Climate Effects on Groundwater Levels in the Bow River Basin, Alberta

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ABSTRACT
Hydrographs were compared against monthly precipitation for six groundwater observation wells in the Bow River Basin of southern Alberta. In the Rocky Mountains, seasonal hydrograph response to precipitation was dramatic and short-term, indicative of pressure effects. On the foothills and prairies, the seasonal response was subdued and delayed. Annual gains or losses, represented changes in storage. A major storm event in June 2005 caused a dramatic rise in water levels throughout the Basin. Long term gains in storage were greatest on the prairies indicating the importance of major storm events for groundwater recharge.

RESUME
Des hydrogrammes ont été comparés contre la précipitation mensuelle pour six puits d'observation d'eaux souterraines dans le bassin fluvial Bow d'Alberta méridional. Dans les montagnes rocheuses, la réponse saisonnière d'hydrogramme à la précipitation était immédiate et dramatique, mais non soutenu, indicatif des effets de pression. Sur les collines et les prairies, la réponse saisonnière a été retardée et assourdie, avec des gains ou la domination annuels de pertes, indicative des changements du stockage. Un événement important d'orage a en juin 2005 causé une élévation dramatique dans des niveaux d'eau dans tout le bassin. Les gains à long terme dans le stockage étaient les plus grands sur les prairies indiquant l'importance des événements importants d'orage pour la recharge d'eaux souterraines.

1 SETTING

The Bow River Basin of southern Alberta captures a diverse landscape within a single hydrologic unit covering 22,600 km^2 (Figure 1). The headwaters of the Bow River rise in the Rocky Mountains passing between mountain ranges and foothills, and through the City of Calgary into rolling prairie grasslands flowing in a wide, deep valley. Major tributaries to the Bow River all originate in the Rocky Mountains. The Bow River merges with the Oldman River west of Medicine Hat, 587 km from its source (Atlas of Canada). The Bow River is the largest contributor of flow to the South Saskatchewan River at its source, making it the headwaters of a vast drainage system that crosses three provinces.

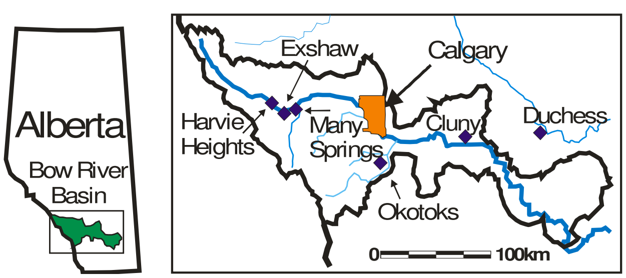

Figure 1. Location of Bow River Basin and Groundwater Monitoring Wells.

The Bow River basin is the most densely populated river basin in Alberta on average. Less water is available per person than in any other river basin in the province. The population is heavily concentrated around the City of Calgary, which accounts for just over one million of the basin's total population of 1.1 million (Bow River Basin Council, 2005). In August 2006, the Bow River was closed to new surface water licenses. A potential consequence is increased demand for groundwater.

Precipitation falling on the basin originates primarily from Pacific air masses, which have crossed the mountain ranges of British Columbia losing moisture along the way. In the headwaters upstream of Lake Louise, over 50 percent of the annual precipitation falls as snow. On the prairies east of Calgary, snowfall accounts for approximately 25 percent of the annual precipitation. Warm, dry Chinook winds in winter can reduce snow pack substantially in the Bow Valley. Normal precipitation in the basin decreases from an average of over 600 millimetres in the mountains to about 300 millimetres on the eastern prairies (Figure 2). Average annual precipitation exceeds potential evapotranspiration in the Rocky Mountains, becoming a deficit in the foothills, which grows eastward to a deficit of 200 mm at the eastern end of the Basin (Atlas of Canada). Major tributaries to the Bow River all originate in the Rocky Mountains and are contained in deep valleys. On the prairies, stream networks are poorly developed and significant land areas do not contribute water to the Bow River (PFRA, 1983).

Most of the precipitation that falls in the Bow River Basin falls in the Rocky Mountains, leaving the foothills and prairies in a rain shadow. This rain shadow can be reversed when warm air masses moving north and west from the Gulf of Mexico push against the eastern slopes of the Rockies releasing their water through orographic effects. These systems are uncommon, but they can drop substantial quantities of water, leading to flooding, including southwestern Alberta in June 1995 and the Bow and Red Deer River basins in June 2005.

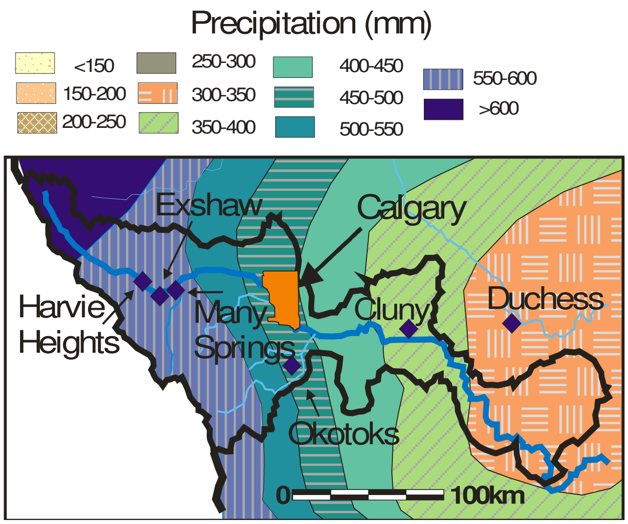

Figure 2. Average Annual Precipitation for Bow River Basin.

2 FACTORS INFLUENCING ON GROUNDWATER HYDROGRAPHS

Groundwater hydrographs depict changes in water levels in aquifers, which are a function of changes in storage and fluid pressure. A continuous water level record of five or more years is generally needed to establish water level trends and ten years is recommended for longer term climatic variations (USGS 2001).

In unconfined aquifers changes in the water levels are representative of changes in storage under atmospheric pressure. In confined aquifers, fluctuations in the piezometric surface may represent changes in aquifer storage. They are also subject to pressure, changes resulting from external loads on the aquifer or well, with no change in volumes of water stored. Barometric pressure is well known to cause water levels to rise or fall in wells depending on the barometric efficiency of the aquifer. It is best seen in highly consolidated aquifers such as cemented sandstone.

Mass loads applied to the land surface will cause an immediate rise in water levels in aquifers. Highly compressible, porous, poorly consolidated aquifers are most subject to loading. The aquifer structure can bear only a small fraction of the surface loads, causing an increase in the load borne by the water (Jacob, 1940).

Precipitation events are the most significant source of surface loading, as masses of water are applied to the land surface over a wide area (Bardsley, 1995). In aquifers susceptible to loading, water levels will rise instantaneously and then will decline gradually as the load is released through evapotranspiration or out movement. The radius of loading influence increases with well depth. (Van der Kamp and Maathuis, 1991; Van der Kamp and Schmidt, 1997; Rasmussen and Mote, 2007)

For the water released by rainfall and snowmelt events to recharge groundwater, the water must first reach the water table. It must flow overland to where the water table approaches the surface or it must pass through the unsaturated zone. The unsaturated zone resists recharge by capturing infiltrating precipitation through surface tension or moisture potential. As increasing amounts of water enter the unsaturated zone, pores fill and connect, a water column builds and moisture potential diminishes. Eventually a threshold known as field capacity is reached where the water mass is no longer held and gravity causes it to drain. When this happens, large and sometimes smaller pores empty, and the process of filling them begins again. The pulse of water can result in a sudden rise in the water table.

The amount of water reaching the water table is a function of the magnitude of the precipitation event and pre-existing reservoir of soil moisture. When soil moisture is high, a moderate precipitation event may trigger a release of water, whereas if soil moisture is very low, water from a larger event may be mostly or entirely captured by the unsaturated zone. (Tesar, et al, 2003) Large or lengthy precipitation events may result in saturated columns extending to the water table, permitting continuous gravity drainage and rapid recharge.

On the Canadian prairies, where potential evapotranspiration exceeds the supply of water, overland flow will take place only when water is supplied at a rate that exceeds the ability of the ground to absorb it. The clays and tills, which dominate the landscape tend to capture and retain water. Runoff is most common on cultivated land, when the ground is frozen in early spring. Runoff is mostly captured by closed depressions, which may take the form of dry hollows or by wetlands that are continuous with the water table. These depressions become focal points for groundwater recharge (Meyboom 1966; Lissey, 1971; Winter 1989; Vander Kamp and Hayashi, 1998, 2009).

Groundwater levels in Alberta aquifers commonly follow seasonal cycles, peaking rapidly in spring and early summer, following snow melt and spring rains, then declining slowly over late summer and through winter when frozen ground inhibits recharge. A secondary peak may be seen in late fall when vegetation is dormant and evapotranspiration is low (Maathuis, 2000).

The range and magnitude of the fluctuations will vary in response to the timing and severity of snowmelt, precipitation or drought events, aquifer properties and the degree of hydraulic connection the aquifer has to the surface. Aquifers having poor hydraulic connection to the surface will have more muted, delayed water level responses to weather, averaging out all but the major events. Moisture deficits or surpluses will be carried forward into the following year creating an upward or downward trend that will either be continued or reversed by the following year's events (Maathuis, 2000).

Drought is a recurring event on the Canadian prairies. The driest part of the prairies is the Palliser Triangle, which includes the prairie portion of the Bow River Basin. Droughts are defined subjectively, depending on timing, geographic extent, duration and degree of moisture deficiency. Drought years on the Bow River Basin were 1987-1990, 1998, 2001 and 2002 (Bonsal and Regier, 2007).

3 OBSERVATION WELL DESCRIPTIONS

Alberta Environment maintains approximately 200 groundwater monitoring wells province-wide as part of its Groundwater Observation Well Network (GOWN). The wells represent a variety of physical, hydrological and hydrogeological settings (Gabert 1986).

The Bow River Basin is the only river basin in Alberta having monitoring wells situated in the province's three main physiographic regions: Rocky Mountains, the foothills and the prairies. Current groundwater monitoring in the Bow River Basin consists of four wells installed across the basin in the late 1980s (Many Springs 364, Okotoks 217, Carseland 220 and Cluny 219) and eight wells added in the Rocky Mountains region after 2000. (Harvie Heights 764, Canmore Tourist 760, Dead Man's Flats 758, Exshaw 759, Evans Thomas 931, Goat Creek 763, Spray Lakes Ranger Station 762 and Driftwood 761). Alberta Environment collects, verifies, and distributes continuous raw water level hydrograph data for its wells.

Six wells monitoring ambient conditions and having a continuous record of at least five years were selected for this study: Harvie Heights 764, Exshaw 759, Many Springs 364, Okotoks 217, Cluny 219 and Duchess 289. Duchess 289 is in the adjacent Red Deer River drainage and was included to add representation at the eastern end of the Bow River Basin (Figure 1). Aquifers include glacial and preglacial sands and gravels and Cretaceous/Tertiary sandstone. The geological and topographic settings are illustrated schematically in Figure 3.

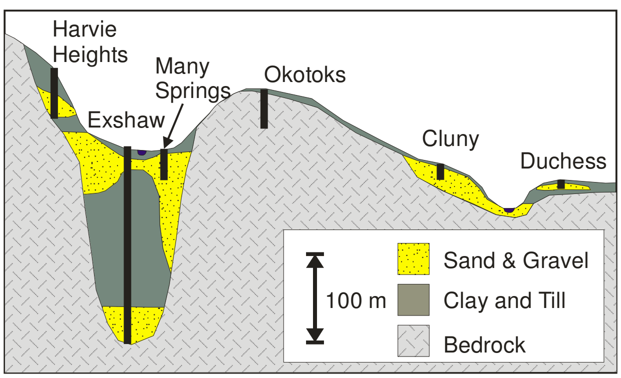

Figure 3. Schematic Cross Section of monitoring wells illustrating position, relative depth and aquifer type.

The wells are described as follows:

3.1 Harvie Heights 764

Harvie Heights 764 located in the Rocky Mountains, in forest reserve 2 km northwest of Canmore, near the hamlet of Harvie Heights. The well has been monitored since 2002. It is situated in a recharge area on a south facing mountain slope. The aquifer is poorly consolidated glacial outwash sand and gravel. Large volume springs emerge from the base of the slopes and flow into the Bow River (Toop and de la Cruz, 2002). The well is completed to a depth of 36.6 to 54.9 m in the upper of two aquifers. The aquifer is confined and has a water level elevation of about 1350 m or 27m below ground. It is underlain by a possibly discontinuous aquitard. The lower aquifer is used for domestic supply and has a water level elevation of about 1320 m, comparable to that of the Bow River.

3.2 Exshaw 759

Exshaw 759 is located in the Rocky Mountains, 15 km east of Canmore, in a cleared valley bottom, below the hamlet of Exshaw. The well has been monitored since 2001. It is situated in a discharge area in the Bow River floodplain near the Bow River. The aquifer is a deep preglacial valley, which consists of sands and gravels at least 25 m thick, overlain by 175 m of clay till and an additional 20 m of sands and gravels at the surface (Toop and de la Cruz, 2002). The well is completed at a depth of 195-201 m. The aquifer is confined and has a water level elevation of about 1287.5 m, which is about 1.5 m below ground, or 3 m above the level of the Bow River. The well is flowing artesian at times.

3.3 Many Springs 364

Many Springs 364 is located in the Rockies 20 km east of Canmore, in a wooded area adjacent to a series of high volume springs, which feed a pool that discharges into the nearby Bow River. The well has been monitored since 1987, although the record is disjointed prior to 2001. It is situated in a discharge area in the Bow River Floodplain. The aquifer is sand and gravel to an undetermined depth, which may be hydraulically connected to the buried valley aquifer. The well is completed in a confined aquifer to a depth of 21.9-29.6 m and the average water level is 1368.5 m or about 1.5 m below ground.

3.4 Okotoks 217

Okotoks 217 is situated south of Calgary, 5 km south of the Town of Okotoks. The well has been monitored since 1986. The well is situated on the upper east facing slope of a major foothill, adjacent to farmland, a landfill and acreages. The well is completed to a depth of 30.5 -38.4 m in sandstones of the Tertiary Porcupine Hills Formation, which is an equivalent to the Paskapoo Formation (AGS, 1999). Sandstone beds are fine grained, discontinuous and often cemented. Fracturing is usually required for it to be a good aquifer. Although Okotoks 217 was classified as a confined well, the average water level elevation is 1133 m or 30 m below ground, slightly above the well screen. Barometric influences are apparent in the 0.1 to 0.3 m range.

3.5 Cluny 219

Cluny 219 is located 90 km east of Calgary along the TransCanada Highway, 7, on Cluny Hill, a site elevated 130 m above and 7 km north of the Bow River near the hamlet of Cluny. The well is surrounded by sparsely populated prairie grassland within the Palliser Triangle. The well has been monitored since 1986. It is completed at a depth of 12.5 to 15.5 m in an extensive sheet of high yielding, pre-glacial gravel and sand connecting to the Calgary Buried Valley Aquifer, overlain by till and clay (Carlson et al 1969). The water level elevation averages 932.4 m or about 12 m below ground.

3.6 Duchess 289

Duchess 289 is located 40 km north of Brooks and 4 km west of the Red Deer River surrounded by prairie pastureland. The landscape is a flat and treeless, but is hummocky on a smaller scale. The well is 7.62 m deep installed in a low yielding, shallow unconfined aquifer of fine sand. The top of the screen is located 6.4m below ground while the water table during the study period was on average 5-6m below ground; with an elevation of about 724–725 m. Monitoring began in 1989.

4 HYDROGRAPH RESULTS

To ensure that the hydrographs were monitoring ambient conditions, background data and information were collected and reviewed, including well construction, completion, pump testing and maintenance details, water chemistries and information on surrounding land developments, water and energy resource wells. Each well site was visited by the author.

Hydrographs were plotted against monthly precipitation data obtained from Environment Canada for the closest climate station covering the same time period, and then inspected for timing and magnitude of water level response to precipitation. Annual net gains or losses were determined by the annual low, which usually occurred in April. Statistical analysis to determine the lag time between precipitation events and hydrograph response using the Pearson Product Moment Correlation (PPMC) was performed by Dr. J. P. Jones, of the Alberta Research Council / University of Waterloo (Toop et al, 2008).

Individual well results are as follows:

4.1 Harvie Heights 764

The hydrograph for Harvie Heights 764 (Figure 4) exhibits strong seasonality, typically rising in May-June, peaking in July and declining at a gradually slowing rate to late April. The hydrograph response to seasonal snowmelt and precipitation events was significant and immediate when compared to monthly precipitation data from Environment Canada's Banff weather station.

The total historical range of water levels from 2003-2008 was 7.7m, from a low of 1347.7 m asl in April 2004 to a high of 1355.4 m asl in July 2005. This range in water levels exceeds that of all other wells examined. A major storm event in June 2005 caused water levels to spike a record 6.2 m in one month.

Annual net changes fell within a 1.2 m range: far less than seasonal variations. Water levels rose most years, but fell in 2004 and 2007 when preceding years were relatively dry. Water levels gained a total of 0.5 m from 2003 to 2008. PPMC analysis failed to find a lag time correlation between precipitation and water levels.

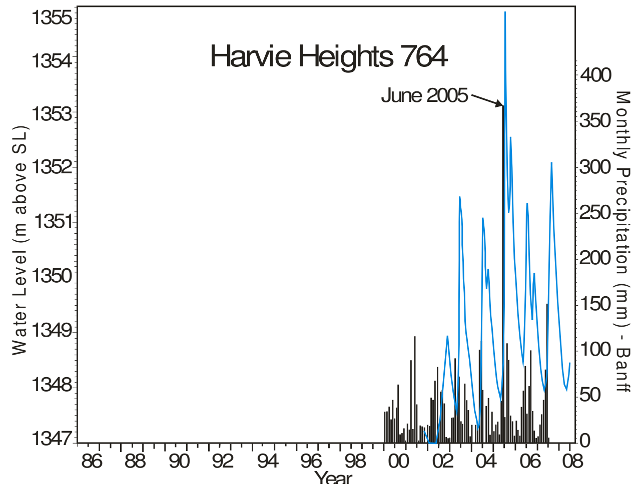

Figure 4. Hydrograph for Observation Well Harvie Heights 764 compared to monthly precipitation.

4.2 Exshaw 759

The hydrograph for Exshaw 759 (Figure 5) exhibits strong seasonality, typically rising in April with snowmelt, forming a sharp peak in June-July declining at a gradually slowing rate to the end of March. Smaller peaks follow major summer storms. The hydrograph shows significant and immediate response to seasonal snowmelt and precipitation events, when compared to monthly precipitation data from Environment Canada's Bow Valley weather station. Despite a lack of recharge, heavy snowfall events triggered small rises in water levels in December 2001, January 2007 and March 2008.

The total historical range in water levels from 2002 to 2008 is 3.25 m from a low of 1287.15 m asl in April 2002 to a high of 1290.4 m asl in July 2005, July 2007 and July 2008, which is one metre above ground level and coincident with the top of casing. Consequently seasonal variations could be greater. Year to year changes fell within a 1.05 m range. Immediately following a major storm in June 2005 water levels spiked 1.8 m to the top of casing and flowed for two months.

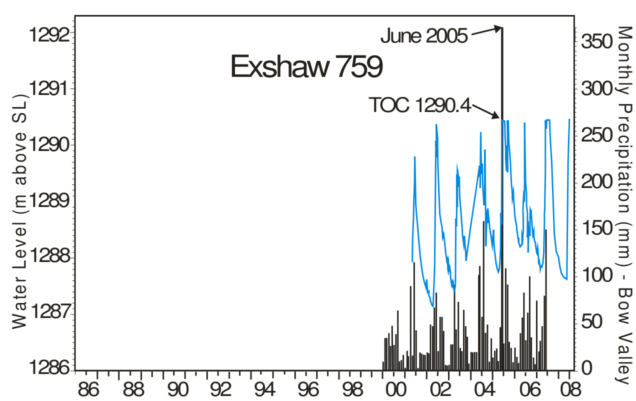

Figure 5 Hydrograph for Observation Well Exshaw 759 compared to monthly precipitation.

Annual net changes fell within a 1.0 m range: far less than seasonal variations. Water levels rose from 2001-2006, falling in 2007-2008. Water levels gained a total of 0.5 m from 2003 to 2008. PPMC analysis failed to find a lag time correlation between precipitation and water levels.

4.3 Many Springs 364

The hydrograph for Many Springs 364 (Figure 6) exhibits strong seasonality, typically rising in May with spring rains, forming a single sharp peak in June-July declining at a gradually slowing rate to April. The hydrograph shows significant and immediate response to seasonal snowmelt and precipitation events, when compared to monthly precipitation data from Environment Canada's Bow Valley weather station.

The total historical range of water levels from 1988-2007 was 1.2 m, from a low of 1368.5 m asl in April 2002, following the drought of 2000-2001, to a high of 1369.7 m asl in July 2005. This was the lowest variability of water levels of the wells in the Rocky Mountains. Water levels rose 0.85 m immediately following a major storm in June 2005.

Annual net changes fall within a 0.7 m range. Prior to 2000, annual changes in water levels were in the 0.2 m range. Average water levels dropped during the drought of 2000-2001, rising until 2006, and then declining. Water levels gained a total of 0.4 m from 1988 to 2007

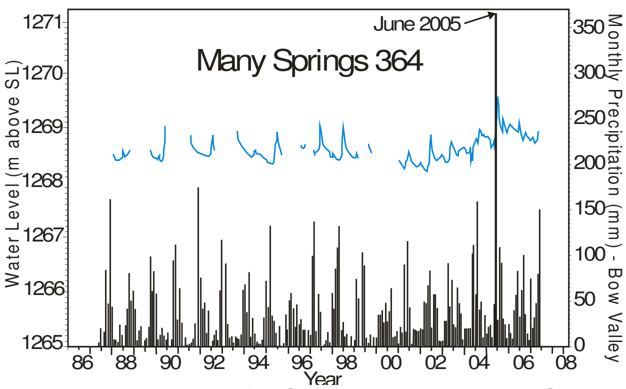

Figure 6. Hydrograph for Observation Well Many Springs 364 compared to monthly precipitation

4.4 Okotoks 217

Water levels in Okotoks 217 (Figure 7) shows delayed, subdued response to precipitation when compared against monthly precipitation data from Environment Canada's High River weather station, Water levels are steady most years, but perceptible seasonal rises may be seen from July through September in years of sufficient summer precipitation. Longer term changes in water levels overshadow any seasonal effect.

The total historical range in water levels from 1988 to 2008 is 4.7 m from a low of 1131.8 m in 1992 to a high of 1136.5 m in January 2006. Water levels have risen 2.4 m over the life of the well, with most of this increase resulting from a 3.8 m rise following a major storm in June 2005. This was the second greatest variability in water levels for any of the wells.

Water levels declined from 1988 to 1992 during and following drought years, reversing after an unusually wet June 1992, rising to 1999, and then declining during and following the drought of 2000-2002. Water levels rose follow a major storm in June 2005, then declined in ensuing years. The magnitude of annual rise or fall in water levels corresponds to the magnitude of the previous months of precipitation.

Water levels peaked five months after the storm of 2005. A similar delay of 5 to 6 months is seen after other major events in 1998 and 2006. PPMC results indicate that it takes about 7.5 months for rainfall to recharge the well.

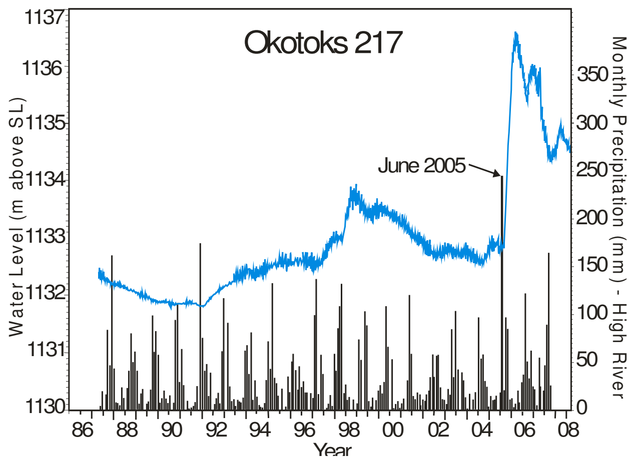

Figure 7. Hydrograph for Observation Well Okotoks 217 compared to monthly precipitation.

4.5 Cluny 219

Water levels in Cluny 219 (Figure 8) shows delayed, subdued seasonal response to precipitation when compared against monthly precipitation data from Environment Canada's Gleichen weather station. Snow pack is minimal in this region. Precipitation is highest from May to July. Water levels peak about four months later, rising slowly from July through September, and then decline to the following spring. In years of poor spring rains (1987, 1988, 2000, and 2001) seasonal responses in water levels are minor, delayed or absent. Seasonal changes in water levels are comparable to annual changes of about 0.3 m.

The total historical range in water levels from 1986 to 2008 is 1.6 m, from a low of 931.9 m in June 1991 to a high of 933.5 m in July 2007. Water levels have risen 1.2 m over the life of the well, including a significant increase of 0.6 m following a storm in June 2005 and a questionable anomalous rise of 0.75 m occurring over three weeks in May 1997, which was initially attributed to melting of heavy snow pack by Alberta Environment and later discounted as a shift in baseline (Butarac and de la Cruz, 2001).

Water levels declined from 1988 to 1992 during and following drought years, rising to 1999 and then declining during the drought of 2001-2002. Water levels have risen annually since 2003. The storm of June 2005, resulted in a 0.60 m rise over five months. The hydrograph shows recharge occurring 2-3 months after precipitation events, consistent with a PPMC result of 2.5 months. The rise in May 1997 was inconsistent with this result.

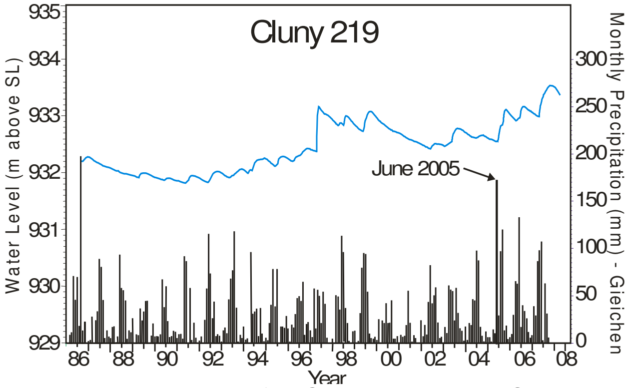

Figure 8. Hydrograph for Observation Well Cluny 219 compared to monthly precipitation.

4.6 Duchess 289

Water levels in Duchess 289 (Figure 9) shows subdued seasonal response to precipitation when compared against monthly precipitation data from Environment Canada's Gem weather station.

Precipitation peaks in early summer and winter snow cover is generally minimal. Minor seasonal fluctuations are seen in 9 years out of the past 19 years of monitoring. The magnitude of fluctuations is from 0.15 to 0.30 m with a late winter low, usually peaking in mid-summer. They are delayed (2002, 2003) or absent (2000 and 2001) during dry years. Year to year changes overshadow seasonal variations. The total historical range of water levels from 1990 to 2008 is 2.9 m, from a low of 724.3 m in June 2005, to a high of 726.2 m in July 2006, following a major storm event in June 2005. Water levels have risen 0.5 m from 1990 to 2008.

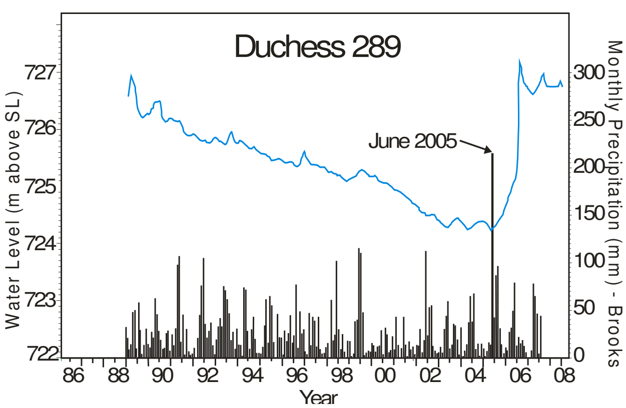

Figure 9. Hydrograph for Observation Well Duchess 289 compared to monthly precipitation.

Water levels declined steadily from 1990 to 2005, dropping a total of 2.6 m, with the exception of 1999, which was wetter than normal. Following a major storm event in June 2005 the water level rose 2.9 m to July 2006, dropping back 0.30 m, before stabilizing into 2008. PPMC analysis determined a 15 month time period for rainfall to recharge the well; comparable to the 13 months it took for the 2005 storm to peak.

5 DISCUSSION

Within the Bow River Basin hydrographs exhibited seasonal and long term responses to variations in precipitation. Seasonal responses predominated in the Rocky Mountains, whereas long-term responses were predominant in the foothills and prairie.

Despite spatial differences in magnitude of rainfall across the basin, water levels for the most part rose and fell synchronously across the region. This may indicate that it is larger scale climate and weather events are more important than small scale events in setting water levels. Most wells were installed during dry years, and have exhibited subsequent gains in water levels. The greatest variability in water levels was seen in wells located on elevated sites (Harvie Heights 764, Okotoks 217).

In the Rocky Mountains, aquifers under observation consist of poorly consolidated sands and gravels, which are susceptible to loading. Water levels in these aquifers show a strong seasonal response, reacting immediately to snow melt and spring rains rising up to several metres then declining over late summer and fall seasons. Seasonal spiking of water levels is likely the result of compression of the aquifer caused by an increased water load on the land surface. Some of this load is quickly lost to runoff, while water that has entered the soil zone is dissipated over the season. Changes in water levels carried forward into the following year mostly indicate changes in storage. In the Rocky Mountain wells, seasonal effects overshadow annual gains or losses, whereas in the wells on the foothills and prairies, annual changes predominate over seasonal effects. Low magnitude seasonal fluctuations are seen in these wells, which may exhibit a time delay of several months. The difference may be attributed to shallower depth of completion, a smaller saturated zone and lower compressibility of the aquifer. It worth noting that PPMC analysis, which measures the time lag in water level response after precipitation was ineffective in wells strongly influenced by pressure loading.

In the Rocky Mountains, annual precipitation exceeds potential evapotranspiration. Water levels rise or fall based on the preceding year's inputs, but overall are relatively stable. Loading at the land surface raises the potentiometric surface of these aquifers in the short term, making them less likely to accept recharge. Aquifer storage appears to be near-capacity and as a consequence aquifers are likely to reject large volumes of recharge as surface runoff.

In the eastern Bow River Basin, which is under moisture deficit, Alberta Environment flood forecasters have noted minimal runoff from events in this region that would have caused flooding in the mountains (pers. comm.). The foothills and prairie wells are located in elevated settings, where no wetlands were observed. Without a wetland to act as a vehicle for recharge, precipitation must penetrate the unsaturated zone to reach the water table. Moisture deficits will capture water in the unsaturated zone, releasing it in transient pulses as field capacity is reached.

Water must be input at magnitude and a rate sufficient to overcome the pre-existing moisture deficit and ongoing losses to evapotranspiration. This will occur when sufficient volumes are added over a limited period of time, such as a closely spaced series of moderate events raising the moisture potential close to threshold, or after a protracted, severe storm.

Spring snowmelt added to the annual precipitation peak is usually sufficient to release vadose water to the water table in pulses. This appears to be the common scenario, resulting in small annual gains or losses depending on the occurrence, timing and magnitude of events. Large magnitude precipitation events are capable of releasing substantial recharge pulses, or even creating saturated conduits through the vadose zone, providing a steady stream of recharge water to the water table.

Between June 1 and 29, 2005, four storms hit southern Alberta, lasting a cumulative total of 16 days. The entire Bow River Basin was affected with anywhere from 50% to 100% of average annual precipitation falling within the month. Heaviest precipitation occurred along the foothills and front ranges of the Rockies (Figure 10). Flooding along the Saskatchewan River drainage affected three provinces. In the Rocky Mountains the hydrograph responses to the storm were dramatic and immediate. These mostly receded the same season and long term gains in water levels were relatively minor. In contrast, a delayed, protracted rise in water levels was seen on wells in the prairies and foothills. There was an initial drop in water levels from the peak, but the bulk of the rise was sustained into the following years.

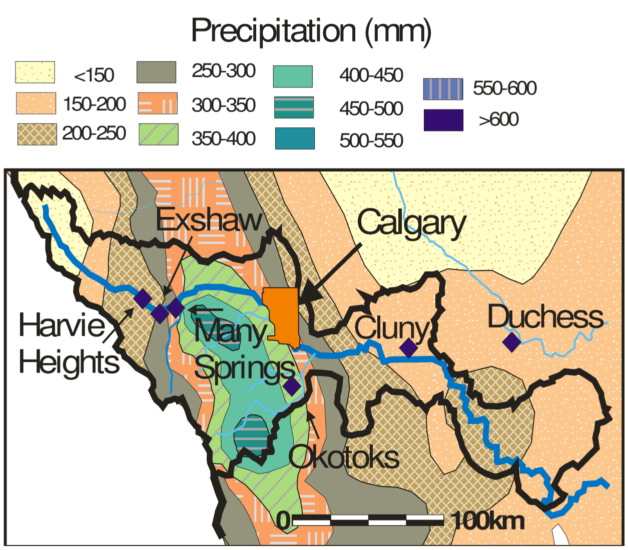

Figure 10. Precipitation for the month of June 2005 encompassing a major storm event, Bow River Basin.

The greatest rise was seen in Okotoks 217, in the epicentre of the storm. The most significant, sustained gain was seen by Duchess 289, located in the part of the Bow River Basin experiencing the greatest moisture deficits. For Duchess 289, this event was sufficient to overcome twenty years of continuous decline

6 CONCLUSIONS

Groundwater monitoring hydrographs for six wells in the Bow River Basin were examined. Three of these wells were located in the Rocky Mountains and three in the foothills-prairie region to the east.

All wells exhibited upward or downward trends in water levels that corresponded to wet or dry years across the region. In the Rockies, immediate seasonal fluctuations resulting from surface loading dominated the hydrographs. Actual changes in storage were determined from yearly changes in the annual low. On the foothills-prairies, small, delayed seasonal responses were seen and longer term gains or losses representative of changes in storage dominated the hydrographs.

In the Rockies, precipitation exceeds potential evapotranspiration. A moisture surplus ensures that soil moisture and aquifer levels remain high. Aquifers quickly fill and excess precipitation generates runoff. All major tributaries to the Bow River originate in the mountains.

Moisture deficits occur in the foothills and increase eastward on the prairies. Water entering the ground is mostly captured in the unsaturated zone. Wetlands have traditionally been identified as the primary agent for groundwater recharge on the prairies. Wetlands are not universally found. In the absence of wetlands, long-term groundwater levels are susceptible to decline, unless reversed by precipitation or snowmelt events of sufficient magnitude to overcome moisture deficits within the unsaturated zone. The prairies are influenced by a cycle of longer-term climate events, which include periodic drought and major storms. Major storm events are critical for sustaining groundwater levels over the longer term, especially in the driest parts of the region.

The severe storm event of June 2005 brought intense rainfall along the front ranges and heavy rainfall to the prairies. In the Rockies the event topped up aquifer levels and long term gains in aquifer storage were minor. Runoff originating along the front ranges caused major flooding downstream. On the prairies however, where water levels in aquifers were low, groundwater recharge was dramatic and sustained, but surface run-off was insignificant.

This is important for understanding both hydrological and hydrogeological processes in the region, with implications for both river forecasting and sustainable groundwater management.

ACKNOWLEDGEMENTS

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DEDICATION

For my father, Allan Toop.

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