This article provides a review of current research on groundwater-surface water interaction, groundwater and ecology of surface waters, and community-based well monitoring. The review is based on research conducted in the West Nose Creek (WNC) watershed located north of Calgary (Figure 1) and St. Denis National Wildlife Area in southern Saskatchewan. The research is led by Dr. Masaki Hayashi, a hydrologist from the University of Calgary.

Underlying WNC watershed is the Paskapoo Formation, a bedrock formation containing one of the largest aquifer systems in the Canadian prairies (Grasby et al. 2008). Use of groundwater from this aquifer system has increased over the past decade, particularly between Calgary and Edmonton (Grieef and Hayashi 2007). Therefore, understanding how groundwater interacts with surface water and ecological processes, along with long-term monitoring of water wells is critical for future development and sustainable management of groundwater in this region.

**Introduction**

Prior research predicted that groundwater generally moves from high (upland) to low (depression) areas within a region (Toth 1980). Recharge is thought to occur in uplands and discharge to occur in low areas containing surface water such as streams, ponds, or wetlands (Figure 2).
Groundwater storage in aquifers can also change over time, depending on the amount of recharge and discharge ($\text{Recharge} - \text{Discharge} = \text{Change in GW Storage}$). More recharge and/or less discharge over time will increase groundwater storage. Recharge and discharge in a natural system does balance over time and GW storage does not change much from an average value.

However, this balance can be altered by pumping water from aquifers through wells, which drawdown water levels. Long-term pumping of groundwater can alter groundwater discharge into surface water and groundwater storage in the region ($\text{Recharge} - \text{Discharge} - \text{Pumping} = \text{Change in GW Storage}$). Therefore, it is very important to increase our understanding of how (and how much) groundwater is recharged, discharged, and pumped in order to develop sustainable management of groundwater in a region.

**Current Research on Groundwater Recharge**

Between 80,000 and 10,000 years before present, massive ice sheets covered and shaped the prairie landscape. The ice sheets melted at different rates, leaving behind an undulating topography of uplands and depressions (Figure 3).
A research team (Hayashi et al. 1998) examined the hydrology of St. Denis National Wildlife Area near Saskatoon, Saskatchewan, which has very similar to the topography of southern Alberta. The team found that as winter sets in, water in the soil begins to freeze and snow covers most of the ground most of the winter. During the winter some of the snow blows into the depressions. In the spring the snowmelt becomes runoff over the frozen soil, also collecting in the depressions. As the soil thaws, water infiltrates the soil below the depressions.

The team also observed that during the growing season the infiltration rate was greatest during the day when plants were transpiring and reduced at night. This process caused most of the infiltrating water to flow laterally away from the depression and up toward the upland areas to be used by plants (Figure 4). As a result, of all the water collecting in the depressions only a very small fraction becomes groundwater recharge. For example, in 1994 only 2 mm of the 376 mm total annual precipitation – less than 1% – became groundwater recharge.

The same research team (van der Kemp et al. 2003) also found that changes in land-use in and around the depressions can impact infiltration rates and water flow. For example, changes in vegetation around the depressions can impact snowmelt capture, runoff, and lateral moisture flow in the soil subsurface due to changes in height of vegetation, soil openings, and evapotranspiration rates. Many of the small depressions can also gradually dry up throughout the spring and summer months with these changes. These results highlight how important wetlands, ponds, prairie sloughs, and surrounding vegetation in the uplands are to groundwater recharge in prairie landscapes.

Current Research on Groundwater Discharge

In the WNC watershed, springs are not only accessed for household and agricultural use, but also provide localized groundwater discharge that contribute to stream baseflow (see, Figure 1 for location of springs). An undergraduate research project conducted by Nathan Green (2007) focused on the influence of geology on springs and the connection between spring discharge and stream baseflow in the WNC watershed.

Nathan noted that the geology in this watershed is composed of low permeability glacial till near the surface followed by interbedded lower permeability siltstones and mudstones, and higher permeability sandstones (Figure 5). Groundwater originates from depression focused recharge areas and moves laterally through the more permeable sandstone layers, where it emerges at a spring outlet. Although the upper sandstone layer discharges the majority of groundwater, some can reach deeper layers. Nathan also noted that all but one spring in WNC watershed was governed by this geology.
An aerial video was taken in late winter to locate springs within the WNC watershed by identifying ice mounds forming around springs. The total spring discharge in the watershed was then calculated by manually measuring discharge from 40-45% of the springs and estimating remaining spring discharge using the aerial video. It was estimated that 75-90% of all spring discharge came from the measured springs and the total discharge of all springs was in the same order of magnitude as the WNC stream baseflow.

Nathan also noted differences in discharge rates among the springs, possibly due to nearby pumping wells and/or fractures in the bedrock. This research not only increased our understanding of how springs help maintain stream baseflows, but also showed that more research is required to understand what causes differences in discharge rates.

This current research also helps increase our understanding that groundwater recharge and discharge in this region is localized and not as diffuse as presented in the idealized conceptual model presented in Figure 2. In addition, it showed that groundwater and surface water are connected and therefore, should be considered as one and the same resource for sustainable water management in this region.
Groundwater & Ecology of Surface Water

Hayashi and Rosenberry (2002) note that continuous exchange of groundwater with surface water also helps to maintain stable temperatures, water levels, and nutrient cycles in surface waters (creeks, ponds, wetlands). This exchange has an impact on ecological processes and organisms living in and around surface waters. For example, many fish species are dependent on stable water temperatures. Water levels impact light depth penetration of the surface water, influencing types of vegetation and organisms living in surface waters. Groundwater exchange also affects nutrient cycling and what lives in the surrounding riparian and hyporheic zones. This review article highlights the need to monitor changes in baseflows, water levels, and vegetation in and around surface waters. The change can indicate change in water table levels due to drought, land-use change, or over-pumping in a region.

**Figure 7.** Typical location of water table (dashed line) and water flow pathways (arrows) of: A) groundwater, B) run-off, C) from vegetation, D) exchange in hyporheic zone (Adapted with permission from Hayashi & Rosenberry 2002).

**Impact of Overpumping from Water Wells**

As water is pumped from a well it causes a drawdown of the water table near the well. As pumping or number of wells increase in an area a larger drawdown can occur, possibly impacting local spring discharge, stream baseflow, and ecological processes. For example, as population increased (Figure 8A), there was increased pumping from the town water wells in Irricana. This increased pumping decreased the water table levels as far away as 1 km from the well (Figure 8B).

**Figure 8.** A) Population increase in Irricana from 1965 to 2005 (From: www.altapop.ca/sources.htm); B) Water level drawdown 1 km from town water well (Adapted with permission from Alberta Environment).
Community-based Well Monitoring

The WNC watershed has not yet experienced significant groundwater storage decline. However, as population and development increases so does demand on groundwater, as it is the primary source of water supply for municipal, domestic, agricultural, and industrial use in this region (Grieef & Hayashi 2007). In order to help prevent negative impact on springs, stream baseflows, or ecological processes, it is important to establish long-term monitoring of groundwater.

As such, Lisa Grieef from Alberta Environment (Calgary) and Dr. Hayashi developed a community-based well monitoring network in cooperation with well owners to collect well water level data (Figure 9A) in twenty existing wells in the WNC watershed (Figure 9B). This water level data not only provides early detection of groundwater overuse, but also helps establish natural fluctuations in seasonal and yearly averages.

The Rocky View County has implemented the pilot program in six other watersheds. Residents can upload and explore water level data through the Rocky View Well Watch website [http://rockyview.geocens.ca]. The program provides a cost-effective approach for groundwater monitoring and engagement of residents in sustainable groundwater management in this region.

Conclusions and Further Research

This research has shown that it is important to take a watershed approach in order to better understand, monitor, and manage groundwater. Groundwater, surface water, and ecological processes are interconnected through hydrological processes such as recharge, discharge, and exchange.

The research has also shown that it is possible to monitor groundwater levels through a low-cost community-based well monitoring network. The data helps establish seasonal and yearly fluctuations, as well as potential impact on water levels, stream baseflows, and ecological systems from increased number of wells or over-pumping in a region.

However, in order to be able to predict what sort of impact increased groundwater use will have, we need wide spread long-term monitoring. We also need to increase our understanding of groundwater flow within and between aquifers of this region, in addition to understanding localized groundwater-surface water interactions.
REFERENCES

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