AN OVERVIEW OF THE ARCHITECTURE, SEDIMENTOLOGY AND HYDROGEOLOGY OF BURIED-VALLEY AQUIFERS IN CANADA

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ABSTRACT
Buried valleys occur across Canada yet no systematic study has been completed of the scale, style, and hydrogeological significance of this aquifer type. This paper reviews geological and hydrogeological knowledge of buried-valley aquifers in Canada. Buried valleys are placed in a stratigraphic classification: i) bedrock, ii) bedrock interface, and iii) Quaternary sediment. The distribution, geometry and scale of valleys and the sediment facies of valley fills are briefly discussed. Important hydrogeological characteristics for buried-valley aquifers include aquifer extent, aquifer continuity and several hydraulic characteristics that influence flow and hydraulic response. The wide range of hydrogeologic settings and functions for buried-valley aquifers explains their variability as groundwater resources, thus emphasizing the need for greater monitoring and understanding of buried valleys at several scales. Knowledge gaps are identified and the need for improved integration of geological and hydrogeological studies to improve understanding of Canada's buried-valley aquifers is advocated.

RÉSUMÉ
Les vallées enterrées se trouvent à travers le Canada pourtant aucune étude systématique n'a été achevée de l'échelle, du style, et de l'importance hydrogéologique de ce type de couche aquifère. Cet article passe en revue la connaissance géologique et hydrogéologique des couches aquifères de vallées enterrées au Canada. Ces vallées sont placées dans une classification stratigraphique : i) roche en place, ii) interface de roche en place, et iii) sédiment quaternaire. La distribution, la géométrie et l'étendue des vallées et les facies des remblaiments de vallée sont brièvement discutés. Leurs caractéristiques hydrogéologiques importantes incluent l'étendue des couches aquifères, la continuité des couches aquifères et plusieurs caractéristiques hydrauliques qui influencent l'écoulement et la réponse hydraulique. La gamme importante de milieux et de fonctions hydrogéologiques pour les couches aquifères de vallées enterrées souligne leur variabilité comme ressources d'eaux souterraines et le besoin de plus grande compréhension des vallées enterrées. Plusieurs lacunes de connaissance sont identifiées et le besoin d'une intégration améliorée des études géologiques et hydrogéologiques est préconisé pour améliorer la compréhension des couches aquifères de vallées enterrées du Canada.

1. INTRODUCTION

Buried valleys are common across Canada and the northern United States where multiple glaciations have buried both pre-glacial and Pleistocene valleys. Productive aquifers commonly occur in buried valleys yet knowledge of their distribution and groundwater resource potential is generally inadequate (e.g. van der Kamp, 1986). Recognition of the importance of this aquifer type in the Prairies prompted mapping of buried valleys across Alberta and Saskatchewan in the 1950's and 60's (Christiansen, 1963; Farvolden, 1963; see Maathuis and Thorleifson, 2000). The spatial distribution of buried valleys has been outlined for this area yet relatively few conceptual models have been developed for the valley fills. In the rest of Canada no systematic mapping or characterization has been undertaken and consequently numerous buried valleys may remain unidentified or under explored.

A review of buried valleys in Canada is appropriate because i) characterization of buried valleys and their fills is inadequate, ii) their sustainable resource potential is significant, iii) important advances in investigative techniques and geological knowledge are available, and iv) there is no national scale overview of buried valley aquifers in Canada. This paper illustrates a geological framework for understanding aquifers in buried valleys. Buried valleys are classified stratigraphically and the regional distribution, geometry, and nature of the valley fill sediment are discussed. General hydrogeological attributes of buried valleys are discussed and highlighted through two case studies. The paper aims to foster the integration of geological and hydrogeological information through the use of basin analysis methods as a predictor of spatial and stratigraphic variability.

1.1 Techniques

An integrated basin analysis approach (using remote sensing, geologic, geophysical, hydrogeologic, geostatistical, and database techniques) is needed to understand the geological history of basins (e.g. Sharpe et al. 2002). Such integration can advance understanding on the length and width scales of buried valley systems and sediment facies variability that determine hydraulic properties.

Geologists commonly collect section and core data to analyse vertical facies relationships. The value of this data can be enhanced through integration with geophysical data to provide a stratigraphic framework for hydrogeological studies (e.g. Wolfe and Richard, 1996). Thus, local geological and geophysical data are extrapolated on the basis of depositional models to arrive at a geological and hydrogeological model of the entire aquifer and its' setting.

Using information on stratigraphic architecture and sediment facies, the hydrogeologist can better evaluate groundwater data and define hydraulic boundaries through the appropriate positioning of pumping and observation wells. Groundwater data, such as the accurate record of static water levels in these key wells, allow determination of hydraulic gradients and provide valuable constraints on the hydraulic continuity of the aquifer- commonly the single most difficult property to determine. Dynamic response of groundwater levels to long-term groundwater withdrawls provides critical information on sustainable rates of use. Flow from springs can also yield invaluable information, as can chemical and isotopic data.

Reliable determination of the sustainable groundwater yields of buried valley aquifers nearly always relies on long-term monitoring of groundwater levels and pumping rates (Maathuis and van der Kamp, 2003) since these aquifer systems are often too complex to be modeled on the basis of limited local data. Thus, it is critical that water-level observations be initiated as soon as possible for the long-term response of the entire system to be determined. Although geological and geophysical data will be of assistance in basin modeling, a lack of data pertaining to past hydrological stress often limits the reliability of the analysis.

Observation wells and pumping wells are ideally positioned on the basis of geological understanding of the aquifer, such as a well for each key stratigraphic unit. This allows groundwater data to provide an integrated response over the whole aquifer system including the adjoining formations. The groundwater information thus provides an independent check of the hydrogeological model and commonly leads to revisions of the geological model. This, in turn, leads to further refinement and evaluation of the hydrogeological model. Hence, the characterization of a buried-valley aquifer system tends to be an on-going story of interplay between gradually improving geological and hydrogeological insights. In short, integration of sparse hydrogeological data into a sound geological framework can improve understanding of aquifer flow systems in buried valleys.

2.0 CLASSIFICATION AND DISTRIBUTION

2.1 Stratigraphic Classification

There has been no attempt to classify the variety of buried valleys in Canada. A non-genetic classification based on stratigraphic relationships is proposed: i) bedrock, ii) bedrock interface, and iii) Quaternary sediment.

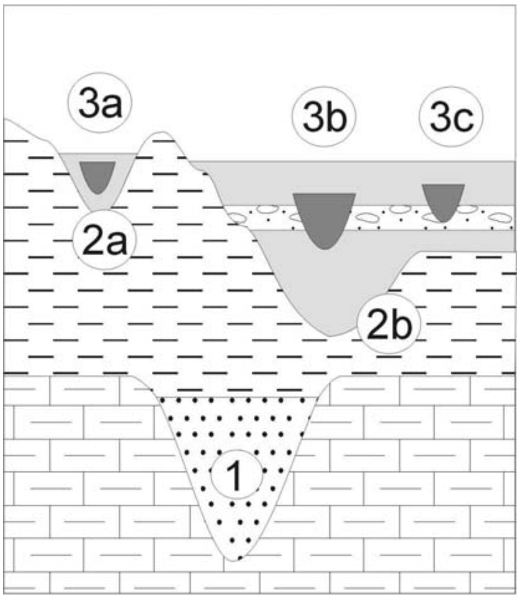

Figure 1: Schematic illustration of valley types, 1 bedrock; 2a partially filled bedrock interface valley, 2b buried bedrock interface valley; 3a Quaternary sediment buried valley nested in a partially infilled bedrock valley, 3b Quaternary sediment valley breaching regional aquitard, 3c Quaternary sediment valley that only partially erodes the aquitard.

Bedrock: Bedrock hosted valleys are pre-Quaternary in age and are often eroded within sedimentary bedrock. The most prominent examples are incised valleys. These valleys are a common exploration target of the petroleum industry but are also exploited, or have potential, for groundwater where the depth of burial is shallow (e.g., Zaitlin et al. 1994; Hamblin, 2004).

Bedrock interface: Bedrock interface valleys are eroded into consolidated or poorly consolidated, pre-Quaternary bedrock. Inter-montane valleys (e.g. Rocky Mountain Trench) are a structurally controlled, partially-filled example of this valley type (e.g. Foweraker et al. 2004). Interface valleys may be partially or completely infilled and buried by Quaternary sediment. These valleys are the most commonly studied type of buried-valley aquifer (e.g. Kehew & Boettger 1986; Ritzi et al. 2000; Maathuis and van der Kamp, 2003).

Quaternary sediment: Quaternary sediment buried valleys are eroded into unconsolidated sediment. These valleys may form nested valleys within buried bedrock interface valleys or be one element of inter-till deposits. This valley type is well documented from parts of southern

Ontario, particularly the Oak Ridges Moraine area where tunnel channels have been defined by reflection seismic data (see in Sharpe et al. 2002).

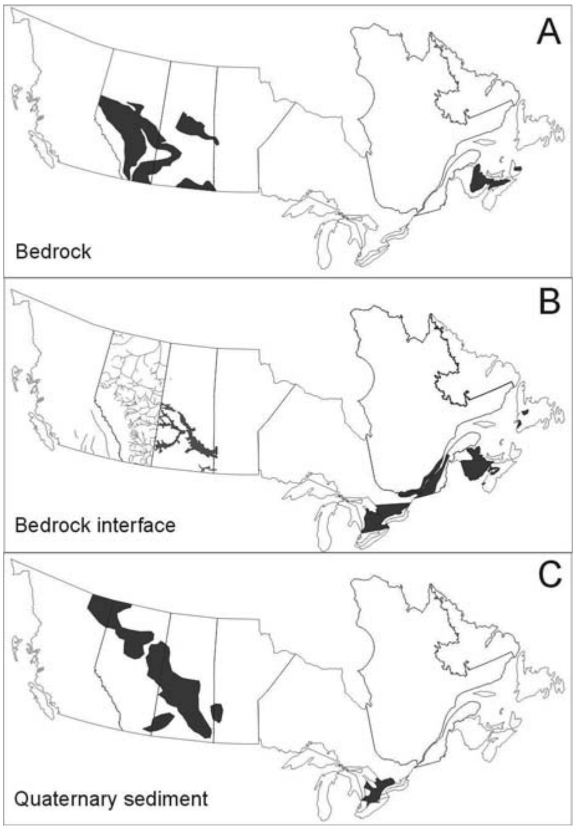

Figure 2: Incomplete distribution of mapped buried valleys in southern Canada and areas of greatest potential for buried valleys. Areas are based on proxy data, such as: bedrock type, and sediment thickness. Lines are mapped valleys, shaded areas have high potential, and unshaded areas have low potential. A, bedrock valleys; B, bedrock interface valleys; C, Quaternary sediment valleys. Data collected from the literature (see Maathuis and Thorleifson, 2000).

2.3 Spatial Distribution

The distribution, style, and fill characteristics of buried valleys are related to tectonics, base level control, and glacial processes. Buried valleys are predominantly associated with sedimentary basins of the Phanerzoic, particularly the Western Canadian Sedimentary Basin, the Palaeozoic of southern Ontario and the St Lawrence lowlands, and the Carboniferous of Atlantic Canada. Less commonly, buried valleys are described from the Canadian Shield region. The distribution of buried bedrock interface valleys has only been mapped in Alberta and Saskatchewan (Fig. 2). It is probable that some of these valley systems extend into Manitoba. In much of the rest of Canada, mapping buried valleys has been completed on individual valleys of interest rather than systematic mapping of valley systems (e.g. Broster, 2004)

Table 1: Upper reported dimensions of buried valleys from selected published sources.

	Bedrock	Bedrock Interface	Quaternary Sediment
Length (km)	350	600	50
Width (km)	90	30	5
Depth (m)	40	300	200
Valley types	fluvial-estuary,	fluvial, glacial, glacifluvial, estuary	fluvial, glacial, glacifluvial,

3.0 VALLEY CHARACTERISATION

3.1 Valley Geometries And Scales

The geometry of valley types spans an order of magnitude in lengths and width (table 1). The variability in depth between classes is less but can be a factor of 3-5. Valleys formed under non-glacial pluvial conditions may develop a dendritic pattern with profiles graded to base level. This common model for bedrock interface valleys is clearly reflected in the network geometry of Alberta buried valleys (Fig. 2). Conversely, other valleys networks may be anabranching, terminate abruptly up flow and have rising down flow longitudinal profiles that are characteristic of erosional subglacial meltwater processes (e.g. Andriashek, 2000; Sharpe, 2002). The understanding of valley networks may be further complicated by the intersection and capture of different valley segments that have formed at different times. In many cases the mapped network geometry is in part predicated on a priori process models rather than mapping from hard data (e.g. Gray, 1991). Buried valley systems have often been inadequately investigated to permit definitive statements on valley geometries and network patterns (e.g. Schumm, 1977). Valley orientations and sinuosity may vary longitudinally and exhibit abrupt changes in response to changes in substrate and landscape controls. These factors complicate exploration strategies. Long buried valleys (> 200 km) are generally restricted to the western Canada basins where they formed in response to large-scale tectonic uplift and fluvial incision. Elsewhere in the country, valley geometries are smaller and have developed in response to smaller-scale tectonic regimes, and/ or dynamic factors associated with glaciation and eustatic sea level changes.

3.2 Sediment Facies Models Of Valley Fills

Sediment fill of many buried valleys in Canada forms complex successions representing depositional events

that occurred during preglacial, glacial and postglacial periods. The fill successions can consist of sediment facies that were deposited in a range of depositional environments and may be separated by regional unconformities. The literature on the style and variability of buried valley fills is most extensive for incised valleys (e.g. Zaitlin et al. 1998). Sediment facies models and the architecture of bedrock-interface valley and Quaternary sediment valleys are less developed. As a result, there is a poorly-developed knowledge base to predict or understand the spatial and vertical facies variability of valley fills and hence aquifer heterogeneity. The complexity of valley fill will depend upon the tectonic history of the area and the range of major depositional environments present in the area, for example, fluvial, lacustrine – marine, glacial – glacifluvial, etc. (e.g. Sharpe, 2002; Broster, 2004). Tectonic control on valley fills is probably significant, particularly if one includes isostatic responses to glaciations. In western Canada, a major control on bedrock-hosted valley incision and fill has been tectonic uplift due to orogenesis. Conversely, in central and eastern Canada, it is proglacial lacustrine or marine conditions
in response to crustal isostasy. Valley fills may be either simple (i.e. deposited during one fill event), or complex, (i.e. deposited in response to multiple cut and fill events). Complex fill successions can result in truncated facies associations, and enhanced vertical connectivity. Even in the case of complex fills, it is possible to identify the probable stratigraphic succession of valley fills based on regional characteristics such as tectonic setting, bedrock types and ages, glacial setting, etc. Zaitlin et al. (1994) present one example of a sediment facies model for a simple fill succession of an incised-valley. The vertical and spatial facies relationships of the estuary model are controlled by base-level change and permit a conceptual understanding of the valley-fill transitions that can serve as a predictor of both vertical and spatial variability. Such models allow improved utilisation of expensive and commonly limited geophysical and geological datasets for aquifer characterization.

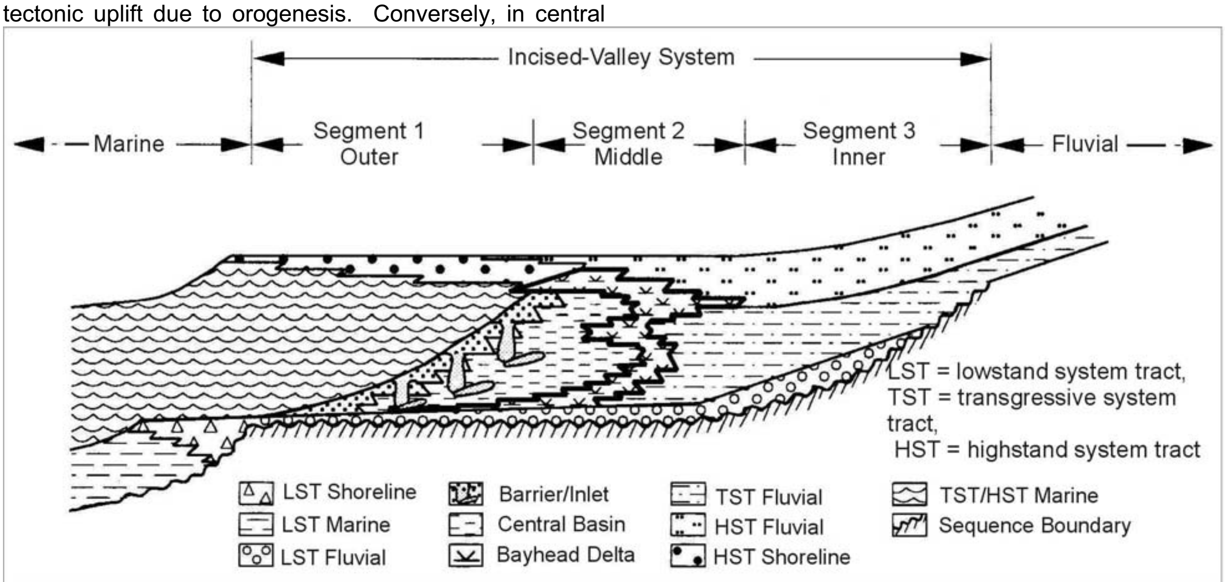

Figure 3: Idealized longitudinal section of a simple incised-valley system showing the distribution of depositional environments and the arrangement of aquifer characteristics. Figure modified from Zaitlin et al. (1994).

4.0 HYDROGEOLOGY

4.1 Important characteristics of buried-valley aquifers

Several characteristics of buried-valley aquifers significant to their hydrogeologic function are listed in Table 2. Since few buried valley aquifer systems in Canada have been fully characterized, it is only possible to draw several generalizations.

The hydrogeologic function of buried-valley aquifers at the local, intermediate and regional scales are variable and depend on the extent and continuity of aquifers. Where buried-valley aquifers are of limited extent due to valley dimensions, limited areal deposition, transitions to fine-textured facies, or truncation by

Table 2. Characteristics significant to the hydrogeologic function of buried-valley aquifers.

Aquifer extent and continuity - valley dimensions, geometry and gradient - extent and nature of sediment facies - heterogeneity - unconformities (truncated units)
Factors affecting flow and hydraulic response - aquifer transmissivity - valley wall hydraulic conductivity - vertical connectivity, aquitard hydraulic conductivity and storativity - lateral and longitudinal hydraulic barriers - valley position and orientation in flow system - link with modern topography and drainage

their subsequent erosion, the hydrogeologic functions and the groundwater resources are mostly local. Where buried valley aquifers are more extensive and continuous, they may significantly influence regional scale flow. For illustrative purposes, two contrasting hydraulic responses observed in buried valley aquifers can provide insight into the importance of aquifer extent and continuity.

i) significant drawdown observed at large distances:

Significant drawdown at long distances is indicative of a continuous aquifer that is well confined both laterally and vertically. Pumping tests indicate well drawdown in excess of those predicted using the Theis equation and the occurrence of negative hydraulic boundaries. This type of response is expected for the bedrock interface aquifers in the prairies where relatively high transmissivity sediment is often confined laterally by low hydraulic conductivity shale and vertically by thick glacial till (e.g. van der Kamp and Maathuis, 2002). However, in other settings (e.g. within Quaternary sediment) where contrasts in hydraulic conductivity among buried valley aquifers, valley walls and valley fill may not be so large, the hydraulic boundaries may not be as apparent, particularly during short term pumping tests.

ii) minimal drawdown observed at short to moderate distances:

The lack of drawdown observed within an area of expected drawdown is often the result of hydraulic barriers that effectively isolate pumped and monitored aquifers (e.g. Shaver and Pusc, 1992). The occurrence of hydraulic barriers in buried valleys has particularly important implications since they may subdivide a buried valley aquifer system into a number of relatively distinct aquifers for which aquifer recharge, groundwater extraction, and aquifer protection need to be considered separately. Accurate determinations of static water levels and hydraulic gradients can serve to identify such segments of the buried-valley system that are more or less hydraulically isolated.

Aquifer extent, continuity and transmissivity are highly variable characteristics due to the wide range of depositional and erosional environments within buried valleys. The lateral and longitudinal extent of buried valley aquifers is frequently poorly defined and may be considerably less than that of the valley system. Interpretation of the depositional environments within a valley fill can constrain the possible vertical, lateral and longitudinal dimensions and ratios of buried aquifers, the style of heterogeneity and the continuity of aquifers, and the nature (e.g. sediment facies transitions or unconformities) and distribution of hydraulic barriers. For example, ratios of vertical to lateral dimensions may vary from approximately 1:50 to 1:1,000 for coarse braided fluvial sand bodies whereas ratios of 1:20 may be more typical of suspended load channels (Galloway and Sharp, 1998). Several depositional environments within alluvial or glacial valleys result in the deposition of coarse-textured fill near the base of the valley. As a result, there is frequently the potential for moderate to high transmissivity aquifers within valley fill, often located just above unconformities. Transmissivities between 400 and 4,800 $m^2 \cdot d^{-1}$ have typically been reported in buried valley aquifers from the Prairies (e.g. Lu and Jin, 2002).

Assessment of the groundwater resource potential and the susceptibility to contamination of buried-valley aquifers requires an understanding of the vertical hydraulic connections between the ground surface and buried aquifers (e.g. Broster, 2004). Vertical hydraulic connections are a function of several factors including the style of heterogeneity, the sand ratio of valley fill, and the hydraulic conductivity, thickness and continuity of confining units. In some cases, the valley fill sediment may provide a preferred hydraulic pathway through aquitards to deeper aquifers (Fig. 1, valley 3b, Sharpe et al. 2002). Therefore, the assessment of buried valley aquifers also requires the consideration of the depositional settings of both fine and coarse textured facies and the stratigraphic architecture of the valley and its fill (e.g. Andriashek, 2000).

Hydrogeologic conceptualization of the groundwater flow systems in buried valley aquifers should take into consideration the relationship of the buried valley with modern topography and drainage. Modern drainage can be a source of recharge (or captured discharge), particularly under pumping conditions, either as vertical flow through valley fill or where aquifers are dissected by modern valleys by lateral flow (Meyboom, 1963). At the regional scale, the position and orientation of buried valley aquifers in the flow system can have a significant influence on groundwater flow and hydraulic head distributions (Walton 1970). For example, two contrasting situations exist in Alberta and Saskatchewan. In southern Alberta modern alluvial valleys may have eroded below the base of buried valleys (Farvolden, 1963). In Saskatchewan the base of buried valleys is up to 90 m deeper than modern drainage (Christiansen, 1963). Consequently, in southern Alberta, buried valleys may not have aquifer potential, whereas, in Saskatchewan buried valleys have productive aquifers.

4.2 Implications of characteristics

Buried valley aquifers can occur in a wide range of geologic settings that have enormous consequences on their hydrogeologic function. The wide range of hydrogeologic settings and functions for buried valley aquifers emphasizes their variability as groundwater resources and the need for greater understanding of buried valleys at several scales. Some buried valleys include very productive aquifers whereas others have little or no suitable aquifer material. Even where productive aquifers are located, the long-term sustainability of production may be limited by the recharge to the aquifer (van der Kamp, 1986). Key controls on hydrogeologic function such as aquifer extent, hydraulic barriers and vertical hydraulic connections are often very difficult to determine without significant data collection. A basin analysis approach to investigation is appropriate for buried valley aquifers. Recognition of the geological setting of buried valley aquifers thus provides a conceptual framework that permits hypothesis formulation and testing while providing predictive capabilities to enable efficient collection of new field data. Geophysical surveys are crucial for valley delineation and fill characterization. Pumping tests of aquifers, quantitative analysis of long-term pumping and regional surveys of hydraulic heads are often the most effective way to demonstrate the existence of hydraulic barriers.

5.0 CASE STUDIES

5.1 Estevan

The Estevan Valley aquifer system formed by the preglacial Yellowstone, Missouri and 'Northwest" River valleys, in southeastern Saskatchewan is a major aquifer of the buried-valley type (Maathuis and van der Kamp, 2003). The aquifer is at least 70 km long, up to 4 km wide and up to 80 m thick (Fig.4). It is incised in low permeable bedrock silts and sands and is overlain by a 60 – 80 m thick aquitard composed mainly of clay-rich glacial till. The aquifer has been subject of numerous groundwater resource evaluations since the early 1960s, including the drilling of numerous stratigraphic test holes, installation of observation wells and piezometers, and collection of continuous water-level records.

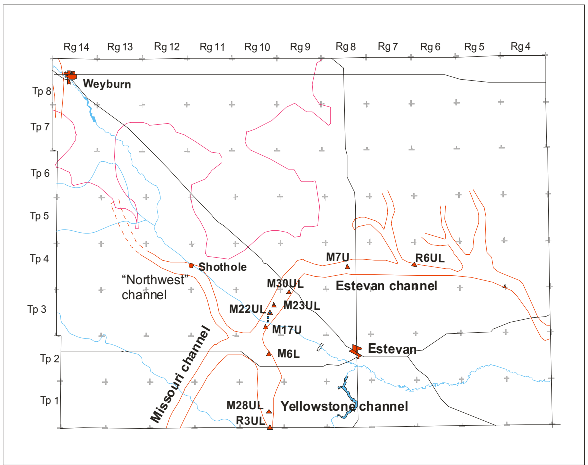

Figure 4. Extent of Estevan buried-valley aquifer in southeastern Saskatchewan (Maathuis and van der Kamp, 2003).

On the basis of this test, the sustainable yield of the aquifer, using a well field centered around the test well, was estimated to lie in the range of 3,800 to 8,400 dam^3/year (van der Kamp, 1986).

In the past four decades, the sustainable yield has been estimated using various methods. In 1965 a 7-day pumping test was conducted (Walton, 1970) and the sustainable yield was estimated to be 16,000 dam^3/year, using an electrical analog model. In 1984, a 29-day pumping test at 76 L/sec (equivalent to 2,400 dam^3/year) was conducted, followed by one year of recovery measurements.

Large drawdowns were observed to extend out along the aquifer to at least 13.5 km from the pumping well (Fig 5). The recovery data obtained after pumping ceased were used to calculate the drawdowns that would have occurred if pumping had continued van der Kamp (1989).

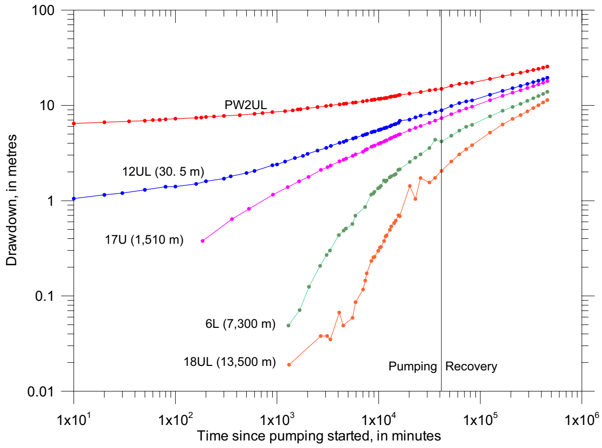

Fig. 5. Measured and extrapolated drawdown of piezometric head in the Estevan buried-valley aquifer during and after a 29 day pumping test (van der Kamp and Maathuis, 2002).

Long-term observation wells completed in the aquifer detected the drawdown due to a flowing shothole in 1965 (see Fig. 4) and indicated the presence of several transverse hydraulic barriers within the aquifer. The presence of these barriers was also indicated by large variations in hydraulic gradient along the aquifer. The 1985 pumping test confirmed the existence of the barriers and allowed quantitative analysis of their impact on the extent of the drawdown "cone" and on the sustainable yield of the aquifer. It should be noted that extensive test drilling has not detected the presence of these barriers and their geological nature is not known.

The aquifer was pumped between 1988 and 1993 at an average annual rate of 3,750 dam^3/year, to supply cooling water for a generating station. Drawdowns in the well field were in the 50 – 60 m range. At well R6UL, 32 km away from the center of the well field, the maximum drawdown was 17 m (Maathuis and van der Kamp, 2003). Drawdown-recovery analyses show that the long-term sustainable aquifer yield is about 2,800 dam^3/a and that recovery to pre-pumping levels will take about two decades (Maathuis and van der Kamp, 1998).

5.2 CALEDON

Using water well data, two hydrogeological studies indicated that there was limited potential for finding new groundwater resources to sustain the Caledon East municipal groundwater demand (Russell et al. 2004). Subsequent collection of a continuous borehole core and 10 line-kilometres of reflection seismic data have identified an increased depth to bedrock of 100 m (100 % increase) along a poorly-defined buried valley. This data collection increased the known volume of the valley fill by 40 percent. There are dramatic changes in seismic facies and thickness along the buried valley. Seismic facies analysis suggests that the valley fill can consist of up to 100 m of sand and gravel. This valley-fill facies has significant potential as a municipal-scale water supply. Additional data collection is needed to verify the seismic facies interpretation, consider potential hydraulic boundaries and assess the water supply potential. The collected data can help identify strategic locations for drilling monitoring wells and for pumping tests. This example highlights the need to collect new data and demonstrates the limited ability to make water supply predictions based solely on analysis of water well records.

6.0 SUMMARY

Although buried valley aquifers are likely widespread across Canada, there are considerable knowledge gaps at national, regional and local scales. At the national scale, the distribution of buried valley aquifers is poorly mapped (except in Alberta and Saskatchewan, Fig. 2). Furthermore, the range of depositional environments within buried valleys and the applicable conceptual models have not been considered. Differences in tectonics, base level and glacial settings suggest that the most commonly used conceptual model for the Prairies (in which bedrock interface aquifers within pre-glacial channels are confined by thick low-permeability till) may not be appropriate for many buried valley aquifers in eastern Canada. At the regional scale, there has been limited investigation of aquifer extent and continuity along buried valleys, the groundwater resource potential of buried valley aquifer systems and the hydraulic role of buried valleys on regional flow. At the local scale, there is insufficient knowledge to assess, develop, manage and protect these groundwater resources. An integrated basin analysis approach should be used to develop systematic strategies for buried valley aquifer exploration, characterization and evaluation.

Generic characteristics of buried valleys that need to be better understood include:

- Valley geometry and distribution – The pioneering work completed in Alberta and Saskatchewan needs to be revitalized and similar knowledge developed for regional settings across Canada. Advances in geophysical and remote sensing techniques during the past 20 years can greatly facilitate such framework development.
- Stratigraphic architecture and sedimentology – Integrated basin analysis studies are needed to investigate and develop appropriate depositional models of valley fill successions. Development of facies models can greatly improve understanding of aquifer distribution, aquifer and aquitard heterogeneity and the nature of aquifer boundary conditions.
- Aquifer extent, continuity and transmissivity – Systematic mapping, monitoring and hydraulic characterization of aquifers within valley fills are the basis for preliminary aquifer assessment.
- Hydraulic barriers and vertical hydraulic connections – These characteristics need to be evaluated using geological data in conjunction with hydraulic testing. Testing and monitoring of aquifers most effectively demonstrate hydraulic barriers and vertical hydraulic connections.
- Hydrochemistry – Better understanding of the controls on water chemistry in buried valley aquifers is required. The potential use of hydrochemistry to delineate aquifers, identify barriers or provide insight into aquifer recharge could contribute to an integrated basin analysis approach.
- Sustainability and protection – Consideration of buried valley aquifer dynamics, in particular groundwater flowpaths and travel times from the ground surface to the aquifer, aquitard leakance and storativity, and aquifer recharge, are important components of an assessment of long-term sustainability and protection. These require long-term monitoring of groundwater levels and pumping rates with high priority given to initiating such monitoring where it is not yet being done.

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