal.	MOE + COP	1988 - 2009
5	**314**	59923	092F.039.1.2.1	30	216	IB(13)	Surficial	Parksville	5462750	402000	1992	105	8.0	To monitor developed aquifers	Thal.	EPCOR	1992 - 2009
6	**321**	48458	092F.039.1.3.3	17	217	IB(14)	Surficial	Qualicum	5466750	399950	1992	138	6.0	To monitor developed aquifers	Thal.	EPCOR	1992 - 2009
Inactive Wells																	
1	**231**	37134	092F.039.1.3.3	28	217	IB(14)	Surficial	Qualicum	5466993	399177	1978	65	6.0	To monitor developed aquifers	-	Eaglecrest Estates	1975-1978
2	**235**	41896	092F.039.1.3.3	7	217	IB(14)	Surficial	Qualicum	5466510	399191	1975	175	8.0	To monitor developed aquifers	-	RDN	1979-1988
3	**313**	59061	092F.039.1.2.1	29	216	IB(13)	Surficial	Parksville	5463039	402161	1991	110	8.0	To monitor developed aquifers	Manual	Hills of Columbia	1992-1992

** Well depth reported as the completed depth of the well and not the total drilled depth.*

Abbreviations:

Thal.	*Thalimedes*
MOE	*Ministry of Environment*
TOQ	*Town of Qualicum*
COP	*City of Parksville*
RDN	*Regional District of Nanaimo*

The observation wells in the AWS area are generally grouped in one main region centered in the Parksville-Qualicum Beach area. Groundwater levels in aquifers can fluctuate in response to several factors including climate effects (precipitation events), pumping effects of wells, changes in river flows and lake levels, and tidal effects. Some of these factors are evident in Figure 3 that shows groundwater fluctuations in Observation Well 314 situated in unconsolidated Aquifer 216 during the period 1988 to 2002 in comparison with precipitation data.

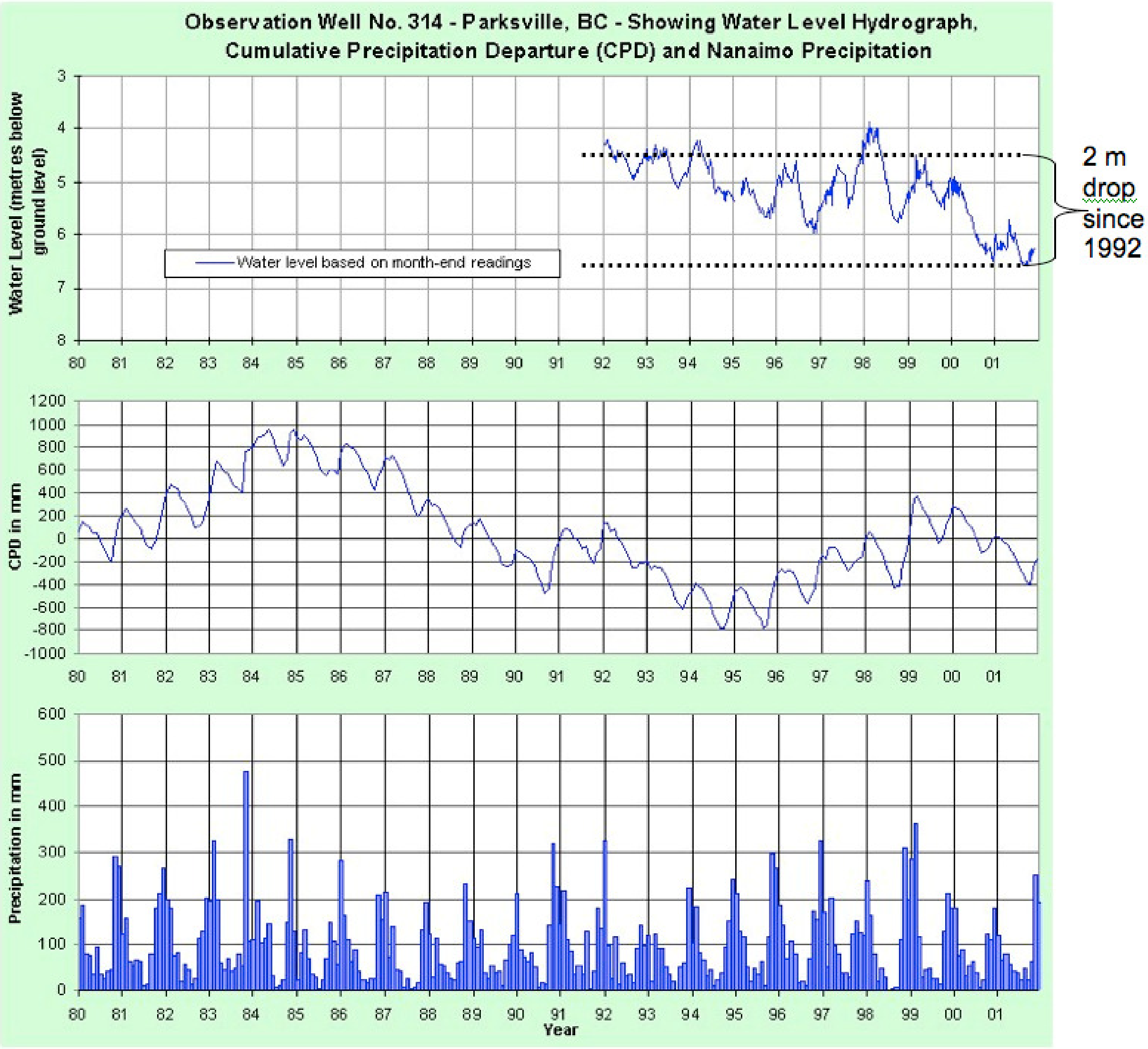


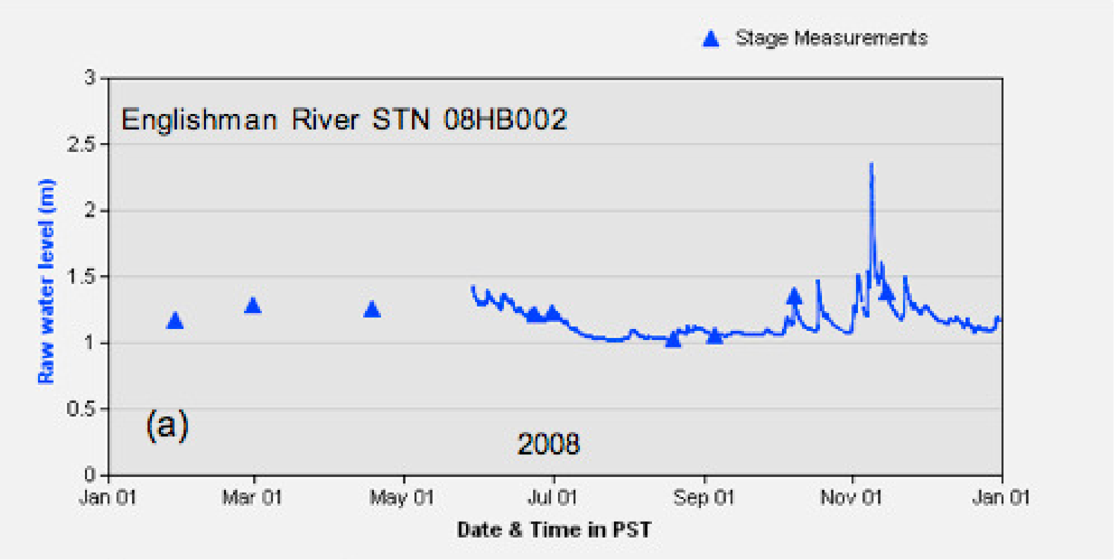
Figure 3. Water level fluctuations, 1992 to 2002, in Observation Well 314 near Parksville (data from Ministry of Environment, 2009b).

The groundwater level fluctuations in Observation Well 314 follow a regular annual cycle, rising during the late fall and winter months and declining during the early spring and summer months. This is in response to annual precipitation that occurs during the fall and winter months when evaporation and transpiration rates are lowest. Peak groundwater levels in Figure 3 show a lag time of between one and two months after the major precipitation periods due to storativity effects in the unconsolidated aquifer. This seasonal pattern, that is dependent upon precipitation, is shown by all observation wells in the AWS area.

Groundwater levels in the existing observation wells also do not correlate with streamflow stage of any of the major streams in the AWS area. Figure 4b, for example, shows water levels in well 314 during 2008 compared with water levels in the Englishman River, Figure 4(a). Groundwater levels in 2008 began recovering in September and peaked in December while river levels remained relatively constant during September and October, peaking in early November.

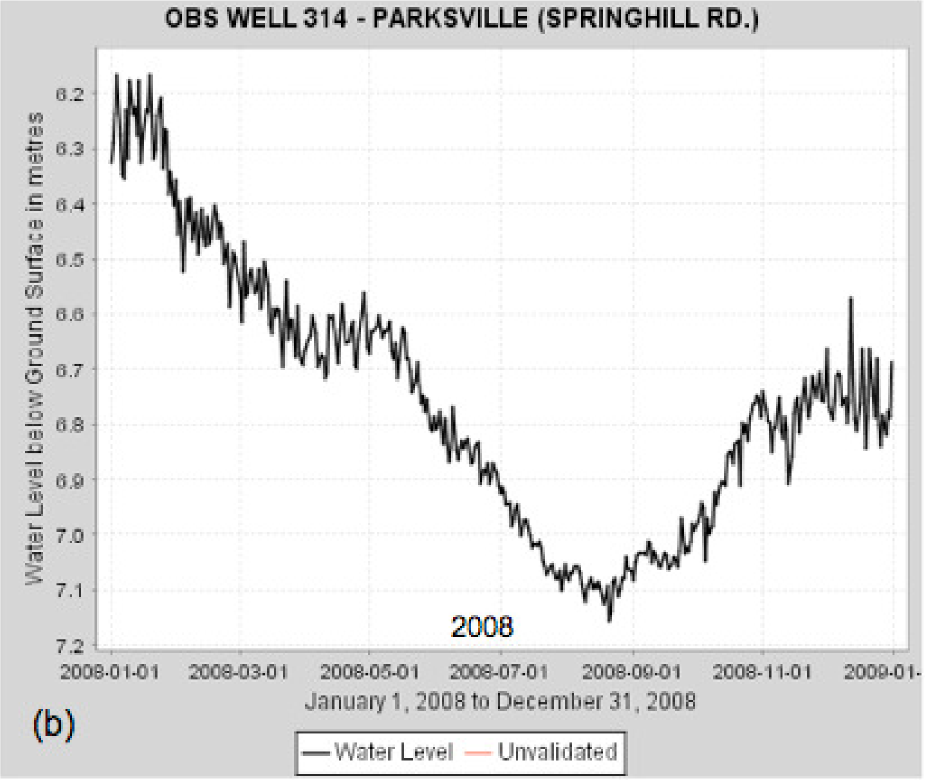
Observation well 314 also shows an overall decline in water levels of about 2 m during the period of record shown in Figure 3, declining from about 4.5 m below ground in 1992 to 6.5 m in 2001. The CPD graph is derived by plotting monthly the cumulative departure from the mean monthly precipitation for the period of record (Ministry of Environment, 2009b). Over the long term, the trend of the cumulative precipitation departure (CPD) graph in this case does not exhibit a good correlation with the groundwater level graph. This indicates that the groundwater in Aquifer 216, while dependent on recharge from precipitation over the aquifer is significantly affected by groundwater withdrawals in the area.

Precipitation data used by the Ministry of Environment in Figure 3 is based on the Nanaimo A climate station situated east of the AWS area. Other climate stations for comparison that have sufficient data are located within the AWS area at Coombs and Little Qualicum Hatchery. A comparison of monthly data from these stations during the 1996 to 2006 period shows similar trends with the Nanaimo A station (Figure 5 and Table 3).



graph from Environment Canada, 2009b

OBS WELL 314 - PARKSVILLE (SPRINGHILL RD.) :



graph from Ministry of Environment, 2009c

Figure 4. Comparison of stage of Englishman River with water levels in Observation Well 314.

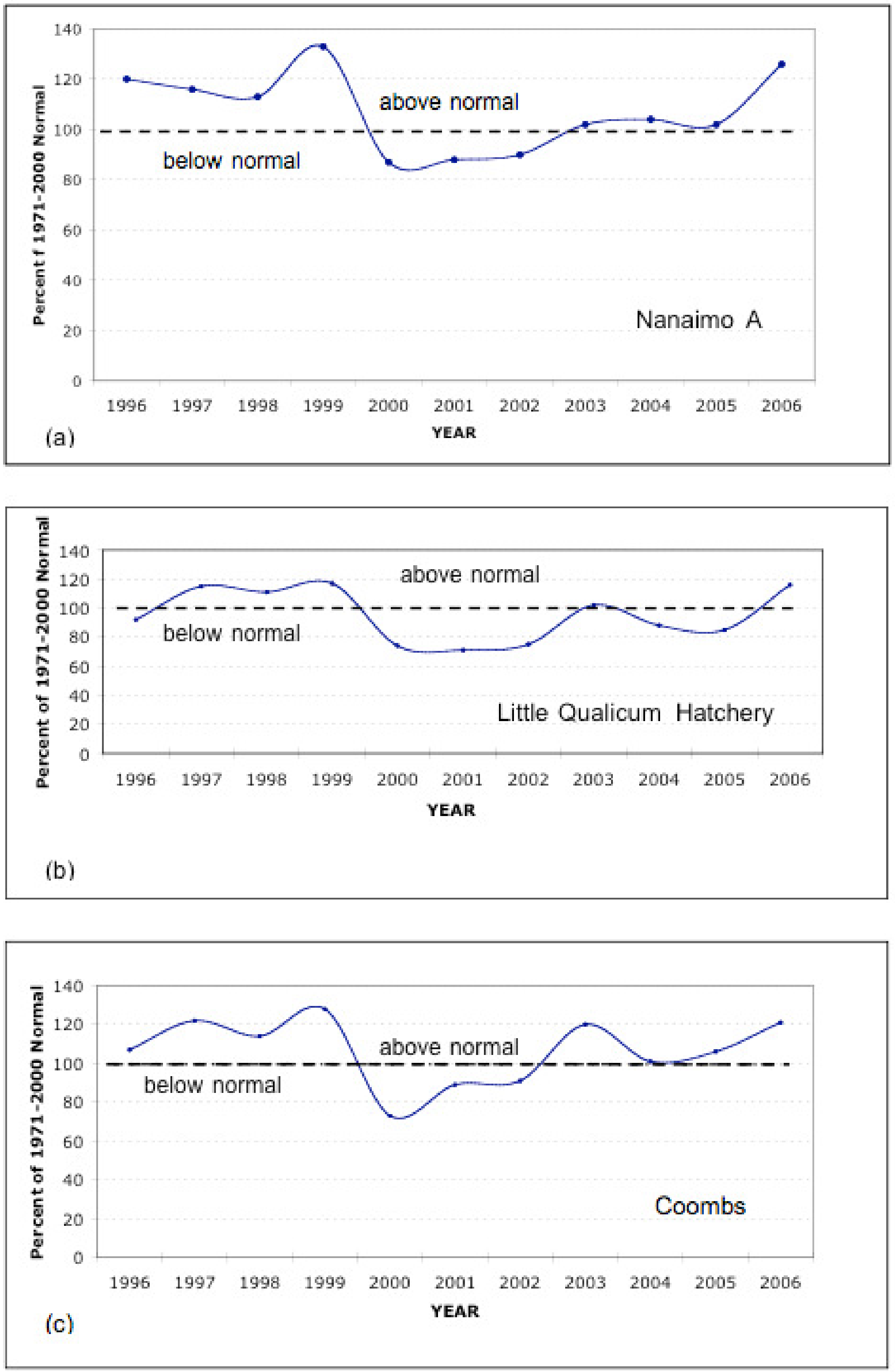


Figure 5. Comparison of precipitation trends for key climate stations during 1996 to 2006. data from Environment Canada, (2009a)

Table 3. Annual precipitation data for period 1996 to 2006 at active climate stations in AWS area and at Nanaimo.

Station No.	Station Name	Elevation (m)	Latitude	Longitude	Year	Total Precipitation (mm)		1971-2000 Normal (mm)	Difference from 1971-2000 Normal (mm)	Percent of 1971-2000 Normal	Comments
1024638	Little Qualicum Hatchery	30.00	49° 21' N	124° 30.6' W	1996	1006.2	*	1098.6	-92.4	92	estimated data
					1997	1265.7		1098.6	167.1	115	
					1998	1216.9		1098.6	118.3	111	
					1999	1290.8		1098.6	192.2	117	
					2000	811.7	*	1098.6	-286.9	74	estimated data
					2001	777.1	M	1098.6	-321.5	71	estimated data
					2002	822.8	M	1098.6	-275.8	75	
					2003	1117.0	E	1098.6	18.4	102	
					2004	972.2		1098.6	-126.4	88	
					2005	929.3	M	1098.6	-169.3	85	estimated data
					2006	1273.7	E	1098.6	175.1	116	
1021850	Coombs	98.10	49° 18.6' N	124° 25.8' W	1996	1209.8	*	1126.4	83.4	107	estimated data
					1997	1375.6		1126.4	249.2	122	
					1998	1287.0		1126.4	160.6	114	
					1999	1436.2		1126.4	309.8	128	
					2000	827.0	E	1126.4	-299.4	73	
					2001	1005.4		1126.4	-121.0	89	
					2002	1022.0		1126.4	-104.4	91	
					2003	1347.6		1126.4	221.2	120	
					2004	1135.3		1126.4	8.9	101	
					2005	1189.8		1126.4	63.4	106	
					2006	1363.6		1126.4	237.2	121	
1025370	Nanaimo A	28.00	49° 3' N	123° 52.2' W	1996	1355.9		1162.7	229.5	120	
					1997	1307.9		1162.7	181.5	116	
					1998	1272.2		1162.7	145.8	113	
					1999	1496.6	E	1162.7	370.2	133	
					2000	977.9		1162.7	-148.5	87	
					2001	990.8		1162.7	-135.6	88	
					2002	1008.9	M	1162.7	-117.5	90	
					2003	1143.4		1162.7	17.0	102	
					2004	1166.7		1162.7	40.3	104	
					2005	1143.8		1162.7	17.4	102	
					2006	1419.4	M	1162.7	293.0	126	

Data from: Environment Canada (2009a), http://www.climate.weatheroffice.ec.gc.ca/Welcome_e.html   ** = incomplete data*   *M = missing data*   *E = estimated*

Water level data after 2001 for Observation well 314 as shown in Figure 6 shows a continuing decline to 2005 with relatively stabilized conditions (6 to 7.5 m below ground) from 2006 to 2009. A similar declining trend is also apparent in Observation Well 304 completed in the same aquifer (Figure 7) where the water level has dropped 3.5 m since 1988.

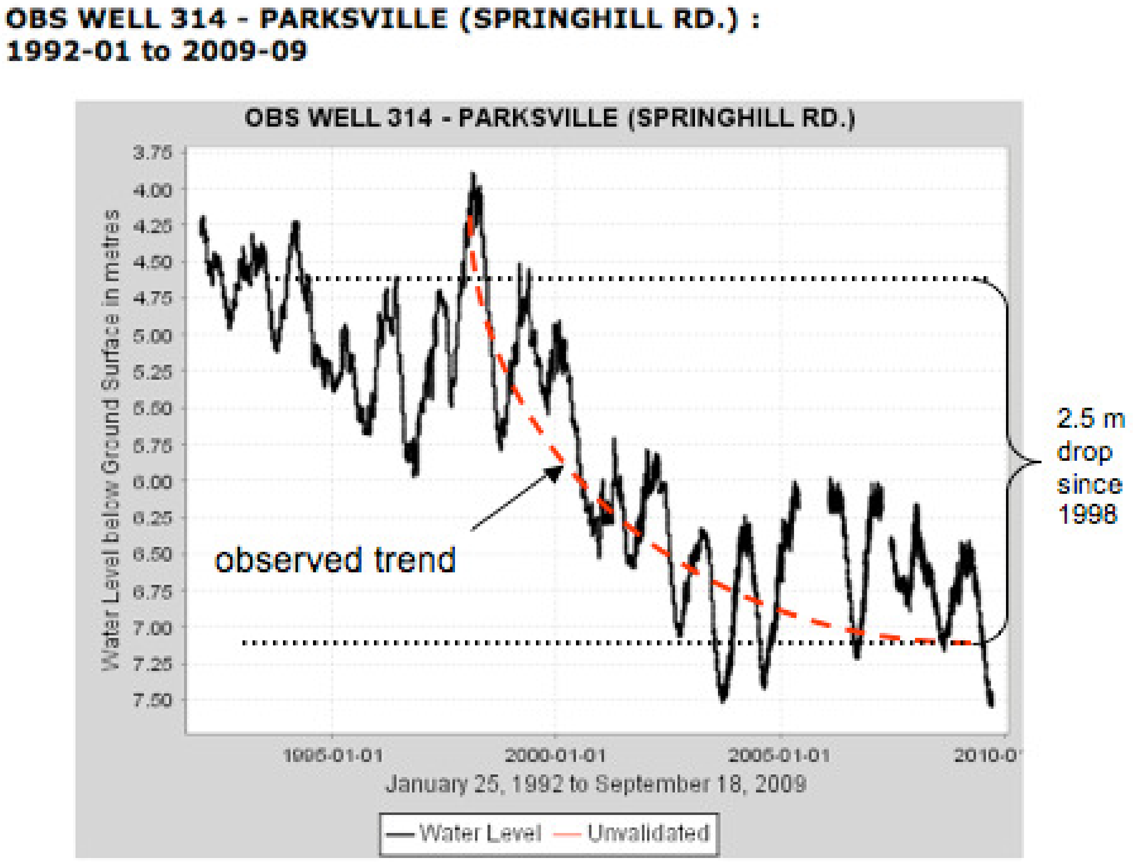


Figure 6. Water level fluctuations in Observation Well 314 near Parksville from 1992 to 2009 (data from Ministry of Environment, 2009c).

OBS WELL 304 - PARKSVILLE (DESPARD RD. AT SPRINGWOOD PARK) : 1988-10 to 2009-09

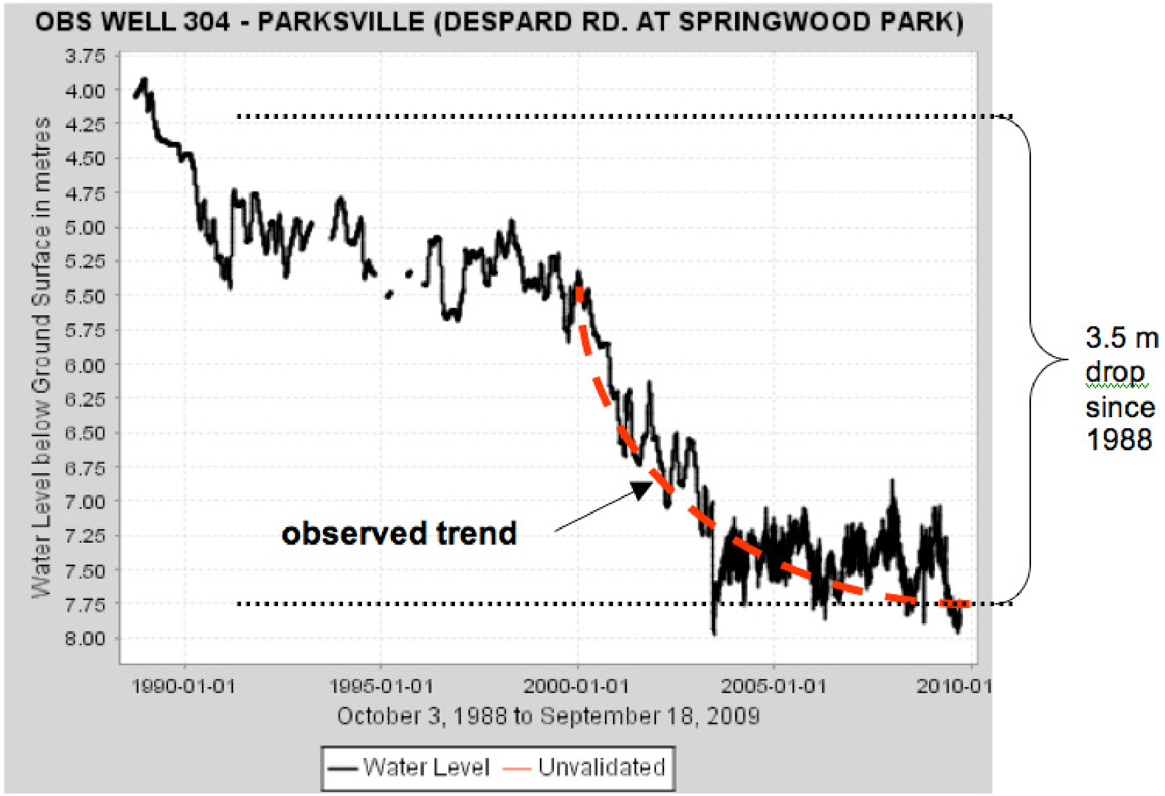


Figure 7. Water level fluctuations in Observation Well 304 near Parksville from 1988 to 2009 (data from Ministry of Environment, 2009c).

Figure 8 shows groundwater level fluctuations in Observation Well 303 situated in unconsolidated Aquifer 217 in the Qualicum Beach area during the period 1988 to 2002 in comparison with precipitation data.

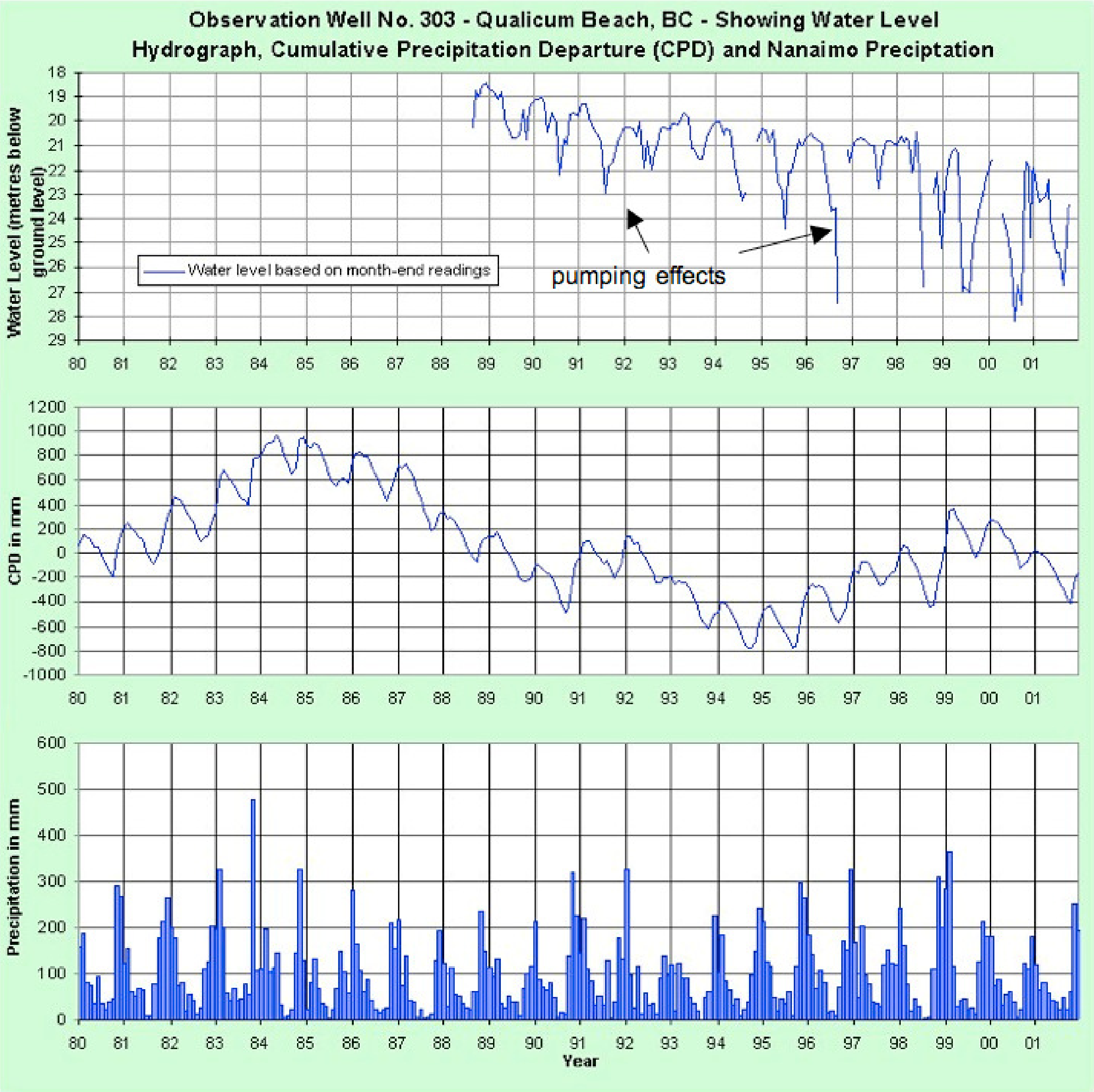


Figure 8. Water level fluctuations in Observation Well 303 near Qualicum Beach from 1988 to 2002 (data from Ministry of Environment, 2009b).

The groundwater level fluctuations in Observation Well 303 follow a regular annual cycle, rising during the late fall and winter months and declining during the early spring and summer months. This is in response to annual precipitation that occurs during the fall and winter months when evaporation and transpiration rates are lowest. Peak Groundwater levels in Figure 8 show a lag time of between one and two months after the major precipitation periods due to relatively high storativity effects in the unconsolidated aquifer.

The observation well also shows an overall decline in water levels of about 6 m during the period of record shown in Figure 8, declining from about 19 m below ground in 1988 to about 25 m in 2001. Over the long term, the trend of the cumulative precipitation departure (CPD) graph (Figure 8) in this case does not exhibit a good correlation with the groundwater level graph. This indicates that the groundwater in Aquifer 216, while dependent on recharge from precipitation over the aquifer, is significantly affected by groundwater withdrawals in the area. Some localized increased drawdown (pumping interference) effects are also evident in the water level hydrograph. Longer term data to 2009 as shown in Figure 9 shows a declining trend until 2004 followed by a rising trend to 2009. This appears due to a lessening of groundwater withdrawals in the vicinity of this observation well, possibly due to the shutdown of a nearby production well with a subsequent recovery of water levels.

OBS WELL 303 - QUALICUM BEACH (YAMBURY RD.) :
1988-09 to 2009-09

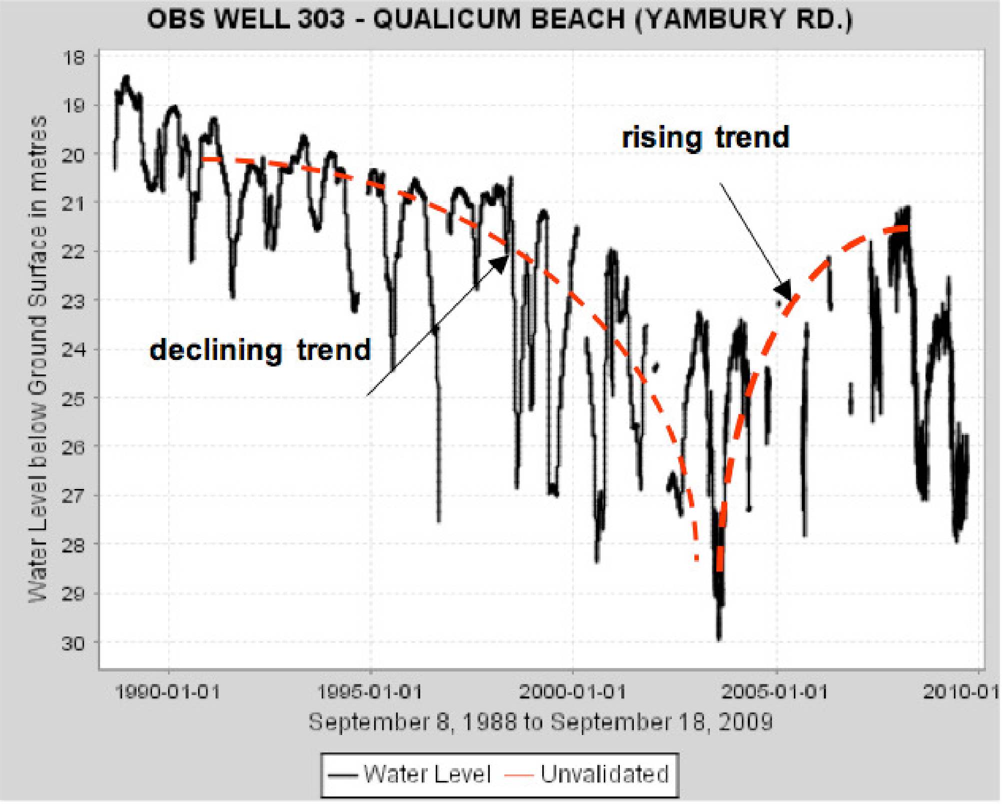


Figure 9. Water level fluctuations in Observation Well 303 near Qualicum Beach from 1988 to 2009 (data from Ministry of Environment, 2009c).

A similar rising trend since 2004 is evident in Observation Wells 321 and 295 that are also located in Aquifer 217 (Figures 10 and 11). Observation Well 295 is situated within the production well field of the Village of Qualicum and experiences greater fluctuations due to well interference.

OBS WELL 321 - QUALICUM (LEEWARD WAY) :
1992-12 to 2009-09

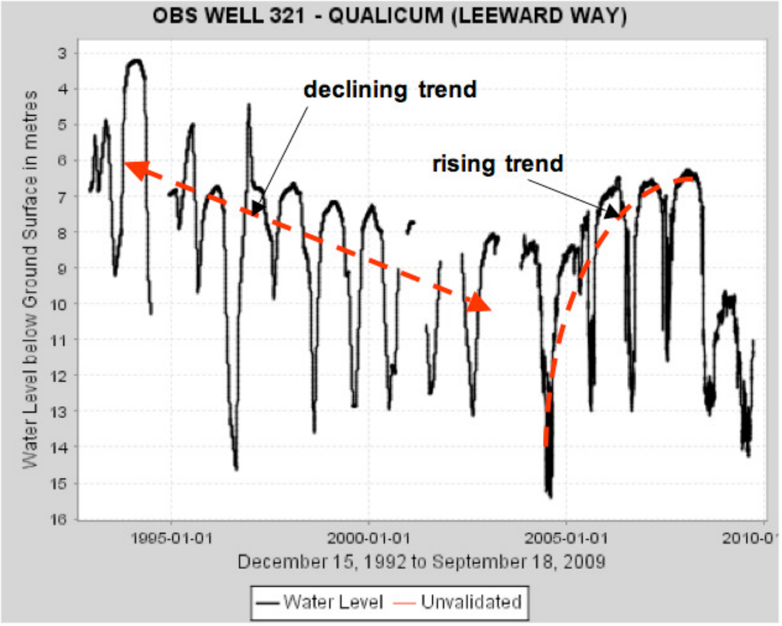


Figure 10. Water level fluctuations in Observation Well 321 near from 1992 to 2009 (data from Ministry of Environment, 2009c).

OBS WELL 295 - QUALICUM BEACH (BERWICK ROAD) :
1986-11 to 2009-09

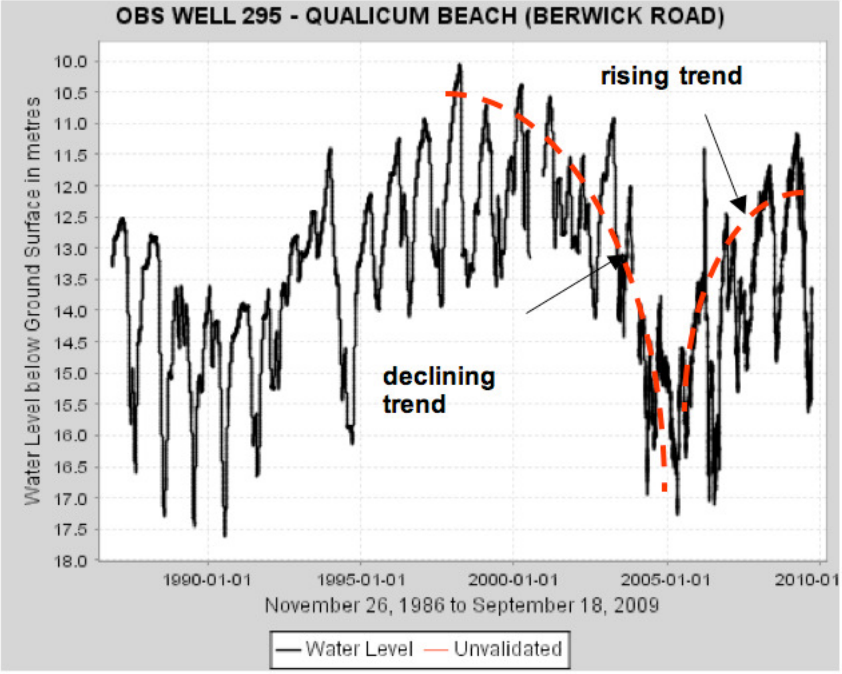


Figure 11. Water level fluctuations in Observation Well 295 from 1986 to 2009 (data from Ministry of Environment, 2009c).

Figure 12 shows groundwater level fluctuations in Observation Well 287 situated in bedrock Aquifer 220 near Coombs during the period 1984 to 2002 in comparison with precipitation data. Groundwater level fluctuations in Observation Well 287 follow a regular annual cycle, rising during the late fall and winter months and declining during the early spring and summer months. This is in response to annual precipitation that occurs during the fall and winter months when evaporation and transpiration rates are lowest. Peak groundwater levels in Figure 12 show a relatively short lag time of about one month after the major precipitation periods due to low storativity effects in the bedrock aquifer. The observation well also shows a slight overall decline in water levels of about 1 m during the period of record in Figure 12, declining from about 3.5 m below ground in 1984 to 4.5 m in 2001.

Over the long term, the trend of the cumulative precipitation departure (CPD) graph in this case does not show a good correlation with the groundwater level graph. This indicates that the groundwater levels in Aquifer 220, while dependent on recharge from precipitation over the aquifer, do not vary much between years of above normal and years of below normal precipitation. This can be attributed to the very low storativity of the bedrock aquifer.

Groundwater levels, for example, did not decline significantly, during the period between 1992 and 1996 when precipitation was below normal.

Some localized increased drawdown (pumping interference) effects are also evident in the water level hydrograph. These effects are more apparent in Figure 13 that shows groundwater levels in Observation Well 287 from 1984 to 2009. In the last few years there has also been a significant lowering of water levels in the vicinity of the observation well due to increased pumping withdrawals and a declining trend is now apparent with a 5 m drop since 2000.

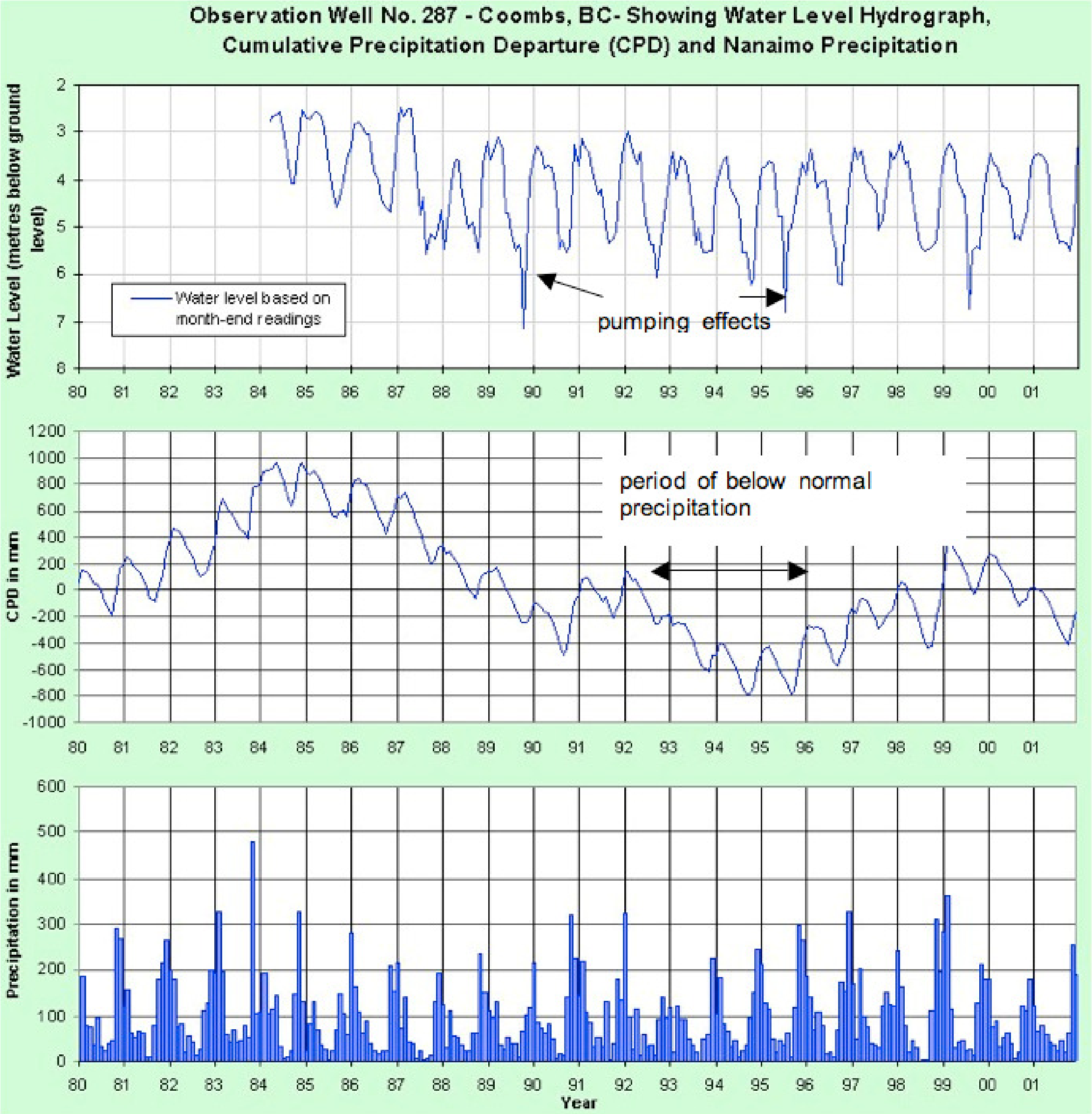


Figure 12. Water level fluctuations in observation well 287 near Coombs from 1984 to 2002 (data from Ministry of Environment, 2009b).

**OBS WELL 287 - COOMBS (BURGOYNE ROAD) :
1984-03 to 2009-09**

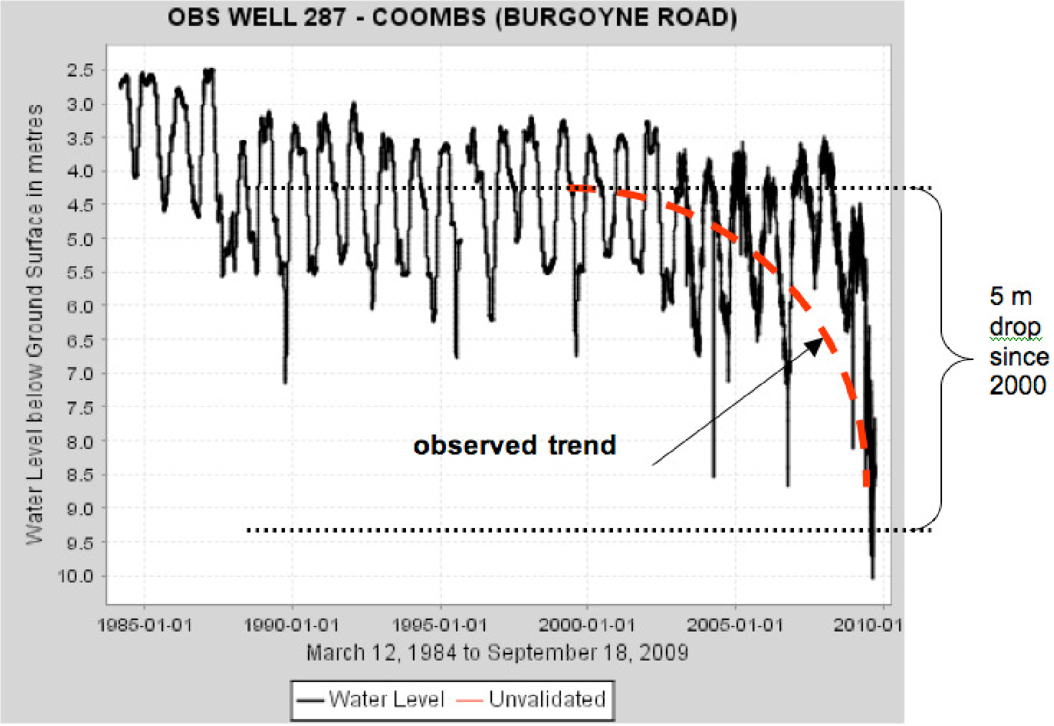


Figure 13. Water level fluctuations in observation well 287 near Coombs from 1984 to 2009 (data from Ministry of Environment, 2009c).

Table 4 summarizes the current trends observed for the Ministry of Environment observation wells in the AWS. Since 2000, groundwater levels have been lowered in the Parksville area (Aquifers 216 and 220) from 2.5 to 5 m. This lowering is attributed mainly to the pumping effects of private and municipal production wells that tend to be grouped in specific areas. The water level lowering is likely to be localized in areas of higher well density. A network of observation wells spread out across the aquifer area are required to make definitive statements about overall aquifer water level trends. Water levels in the Qualicum Beach area (Aquifer 217) have been rising since 2004 and appear to be due to lessening of groundwater withdrawals in the vicinity of Observation Wells 321 and 295, possibly due to the shutdown of nearby production wells.

Table 4. Summary of current trends observed for Ministry of Environment observation wells in the Arrowsmith Water Service area.

General Area	MOE Obs. Well No.	Well Depth (feet) *	Location	Period of Record	Aquifer Type	Aquifer No.	Aquifer Class & Ranking	Water Level Trend	Magnitude of Decline (m)	Owner of Well	Comments
Parksville-Qualicum Beach	**231**	65	Qualicum	1975-1978	Surficial	217	IB(14)	insufficient data		Eaglecrest Estates	short record, currently not active as an observation well
	235	175	Qualicum	1979-1988	Surficial	217	IB(14)	hydrograph not available		RDN	currently not active as an observation well
	287	303	Coombs	1984 - 2009	Bedrock	220	IIB(10)	declining since 2000	5	MOE	
	295	91	Qualicum	1986 - 2009	Surficial	217	IB (14)	rising 1990 to 2000, declining from 2000 to 2004 and rising since2004		Town of Qualicum	
	303	175	Parksville	1988 - 2009	Surficial	217	IB(14)	declining from 1988 to 2004, rising from 2004 to 2008		MOE	
	304	73	Parksville	1988 - 2009	Surficial	216	IB(13)	declining since 1988	3.5	MOE + COP	
	313	110	Parksville	1992-1992	Surficial	216	IB(13)	insufficient data		EPCOR	short record, currently not active as an observation well
	314	105	Parksville	1992 - 2009	Surficial	216	IB(13)	declining since 1992	2.5	EPCOR	
	321	138	Qualicum	1992 - 2009	Surficial	217	IB(14)	declining from 1992 to 2004, rising from to 2004 to 2008		EPCOR	

Abbreviations:
MOE = Ministry of Environment
COP = City of Parksville
RDN = Regional District of Nanaimo

6.0 POTENTIAL IMPACTS OF CLIMATE CHANGE

The climate of British Columbia is changing and hydrological resources are projected to be at risk in the future (Rodenhuis et al., 2009). Regional hydrological changes are related to temperature and precipitation trends (Walker and Sydneysmith, 2008). Average annual temperatures in British Columbia have warmed by between 0.5 and 1.7 degrees Celcius in different regions of the province during the 20th century while total precipitation has increased by about 20 per cent and the snowpack has been reduced (LiveSmart BC, 2009). Hydrologic impacts of a changing climate include significant decreases in snowpack, retreating glaciers, changes to streamflow timing and magnitude, and earlier lake ice break-up along with shorter lake ice duration (Rodenhuis et al., 2009). Sea levels are also expected to rise up to 30 cm on the north coast of British Columbia by 2050 (Livesmart BC, 2009). Climate change also impacts groundwater systems with the greatest changes more evident in shallow aquifer systems (Rivera et al., 2004). In coastal areas groundwater quality will be locally impacted due to saltwater intrusion in response to sea-level rise.

Global climate models (GCMs) are used to project future climate based on plausible scenarios of future greenhouse gas emissions and physical models that include atmospheric, ocean, ice and land surface components (Walker and Sydneysmith, 2008). Projections are that Coastal BC will warm less than the interior with the Georgia Basin region being warmer in all seasons (Walker and Sydneysmith, 2008). Coastal BC will have less snow throughout and more locations with no snow on April 1 (Walker and Sydneysmith, 2008). Scenarios of precipitation by season suggest that BC will be wetter over much of the province in winter and spring, but drier during the summer in the south and on the coast (Walker and Sydneysmith, 2008). A higher incidence of extreme events such as short periods of intense rains and periods of prolonged drought can occur (Allen, 2009). Intense rainfall events may result in more frequent flooding of lowland areas.

Allen (2009) reports that to determine the potential impacts of climate change for a particular aquifer requires a detailed characterization of the aquifer with suitable quantification of the water budget components. In coastal regions, changes in recharge may result in not only impacts to water levels, but to water quality as coastal aquifers are highly sensitive to hydrologic stress due to the complex chemical and physical interactions between fresh water and ocean water (Allen, 2009). Shifts in the timing of river discharge may have a strong impact on groundwater levels in interconnected aquifer systems. Peak flow in many BC rivers is predicted to shift to an earlier date and there will be a prolonged and lower baseflow period (Allen, 2009).

6.1 Effects on Groundwater Recharge

Groundwater in the AWS area is principally recharged on an annual basis through:

(a) the direct infiltration of precipitation (rain and snowmelt), and;
(b) infiltration of surface waters along rivers, streams and creeks. Some aquifers are also hydraulically interconnected with lakes, ponds and wetlands where groundwater levels reflect surface water levels.

Available observation well data for the AWS area as discussed in Section 5.2 shows that some aquifers such as Aquifer 216 and 217 are recharged by direct precipitation. Other aquifers such as Aquifer 664 along the Little Qualicum River are recharged by infiltration of river water. Based on an analysis of observation well hydrographs in British Columbia, Moore et al. (2007) recognized two main types of well responses based on their hydro-climate regime; namely rainfall-dominated (pluvial) and snowmelt-dominated (nival). Mixed regimes were also identified. For each of these regimes they also recognize two main aquifer-stream system types:

(a) stream-driven systems - in which groundwater flow to and from streams is bi-directional, and varies seasonally depending on the magnitude of the streamflow and precipitation, and;
(b) recharge-driven systems - in which the aquifer is raised above the surrounding land surface and which drains to lower elevation. In this type of system, groundwater is recharged solely by precipitation and dominantly discharges to streams during periods of low flow.

Further analysis of observation well hydrographs by Allen at al. (2008) indicated that "summer groundwater levels seem to have lowered across the province, despite an increase in winter precipitation and recharge during the same time period. Due to the limited availability of long well records near gauged streams, the attribution of whether and how these changes have affected low flows proves difficult."

In case studies referred to by Allen (2009), modeling of direct recharge via precipitation showed relatively small impacts of climate change groundwater recharge (a few percent different from current rates) and groundwater level differences of only a few centimeters. On the basis of winters becoming wetter in coastal areas it is anticipated that both bedrock and unconsolidated aquifers that are recharged directly by infiltrating precipitation would experience slightly higher groundwater levels during the winter and spring.

Aquifers interconnected to coastal rivers that are dependent upon snow melt would be expected to experience recharge earlier in the year and lower water levels during the rest of the year upstream of their estuary areas. Since a number of interrelated factors can affect groundwater levels in various parts of an aquifer, the net effects of climate change on any particular aquifer at any one time may not be entirely predictable with a high degree of certainty. Moreover, there is a high degree of uncertainty in the application of current Global Climate Models (GCM) to groundwater systems in British Columbia, Allen (2009). Hence there is a need to monitor individual aquifers with an appropriate number of observation wells. Table 5 summarizes some of the potential impacts of climate change on the mapped AWS area aquifers.

6.2 Effects on Supply and Demand

Many regions and sectors of British Columbia will experience increasing water shortages (Walker and Sydneysmith, 2008). While wetter winters in coastal areas may result in increased groundwater recharge and higher groundwater levels for some aquifers in the winter and spring, increased groundwater demand from all sectors due to drier summers could result in lower summer and fall groundwater levels. In general aquifers will receive more recharge annually and will need to produce more water annually. However, aquifers interconnected with river regimes could experience reduced groundwater availability and increased demands.

6.3 Groundwater Quality Effects

In coastal areas groundwater quality will be impacted locally due to saltwater intrusion in response to sea-level rise. Drier summers, increased demands and lower groundwater levels at times may result in some degradation of groundwater quality particularly in bedrock wells with low storativity. Oxidation of dissolved iron and manganese, occurrence of hydrogen sulphide and increased levels of dissolved solids can accompany lower water levels in bedrock wells of the Nanaimo Group sedimentary rocks.

Table 5. Potential effects of climate change on AWS area aquifers.

Item	Aquifer Number	Aquifer Type	Location Description	Hydro-climate Regime*	Aquifer-Stream System Type*	Potential for Sea-water Intrusion	Potential Effects
1	209	Uncon	Errington	Rainfall and snowmelt dominated	Recharge- driven and Stream-driven	No	slightly higher water levels in winter and spring
2	210	Bdrk	Nanoose Bay	Rainfall dominated	Recharge- driven and Stream-driven	No	slightly higher water levels in winter and spring
3	212	Bdrk	Parksville	Rainfall dominated	Recharge- driven	Yes	Water quality degradation. higher water levels
4	213	Bdrk	Lantzville	Rainfall dominated	Recharge- driven	Yes	Water quality degradation. higher water levels
5	214	Bdrk	Madrona Point/Parksville	Rainfall dominated	Recharge- driven	Yes	Water quality degradation. higher water levels
6	216	Uncon	Parksville	Rainfall and snowmelt dominated	Recharge- driven and Stream-driven	Yes, localized	Water quality degradation. higher water levels
7	217	Uncon	Qualicum	Rainfall and snowmelt dominated	Recharge- driven and Stream-driven	Yes	Water quality degradation. higher water levels
8	218	Bdrk	Nanoose Hill	Rainfall dominated	Recharge- driven	Yes	Water quality degradation. higher water levels
9	219	Uncon	Nanoose Creek	Rainfall dominated	Recharge- driven	Yes, localized	Water quality degradation. higher water levels
10	220	Bdrk	Errington	Rainfall and snowmelt dominated	Recharge- driven and Stream-driven	No	slightly higher water levels in winter and spring
11	221	Uncon	Parksville	Rainfall and snowmelt dominated	Recharge- driven and Stream-driven	Yes	Water quality degradation, higher water levels
12	664	Uncon	Little Qualicum River valley and delta	Rainfall and snowmelt dominated	Recharge- driven and Stream-driven	Yes, localized	Water quality degradation, higher water levels
13	663	Uncon	Upper reaches of Whiskey Creek	Rainfall dominated	Recharge- driven and Stream-driven	No	slightly higher water levels in winter and spring

* Classification system based on Moore et al. (2007).

7.0 ANNUAL RECHARGE, STORAGE AND WITHDRAWAL FROM AQUIFERS

Groundwater availability has two components; storage volume and the annual replenishment volume (recharge). Furthermore, when estimating the amount of water available for development the present level of usage must be considered. Water storage in the mapped aquifers has been estimated by determining aquifer volumes and multiplying by the storage coefficient (essentially the open space in the body of the aquifer that is filled with water). The coefficients used were 0.25 (25%) for unconsolidated aquifers and 0.0003 to 0.05 (0.03 to 5%) for bedrock aquifers depending on rock type.

Recharge has two components; direct infiltration from precipitation and lateral groundwater flow from upslope regions. Recharge from upward flow from underlying aquifers plus recharge from rivers and other surface water bodies may be significant but are not considered due to lack of information. Infiltration is estimated as a percentage of wet season precipitation. Infiltration will vary with soil types and this has also been factored into the analysis. Recharge from lateral groundwater flow (from upslope regions) has been calculated using standard groundwater flow calculations (Dupuit-Forchheimer methodology).

Table 6 below summarizes the volumes of water available and compares these to present estimated groundwater demand or usage from existing wells. For the thirteen mapped aquifers *demand versus storage ratios* range from 0.1 to 28.4 percent and *demand versus recharge ratios* range from 4.1 to 78.7 percent. These potential demand versus supply balances where they are high (e.g. 70.6 and 78.7 % in aquifers 216 and 220), for example, and highlighted in red shading in Table 6 indicate concerns for groundwater supply in some of the aquifers. Natural recharge in these aquifers of concern could be augmented by artificial recharge through aquifer storage and recovery (ASR). However significant future development (increased groundwater pumping) is sustainable for most of the mapped aquifers. Low demand versus supply balances, (e.g. 4.1 and 5.7% in aquifers 663 and 209), for example, and highlighted in green shading in Table 6 indicates further groundwater development is possible in these areas.

When annual groundwater pumping is greater than annual recharge this condition is called *groundwater mining* which is <u>not sustainable</u>. When the groundwater pumping volume is above 50% of average annual recharge this is a situation requiring close monitoring. As rainfall can vary from average significantly in dry years this may lead to significant lowering of aquifer water levels during these periods. Thoughtful management of the groundwater resource becomes more critical as the demand approaches the natural replenishment rate.

Additional groundwater could also be available from aquifers within the AWS region that have not been mapped. Further groundwater exploration and development may expand the area of mapped or known aquifers and identify new aquifers in some areas.

Table 6. Groundwater Recharge, Storage and Demand Estimates - AWS Aquifers

Aquifer Number	Aquifer Location	Aquifer Type	Aquifer Area	Aquifer Thickness	Storage*	Number of Wells		GW** Pumping	Recharge from Precipitation	Recharge from Lateral Flow	Total Recharge	Demand vs. Storage	Demand vs. Recharge
						Domestic	Municipal Industrial						
			Ha.	m.	m^3			m^3/yr.	m^3/yr.	m^3/yr.	m^3/yr.	%	%
664	Little Qualicum River	SG-Unc.	496	10	12,400,000	44	3	279,130	892,800	2,847,000	3,739,800	2.3	7.5
663	Upper Whiskey Creek	SG-Unc.	963	7	16,852,500	22	1	97,590	1,733,400	622,781	2,356,181	0.6	4.1
217	Qualicum	SG-Pcon.	4,201	10	105,025,000	196	27	3,091,520	5,671,350	370,703	6,042,053	2.9	51.2
212	Parksville	BR-Con.	590	75	22,125,000	40	1	108,750	265,500	24,809	290,309	0.5	37.5
216	Parksville	SG-Pcon.	2485	10	74,550,000	151	37	3,112,820	3,354,750	1,053,938	4,408,688	4.2	70.6
220	Errington	BR-Con.	2658	75	49,837,500	353	9	974,410	1,196,100	41,576	1,237,676	2.0	78.7
209	Errington	SG-Con.	852	10	21,300,000	51	0	31,620	383,400	171,094	554,494	0.1	5.7
219	Nanoose Creek	SG-Con.	2742	30	205,650,000	128	23	1,436,360	1,371,000	7,945,594	9,316,594	0.7	15.4
221	Parksville	SG-Unc.	403	6	6,045,000	21	5	432,770	725,400	391,463	1,116,863	7.2	38.7
214	Madrona Point	BR-PCon.	562	75	21,075,000	17	3	262,390	758,700	24,165	782,865	1.2	33.5
218	Nanoose Hill	BR-PCon.	1363	120	1,635,600	71	5	463,770	1,840,050	286,069	2,126,119	28.4	21.8
210	Nanoose Bay	BR-Con.	335	70	5,862,500	42	0	26,040	150,750	14,851	165,601	0.4	15.7
213	Lantzville	BR-Con.	4195	70	88,095,000	237	12	1,154,340	1,887,750	594,038	2,481,788	1.3	46.5

** Porosity in overburden = 0.25 and bedrock variable ** Domestic wells avg. flow = 1700 L/d; Municipal Industrial wells - pumping records*

Abbreviations : SG = Sand & Gravel, BR = Bedrock, Con. = Confined, Unc. = Unconfined, Pcon. - Partially confined

8.0 GROUNDWATER DEMAND GROWTH

Groundwater demand growth is indicated by the increase in number of wells in the AWS region aquifers since 1995-96. The increases have been quantified by comparing Hodge's (1995-96) aquifer mapping data to 2009 aquifer statistics. Current well data is provided at the *BC Water Resources Atlas* web page. The well and aquifer data in the Atlas is maintained by the Ministry of Environment, Groundwater and Aquifer Science Section (pers. comm.- Lindsay Macfarlane, Oct. 2009). The well database has been reviewed considering the following facts:

- A significant percentage of wells in the database may no longer be in use
- Some wells constructed in the AWS region are not reported, it is not mandatory for drillers to submit well records to the Government.
- We estimate the well database for the AWS region contains 60 - 80% of the existing wells.

The increase in number of wells in the AWS region over the last thirteen years is provided in Table 7 below.

Table 7. Increase in number of wells in the AWS region

Aquifer No.	Aquifer Location	Reported Wells 1995-1996	Reported Wells 2009
664	Little Qualicum River	47 (2004)*	47
663	Upper Whiskey Creek	14 (2004)*	23
217	Qualicum	120	223
212	Parksville	16	41
216	Parksville	125	188
220	Errington	145	362
209	Errington	NR	51
219	Nanoose Creek	NR	151
221	Parksville	10	26
214	Madrona Point	28	20
218	Nanoose Hill	52	76
210	Nanoose Hill	NR	42
213	Lantzville	129	249

* *More recent 2004 aquifer mapping.*

The increase in the number of wells is generally substantial and ranges up to a 250% increase over the thirteen year time period.

9.0 WELL CAPACITIES AND PRODUCTION VOLUME

Comparing water production data from the local community water systems versus the actual total well capacities indicates that each system has substantial unused capacity. Percentages of capacities used on an annual basis are as follows:

Table 8. Percentage of Well Capacities Used Annually

Water Supply System / Aquifer Number(s)	Number Of Wells	Annual Groundwater Production Mm^3/yr	Estimated Annual Well Capacity Mm^3/yr	Percent of Well Capacity Utilized
Nanoose / 219	13	0.767	1.83	42
Parksville / 216	18	2.190	3.65	60
EPCOR / 216, 217	17	0.650	2.03	32
French Creek / 217	6	0.065	0.12	54
Qualicum / 217	11	1.830	7.88	23

Mm^3/yr = Million cubic meters per year

The percentages of well capacities utilized ranging from 23 to 60 percent indicate that existing well fields may be able to produce more water. However these percentages are based on annual volumes and we do not think all the wells could be pumped at 100% annual capacity (running continuously 24/7 at maximum flow rates). The ultimate capacity of some of the well fields will be limited by well interference but it is evident that the Parksville and French Creek systems are closer to their ultimate capacities than the others. The numbers in Table 8 were derived from reported well capacities and water production data for the systems except for the Nanoose System where pump run time data and water production data were utilized.

10.0 SUMMARY

Available groundwater data and information for the AWS area was compiled, examined and summarized including information on classified aquifers and groundwater level trends in Ministry of Environment observation wells. Potential impacts of the effects of climate change on existing aquifers, groundwater recharge, supply and demand were also examined. Estimates were made of annual recharge, storage and withdrawal from existing aquifers and compared to determine the *demand versus storage ratio* and *demand versus recharge ratio* for each aquifer. Groundwater demand growth since 1995-96 was estimated based on the increase in the number of wells over the past 13 years. Groundwater production data from major water systems in the AWS area was also examined. Based on this work a number of conclusions can be made and are reported below.

11.0 CONCLUSIONS

1. Thirteen (13) developed aquifers have been identified and classified in the AWS area based on the *BC Aquifer Classification System* (BCACS). These include seven (7) unconsolidated, sand and gravel aquifers, and six (6) bedrock aquifers. Other potential aquifers exist in the AWS area but have not yet been mapped due to limitations in the availability of well record information. Existing aquifers may also be found to be more extensive when confirmed by future well drilling.

2. The most significant unconsolidated aquifers, based on their level of development, are Aquifers 216, 217 and 219, situated in the Parksville, Qualicum Beach and Nanoose areas.

3. The Ministry of Environment currently maintains six (6) active observation wells in the AWS area as part of the provincial Observation Well Network. Five of the wells were established in partnership with the City of Parksville, Town of Qualicum, and EPCOR, with historic data dating back to 1986 (up to 24 years). Most of the observation wells are grouped in the Parksville-Qualicum Beach area (Aquifers 216, 217 and bedrock Aquifer 220).

4. Groundwater level fluctuations follow a regular annual cycle, rising during the late fall and winter months and declining during the early spring and summer months. This seasonal pattern, that is dependent upon precipitation, is shown by all observation wells in the AWS area. A number of the observation wells also show the effects of pumping interference from neighbouring production wells and increasing groundwater withdrawals from aquifers.

5. Since 2000, groundwater levels have been lowered in the Parksville area (Aquifers 216 and 220) from 2.5 to 5 m (Figures 6, 7 and 13). This lowering is attributed mainly to the pumping effects of private and municipal production wells that tend to be grouped in specific areas. Long-term monitoring records from observation wells are a key component for understanding the effects of groundwater withdrawals in aquifers and developing appropriate plans for groundwater management.

6. Water levels in the Qualicum Beach area (Aquifer 217) have been rising since 2004 and appear to be due to lessening of groundwater withdrawals in the vicinity of Observation Wells 321 and 295, possibly due to the shutdown of nearby production wells.

7. Groundwater in the AWS area is principally recharged on an annual basis through the direct infiltration of precipitation (rain and snowmelt) and infiltration of surface waters along rivers, streams and creeks. Some aquifers are also hydraulically interconnected with lakes, ponds and wetlands where groundwater levels reflect surface water levels. Production wells are also replenished through lateral groundwater flow from upslope regions of aquifers.

8. Based on climate change predictions for British Columbia, where winters are becoming wetter in coastal areas, it is anticipated that both bedrock and unconsolidated aquifers that are recharged directly by infiltrating precipitation would experience slightly higher groundwater levels during the winter and spring. Aquifers interconnected to coastal rivers that are dependent upon snow melt would be expected to experience recharge earlier in the year and lower water levels during the rest of the year upstream of their estuary areas. While wetter winters in coastal areas may result in increased groundwater recharge and higher groundwater levels for some aquifers in the winter and spring, increased groundwater demand from all sectors due to drier summers could result in lower summer and fall groundwater levels. Overall annual groundwater demand is also expected to continue to increase in the AWS area as new wells are constructed. The potential impacts of climate change for a particular aquifer requires a detailed characterization of the aquifer with suitable quantification of the water budget components. Also the net effects of climate change on any particular aquifer at any one time may not be entirely predictable with a high degree of certainty. Hence there is a need to monitor individual aquifers with an appropriate number of observation wells.

9. In coastal areas groundwater quality will be impacted locally to some degree due to saltwater intrusion in response to global sea-level rise. Nine of the developed aquifers could be potentially affected to some degree.

10. Water demand versus estimated potential groundwater supply (recharge) ratios indicate concerns for future supply in some aquifers (Aquifers 216 and 220, ratios of 71 and 79% respectively). <u>Significant future groundwater development</u> however is sustainable for most of the mapped aquifers in the AWS area. Furthermore it should be considered that the groundwater flow system is dynamic and when it is stressed (pumping from wells) the system will react. In response to pumping, more water will be taken in by the aquifer, from the natural recharge sources including direct infiltration from precipitation plus surface sources and lateral flow from upslope regions. Therefore potential groundwater supply can be increased up to two times by developing the aquifer. This effect is not considered in our analysis. Aquifer computer modeling will be required to produce more accurate estimates of ultimate aquifer water supply potential. This concept is well described in *Freeze and Cherry* (1979 – P. 365) *" Transient Hydrogeologic Budgets and Basin Yield"*

11. Annual groundwater production from the AWS aquifers is estimated at **11.5 Mm^3**. The sustainable yield is significantly more than this, potentially several times this amount. Furthermore strategies to develop the existing aquifers to their maximum potential, to explore and develop unmapped aquifers, to increase groundwater recharge - Aquifer Storage and Recovery (ASR) and artificial recharge can further increase the groundwater supply available for AWS consumers.

12. Groundwater is a very important source of water in the AWS now and in the future. Additionally the Arrowsmith Dam water license allows a maximum annual use for water utilities of **7.7 Mm^3**. The ultimate water supply capacity for the AWS can best be achieved with the conjunctive use of groundwater and surface water.

13. The groundwater demand versus storage ratios for the region's aquifers, ranging from 0.1 to 28%, show no cause for concern. Storage volumes are many times the volume of estimated annual demand so there are significant reserve supplies to sustain production in drought years. Many of the aquifers also have unused storage capacity. Thick layers of unsaturated sand overly some aquifers and this layer could be utilized to increase water supply by injecting excess winter stream flows and extracting that water in the summer dry season. This 'artificial recharge' or aquifer storage and recovery (ASR) strategy has been used in many other locations in North America.

14. Most well fields in the AWS region are designed with many wells in a limited area. The wells in tightly spaced fields interfere with each other in that one well lowers the groundwater level at the neighboring well and decreases its yield potential. The well field produces a cumulative water level 'drawdown cone' in the aquifer that may severely limit production potential in some wells. Production wells/well fields must be spread out over the area of the aquifers more evenly to tap the full water supply potential of the aquifers. Cumulative drawdown cones are (or will be) a limiting factor in the Qualicum Beach, French Creek, EPCOR and Parksville well fields.

12.0 RECOMMENDATIONS

1. As groundwater demand appears to be increasing in the AWS area (inferred from the increase in the number of wells reported and population growth) and existing well fields may need to be expanded, additional observation wells will be necessary to monitor the effects of groundwater use. Development of an overall groundwater monitoring strategy or plan for expanding observation well coverage in the AWS would be beneficial. It may also be helpful to develop and set objectives for the plan through consultation and partnership among the various private and public groundwater users in the area and with the Ministry of Environment. Both water level (quantity) and water quality monitoring may need to be considered.

2. It would also be beneficial to develop well protection plans for major production wells and well fields in the AWS, following the approach outlined in the *Well Protection Toolkit* (Ministry of Environment, Land and Parks, and Ministry of Health and Ministry Responsible for Seniors, 2000), for safeguarding the water quality and sustainability of these important sources of drinking water. Developing and setting objectives for these plans through consultation and partnership among the various private and public groundwater users in the area with the Ministry of Environment and Vancouver Island Health Authority may be appropriate. Well protection planning could also be incorporated within overall groundwater protection planning for specific aquifers, watersheds or zones within the AWS area. The *Township of Langley Water Management Plan* provides a recent example where local government has developed a comprehensive plan to ensure safe and sustainable groundwater for their community (Township of Langley, 2009).

3. There are a significant number of private large scale groundwater users in the region but little available information on their actual groundwater use. These include agricultural and golf course irrigation, resorts, commercial operations, and industrial users. The scope of this discussion paper limited detailed collection of data in this area. Future studies should address this data gap.

4. More detailed aquifer characterization studies including computer modeling should be considered, particularly for Aquifers 216, 217 and 220 to quantify the water budget components of these aquifers where demand is the greatest.

5. Well field operating strategies should be investigated for the major AWS well fields. An example outline for these strategies can be found in the report, *Water Source Assessment Study for Electoral Area E in the District of Nanaimo, 2008* (Lowen and Livingston, 2008), prepared for the Regional District of Nanaimo.

6. The potential for artificial recharge projects or Aquifer Storage Recovery (ASR) projects where the same well injects and extracts water should be investigated. In our opinion these types of water supply strategies represent the greatest water management opportunities available in the AWS region.

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