

**Prairie
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Preface

The 37th Annual Meeting of Prairie Division, Canadian Association of Geographer was hosted by the Department of Geography and Environmental Studies, University of Regina on the weekend of September 20 to 22, 2013. As in most years, the meeting was conducted off campus with the community of Esterhazy serving as the venue. Meeting facilities were provided at Esterhazy High School with teachers and students offered free admission to the paper sessions. Sixty five delegates including 30 students and CAG President Dr. Theresa Garvin of University of Alberta attended the meeting. Friday evening was assigned to the annual PCAG Executive Meeting and to social activities. On Saturday morning, 40 papers were presented in a series of eight sessions. Sixteen of these papers were presented by students each of whom was awarded a Paul Simpson-Housley/CAG Student Travel Award and a one-year annual membership of CAG. Saturday afternoon was devoted to field trip activities that explored various economic, cultural and physical aspects of the Esterhazy area. Visits to the Saskatchewan Potash Interpretive Centre, Esterhazy Flour Mill National Historic Site and Kapsovar National Historic Site were followed by an excursion into the Qu'Appelle Valley to examine features of glacial erosion and deposition. Notes for the excursion were prepared by Dr. Ulrike Hardenbicker and are included in this volume.

The Saturday night banquet was held at the S.N. Boreen Community Centre in Esterhazy with excellent catering provided by Kim Drozda of Majestic Catering. Dr. Bruce Mitchell from the University of Waterloo Department of Geography and Environmental Management delivered a much appreciated keynote address entitled Water Ethics and Rights. Saturday night's activities concluded with the Annual Slide Competition with Drs. Garvin and Mitchell acting as judges of slides entered in five categories – physical geography, human geography, prairie, most geographical and humour. In an attempt to maintain a geographical theme, the winner of each category received a bottle of wine selected from a viticulture region of world renowned.

Of the 40 conference papers, four are presented in this volume. Hanyang Wang and Robert (Bob) Patrick review source water protection planning in southern Saskatchewan and identify capacity-building factors that could improve plan implementation. Remaining in southern Saskatchewan, Roberta Kotowich and Ulrike Hardenbicker compare borehole cores from two alluvial fan sites in the Qu'Appelle Valley. They determine that greater core length reflecting more active erosion and deposition is found in the fan downstream of the area with the greater history of intensive agricultural practices. Moving to northern Manitoba, Samantha Fraser, Jeremy Sewell, Joni Storie, Adrian Werner, Charles Enns and Genevieve Berard argue that better detection of heterogeneous vegetation cover is a key to improving coastal mapping of the Hudson Bay shoreline. Results of remote sensing analysis suggest that such detection is possible when using the first derivative of the red edge. Remaining in northern Manitoba, Morrissa Boerchers, Matthew Metcalf and Christopher Storie report on food security and consumer habits in the isolated community of Churchill. They conclude that

the potential for food insecurity in Churchill is offset by online shopping and community/business initiatives.

The editorial process has been a lengthy one. I would like to thank both the reviewers for providing their critical assessments of the papers and the authors for their attention to scholarship. A special thank you is offered to Weldon Hiebert at University of Winnipeg without whose technical and production assistance publication of this volume would have been impossible.

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Implementing source water protection plans in Saskatchewan: Local watershed perceptions

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Source water protection (SWP) is defined as a land-use management and planning process aimed at the protection of surface and groundwater sources from contamination. In the province of Saskatchewan, Canada, the Saskatchewan Water Security Agency assists local watershed groups in the development of watershed-scale SWP plans. Since 2007, a total of ten SWP plans have been completed across the southern portion of the province. To date, there is little research into the implementation rate of these plans thus offering little to assess the effectiveness of SWP planning in Saskatchewan. This article examines the rate of plan implementation with the goal of identifying capacity-building factors that facilitate SWP planning in the province. The research method employs document review and participant interviews across four case study areas. The research results show that areas in need of improvement include stable financial resources, training opportunities for local watershed groups, public awareness, adequate stakeholder involvement, SWP plan re-evaluation, and information/data access. This article contributes to the understanding of SWP plan implementation relating to capacity building needs at the watershed scale in the Canadian prairie region and beyond.

Keywords: source water protection, implementation, Saskatchewan, safe drinking-water

Introduction

Protecting the quality of drinking water resources in Canada has become a priority due to several recent water-borne contamination events. For example, drinking water contamination resulted in seven deaths and more than 2300 illnesses in Walkerton, ON, in 2000. One year later a second water contamination event in North Battleford, Saskatchewan, caused an estimated 5000 illnesses. As of September 2013, approximately 1200 boil water advisories were issued for community drinking water systems across Canada (Waterca Inc 2013). A healthy and sustainable water resource is a critical issue for all communities in Canada and in order to maintain a safe water supply, the multi-barrier approach has been promoted (CCME 2002). The multi-barrier approach consists of five components, namely source water protection, drinking water treatment, distribution system monitoring, water quality monitoring, and an emergency response

program. Municipalities, or local water management agencies, have traditionally focused on water treatment and the water distribution system to ensure safe water delivery to the public. After the events of Walkerton and North Battleford, provincial and territorial governments began to give greater attention to the first barrier in the multi-barrier approach, source water protection.

Source water protection (SWP) involves protecting a surface or groundwater source of public water supply from contamination. SWP requires development of a land-use planning and management program aimed at preventing the contamination of source water. Across Canada, provincial governments have enacted a mix of regulations and policy to guide SWP planning. Soon after the North Battleford water supply contamination event (April 2001), the Government of Saskatchewan developed the Safe Drinking Water Strategy. The goal for this strategy is to protect the water resource, to supply safe, clean and sustainable drinking water, to improve water treatment plants, and to

develop an effective water regulation system (SWA 2002). A number of different provincial agencies and local groups are directly involved in protecting water resources, including the Water Security Agency (WSA), the Ministry of Agriculture, the Saskatchewan Association of Watersheds (SAW), local watershed groups or associations, and many other stakeholders. As part of Saskatchewan's Safe Drinking Water Strategy, the WSA, formerly the Saskatchewan Watershed Authority, has been leading SWP planning with the goal of ensuring access to safe drinking water sources and reliable water supplies (SWA 2010a). In Saskatchewan, SWP plans began to be completed as early as 2007; however, there is no information available describing factors that have served to facilitate the implementation of these plans. This article reports on the factors that serve to facilitate the implementation of existing SWP plans in Saskatchewan. The four case studies chosen here are those plans first developed in the province. They were chosen based on their longevity and thus their potential for full implementation.

Source water protection

Ivey et al. (2006, 193) stated that "source waters are the lakes, rivers, and aquifers from which 'raw' drinking water is drawn." SWP aims to protect drinking water quality at the source of supply, reduce the risk of water borne contamination, and protect future water sources (Ivey et al. 2006; Patrick 2011). Typical elements of SWP involve a water system assessment, water quality monitoring, vulnerability or threats assessment, delineation of sensitive water protection areas, selection and implementation of tools to protect water quality, and public education (National Research Council 2000). According to Ivey et al. (2006), a successful SWP plan requires the necessary social, political, technical, financial, and institutional capacity to support plan implementation. Timmer et al. (2007) state that protecting source water supplies includes clear government leadership, appropriate institutional arrangements at both local and provincial levels, adequate financial resources, supportive community members, technical skills, and committed personnel. At the same time, SWP is challenged by political boundaries that cut across watersheds. Land-use activities in one region may affect the water quality of another region or a downstream water supply. A region's capacity to protect its drinking water resources is strengthened by adequate access to knowledge as well as financial, technical, and human resources, social and political commitment to source protection, and the integration of land and water management objectives (Ivey et al. 2006).

Capacity

The concept of "capacity" is linked to various fields, including public sector agencies and institutions, local economic development, local environmental management, and public health (de Loë et al. 2002; Timmer et al. 2007). Capacity in this context refers to the capability of an organization or group to undertake action to bring about meaningful change. SWP planning continues to be challenged by capacity-related factors. Research in Ontario and Nova Scotia suggests that four areas of capacity are critical to the successful implementation of SWP plans, namely

financial capacity, institutional capacity, technical capacity, and social capacity (Ivey et al. 2006; Timmer et al. 2007).

Financial capacity is the ability to generate and access funding, the presence of adequate resources to meet operating expenses and manage water suppliers, the sustainable and prudent use of financial resources including the use of market mechanisms, and financial flexibility (Timmer et al. 2007).

Institutional capacity encompasses the governance of SWP, including local by-laws, provincial statutes and regulations, policies and programs, as well as plans developed and supported at local or provincial scales. An institutional environment that is conducive to SWP at the local level should provide legal support for land-use planning, land acquisition, and protective zoning (Timmer et al. 2007).

Technical capacity includes the physical infrastructure to support and personnel to develop SWP plans (de Loë et al. 2002). The ability of SWP plans to be developed at all depends, at least in part, on the ability of professionals to access watershed data, water monitoring data, watershed delineation, and analysis of past and present land-use activities that may pose potential source water contamination (Timmer et al. 2007).

Social capacity involves three critical elements, namely leadership, partnerships, and communication (Leach and Pelkey, 2001). De Loë et al. (2002) state that social capacity can be measured by examining levels of community awareness and involvement. Community awareness is partly a function of citizens' ability to communicate with one another. Timmer et al. (2007) also note that social capacity can be measured by community involvement in the municipal decision-making process. Similarly, de Loë et al. (2002) state that social capacity can be measured by the level of public awareness of SWP issues. Support from non-government organizations, industry and commerce, landowners, and local residents is essential if municipalities are to prioritize the protection of drinking water sources among other multiple priorities (Ivey et al. 2006).

Methods

Two methods of data collection were utilized: first, a document review was conducted of relevant SWP plans and supporting documents in Saskatchewan; second, semi-structure interviews were conducted with participants from selected local watershed groups. Local watershed organizations for each of the SWP plan areas were delegated authority by the province of Saskatchewan to implement their respective plans. The interviews for this research targeted the local level, and specifically each watershed group charged with SWP implementation. Fourteen interviews were conducted in person, from November 2012 to February 2013. Participants were contacted by telephone to arrange a meeting time and place. Anonymity was offered to the participants by agreeing that personal names would not be used. Ensuring full anonymity was not entirely possible given that each watershed organization had only two individuals to be interviewed, the staff manager and a board member who was usually the respective watershed organization board chairperson. Participant

interviews were conducted in the respective workplace of each watershed coordinator. These semi-structured interviews lasted approximately 40 minutes and were conducted using a questionnaire instrument of predetermined questions. A semi-structured interview process was chosen to enable specific questions to be asked while generating open discussion that would not limit the responses of participants. The line of questioning during each interview sought to explore factors facilitating the implementation of existing SWP plans in each of the four case study areas. With consent of the participants all interviews were digitally recorded and transcribed verbatim. The transcriptions were then shared with the participants to ensure accuracy. No personal information, value judgments, or personal opinions about individuals or agencies was collected during the interviews. Participants, in this case the watershed coordinator for each of the four case studies, were first asked to confirm the rate of SWP plan implementation.

Each SWP plan in Saskatchewan contains a list of “key actions” or recommended policy actions that have been identified in the plan. Key actions are those policy directives that require some form of action, hence the term key actions. It is the implementation of these key actions that were the subject of inquiry in this study. Examples of key actions include the decommissioning of an abandoned well and the development/introduction of a watershed protection education program for the general public. Participants were asked to describe factors that facilitated the implementation of key actions in their SWP plan. Specific key actions were not addressed but rather the factors that worked to facilitate the broad implementation of those key actions.

Analysis of the transcriptions enabled the coding and categorization of participant responses based on four components of capacity taken from the literature, namely financial capacity, institutional capacity, technical capacity, and social capacity. The resultant coding formed the core data for the study. These forms of capacity are common to the water resources literature and were selected to help determine the main causal factors contributing to implementation success rates among SWP plans in Saskatchewan. More specifically, analysis was directed at answering several questions. Are certain forms of capacity more critical to plan implementation? Are these, in fact, the primary factors contributing to SWP plan implementation? What lessons can be learned in terms of capacity-building factors that are requisite to the effective implementation of SWP plans in Saskatchewan?

In all case studies, participant responses were recorded. The output of data represented below reflects participant responses, and not clustered or group responses. In many instances a participant may report multiple factors that facilitated key action implementation. In such cases all key actions were listed. In some instances a participant was asked to prioritize the facilitating factors leading to key action implementation as presented in the data for the study.

Implementation of key actions across all four case studies was broken down into three categories. These categories are: implemented key actions; key actions in progress of implementation; and key actions that have not been implemented. It should be noted that certain key actions in any plan may never be fully

implemented. This would include an education program or a long-term monitoring program. Even a fund raising program to relocate a landfill or a sewage lagoon may be in progress but not be fully implemented. In these examples, such key actions have been recorded as in progress.

Planning and watershed context

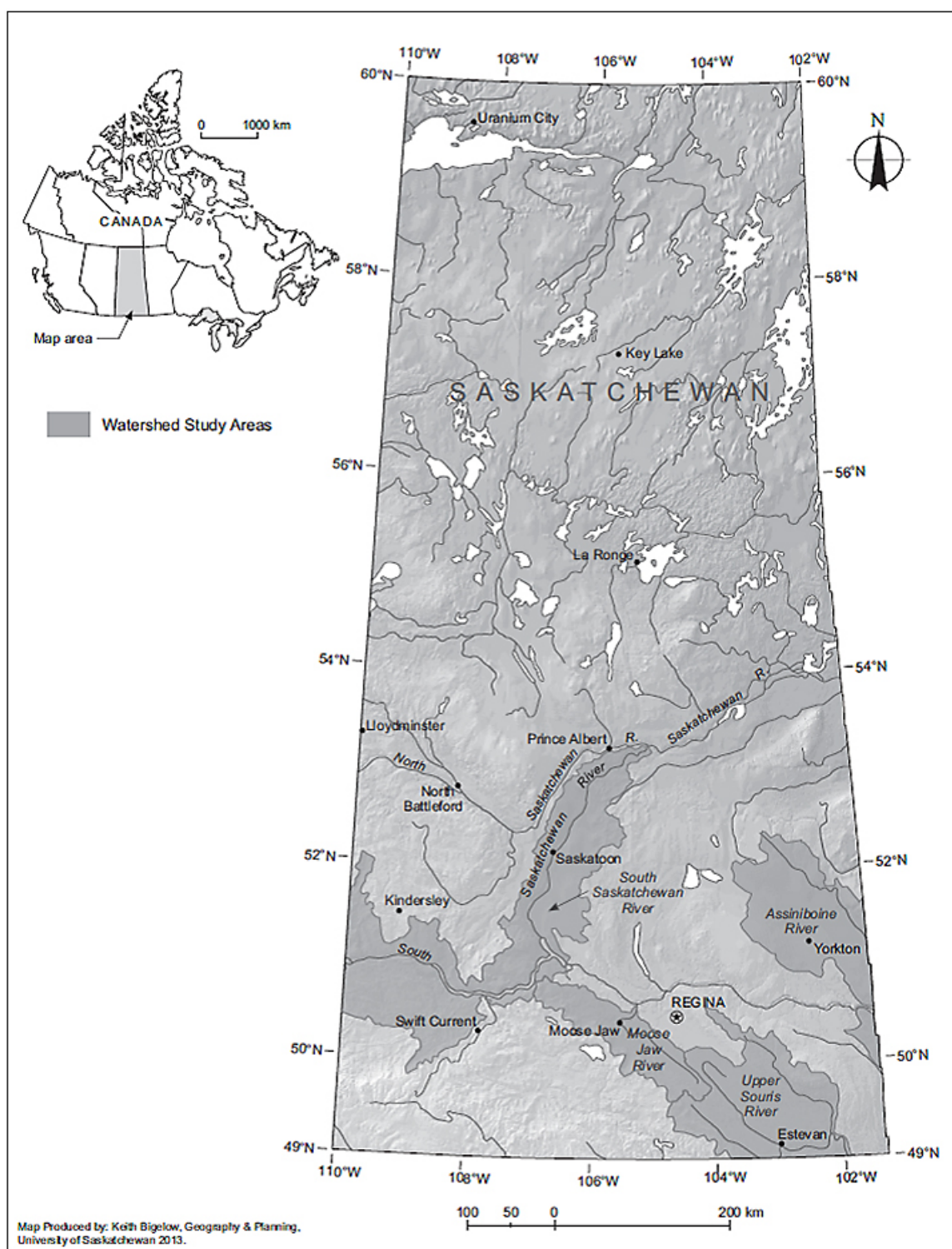
In 2002, the Saskatchewan Watershed Authority began consultation with local community members and stakeholders across the province followed by the planning process for SWP in various watersheds (SWA 2008). By 2003, watershed advisory committees began to be established for those watershed areas interested in pursuing SWP planning. After each watershed advisory committee completed their SWP plan, a local watershed organization was established. Although the initiative came from the provincial government agency, the local watershed group in each watershed is responsible for SWP plan implementation.

In 2006, the Moose Jaw River watershed, Lower Souris River watershed, Assiniboine River watershed, and City of Yorkton initiated SWP programs followed by plan implementation. From 2007 to 2013, six additional SWP plans were developed in southern Saskatchewan followed by plan implementation. Four SWP plans were selected in this research based on their early date of adoption, size of watershed, and source of drinking water supply. These plans cover the Moose Jaw River watershed, Assiniboine River watershed, Yorkton Region, and South Saskatchewan River watershed (Figure 1).

Case study areas

Moose Jaw River Watershed

The Moose Jaw River is the largest tributary of the Qu'Appelle River. Its source is located west of Weyburn from where it flows northwest, paralleling the edge of the Missouri Coteau, with many small tributaries entering the river from the more rugged, higher terrain to the southwest (SWA 2006a). The Moose Jaw River watershed includes 22 rural municipalities, two towns, ten villages, and the city of Moose Jaw. The population of the watershed is approximately 40,500. Seventy-nine percent of the population resides in Moose Jaw, 12% within the 22 rural municipalities, and 9% within smaller communities (towns, villages). Cereal crops, cattle and hogs, manufacturing, and service and retail are the main economic activities in the watershed. Agriculture is a major leading economic sector; approximately 70% of the land is used in annual crop production. Major agricultural and related activities include feedlots, pork production units, cow and calf production operations, orchards, and inland grain terminals. Food processing industries (World Wide Pork, XL Foods), machinery manufacturing (Raider Industries, Doepker Industries Ltd., Bombardier), mining (Mosaic Corp), and the Canadian Pacific Railway also contribute to the area's economy, and, like the agricultural activities, they also act as origins of potential water pollution for drinking water sources (SWA 2005).

**Figure 1**

Map of watershed study areas, Saskatchewan, Canada. Data Source: Water Security Agency of Saskatchewan

Assiniboine River Watershed

The Assiniboine River Watershed covers an area of 17,300 km² within Saskatchewan. This area includes 24 rural municipalities, eight towns, 15 villages, and the cities of Melville and Yorkton. The population of the portion of the Assiniboine River Watershed within Saskatchewan is approximately 45,500. The rural population represents about 34% of this total, with the urban or community population making up the remaining 66%. Economic activity and land use in the watershed are dominated by mixed grain farms, with pasture and hay lands common. Traditionally, the beef cattle industry has dominated the livestock sector (SWA 2006b).

Yorkton Region (groundwater)

Yorkton is supplied water from the Yorkton Aquifer. The aquifer protection plan for the Yorkton region was chosen for inclusion in this study as it is a groundwater protection plan while the other case studies are defined by surface water sources (SWA 2006c). The groundwater in the Yorkton area has played a vital role in the socio-economic development of the city since the start of the 20th century as it constitutes the most available source of water. Yorkton is the largest urban centre in the Assiniboine River Watershed containing 37% of the total watershed population.

South Saskatchewan River Watershed

The Bow, Red Deer, and Oldman rivers originating in Alberta’s Rocky Mountains contribute the major water supply to the South Saskatchewan River. The portion of the South Saskatchewan River in Saskatchewan drains an area of 35,000 km² and flows easterly for 716 km through this watershed where much of its volume is stored in Lake Diefenbaker. At the village of Elbow, the river turns north and flows 380 km until it joins the North Saskatchewan River east of Prince Albert (SWA 2007). The South Saskatchewan River watershed is the most heavily populated watershed in Saskatchewan with approximately 300,000 residents, the majority of whom live in Saskatoon, Saskatchewan’s most populace city. Most of the municipalities in the watershed get their drinking water from the South Saskatchewan River. However, most individual land owners tap into aquifers through private wells. Diversion of water from the watershed means that nearly half of the province’s population depends on the river for their drinking water source. Within the watershed there are 19 irrigation districts covering a total of 272,000 ha (672,000 acres). The economic sector consists of a variety of agricultural activities including livestock rearing, irrigated and dry land crop production, as well as potash mining, and oil and gas production particularly in the western portion of the watershed (SWA 2007).

Results

This section presents the results from interviews conducted with participants to assess capacity building needs for SWP plan implementation in the four selected watersheds. Interview results of this research revealed four capacity factors that operate to fa-

cilitate SWP plan implementation. These factors include financial, institutional, technical, and social capacity issues.

Moose Jaw River Watershed SWP Plan and Watershed Stewards

The implementation success rate of the Moose Jaw River Watershed Source Water Protection Plan (SWA 2006a) is reported in Table 1. This plan was the first to be adopted in Saskatchewan by the WSA. There are 63 key actions in the plan; 40 key actions have been implemented, seven have not implemented and 16 are in progress of plan implementation.

Facilitating factors. Participants reported a total of 60 facilitating factors (Table 2) for the 56 key actions that were either fully implemented or in progress of being implemented (Table 1). Of all 60 facilitating factors, Table 2 shows that institutional capacity is the most frequently reported capacity factor (37%) facilitating key action implementation in the Moose Jaw SWP Plan. For example, a participant from the Moose Jaw River Watershed Stewards noted that “the Water Security Agency is looking to expand hydrometric stations, and it is also responsible for the drought and soil moisture program. The Water Supply Expansion program through the Water Security Agency will identify the current water allocation in our watershed, and there are some developments here.” Social capacity (33%) is the second most reported capacity factor facilitating key action implementation in

Table 1
Moose Jaw River watershed SWP plan implementation status

Implementation Status	Key Action Number	Implementation Percent
Yes	40	63
In progress	16	25
Sub total	56	89
No	7	11
Total	63	100

Table 2
Capacity factors facilitating Moose Jaw River SWP key actions

Capacity	Facilitating Factors	Percent
Financial	6	10
Institutional	22	37
Technical	12	20
Social	20	33
Total	60	100

the watershed. Social capacity involves three critical elements: leadership, partnerships, and communication (Leach and Pelkey 2001). As one participant stated that “we have the partnership with PCAB (Provincial Council of Agriculture Boards) to minimize impacts from unapproved drainage activities.” Another example is communication, one of the three critical social capacity elements. According to Moose Jaw River Watershed Stewards Yearly Results Report (SWA 2010b), local producers were effectively influenced by Moose Jaw River Watershed Stewards newsletters and articles. Some environmental adjustments in the agricultural operation have been made by local producers. Finally, technical capacity (20%) and financial capacity (10%) are the two least reported factors facilitating plan implementation.

Assiniboine River Watershed SWP Plan and Association
The implementation success rate of the Assiniboine River Watershed Source Water Protection Plan (WSA 2006b) is reported in Table 3. There are 44 key actions in this plan 21 of which have been implemented, seven have not been implemented and 16 are in progress of implementation. The Assiniboine Source Water Protection Plan was the second SWP plan to be adopted by the WSA.

Facilitating factors. Participants reported a total of 53 facilitating factors (Table 4) for the 37 key actions that were either fully implemented or in progress of being implemented (Table 3). Of the 53 facilitating factors, financial capacity is the most frequently reported capacity factor (43%) facilitating key action implementation in the watershed (Table 4). Sufficient financial support from different organizations was helpful in conducting SWP projects and prompted the watershed coordinator to report that:

We get funding from the Saskatchewan Ministry of Environment to undertake watershed inspections and to undertake communication between us and other organizations. Also the most significant, we receive funding from the Water Security Agency and Saskatchewan Wildlife Federation to remove fish barriers.

Table 3
Assiniboine River watershed SWP plan implementation status

Implementation Status	Key Action Number	Implementation Percent
Yes	21	48
In progress	16	37
Sub total	37	84
No	7	16
Total	44	100

Table 4
Capacity factors facilitating Assiniboine River SWP key actions

Capacity	Facilitating Factors	Percent
Financial	23	43
Institutional	20	38
Technical	2	4
Social	8	15
Total	53	100

Institutional capacity (38%) is the second greatest reported capacity factor facilitating key action implementation with local watershed groups. Other government agencies such as the Ministry of Agriculture and Ministry of Environment are also leading several SWP related projects. In the words of the watershed coordinator: “we have the help of the Saskatchewan Ministry of Agriculture for direction on beneficial management practices (BMPs), so we can work with producers to develop AEGPs (agriculture environmental group plans) to address environmental issues.” Finally, social capacity (15%) and technical capacity (4%) were identified as the two least reported capacity factors facilitating plan implementation.

Yorkton Area Aquifer SWP Plan
The Yorkton Area Aquifer SWP Plan is selected in this research because it is the only groundwater protection plan of the WSA (SWA 2006c). Table 5 shows that there are 23 key actions in this plan of which 14 have been implemented, four have not been implemented, and five are in progress of implementation.

Facilitating factors. Participants reported a total of 25 facilitating factors (Table 6) for the 19 key actions that were either fully implemented or in progress of being implemented (Table 5). Of the 25 facilitating factors, financial capacity is the most frequently reported capacity factor (56%) in the Yorkton region (Table 6). The Assiniboine watershed coordinator reported that:

We had funding from Saskatchewan Ministry of Environment to develop the vulnerability contamination aquifer map. So now we have created the map and we keep distributing it. We have had the financial support to create browsers, publications, and keep educating people.

Institutional capacity (24%) is the second greatest reported capacity factor facilitating key action implementation in this region. One example is the well decommissioning program where the local watershed group takes direction from the WSA in order to decommission an unused well. In another example, the Assiniboine watershed coordinator expressed: “zoning districts are being established, so we have the ability to restrict certain land uses and therefore plan for aquifer protection. Water Security

Table 5

Yorkton area aquifer SWP plan implementation status

Implementation Status	Key Action Number	Implementation Percent
Yes	14	61
In progress	5	22
Sub total	19	83
No	4	17
Total	23	100

Table 6

Capacity factors facilitating Yorkton aquifer SWP key actions

Capacity	Facilitating Factors	Percent
Financial	14	56
Institutional	6	24
Technical	1	4
Social	4	16
Total	25	100

Agency and municipalities wanted us to attend and participate with the new zoning districts. So they are willing to work with us.” Social capacity (16%) and technical capacity (4%) were identified as the two least reported capacity factors facilitating plan implementation.

South Saskatchewan River Watershed SWP Plan and Stewards

The South Saskatchewan River watershed is an important study area because more than half of Saskatchewan’s population depends on drinking water from the South Saskatchewan River (SWA 2007). The implementation success rate of the South Saskatchewan River Watershed Source Water Protection Plan is reported in Table 7. There are 35 key actions in this plan of which 13 have been implemented, 13 have not been implemented and nine are in progress of implementation. The South Saskatchewan River SWP Plan was adopted in 2007. This plan represents one of the earliest plans of the WSA.

Facilitating factors. Participants reported a total of 26 facilitating factors (Table 8) for 22 key actions that were either fully implemented or in progress of being implemented (Table 7). Of the 26 facilitating factors, social capacity (35%) is the greatest reported capacity factor facilitating key action implementation in the South Saskatchewan River watershed. One example is to develop a watershed education strategy with diverse part-

Table 7

South Saskatchewan River watershed SWP plan implementation status

Implementation Status	Key Action Number	Implementation Percent
Yes	13	37
In progress	9	26
Sub total	22	63
No	13	37
Total	35	100

Table 8

Capacity factors facilitating South Saskatchewan River SWP key actions

Capacity	Facilitating Factors	Percent
Financial	3	12
Institutional	6	23
Technical	8	31
Social	9	35
Total	26	100

ners such as municipalities, technical committee members, local producers, and provincial agencies. The watershed manager reported:

We have source water protection information on our website and we also provide it in our newsletters. We have presentations at different conferences. The most important thing is the commitment; our board members are from rural municipalities, the City of Saskatoon, and many local producers. They appreciate the commitment.

Technical capacity (31%) is the second greatest reported capacity factor facilitating key action implementation. The watershed manager stated that “our full time education coordinator can work, communicate, and get in touch with industry, the Water Security Agency, and other organizations and stakeholders.” Finally, institutional capacity (23%) and financial capacity (12%) are the least reported capacity factors facilitating plan implementation.

Discussion

Discussion of results is separated into the following sections: 1) financial capacity, 2) institutional capacity, 3) technical capacity, 4) social capacity, and 5) capacity relationships.

Financial capacity

Funding opportunities, especially stable and consistent internal and external financial support, is considered crucial for SWP plan implementation. Most local watershed groups in Saskatchewan have been facing financial constraints since their associations were established. The Saskatchewan government has already recognized that local watershed groups require assistance to implement their SWP plans. Unfortunately, the amount of funding, and the distribution of that funding, does not necessarily address concerns related to the daily operating costs and long-term ongoing objectives. A participant suggested that the average annual operating expense is about \$150,000 for each local watershed group, an amount far higher than the \$92,500 of core funding now made available. Moreover, participants from all local watershed groups reported that the main constraining factor is project cost, and that there is no payment program unless the government sets up the payment. According to de Loë and Kreutzweiser (2005), overcoming variations in the ability and willingness of local organizations to secure and commit funds for SWP is a major challenge. Litke and Day (1998) state that a lack of financial support reduces the effective planning and management ability of different agencies and organizations. The US Environmental Protection Agency experience provides a positive lesson that encourages states to use a portion (15%) of funds granted under the Clean Water Act for groundwater protection. Some of the funding available (\$26 billion) through the State Drinking Water Revolving Fund can be set aside for groundwater protection and capacity building (de Loë and Kreutzweiser 2005). Indeed, local water protection organizations in the US have the availability of these funds to undertake SWP activities. In Saskatchewan, the WSA provides a portion of core funding in the beginning of the year to help the operation of local watershed groups.

The second observation is that local watershed groups should be financially independent to conduct their long-term projects. In Saskatchewan, although local watershed groups receive core funding from the WSA, they still need external financial support from different government agencies and NGOs. Several successful local watershed groups have applied for funding support from the Saskatchewan Ministry of Environment, Ministry of Agriculture, Ducks Unlimited, and Saskatchewan Wildlife Federation. This funding has been applied to wetland conservation, fish habitat, and agriculture environmental plans in certain watersheds. Even though core funding from the WSA is made available, local watershed groups would be wise to secure external funding. Similarly, it has been noted in Ontario that reduced provincial funding sources could seriously undermine a local water management group's ability to deliver SWP programs (de Loë et al. 2002).

Institutional capacity

Institutional arrangements need to be developed that encourage water-related agencies to coordinate and establish mutually agreed priorities for investment, regulation, and allocations to support SWP. This approach is supported in the water resources literature (Hamdy et al. 1998). Timmer et al. (2007) also state that a provincial water protection agency should consult with local community members to help develop and enforce regulations in local watersheds. Following this framework, it is important that the WSA establish a priority to review local watershed management activities and enforce consistency with the provincial safe drinking water strategy. A significant role for the WSA is to help local watershed groups establish their associations to reach non-profit status and to establish constitutional bylaws. Another example is for planners from the WSA Planning Branch to work directly with local watershed groups to initiate SWP plan development and implementation.

Provincial governments define the legislative power of municipal governments in Canada; therefore, any weakness in provincial legislation and regulation has a direct impact on the effectiveness of municipal actions (Timmer et al. 2007). In Saskatchewan, SWP enforcement is not enough because SWP plan implementation is voluntary and non-legislated. It would be helpful for SWP plans to be established through legislation and enforced by regulations. Based on the interviews, it appeared that regulations are needed to prevent activities such as illegal dumping and littering that would result in source water pollution. One local watershed coordinator indicated that local watershed groups have insufficient human resources to enforce littering restrictions set out in the SWP key action list. This calls into question the validity of certain key actions.

Technical capacity

Two observations are discussed in this section: human resources, and information/data sharing and availability. These observations are consistent with de Loë et al.'s (2002) contention that technical capacity includes both the adequacy of physical infrastructure and the training of human resources. In the first observation, limited human resources were noted as barriers to SWP plan implementation. In Saskatchewan, human resources are highly variable among local watershed groups. According to interviews, several local watershed groups have two or three staff members in their daily operations; they employ better management practices, technicians, financial officers, and environment and education coordinators. Critical in this regard are staff resources, especially, the availability of staff with specialized knowledge needed to undertake the activities, or to process and use the information relating to water protection (de Loë et al. 2002). During interviews, staff members from the WSA recommended that two or three people working at each local watershed group would be the desirable number rather than one coordinator. The WSA also suggested that hiring the coordinator and adopting the plan at the same time would help local watershed groups avoid staff turnover. However, in smaller watershed areas with limited financial resources it will remain difficult to fund human resources (Timmer et al. 2007). For example, the

Upper Souris Watershed Association has only one full time coordinator. Limited human resources were reported as a constraining factor to plan implementation.

Results from this study indicate that there is a need for more training especially among coordinators and more professional education for local watershed groups. Training and staff development should have high priority for SWP (Hamdy et al. 1998). According to the interviews, government agency participants stated that the coordinator should receive some skills management training. Hartvelt and Okun (1991) also stated that water protection staff members are motivated and challenged with opportunities to increase skills and abilities through training and education programs.

The second observation is the lack of data/information for implementing SWP plans. Since the ability of local organizations to undertake water protection depends on technical capacity, it is essential to have access to data such as water quality and potential chemical contaminants (Ffolliott et al. 2002; Focazio et al. 2002). Local watershed coordinators often reported that they did not have access to water data. When data were available they lacked professional knowledge to analyze it. One participant complained that the water monitoring system in Canada is not as detailed as in other countries, and that the government lacks resources to conduct water quality testing. Also, some local watershed participants claimed that they had difficulties accessing information on water contamination and water quality because of privacy issues of government agencies. Timmer et al. (2007) reported that the technical capacity of governments to protect source water supplies can be demonstrated by the existence of watershed monitoring programs, the availability of easily accessible watershed data, and inventories of potential contaminants. This observation suggests that government agencies need to share information and data for local watershed groups working on SWP plan implementation. Therefore creating and stimulating open communication and participation are essential conditions from which to achieve technical support for plan implementation (Hamdy et al. 1998).

Social capacity

Lack of public involvement for SWP plan implementation was recognized in this study. The public within each watershed were involved in their respective SWP plan implementation process, but the extent of the involvement was not always sufficient. The interview results show that greater public involvement is needed for SWP implementation. This is consistent with observations that the benefit of citizen participation in SWP is a strong base of support for water protection initiatives (de Loë et al. 2002). For example, of the AEGPs in Saskatchewan, the lack of local land owners' support and participation is a constraining factor. This situation meant that only a small number of local people may be aware of the AEGP project. If local land owners have gained the interest and awareness during the SWP plan implementation process, particularly for conducting the AEGP program, they would more likely participate in such a program. Overall, based on all interview results, local support and involvement is an important path to SWP plan implementation in Saskatchewan.

Social capacity building in the form of partnerships has played an important role in SWP plan implementation in Saskatchewan. Many local watershed groups have been working with different organizations and academic research institutes (e.g., University of Saskatchewan). Such partnerships encourage knowledge transfer as well as technical and financial assistance. According to Ivey et al. (2006) building social capacity is an important facilitating factor in SWP.

Conclusion

This article reports capacity-building needs for SWP plan implementation in Saskatchewan. Local watershed groups and government agencies reported multiple examples of SWP plan implementation that validated the importance of financial, institutional, technical and social capacity factors. These include: basic core funding and NGO financial support and watershed membership fees (financial capacity); government cooperation and assistance (institutional capacity); permanent watershed coordinator positions and mapping (technical capacity); and education programs, public awareness and engagement (social capacity). These examples were all identified, in varying degree, as facilitating factors for SWP plan implementation. However, additional capacity-building needs were also identified as necessary to support SWP plan implementation. These included: stable funding source and long-term budgeting (financial capacity); identification of a lead agency, inter-government communications, and adequate provincial regulations and policies (institutional capacity); increased data and information sharing, reduced watershed staff turnover, and staff training programs (technical capacity); and landowner involvement, enhanced partnerships as well as improved industry and community communication (social capacity).

The following recommendations are provided to help improve SWP plan implementation in Saskatchewan. First, financial support from the WSA needs to be more reliable especially for local non-government groups working on SWP plan implementation. Without sufficient funding, plan implementation will face certain challenges, such as lack of public education and awareness, limited government communication, uncertain staff levels, insufficient information sharing, and lost opportunities for professional development. Second, standard training provided by the WSA is needed for local watershed staff members. Training opportunities such as accounting, financial management, and human resource management will help to improve skills needed to generate external funding support. Third, the fixed core funding formula provided by the WSA needs to be revised. The amount of funding distributed to watershed groups should be pro-rated based on watershed characteristics such as population, watershed size, and the number of cities or towns within a given watershed. A set of watershed metrics should be developed to help guide a more equitable funding formula. Fourth, the key actions contained in a SWP plan need to be clear, concise, and realistic. Many of the participants believe that certain key actions are not sufficiently concise, nor realistic, to give

watershed groups clear instruction regarding implementation. Additionally, some key actions were deemed to be unachievable in terms of their implementation. Arguably, SWP plan implementation will be more effective by creating greater opportunities for enhanced consultation and engagement between and among the WSA, local watershed groups, industry, residents, and landowners.

SWP planning is relatively new in Saskatchewan. The framework under which these plans were developed was previously untested elsewhere in Canada. In the absence of other frameworks from which to draw examples and experiences, the Saskatchewan approach to SWP is both novel and ambitious. The “first generation” of SWP plans, most now five years on, offer opportunity for reflection and analysis to help inform the evolution of SWP planning in Saskatchewan and elsewhere in Canada.

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Alluvial fans as archives for land-use changes in the Qu'Appelle Valley

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Land-use change in upland catchment plateaus has modified the pattern and rate of sediment delivery to alluvial fans deposited by tributary valleys entering the Qu'Appelle Valley drainage system. Two alluvial fans in the valley were chosen to analyze the influence of agricultural land-use changes on sediment deposition and to document geomorphic response. The first alluvial fan is situated downstream of an upland catchment with intensive agricultural land use near Lumsden, Saskatchewan. The second alluvial fan is located within Cowessess First Nation near Broadview, Saskatchewan. The catchment area of this fan has undergone little to no agricultural tillage. The first result indicating increased erosion and sedimentation reflecting agricultural land use is the length of core extracted above the till layer. On the First Nation the length of core is 350 cm and near Lumsden the length is 800 cm. In both cores the most prominent stratigraphic markers are buried soils and layers of organic material containing charcoal. Fossil A-horizons represent times of stability, whereas coarse grained layers identify periods of active erosion. The Lumsden core exhibits more periods of fan aggradation than the First Nation core as a result of increased erosion in the catchment area. While the impact of agricultural land use could be clearly documented in the sediments of the cores, it was not possible to correlate geomorphic events with stratigraphic layers because of the limitation of dating methods and the lag time in the sedimentation process.

Keywords: alluvial fan, land use, Qu'Appelle Valley

Introduction

Alluvial fans are gently sloping fan-shaped landforms developed at the base of valleys where flow emerges from a confined feeder channel and spreads laterally as a result of sudden loss of stream power (Blair and McPherson 1994). They can form in both humid and arid environments and can be distinguished into two major types. Steep fans ($\sim 5^{\circ}$ - 15°) are formed by debris flow processes, whereas gently sloping fan surfaces ($\sim 2^{\circ}$ - 6°) are formed by fluvial processes. Changes in the alluvial fan environment can be controlled by tectonic activity, climatic change and human factors (Harvey 2004).

Sedimentation on gently sloping alluvial fans is controlled by fluvial erosional processes occurring in upland drainage ba-

sins and subsequent transport processes which deliver sediment to the fans. Alluvial fan systems are composed of three geomorphological units: a fan catchment which is the main source of the sediments; the feeder channel and associated valley slopes which mainly transport sediments; and the fan surface which is the depositional area (Blair and McPherson 1994). Sedimentation on alluvial fans is intermittent, deposition occurring only in discrete sections of the fans. When feeder channels enter the main valley sediment-laden flows spread out forming alluvial fans in the valley bottom along the boundary of the lower hill slopes and valley floors. Most of the sediments are deposited when suspended sediment spreads onto the fan apex. Alluvial

sediments that are transported as bedload and deposited during larger events are typically coarser grained (Bull 1977; Blair and McPherson 1994).

Alluvial fan depositions are not only the result of different styles and rates of sedimentation but also of subsequent weathering and reworking of the fan sediments (Blair and McPherson 1994; Harvey 2004). The stable periods between depositional events are characterized by incipient soil formation. Alluvial fan sediments can act as an archive of landscape development and land-use changes since they are derived from the upstream catchment and feeder channel slopes (Beach 1994; Baker et al. 2000; Bettis-III 2003).

Alluvial fans in the Qu'Appelle Valley are subtle landforms, with gradients less than 4° and total relief less than 25 m. These low gradient fans are composed of fine-grained sediment, primarily silt with sheets of sand and gravel. The Qu'Appelle Valley is one of the largest meltwater channels in Canada and was carved approximately 14,000 years ago during the Wisconsinan when large volumes of meltwater cut into the glacial deposits (Klassen 1975; Christiansen et al. 1977). Since glacial retreat, slopes have been subject to mass wasting and erosion processes. It is estimated that at present, the Qu'Appelle Valley is one-third filled with alluvium (Christiansen et al. 1977). The rate of deposition was high immediately following glacial retreat and has decreased to the present time (Klassen 1989).

Holocene alluvial fans are covering the Quaternary Qu'Appelle Valley alluvium. Climate conditions have fluctuated throughout the Holocene and influenced deposition of the fans (Roberts 1998; Yanza 2006). Modern agriculture practices, especially tillage agriculture, over the last 120 years have increased erosion in the contributing catchment areas and thus sedimentation on the alluvial fans (Heginbottom 1989).

In Saskatchewan, water is the dominant agent of erosion, particularly during spring snowmelt over partially frozen soils (Ashmore 1993; McConkey et al. 1997). Since large portions of the prairie surface are regions of internal drainage that are not connected with regional river systems, net erosion rates are low because the eroded sediments never leave the catchments with alluvial fans storing sediments from the upland catchments (Ashmore 1993). For near level fields, Sutherland and de Jong (1990) identified wind erosion as the major erosion process. In fields with slopes greater than 2°, sheet and rill erosion were the dominant erosion processes.

Soil erosion by spring snowmelt of thawed surface soils above frozen soils is especially effective because infiltration below the frozen soil layer is not possible (de Jong et al. 1983; Singh et al. 2009; Jensen et al. 2011). During early settlement and the establishment of wheat agriculture operations, soil erosion rates remained fairly low before the adoption of mechanized tillage practices. From the 1920s to 1940s, increased erosion rates are documented for southern Saskatchewan, which are the result of these intensive tillage practices (Koroluk and deBoer 2007). Pennock et al. (1994) and Koroluk and deBoer (2007) estimated that the greatest rate of soil distribution would occur in the first 12 years of cultivation due to the clearing of the native prairie vegetation and tillage erosion. In the last three de-

cades, new rotation practices and the adoption of new minimum and no tillage practices have improved physical and chemical soil quality and reduce soil erosion (McConkey et al. 2003; Jensen et al. 2011).

The overall objective of this study was to develop a relative chronology of the geomorphic development of two sediment cores from two alluvial fans. Possible environmental controls responsible for periods of lower erosion and sedimentation rates and periods of accelerated geomorphic activity with high erosion and sedimentation rates within the alluvial fans and their drainages were identified.

Study area

The Qu'Appelle Valley is located in east-central Saskatchewan and extends from Lake Diefenbaker in the west to the Saskatchewan-Manitoba border in the east where it joins the Assiniboine River Valley. Cut into the relatively flat plain, the valley provides an important sedimentation area for materials eroded from the surrounding agricultural cropland.

The agricultural research site (AR site) is located approximately six km west of the town of Lumsden. The First Nation research site (FNR site) is located on Cowessess First Nation, at the east end of Crooked Lake, approximately 20 km north of Broadview, Saskatchewan (Figure 1). The two selected alluvial fans are downstream of tributary valleys that drain south to north (Figure 1). The FNR site has little to no documented history of agricultural land use in the upland catchment plateau. The slopes are covered with native prairie grasses and parkland trees, including *Populus tremuloides* (trembling aspen) and *Quercus macrocarpa* (bur oak). Native grasses are found along the floor of the lower tributary valley and atop the alluvial fan. In contrast, the soils of the upland catchment and valley sides of the AR site have been intensively used for agriculture since the late 1890s. Today, crop rotation species including peas and wheat are common. Source area soils for both alluvial fans are chernozemic. Typically, they are 45 cm to 50 cm thick with neutral to slightly alkaline pH and have developed on medium to moderately fine textured silty glaciolacustrine deposits and till (Ellis et al. 1965; Saskatchewan Soil Survey 1987).

Methods

The alluvial fans selected for comparative study are located on the floor of the Qu'Appelle Valley. One is associated with an upland catchment dominated by agricultural cropland and the other is associated with a native prairie headwater catchment. A single borehole core extracted from each alluvial fan was examined in detail.

Initially, topographic maps and aerial photographs were evaluated for the identification of potential north-facing side valley catchments of approximately 2.5 km² which had close proximity to access roads, and were classified as either agricultural land or native prairie.

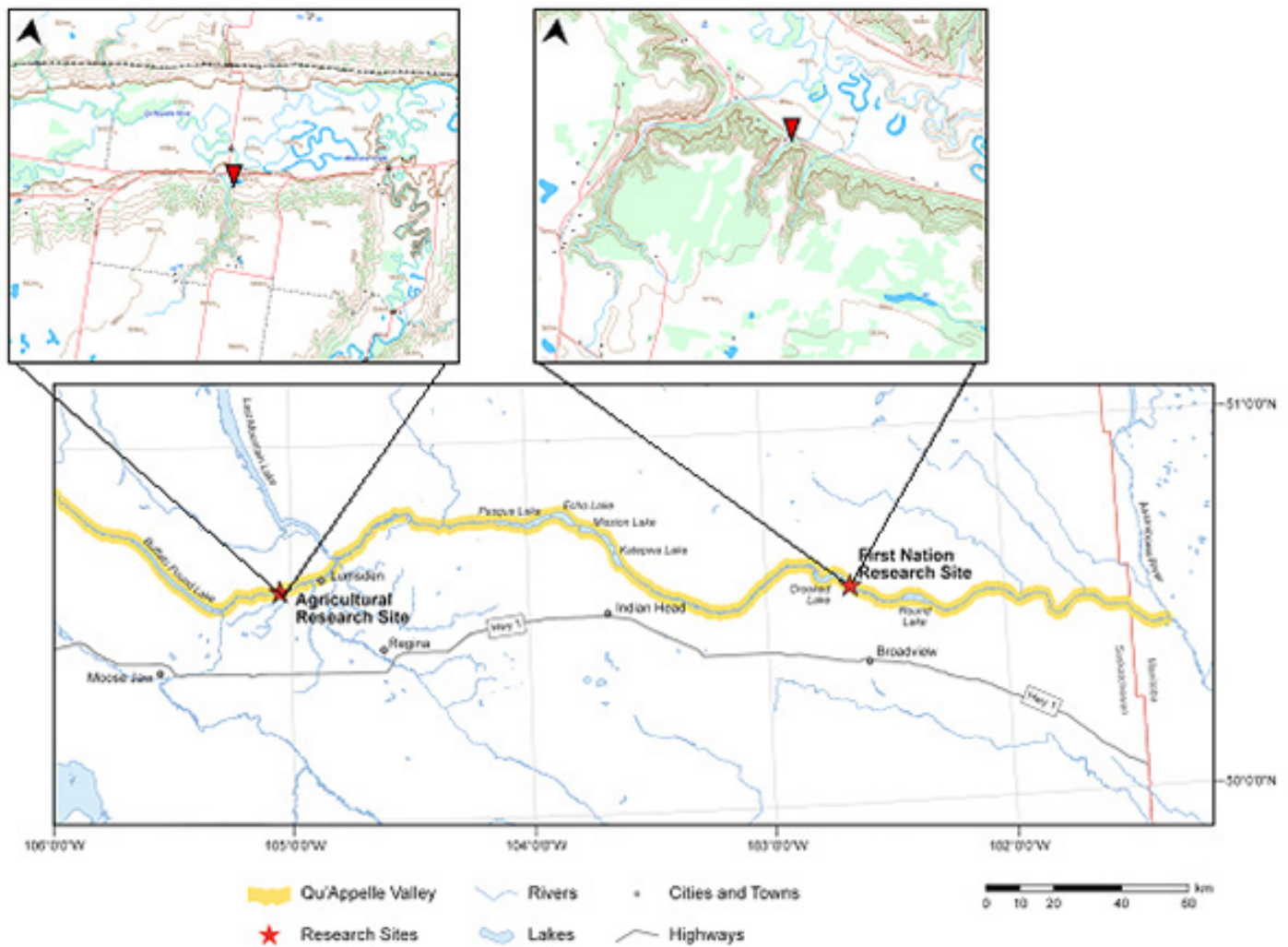


Figure 1
Locations of the research sites in southeastern Saskatchewan's Qu'Appelle Valley

Core extraction drilling sites need to be towards the apices of alluvial fans in order to capture the most complete sedimentary records (Bull 1977; Christiansen et al. 1977). A 2-ton truck equipped with a mechanical hollow stem auger, and 1.5 m long and 7.5 cm diameter sampling barrels, cored selected sites to a depth of 4 to 9 m. Cores were photographed and described before and during the subsampling process.

From each of the 1.5 m extracted cores, subsampling was performed based on changes in colour, texture and other unique attributes such as the presence of charcoal, shells and roots. The dry colour was matched using the universal Munsell Color Chart (Munsell Color 2000) and texture was determined by feel and general perception. Along the length of the core, subsampling ranged from 2 cm to 10 cm intervals. Sampling units that were homogeneous over greater lengths were subsampled at 15 cm intervals.

Two organic carbon samples buried by alluvial fan sediments were sent to Beta Analytic Incorporated in Miami, Florida for ^{14}C dating. Following 2-sigma calibration made by Beta Analytic using the Pretoria calibration curve, the conventional

radiocarbon age of the two samples was measured (Vogel et al. 1993). Coarse fraction ($\geq 2\text{ mm}$) particle size analysis was performed by dry sieving. The fine fractions ($< 2\text{ mm}$) were analyzed by using the Malvern Instruments Mastersizer 2000 laser diffractometer with Hydro 2000MU pump accessory (Sperazza et al. 2004). Percentage organic matter was determined by loss on ignition techniques (Pansu and Gautheyrou 2006).

Topographic data (latitude, longitude and elevation) were collected using a Trimble handheld global positioning system (GPS) unit with a vertical accuracy of 1.0 m to 1.5 m and a horizontal accuracy of 1.5 m to 2.5 m. Along with each topographic data point, notes on vegetation cover were recorded. Topographic data points were taken at intervals of approximately 10 m in horizontal distance and 1 m in vertical height. The gradients of slope segments were measured using a Suunto clinometer with a precision of 0.25° .

Using Golden Software Surfer 8.0, topographic data for each site were subjected to the Kriging algorithm to create digital elevation models (DEMs). The DEMs became the contour base maps of the geomorphic map for each site, and additional infor-

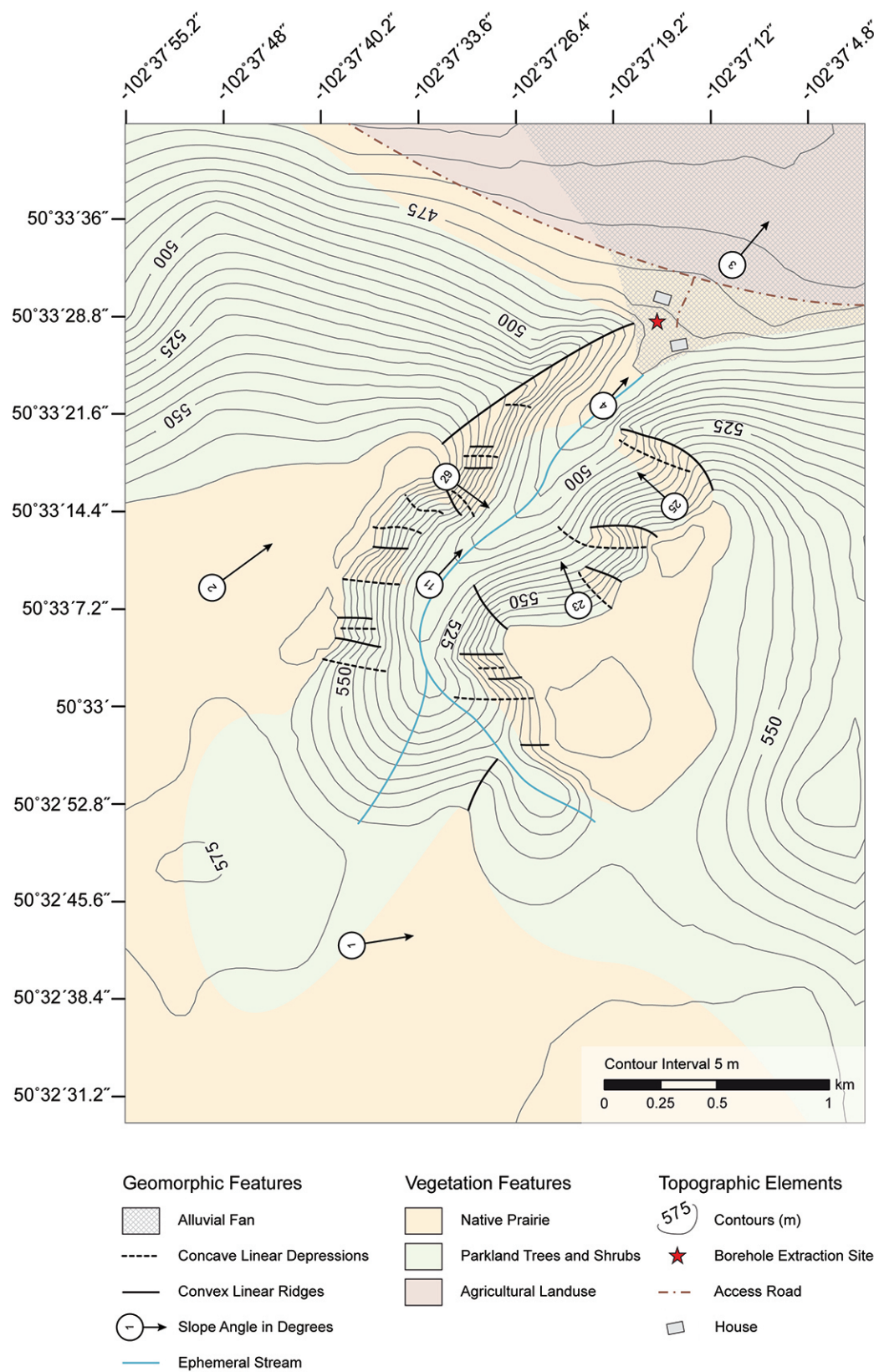
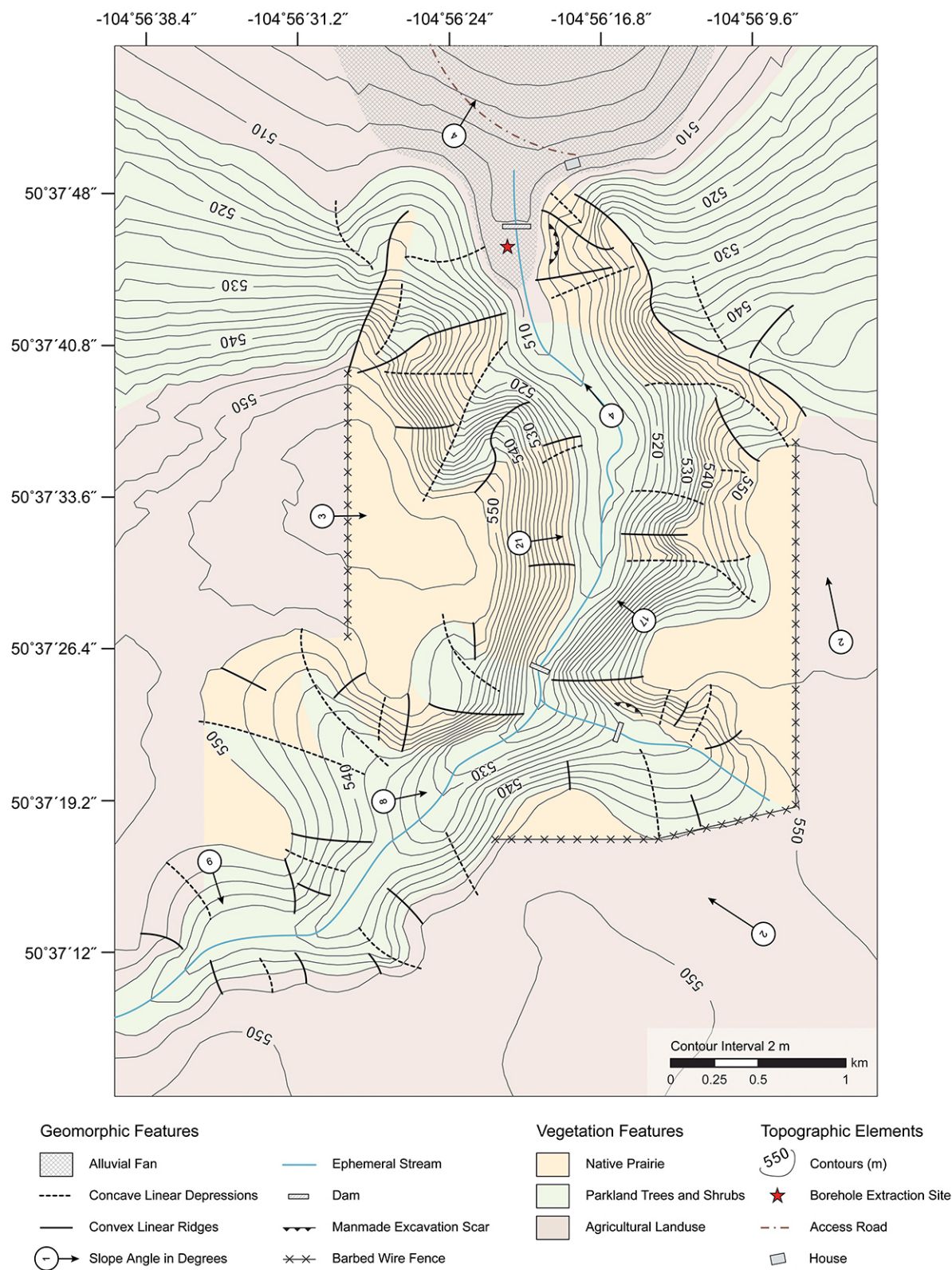


Figure 2
Geomorphological map of the First Nation research site with location of borehole core



mation and features were added as geomorphic layers (Figures 2 and 3).

Results

The most noticeable differences between the two cores are core length and the thickness of the alluvial sediments above the Pleistocene till. The FNR site has a core length of 350 cm whereas the AR site core is 800 cm long. Both cores indicate a dynamic erosional and depositional environment documented in a sequence of episodic sedimentation and incipient soil formation spanning the Holocene.

Periods of fan stability with little to no erosion in the catchment area are characterized by a high percentage of clay and organic matter, and the presence of in situ roots in the fan sediments. These characteristics indicate that these sediment layers supported the development of a vegetation cover and in situ soils. Buried A-horizons were identified by the presence of in situ roots and their dark colours. The latter ranged from dark greyish brown (2.5Y 4/2), through very dark grey (2.5Y 3/1) to black (2.5Y 2.5/1), and contrasted sharply with the surround-

ing sediments ranging in colour from pale yellow (2.5Y 7/3), through light yellowish brown (2.5Y 6/3) to light olive brown (2.5Y 5/3). These light coloured sediments were similar in colour to sediments found in the source catchment plateau.

It is difficult to determine if a thin organic-rich layer represents deposited organic sediment from the upslope catchment area or in situ A-horizon development during periods of stability, whereas a thicker organic horizon (> 3 cm) is likely the result of in situ soil development. Alluvial fan sediments containing organic components would support vegetation growth following deposition and develop an in situ A-horizon (Alexandrovskiy et al. 2004). Layers deficient in organic matter with high sand and coarse sediment characterize times of erosion in the catchment areas (Beach 1994; Elliott and Parker 2001).

The most distinct stratigraphic layers within the FNR site core comprise a dark organic layer from 315 cm to 305 cm, a thick, black charcoal-rich layer with a sharp transition from 227 cm to 225 cm, a sandy layer from 225 cm to 210 cm, and a thick A-horizon from 30 cm to 0 cm (Figure 4). The most distinct stratigraphic layers and features within the AR site core are coarse sand and gravels at 310 cm to 295 cm, a coarse sandy layer at 90 cm to 80 cm directly beneath the thick A-horizon

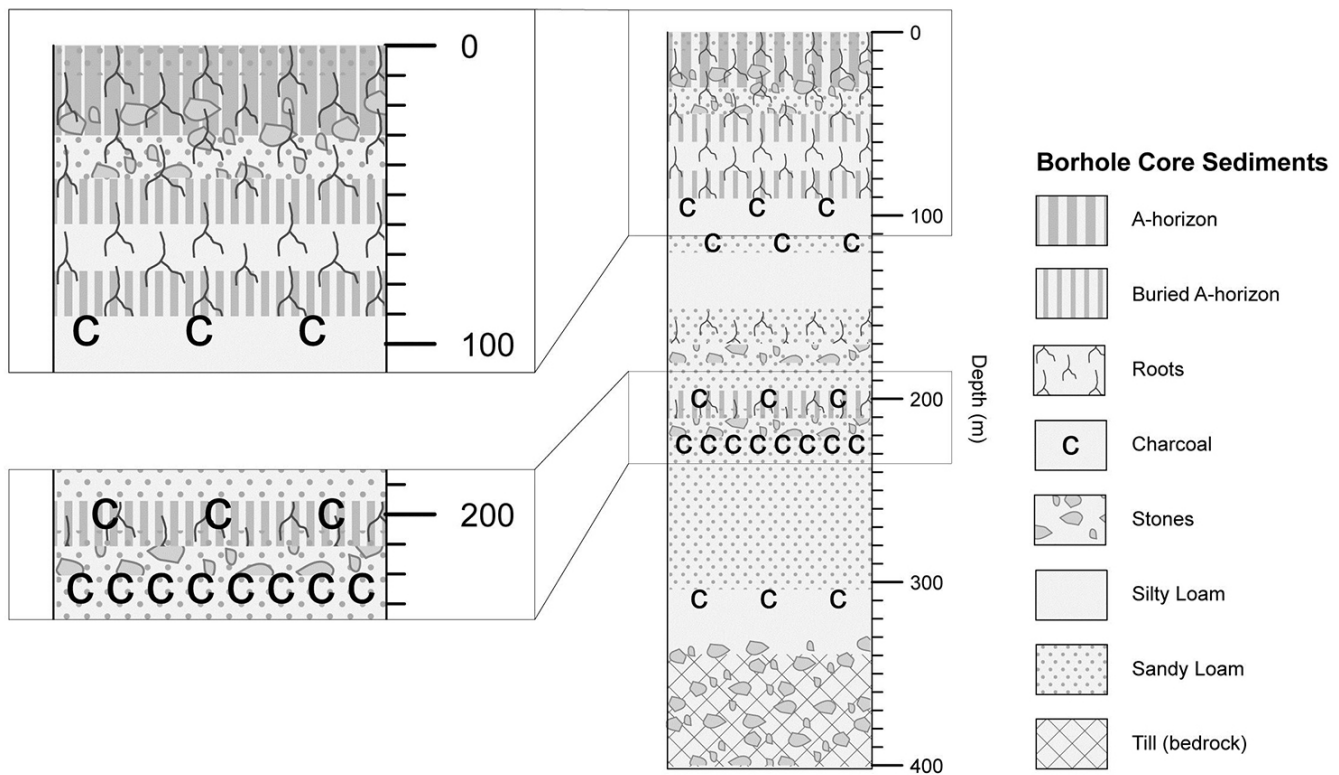


Figure 4
First Nation research site extracted borehole

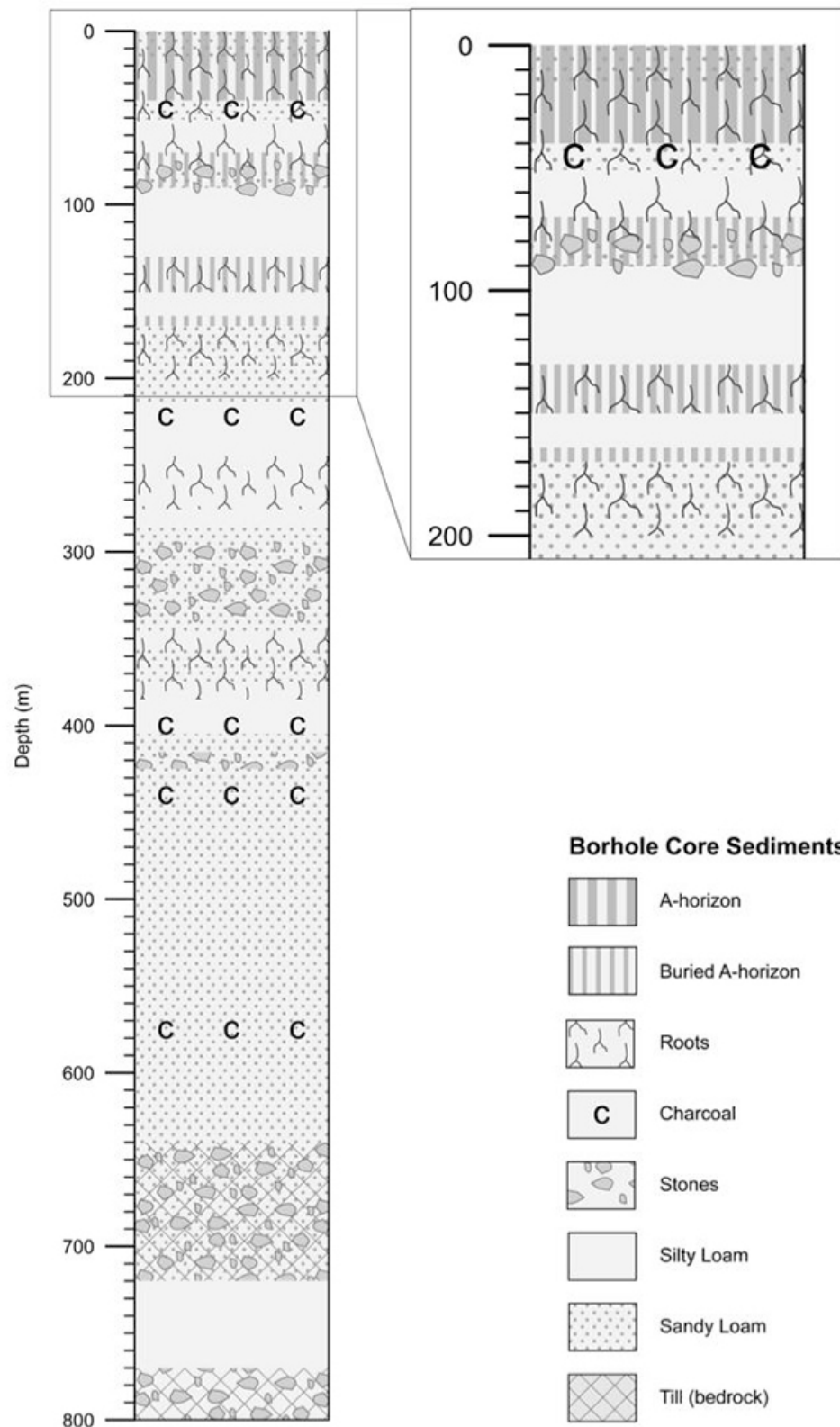


Figure 5
Agricultural research site extracted borehole core

with a sharp transition, and a thick A-horizon from 80 cm to 0 cm (Figure 5).

Discussion

First Nation research site core

In the FNR site core (Figure 4), the sediment layers between core depths 245 cm and 195 cm are considered to be the result of alternating erosion events. There is a distinct 2 cm thick charcoal layer at 227 cm to 225 cm overlain by a 15 cm thick unit composed of loose sand and gravel (2 mm to 6 mm diameter). These sediments contain sand and gravel indicating an extreme short-term erosion event in the catchment area following fire-induced changes in slope hydrology and erodibility. The charcoal layer was probably deposited during a brief time of accelerated erosion following a fire disturbance in the upland catchment area before vegetation became re-established (Beach 1994). Accelerated mass spectrometry (AMS) measured a radiocarbon age of a charcoal sample at 225 cm depth of 4520 ± 40 BP. Following 2-sigma calibration using $^{13}\text{C}/^{12}\text{C}$ ratios, the conventional radiocarbon age was measured as 4530 ± 40 BP. Incipient soil layers at 90 cm to 75 cm and 60 cm to 40 cm with in situ roots indicate times of relative fan stability. A distinct layer of sandy gravels at 75 cm to 60 cm capping a buried A-horizon was deposited following bedload dominant erosion events in the catchment and fan area.

Agricultural research site core

In the AR site core (Figure 5), thick layers of sandy loam sediments from 640 cm to 425 cm are interpreted as a result of erosion in the catchment area under pre-agricultural conditions resulting in thick, homogeneously coloured and textured sediments. The dominant agents of erosion/sediment transportation under pre-agricultural land-use conditions are considered to be sheetflow and rill erosion. These result in sandy loam textured sediments deposited on the alluvial fan. At 640 cm the core reaches the till. Sand and gravel strata are found at 420 cm to 415 cm, 342 cm to 340 cm, 335 cm to 315 cm, 312 cm to 285 cm, and 90 cm to 75 cm, respectively and are deposited by bedload dominated erosion events occurring in the catchment and the associated fan area. Roots and other organic matter indicating A-horizon soil development were found from 385 cm to 345 cm, 275 cm to 245 cm, 200 cm to 170 cm, 150 cm to 130 cm, and 80 cm to 0 cm. Numerous layers of coarse sediment from 200 cm to the surface are interpreted as a result of recent alluvial fan aggradation.

A sample of charred material taken at a depth of 220 cm was selected for AMS analysis. Although the sample was too small for a $^{13}\text{C}/^{12}\text{C}$ ratio measurement, a ratio including both natural and laboratory effects was measured during ^{14}C detection. From this ratio, calendar calibration was calculated, resulting in a conventional radiocarbon age of 108.9 ± 0.5 pMC, where pMC is the percent of modern reference carbon. Beta Analytic indicates that the calibrated age of 108.9 ± 0.5 pMC suggests the material was alive within the last 50 years (Hua et al. 2013).

The sand and gravel layers between 475 cm and 285 cm could represent erosion events triggered by intense agriculture and tillage practices within the upland catchment area and/or on the alluvial fan. Since the soils in the contributing area are not truncated and till is not exposed, most of the coarse sediment was probably relocated from the feeder channel of the fan during an erosion event. From 345 cm to 285 cm coarse sediments indicate a period of successive bedload dominant sedimentation.

Sedimentation interpretation

Borehole cores from the FNR and AR sites exhibit alternation between times of sedimentation and times of stability in the top third of the cores. However, it cannot be conclusively determined where the pre-European sediments end and the European sediments begin.

Figure 6 shows a distinct layer of sandy gravel which indicates that erosion events occurred at 425 cm (~220 cm above till) for the agricultural core and at 180 cm (~160 cm above till) for the First Nation core. This layer may be a marker that indicates settlement and ground breaking in the catchment areas. Sheet and rill erosion was probably the dominant process under pre-agricultural land use on both research sites, resulting in a preponderance of sandy loam sediment. The stratigraphic layers of the AR core indicate increased erosion rates caused by tillage practices as discussed by Lobb et al. (1995). When a second phase of increased erosion and subsequent sedimentation occurred as a result of tillage practices, underlying sediments including lighter coloured B-horizon sediments were eroded, transported and deposited on the alluvial fan at 295 cm to 345 cm.

Over the last 50 years, the AR site was subject to soil erosion reducing practices such as zero tillage. Although erosion events are continuing to occur, the amount of sediment deposited in the area of accumulation is less than that of past tillage induced erosion and phases of increased sedimentation.

Conclusion

The alluvial fan stratigraphy from two borehole cores and the topography indicate that a relationship exists between an increase in erosion due to agriculture in the catchment area and sedimentation on the alluvial fan. Layers indicating extreme erosion events are characterized by high sand and gravel content and low organic matter. Layers with high silt and fine sand content could be the result of erosion events with lower runoff rates that are unable to transport coarse sediment. Times of extended stability are characterized by layers with high organic matter in combination with higher clay content as a result of in situ weathering and soil development.

The borehole cores at both research sites show a pronounced sandy gravel layer between approximately 220 cm and 180 cm above the underlying till (Figure 6), which may be attributed to ground breaking and settlement in the catchment area. The sediments above this sandy gravel layer are over twice as thick adjacent to agricultural vegetation and land use (415 cm) as

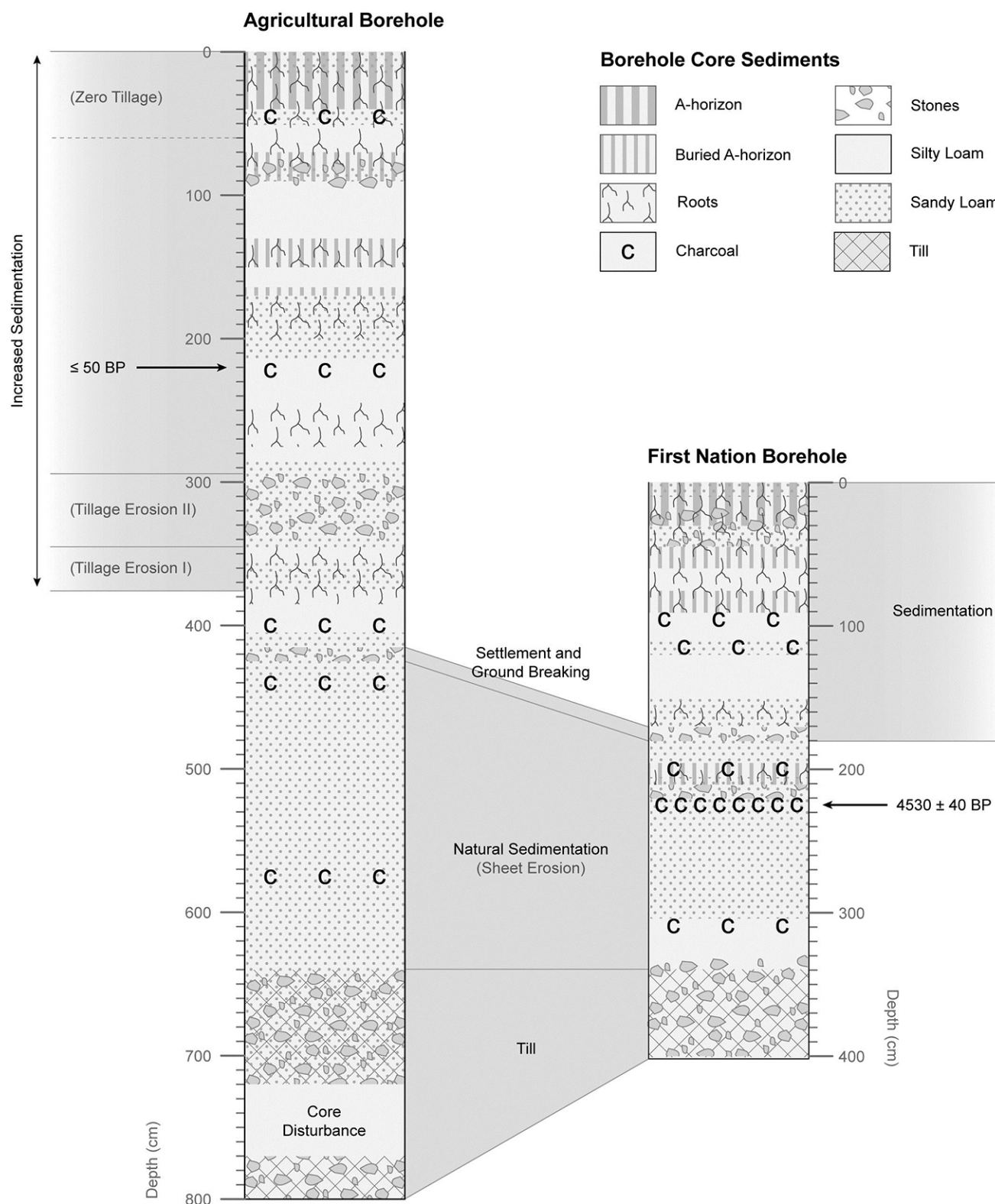


Figure 6
Schematic representation of the sedimentary succession interpretation of the two borehole cores

compared to native prairie vegetation (170 cm). The thickness of sediments indicates that agriculture, especially tillage practices, increased erosion rates and thus increased sedimentation on the alluvial fan. Further, the topography of the side valleys adjacent to agricultural land exhibits the reduction of slope angles due to the deposition of sediments in depressions and the smoothing of ridges including that of the transition between side valley slopes and upland catchment area.

However, due to the complexity of the sedimentation processes on the alluvial fans, the chronology of the sedimentation events may not be complete. During a sedimentation event not only does the deposition occur, but there may also be removal of sediments. The evaluation of single borehole drilling is not sufficient to reconstruct the complex structure of an alluvial fan and can be used only for a first estimation of factors influencing the fan development (Lewin et al. 2005).

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Red edge spectral characteristics of Hudson Bay coastal vegetation

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Improving the discrimination of coastal vegetation with remotely sensed imagery is needed for accurate mapping of shoreline position to determine sea level changes. Homogeneous vegetation cover can be successfully discriminated using remotely sensed data. However, the key to improving coastal vegetation mapping is better detection of heterogeneous vegetation cover. The focus of this article is to explore the relationship between vegetation cover amounts (homogeneous, heterogeneous) with remotely sensed visible-infrared spectra to improve mapping of coastal vegetation. This goal is achieved by quantifying the relationship between plant area index (PAI) values and change from homogeneous and heterogeneous vegetation cover. If PAI values can be used as an indicator for vegetation cover, then the statistical relationship between the PAI values and the first derivative of the red edge in the hand-held spectra can be determined. Results showed that the PAI values were statistically different for the two vegetation zones and thus PAI can be used as an indicator. Significant linear relationships were found between PAI values and the first derivative with the best correlation obtained using the amplitude characteristics ($R^2 \sim 0.90$) for both vegetation zones. A negative correlation was found for the PAI spectra in the homogeneous vegetation while a positive correlation was found for the PAI spectra in the heterogeneous zone. It was concluded that spectral discrimination between homogeneous and heterogeneous vegetation is possible when using the first derivative of the red edge. The next step is to incorporate spectral information into an object-based classification to improve coastal vegetation mapping.

Keywords: wetlands, hydrology, remote sensing, coastal, shoreline mapping

Introduction

This article investigates the spectral difference between homogeneous and heterogeneous vegetation near Churchill, Manitoba for the purpose of improving coastal vegetation mapping using remotely sensed data. This is the first phase of a larger project aimed to use the transition from homogeneous to heterogeneous vegetation as a detectable, stable feature for geocoding remotely sensed images. If a reliable geocoding feature can be detected, this would improve change detection of shoreline position using multi-temporal images. Subarctic coastal vegetation has a short growing season (late June to September) and, as a result, the distribution and composition of vegetation changes little from year to year. The stability of coastal vegetation means that it may be useful as a geocoding feature compared to geomorphic shoreline features which experience annual erosion and deposition changes due to yearly sea ice on Hudson Bay.

The boundary between the change from homogeneous to heterogeneous vegetation is defined as the decrease in vegetation percent cover from homogeneous vegetation (100% cover) to heterogeneous vegetation (<90% cover). This change was observed in the field and statistically validated based on change in plant species, percent cover and elevation (Werner et al. *in press*). In remote sensing literature, the terms ‘homogeneous’ and ‘heterogeneous’ are used to describe the amount of vegetation cover or amount of vegetation type (Bartlett and Klemas 1980; Curran 1980; Asner and Heidebrecht 2002). In this article, homogeneous and heterogeneous vegetation refers to amount of vegetation cover, not amount of vegetation type.

The goal of improving the detection of heterogeneous vegetation for mapping coastal vegetation was identified through remote sensing literature with researchers who noted inadequate detection, classification and mapping of heterogeneous land cover as a significant contributor to reduced classification accuracy (Asner and Heidebrecht 2002; Schmidtlein et al. 2007; Kearney et al. 2009). The objectives identified to meet this goal were (a) to quantify the relationship between vegetation cover and plant area index (PAI) values so that PAI values could be used as an indicator of vegetation cover amount, and, (b) to quantify the relationship between PAI values and hand-held spectral data to map changes in vegetation cover. This project used PAI values because the relationships between PAI values and vegetation biophysical characteristics (e.g., above ground biomass) are well documented in the literature (Asner et al. 2003; Leblanc et al. 2005; Soudani et al. 2006). PAI values were used instead of leaf area index (LAI) since PAI values take into account all of the phytomass rather than only the green phytomass associated with LAI values. PAI values were deemed important for the mapping of vegetation in this region which can transition from green to dark red (senescence) throughout the growing season. However, information from the literature that refers to LAI and remote sensing relationship can be used to inform results of PAI relationships based on vegetation change.

The second objective compared PAI values with visible and infrared spectra data collected *in situ* using a hand-held spectrometer. This experimental design was identified by Brook and

Kenkel (2002) who advocated that researchers carefully examine the relationship between ground and spectral data for vegetation mapping near Hudson Bay. This “provides a highly robust and flexible approach to thematic mapping since the analyst is able to make informed choices at all stages of the decision-making process” (Brook and Kenkel 2002, 4774). If the results show a statistically significant difference between PAI values for the two vegetation zones, and a distinct relationship between PAI values and reflectance spectra for each zone, this provides informed decisions for classification of vegetation along the coast (the next step of the project).

Background

Geospatial data and tools have been used for mapping shorelines susceptible to slow erosion processes, rising water levels, and subarctic vegetation change (Stow et al. 2004; Maiti and Bhattacharya 2011; Ahmad and Lakhan 2012). However, these studies show that shoreline position is challenging to detect due to the dynamic nature of tides, changes in deposition and erosion landscapes due to sea ice, and the systematic temporal requirements of satellite-based image collection (Boak and Turner 2005; Maiti and Bhattacharya 2011). Thus indicators of shorelines are used in mapping projects to detect changes of shorelines over time.

Vegetation distribution along coastlines can be used as an indicator of shoreline position since vegetation has been found to be representative of changes in landscape ecological properties (Schmidt et al. 2004). Success in mapping coastal vegetation is obtained if the vegetation has homogeneous cover (e.g., 100% vegetation). Mapping vegetation based on spectral reflectance is based on characteristics such as plant tissue (leaf, woody stem, and standing litter), biochemistry, canopy biophysical properties (leaf and stem area, leaf and stem orientation, and foliage clumping), soil reflectance, illumination conditions and viewing geometry at time of image acquisition (Curran et al. 1992). For example, Schmidt and Skidmore (2003) mapped the distribution of vegetation of coastal wetlands while Kennedy (2012) mapped spatial and temporal changes in subarctic homogeneous vegetation.

Along the Hudson Bay coastline, the amount of vegetation cover decreases with proximity to the shoreline due to high soil and atmospheric salinity, strong coastal winds, and successive vegetation ridges from post-glacial uplift (Laliberté and Payette 2008). While homogeneous vegetation can be successfully mapped, the challenge is to map heterogeneous vegetation cover with better classification accuracy. Heterogeneous vegetation amounts result in image “mixel” where pixel reflectance values are a product of mixed land cover; in this case, coastal vegetation, sediment and rock (Asner and Heidebrecht 2002; Schmidtlein et al. 2007; Kearney et al. 2009). The variable proportions of vegetation, sediment and rock within an image pixel results in highly variable reflectance values within each pixel for heterogeneous vegetation (or any heterogeneous surface). The wide range of reflectance values will result in poor classifica-

tion accuracy because the traditional classification algorithms require unique and non-overlapping reflectance values for each land-cover class (Curran et al. 1992).

To overcome the poor classification of heterogeneous vegetation, researchers have suggested the use of spectral curve shape or spectral ratios from hyperspectral data. Figure 1a provides a schematic of the typical shape expected for a spectral curve of healthy, green vegetation. In Schmidt and Skidmore (2003), the ability to discriminate salt marsh vegetation was done using the shape properties of the spectral signature curve. The authors concluded that the ability to differentiate salt marsh species was maximized when the near-infrared (NIR) and short wave infrared wavelengths (740 to 1820 nm) were included in the classification. Schmidt and Skidmore (2003) state that the leading edge of the near-infrared (NIR) plateau was essential for discriminating salt marsh vegetation. The NIR plateau region appears after reflectance values increased from the red to the NIR region (Figure 1a).

To detect changes in vegetation, other researchers have developed indices using ratios of red and NIR reflectance values because these two values vary depending on plant health, amount and type. Simple ratio (SR), normalized difference vegetation index (NDVI) and soil adjusted vegetation index (SAVI) are all ratios that have been found to correlate with LAI values (Turner et al. 1999; Brown et al. 2000). Turner et al. (1999) concluded that use of these surface reflectance indices was far superior for vegetation discrimination when compared to digital number, radiance or top of atmosphere reflectance alone. Brown et al. (2000) used a modified SR vegetation index to investigate the potential of the shortwave infrared signal to improve LAI retrieval in the boreal forests of Canada. These results showed that red-NIR ratio values were vegetation-type, phenological and health dependent, and were most successful for broad leaf forest land cover and less successful for conifer forest, shrubland and grassland. The success of the modified SR was because it optimized the characteristic shape of vegetation spectral curve compared to using individual reflectance values of the visible and infrared wavelengths (Brown et al. 2000). The typical shape of vegetation spectral signature includes a dip in red spectra (low reflectance) followed by a steep increase in NIR reflectance

(Figure 1a). Healthy vegetation has a steeper slope between the recorded red and NIR reflectance values because healthy vegetation reflects more NIR radiation.

Both Nemani et al. (1993) and Brown et al. (2000) found a large range in SR values associated with low LAI values and concluded that indices alone could not be used to estimate LAI in open forest canopies or low vegetation environments. Chen and Cihlar (1996) suggest that the scattered reflectance observed for low vegetation environments (low LAI values) would explain the variation in background reflectance from such vegetation and thus lower classification accuracies would result. The findings of Nemani et al. (1993) and Brown et al. (2000) are important for non-forested environments where heterogeneous land cover could yield analogous scattering issues.

To overcome the limitations of background reflectance on the red-NIR ratio relationships, researchers have proposed taking the first derivative of the spectral reflectance ratio index. The typical vegetation signature curve results in a slope from red to NIR reflectance (680 to 780 nm) that is known as the red edge (Figure 1a). When the vegetation curve is transformed using the first derivative of vegetation spectral curve, the red edge appears as a peak (Figure 1b) with the position and shape of the peak found to be affected by chlorophyll content and scattering properties of the vegetation (Horler et al. 1980; Boochs et al. 1990; Filella and Penuelas 1994). The characteristics that are used to improve vegetation mapping from the first derivative curve include the amplitude, area ($\Sigma 680$ to 780 nm) and 725/702 nm ratio calculated from the average spectra data (Figure 1b). The amplitude is represented by the maximum value of the peak, the area is represented by the sum of the values from 680 nm to 780 nm, and the 725/702 nm ratio is the ratio between reflectance values in the NIR range which have been shown to be sensitive to vegetation stress and heterogeneity.

Advantages to using derivative spectra characteristics include a minimization of additive constants (e.g., illumination changes) and a reduction in the sensitivity to variable background reflectance (Curran et al. 1990; Imanishi et al. 2004; Kochubey and Kazantsev 2012). The first derivative technique has been applied to improve vegetation classification by overcoming interference from soil background reflectance or for resolving

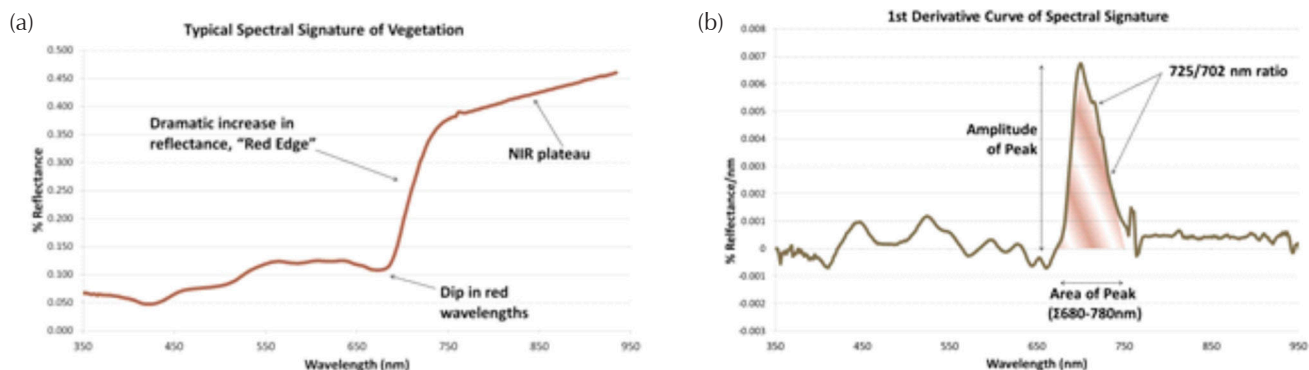


Figure 1

(a) Typical reflectance spectra of healthy vegetation within the study; and (b) the first derivative curve of the spectra from Figure 1(a)

complex spectra of several target species (Demetriades-Shah et al. 1990). Demetriades-Shah et al. (1990) showed that derivative spectral indices were superior to the conventional broadband spectral indices (e.g., SR, NDVI, SAVI) for monitoring chlorosis in vegetation. The position and shape of the first derivative peak has been found to be affected by chlorophyll content and scattering properties of the vegetation (Horler et al. 1980; Boochs et al. 1990; Filella and Penuelas 1994). The derivative peak has been used to measure chlorophyll content (Horler et al. 1980; Curran et al. 1990; Filella and Penuelas 1994; Gitelson et al. 1996), to monitor nitrogen stress (Boochs et al. 1990; Filella and Penuelas 1994) and drought (Filella and Penuelas 1994; Mano et al. 1999), and to identify sulphide stress (Collins et al. 1983) and areas of high vegetation damage (Rock et al. 1988).

Characteristics of the first derivative peak have also been found to be correlated with LAI values (Filella and Penuelas 1994; Danson and Plummer 1995). Filella and Penuelas (1994) found strong correlations between both the area and amplitude of the first derivative peak and LAI values. Danson and Plummer (1995) also observed a strong non-linear correlation between LAI values and the position of the first derivative peak. The area of the first derivative peak appears to better follow the evolution of LAI values (change in values from low to high based on vegetation biomass) compared to the amplitude of the peak. Filella and Penuelas (1994) concluded that the area of the first derivative curve was dependent only on the contrast of red and NIR reflectance values while the amplitude was also dependent on the amount of energy reflected in these two wavelength regions.

In addition to using the shape characteristics (amplitude, peak, area) of the first derivative curve, other researchers have

incorporated ratios based on measured values found along this curve. Kochubey and Kazantsev (2007) proposed an index where the ratio of the two peak intensities, 725 nm and 702 nm, be computed and used to map vegetation. Although the peak wavelengths did not always coincide with maxima in the derivative plot, the 725/702 nm ratio did show the most reliable interrelation between chlorophyll contents and the derivative index (Kochubey and Kazantsev 2012). The authors found the 725/702 nm ratio was successful when tested against a variety of plant species and is computationally simple compared to identifying the maxima for each individual curve. Both Filella and Penuelas (1994) and Danson and Plummer (1995) related LAI values to first derivative characteristics or ratios in controlled experiment and forested regions, respectively. However, no work has been done on using characteristics of the first derivative curve for subarctic coastal vegetation.

Study site

The field work was conducted at Bird Cove (58° 47'N, 94° 11'W) close to the Churchill Northern Studies Centre (CNSC), which is situated approximately 20 km south-east of the town of Churchill, Manitoba. The study site is on the western edge of Hudson Bay and is situated near an estuary carrying freshwater from the southern plains and boreal forest (Figure 2). This creates a unique and fragile ecology in the region that is susceptible to climate change due to loss of permafrost, sea level rise and post-glacial isostatic rebound (Rouse et al. 1997). The heterogeneous zone along the western coast of Hudson Bay is an area

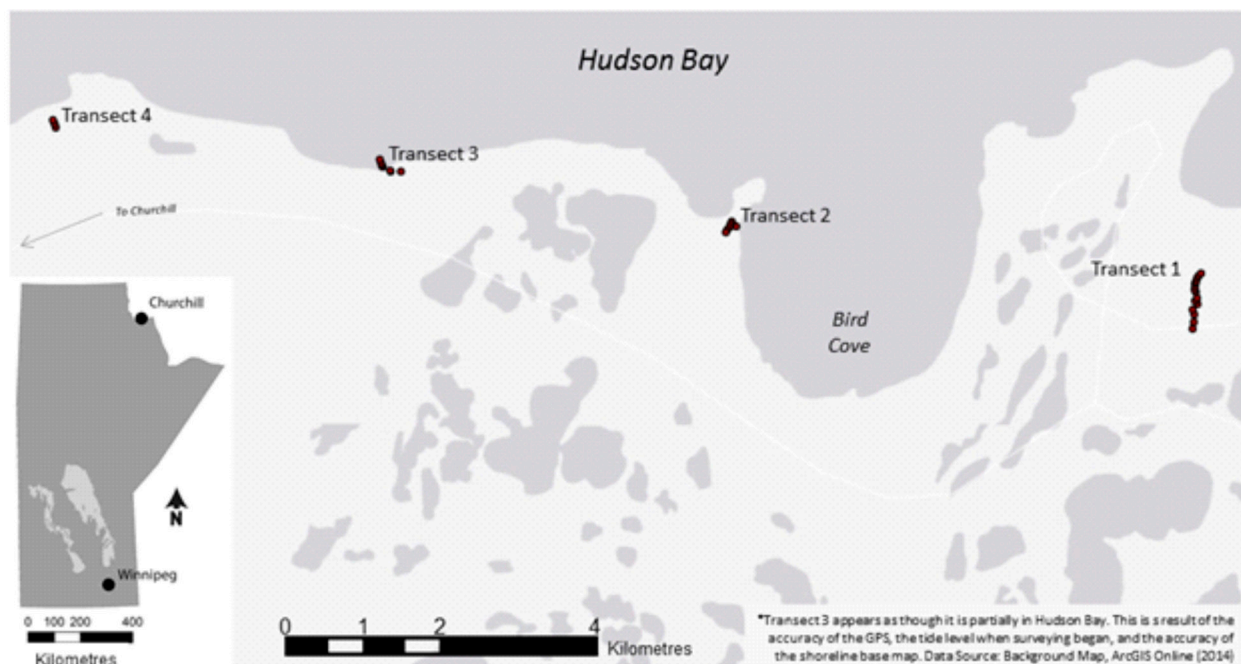


Figure 2

Bird Cove transects for in situ data collection, east of Churchill, Manitoba on Hudson Bay. (Map Data: ©2013 Esri, DeLorme, NAVTEQ, Survey Data from the authors)

several hundred metres wide that is characterized by a combination of geologic materials (sediment, rock), ponds and reduced vegetation cover approaching the bay. The Hudson Bay Lowlands region is underlain by calcareous Paleozoic limestone and dolomite, both considered soft rock with values of 3 to 4.5 on the Mohs hardness scale. These soft rocks experience significant erosion due to seasonal storms and annual sea ice advance and retreat (Ritchie 1957; Johnson et al. 1987).

This region was chosen because it represents the interface between the Arctic tundra, boreal forest and Arctic marine biomes. There are approximately 400 vascular plant species native to the Churchill area, including horsetails (*Equisetum* spp.), clubmosses (*Lycopodium* spp.), ferns, conifers, and flowering plants (Johnson et al. 1987). These species represent 17 vegetation communities found in the region with two, strand and salt marsh communities, existing within the study site. Homogeneous and heterogeneous vegetation cover was observed and quantified by Werner et al. (in press) with the vegetation zones corresponding with changes in vegetation percent cover, cover type, colour and texture.

Methods

The sites of four transects (Figure 2) were chosen for their accessibility, vegetation composition and safety. This study area is adjacent to “polar bear alley” so the four transects required good proximity to road/track access which allowed for a safety vehicle to be located nearby. Access to potential study sites was also limited by rock outcrops which prevented safe transport beyond these locations. The Bird Cove site is commonly used by CNSC researchers. Thus this project is contributing to the overall knowledge of the physical landscape of the area. In Figure 2, transect 3 appears to be floating in Hudson Bay. This is a result of the accuracy of the GPS unit (± 10 m) but also the accuracy of the shoreline position on the base map. This further emphasizes the need for more precise mapping of shoreline position as input into models.

Collection took place in late August 2012. Data collected from transects 1, 2 and 3 were used for the PAI values-vegetation zone analysis while transect 4 data was lost due to computer failure. In addition, limited battery life of the hand-held spectrometer meant that data were collected for only transects 1 and 3 for use in the PAI-spectra analysis. The transects varied in length from 202 m to 765 m with a maximum elevation of 9 m asl. Nineteen plots were sampled in the homogeneous zone and 13 in the heterogeneous zone. Although the heterogeneous region is of most importance for the current analysis, this zone represents a narrower swath of the coast resulting in a reduced number of plots compared to the homogeneous zone. To maximize the number of plots collected in the heterogeneous zone, a continuous sampling method was applied to capture the subtle changes in this narrow region (Werner et al. in press).

The biophysical variables collected in the field were chosen based on an understanding of the coastal environment and the ecological literature on the Hudson Bay Lowlands (Mc-

Clure 1943; Ritchie 1957; Kershaw 1976; Johnson et al. 1987; Houle 1996; Imbert and Houle 2000; Brook 2001; Gagne and Houle 2002). Hemispherical photographs were collected so that PAI values could be generated to provide an indicator of percent cover for homogeneous and heterogeneous vegetation cover amounts. The hand-held spectra data were used to collect vegetation spectral reflectance across the visible and NIR wavelengths with the reflectance amounts for each wavelength being connected to form a spectral curve. The spectral curves for the vegetation regions were then transformed into first derivative spectra curves which allowed for the generation of shape characteristics (e.g., amplitude, area, and ratio).

In each 10 m x 10 m plot along the transects, hemispherical photographs and hand-held spectra data were collected in a z-pattern to ensure that the samples were random and representative of the vegetation within the plot (McCoy 2005). Hemispherical photographs were obtained using a Canon EOS60D camera with a Sigma 10 mm fisheye lens at a height of 0.95 m with an IFOV of 3.46 m². The photographs were sampled using a random walk method at transect 1, and this method was modified to account for red and green plant colour for the remaining three transects as plant colour change due to senescence is evident in late August in this area. The standard protocol of collecting eight hemispherical photographs within each plot was followed. These eight photographs were then input into CanEYE software to calculate true PAI values using the Miller formula (Miller 1967; EMMAH 2003).

Spectroscopy of the vegetation cover was collected using the ASD Fieldspec Pro at an angle of 0° facing downward perpendicular to the ground surface (ASD 2014a). The sensor subtended a viewing angle of 25° at a constant measure distance of 1.25 m for an instantaneous field of view (IFOV) of 0.28 m². The Fieldspec Pro unit averaged 500 counts per sample. A table was output from the ViewSpec Pro of the percentage reflectance per unit wavelength. An average curve of reflectance value for each plot was generated based on eight samples collected for each plot. From the average curve reflectance, the first derivative curve for each plot was then calculated using the RS³ Spectral Acquisition Software (ASD Inc 2014b.). The first derivative characteristics include the amplitude, area ($\Sigma 680$ to 780 nm) and 725/702 nm ratio of the first derivative peak.

Statistical correlations between PAI values for the vegetation zones were calculated using IBM SPSS Statistics 19. Characteristics of the first derivative curve were analysed using ROOT 5.34.02 (Brun and Rademakers 1997). A Z-test ($p=0.05$) was used to quantify the difference in PAI values between homogeneous and heterogeneous vegetation zones. The relationships between PAI values and first derivative spectral characteristics values were derived using regression analysis (Chen et al. 1997; Turner et al. 1999; Colombo et al. 2003).

Results and discussion

The first objective of this study was to determine if PAI values could be used as an indicator for differences in the homogeneous

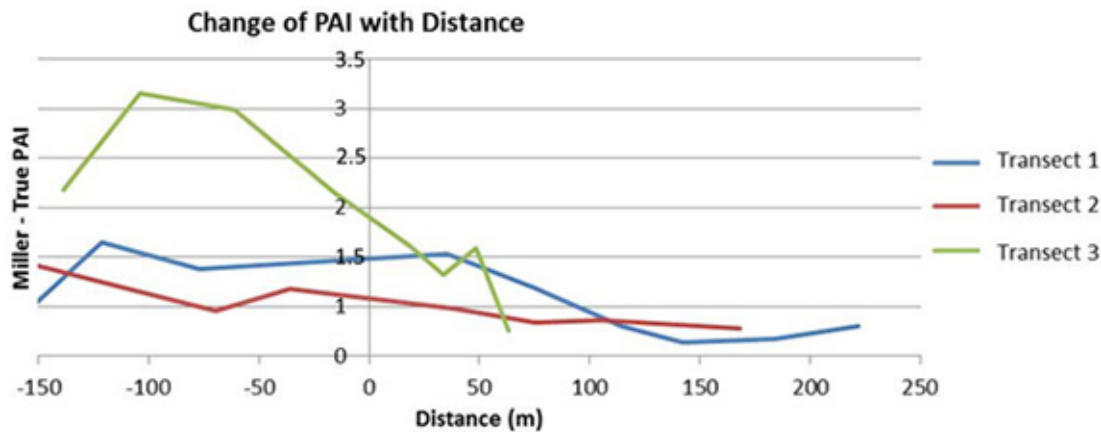


Figure 3
Change in PAI values relative to the boundary separating homogeneous and heterogeneous vegetation zones for transects 1 (blue), 2 (red) and 3 (green). The vertical line at 0 m represents the observed and quantified division between homogeneous and heterogeneous vegetation

and heterogeneous vegetation cover. The results showed there was a decline in PAI values from the homogeneous to the heterogeneous vegetation (Figure 3), which is particularly evident at the transition boundary. The PAI values pattern observed in Figure 3 corresponds with a decrease in vegetation cover (33% in salt marsh of transect 1; 10.5% in strand community of transect 3) from the homogeneous to the heterogeneous zone. In transect 1, when the sampling design did not account for vegetation colour, there were no significant differences obtained in PAI values between the homogeneous and heterogeneous vegetation cover (Table 1). In transects 2 and 3, when the sampling method did account for vegetation colour (red and green), there were statistically significant differences in PAI values between homogeneous and heterogeneous vegetation zones. Thus, PAI values can be used as an indicator of vegetation cover amount if colour is accounted for in the sampling and analysis.

The second objective was to quantify the relationship between PAI values and first derivative spectra characteristics to determine if the spectral data can be used to map the change from homogeneous to heterogeneous cover. The PAI values were plotted against the amplitude, area $\Sigma 680$ to 780 and the 725/702 nm ratio data (Figure 4) based on $n=273$ field samples.

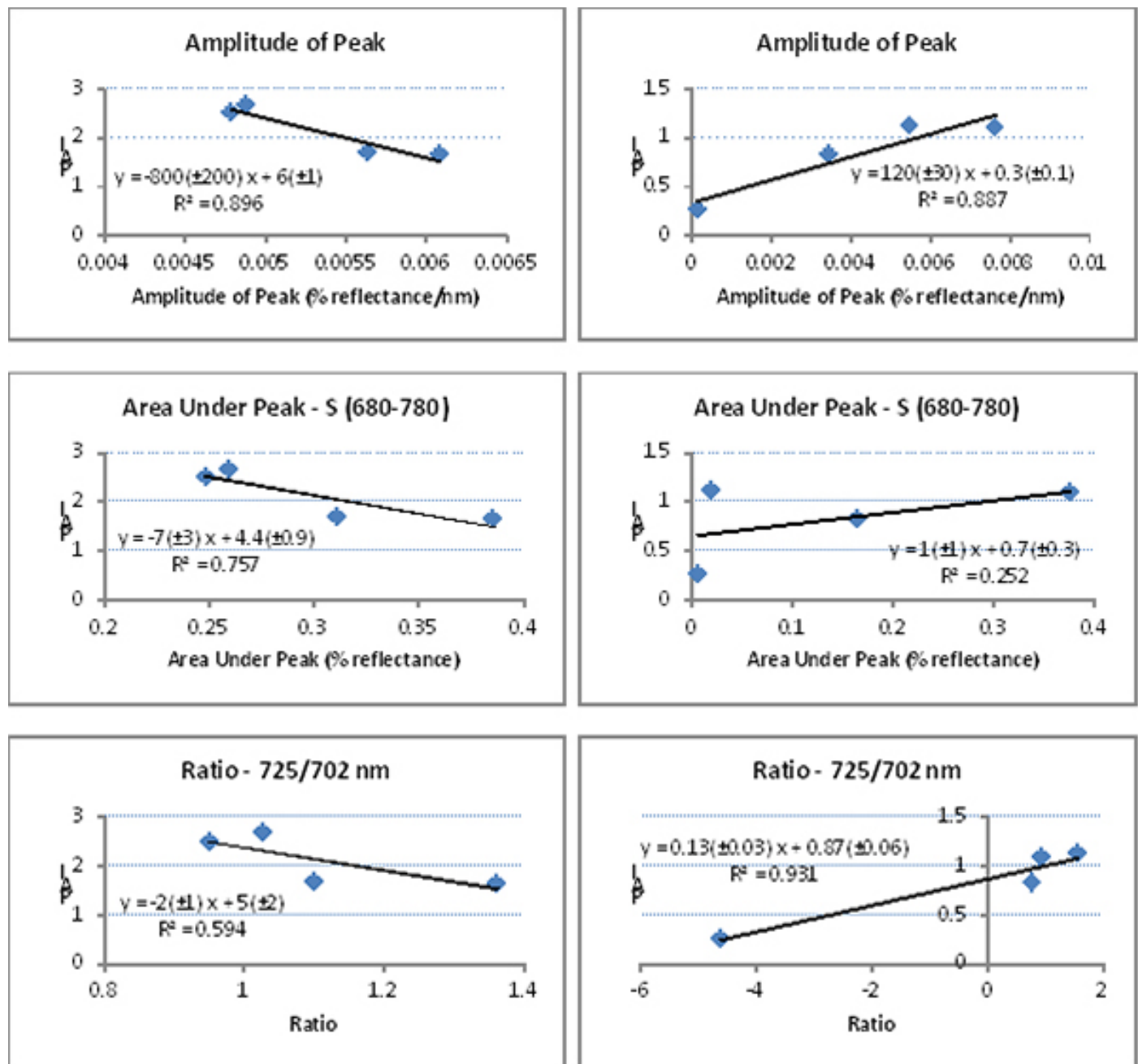
Table 1
Comparison of PAI values between homogeneous and heterogeneous vegetation

Transect	Sampling Design	Sample Size (n)	Z calculated (True PAI-Miller)	Z-Critical Value	Difference
Site 1	random	124	0.331	0.754	No
Site 2	stratified random	175	2.258	0.109	Yes
Site 3	stratified random	98	5.709	0.011	Yes

The results of the regression analysis showed that the relationship between PAI and first derivative spectra is dependent on the amount of vegetation cover. Figure 4 presents the results based on the homogeneous (left) and heterogeneous (right) vegetation cover amounts. In the heterogeneous zone, the strongest correlation was obtained for PAI values and the 725/702 nm ratio data ($R^2= 0.931$). In the homogeneous zone, the strongest relationship was obtained between PAI values and the amplitude data ($R^2= 0.896$). When considering both the homogeneous and heterogeneous zones, the amplitude characteristics of the first derivative curve resulted in the best overall results ($R^2\approx 0.90$ for both).

These results corroborate other literature which state that the characteristics of the first derivative peak is influenced by both chlorophyll and LAI/PAI variability (Boochs et al. 1990; Filella and Penuelas 1994). The findings of Filella and Penuelas (1994) also found a strong correlation between PAI values and the amplitude for some plants with variable water and nitrogen amounts. However, unlike Filella and Penuelas (1994), the results of this research did not show the area of the red edge peak as following the PAI evolution better than amplitude. The ratio is related to chlorophyll content of the vegetation (Kochubey and Kazantsev 2007). It is stated that the total phytomass (PAI) predicted with red and NIR indices will have a better relationship with vegetation than ratios that incorporate green wavelengths (Shippert et al. 1995; Riedel et al. 2005; Raynolds et al. 2006).

Although both homogeneous and heterogeneous vegetation cover have a strong correlation with first derivative characteristics, the observed direction of this relationship changed based on the percent cover categories. For homogeneous vegetation, there was a strong negative correlation between first derivative characteristics and PAI values, that is, higher PAI values were associated with lower spectral values (Figure 4). Conversely, in the heterogeneous vegetation, strong positive correlations between PAI values and first derivative characteristics were observed (Figure 4). Filella and Penuelas (1994) showed positive correlations for homogeneous vegetation cover. The PAI values should

**Figure 4**

Relationships found between first derivative red edge peak characteristics (top-amplitude; middle-area; bottom-ratio) and PAI values for homogeneous cover (left) and heterogeneous cover (right)

rise with the increase in percentage of stem material in the canopy because of the decrease reflectance in the 680 nm due to chlorophyll absorption, and decreased magnitude but increased slope of the NIR plateau (Asner 1998). However, according to Danson and Plummer (1995), the difference in relationship direction may be attributed to strong non-linear relationships found between LAI values and first derivative amplitude values when a larger sample dataset is available.

Changes in vegetation species and change in sampling design in the two zones may also be potential reasons for the change in correlation direction. The vegetation transition boundary observed in the field was shown to be related to changes in plant species, percent cover and elevation based on Werner et al. (in press). An analysis of PAI values resulted in lower PAI values associated with the dominance of lichen, willow (*Salix* sp.) and sedges (*Carex* sp.) intermixed with bare ground or water. Higher PAI values were associated with willow, birch shrub and freshwater meadow marsh communities which consist almost entirely of vascular plants. These results are consistent with Brook and Kenkel (2002) who mapped Hudson Bay vegetation using traditional pixel-based methods. The change in sampling design from homogeneous (random) to heterogeneous (stratified random) may also contribute to the negative and positive correlations differences observed. The random sampling within the homogeneous zone resulted in larger variability in PAI values compared to PAI values in the heterogeneous zone. When the sampling was stratified, the regression relationships were stronger as the PAI values better represented the change in plant colour within the heterogeneous zone.

Conclusion

The results of this study showed that there were significant differences between PAI values collected in homogeneous versus heterogeneous subarctic coastal vegetation but only when the variation in plant colour is taken into consideration. Thus PAI values can be used as an indicator of plant cover amount when mapping homogeneous and heterogeneous vegetation differences. The differences in PAI values also independently validated the observed changes in homogeneous-heterogeneous vegetation found by Werner et al. (in press).

Once the difference in PAI values for homogeneous and heterogeneous zones was determined, the next step was to determine how the changes in PAI values were related with first derivative spectral curve characteristics. Strong linear relationships were found between PAI values and amplitude of the first derivative curve when the homogeneous and heterogeneous vegetation data were assessed separately. A strong positive correlation was found in the homogeneous zone compared to a strong negative correlation observed in the heterogeneous vegetation zone. The results of this project for coastal vegetation confirm those found in literature for experimental and forest applications. If hyperspectral data are available for mapping homogeneous and heterogeneous coastal vegetation, use of the first derivative amplitude will result is the best possible classi-

fication outcome (highest overall classification accuracy). Thus the next step of this project is to use hyperspectral image data to improve classification of the heterogeneous zone. This will allow for the identification of the homogeneous-heterogeneous boundary across space. Once identified, it can be used to more accurately georeference multi-temporal images for shoreline change detection.

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Food security and consumer habits in Churchill, Manitoba

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Food security in northern Canadian communities is a major concern. Churchill is an isolated community in northern Manitoba. Although considered northern, it has daily access to communities in southern Manitoba and beyond via rail or air services. Consequently the community has not received much attention in the food security literature. This article seeks to better understand the general consumer tendencies of Churchill residents for both food and non-food items. Through a researcher-administered survey, 30 respondents were interviewed and their general consumer tendencies were examined. The results suggest that whereas the potential for food insecurity exists, offsetting factors including online shopping and specific community/business initiatives help relieve the potential severity of food insecurity for individuals and families.

Keywords: food security, northern communities, Churchill, consumer tendencies

Introduction

Access to adequate and nutritional food is a major determinant of quality of life and life chances (Che and Chen 2001). Understanding the causes and characteristics of food insecurity allows policy makers to enact policies and programs which seek to limit such insecurity and increase overall health and wellbeing in northern communities (Lawn et al. 2003; Gates et al. 2012).

The goal of this research is to provide baseline data on the retail tendencies of the remote, isolated community of Churchill, Manitoba. The research will fill a void in the food security literature which has tended to focus on food security in more northerly communities and has largely ignored the broader consumer tendencies of residents relating to where and how they consume for their overall needs in addition to their nutritional requirements. The current body of food security literature tends to focus on communities that are more remote than Churchill. These communities are entirely dependent on air or seasonal shipping

services which places them at high risk of food insecurity. In contrast, Churchill is served by year-round train service two to three times per week and by daily air service. Consequently, the risk of food insecurity in the community is perceived to be much lower because of this more regular access and the lower costs associated with it.

This research has three main objectives: (1) to understand the demographics of Churchill in relation to the current literature on northern communities; (2) to examine (identify) if residents shop in Churchill or in other highly visited communities; and (3) to determine what items residents purchase most frequently when shopping in Churchill. The underlying goal is to determine whether or not the condition exists in Churchill for people to become food insecure.

Food security in the Arctic

All human beings require access to an adequate amount of safe and nutritious food. This requirement is known as food security (Pinstrup-Andersen 2009). Recently academics and policy makers became interested in the precise definition and measurement of food security on both an individual and household level. In the past, hunger was the main way that researchers quantified food insecurity, but this is no longer a sufficient measure in the Canadian context (Che and Chen 2001). In Canada, and in North America as a whole, hunger is not as widespread or severe as the hunger that exists in the world's poorest areas. In order to suit the Canadian context, food security and insecurity need to be defined more broadly (Carlson et al. 1999).

In the context of the developed world, food security goes beyond hunger or a basic lack of food and is defined as the "ability to acquire safe, nutritionally adequate, and culturally acceptable foods in a manner that maintains human dignity" (Goldhar et al. 2010, 286; Van Esterik 1999). Food insecurity exists when "food systems are stressed, compromising the ability to attain foods in appropriate quantities or of sufficient quality" (Goldhar et al. 2010, 286; Ford 2009). In Canada, Ledrou and Gervais (2005) estimated that approximately 15 percent of individuals experience food insecurity. More recently, Tarasuk et al. (2013) estimated that 12 percent of Canadians live in households that are classified as food insecure.

Northern and Inuit communities tend to have higher rates of food insecurity than southern communities and the country as a whole (Beaumier and Ford 2010). Research shows that 53 percent of Inuit households in Nunavut are classified as food insecure and food insecurity in Kugaaruk, Nunavut (formerly Pelly Bay) is estimated at 83 percent of households (Lawn et al. 2003; Beaumier and Ford 2010). In northern Manitoba, 75 percent of communities are identified as food insecure (Thompson et al. 2012).

Since food security is such a salient topic for Canadian sub-Arctic and Arctic regions it has been the focus of many academic and government studies. Furthermore, the issue of food security has become more widespread within the mainstream media as well. A Google News search using the terms "Food Security Canada North" found 20 results dealing specifically with food security and northern communities and seems to confirm the need for continued research in this area.

Food security research has been conducted from a variety of perspectives and has generally pursued one or more of four goals, namely: examination and quantification of food security in a specific geographic region; identification of population characteristics in food insecure situations; assessment of change in food security in response to policies and programs; and identification of possible stressors or causes of food insecurity. Each approach is helpful when attempting to understand a complex social, economic, and natural phenomenon such as food insecurity. For the purposes of this research, the first two goals are most appropriate for consideration.

Northern Manitoba

Most of the food security literature focuses on communities in Nunavut as it has the highest rate of food insecurity in Canada (Tarasuk et al. 2013). This geographic focus is most likely due to the fact that there is a large population of Inuit people in Nunavut and it is a region that is extremely susceptible to climate change (Chan et al. 2006; Ford and Berrang-Ford 2009; Beaumier and Ford 2010). Chan et al. (2006) suggest that Inuit are especially prone to food insecurity because of social and environmental factors. The introduction of expensive market foods has resulted in an inability to purchase supplemental food. Climate change is altering and or changing completely the habitats and availability of traditional foods (e.g., seal, caribou, beluga). For these reasons, Inuit communities in the Arctic are often at risk of food insecurity and therefore become ideal subjects to study. However, more recently, Fieldhouse and Thompson (2012) and Thompson et al. (2012) have examined Manitoba and specifically northern Manitoba's food security issues.

As previously mentioned, much of the literature focuses on the Inuit people of northern Canada. One study suggested using various sampling techniques to examine the food security of the general adult population as the researchers felt the adult population could best portray food insecurity in the community (Huet et al. 2012). Other researchers wanted to compare food insecurity and the perception of food insecurity between men and women (Chan et al. 2006), or the data they had access to included responses for the general adult population (Che and Chen 2001).

Interestingly, several studies focused on only women (Lawn and Harvey 2001; Lawn et al. 2003; Beaumier and Ford 2010). Women of childbearing age (15 to 44 years) were chosen as the focus because they are often at risk of nutritional problems. Also, women often possess detailed knowledge of their households nutrition, and the health of women has a profound impact on their children as well as the community as a whole (Lawn and Harvey 2001; Lawn et al. 2003). One study by Gates et al. (2012) examined food security among children. Researchers made the decision to use children as the population group because they were specifically testing the effects that a healthy food school program had on the food insecurity of children.

Summary of review

Emerging from the review of literature are three prominent trends in the findings, namely: access to traditional food lowers food insecurity; the higher the income the lower the food insecurity; and food insecurity is higher among women. Most importantly, research clearly demonstrates that food insecurity exists and is especially prominent in the Arctic.

Access to and consumption of traditional foods lowers food insecurity. Research by Erber et al. (2010) shows that traditional foods lead to food security because they are nutritionally dense. Others state that traditional foods lead to food security because the harvest and hunting is local and in most cases sustainable (Ford and Berrang-Ford 2009). Studies found that households with a hunter had lower rates of food insecurity than those without a hunter (Beaumier and Ford 2010; Huet et al. 2012). De-

cline in the amount of traditional foods consumed is attributable to high costs associated with hunting, changes in lifestyle and cultural practices, and climate change leading to shifting animal and plant habitats (Chan et al. 2006; Goldhar et al. 2010).

Food insecurity tends to decrease as household income and educational status increase (Huet et al. 2012). Since market foods are transported long distances to reach communities in the Arctic they tend to be expensive. This is especially the case with healthy perishables such as fruits, vegetables, and dairy products (Erber et al. 2010) as many of these products arrive by plane. Socioeconomic factors play a large role in determining a household's food security (Goldhar et al. 2010). For this reason, lone parent families as well as families with divorced or separated parents are more susceptible to food insecurity (Che and Chen 2001).

Women are at a higher risk of food insecurity than men (Che and Chen 2001; Beaumier and Ford 2010). Researchers posit several theories as to why this may be the case. Women could be more at risk because they tend to hunt traditional food less than men and they tend to have lower incomes. As women are often primary caregivers they may feel food insecurity more acutely because they sacrifice their own food for the needs of their children (Lawn et al. 2003). Conflicting results are reported for food insecurity among children. Che and Chen (2001) suggest that food insecurity is higher among children while Ford and Berrang-Ford (2009) suggest that food insecurity does not differ by age.

Study area

The community of Churchill (Figure 1) is situated on the western shore of Hudson Bay in northern Manitoba (Stewart et al. 2008). There are no accessible roads from more southerly communities that service Churchill. Consequently, the community must rely on rail and air services to transport both people and goods. It is possible that this reliance leaves Churchill prone to food insecurity as studies suggest that consumer goods arriving by train and especially plane are usually sold at relatively high prices within the retail stores of the community. Churchill also has a large Aboriginal population. According to the 2011 National Household Survey (Statistics Canada 2013) 435 (51 percent) of Churchill's 850 residents identify as Aboriginal. The Aboriginal population in Churchill consists of Dene, Cree, and Métis (Brandson 2002). A high Aboriginal population coupled with the community's remote northern location suggests that levels of household food insecurity could be higher than in the rest of Canada. As yet, there has been no academic study or measurement of food security or consumer habits in Churchill or similar northern communities.

Methods

Food security is considered a scientific (nutrition) and social (socio-economic and ethnic) issue. Researchers have developed

many methods to assess food security and have utilized quantitative as well as qualitative methods in their assessments. Many studies have employed mixed methods approaches including surveys, semi-structured interviews, and focus groups to better understand the nuances of food security.

The majority of literature reviewed used various forms of survey to obtain data. Surveys are an excellent way to gather data from large numbers of people concerning various questions and topics. They are useful because they allow researchers to posit both quantitative and qualitative questions. Most of the researchers chose to administer the surveys with trained research assistants and interpreters when necessary (Goldhar et al. 2010). Administering surveys orally helps to overcome literacy barriers that exist in northern communities, especially in the older generation (Ford and Berrang-Ford 2009). However, one problem associated with oral surveys is the Hawthorn effect wherein participants may overestimate behaviours that they deem favourable. This could be a major stumbling point in research projects directed at quantifying the amount of healthy perishables (fruits and vegetables) consumed by households (Lawn and Harvey 2001; Lawn et al. 2003; Erber et al. 2010). The amount of healthy foods consumed could be exaggerated and leave the researchers with an inaccurate understanding of food security and health in a community. Surveys are also useful tools for conducting exploratory research in previously unstudied communities because they can be used to target specific or sample populations with appropriate questions in order to gain a better understanding of social, economic, cultural, and environmental factors affecting food security (Ford and Berrang-Ford 2009).

Three of the ten reviewed studies utilized semi-structured interviews and focus groups to collect data. One study conducted by Goldhar et al. (2010) integrated data from both semi-structured interviews and quantitative surveys. Qualitative interviews and focus groups appear to be the best collection methods when dealing with perceptions concerning food security (Chan et al. 2006) or when trying to understand the various subtle aspects of food security such as environmental stressors (Goldhar et al. 2010).

Data collection

The data were collected using a semi-structured survey consisting of 26 questions that fell into three major categories, namely (1) demographics, (2) travel frequency, and (3) shipping and shopping methods. The researchers developed a draft survey and tested it on a small sample group of staff and scientists who work at the Churchill Northern Studies Centre. These individuals are also full-time residents of Churchill. This sample test was meant to identify any errors and inconsistencies, and was also conducted to ensure that questions were asked in a manner that would minimize any potential offense because of cultural misunderstandings. After testing, several questions needed revision.

Thirty oral surveys were conducted over a two-day period with randomly chosen residents of Churchill. Researchers approached residents on the street and asked if they would be willing to participate in a survey on retail habits conducted by geography students from the University of Winnipeg. If a resident



Figure 1
Context map
Source: Manitoba Land Inventory 2014

indicated that they were interested in participating, a researcher would explain the ethical requirements of the survey. The researcher ensured participants that their responses would receive full anonymity and confidentiality. Participants were informed that they could remove themselves from the survey at any time, refuse to answer any question they did not want to answer, and contact the project advisor if they had any concerns with the survey. Respondents provided verbal consent if they agreed to take part in the survey. Residents who did not appear to have reached the age of legal consent (18 years) were not surveyed.

Results

Population description

According to the 2011 census, the town of Churchill has a population of 850 with 51 percent identifying as Aboriginal (Figure 2a) and a similar percent recorded as male. Of the residents surveyed, only 23 percent identified as Aboriginal (all related ethnic groups) with the vast majority of respondents identifying as Caucasian. Similarly, males comprised only 23 percent of respondents. Over half of respondents had lived in Churchill for less than 20 years (Figure 2b) and were under 35 years old (Figure 2c).

Travel tendencies

The majority of respondents (70 percent) had not left Churchill to travel to southern communities within the last month (Figure 3a). When residents traveled, they were marginally more likely to travel by train than by plane (Figure 3b). When asked about their reasons for travel, 50 percent of respondents selected personal reasons as their main motivation (Figure 3c). When asked which city residents visited most frequently for shopping, the most common response was Winnipeg.

Shipping and shopping

While 67 percent of respondents indicated that they shop online, the items purchased vary considerably. When examining local shopping patterns, produce and non-perishable foods (Figure 4a) dominate local consumption. This is in stark contrast to online purchasing patterns in which all other categories dominate individual consumption patterns (Figure 4b). Of particular note is the small number of individuals that purchase produce (a perishable item) online while no respondents indicated purchasing non-perishable foods online. The survey found that consumers were unlikely to purchase electronics or vehicles in Churchill due to their inflated price and lack of selection (Figure 4b). In the "other" category, some respondents indicated that they would buy alcohol in Churchill. However, they would not buy clothes or baby products such as diapers. Many of the residents surveyed suggested that, although they buy produce in Churchill, they do so out of necessity, and they would like to see better selection, quality, and prices when it comes to fresh foods.

Finally, when examining access to cultural foods, specifically game or bush meat, 90 percent of respondents indicated

they know someone who hunts but less than 25 percent of those surveyed indicated that they source their meat locally.

Discussion

With respect to population, the high rate (70 percent) of female participants in the survey was expected in this kind of study and is backed up by the literature (Lawn et al. 2003). Women are often more preferred in retail studies because they are seen as being the major consumers and buyers for households. Additionally, given that the under 35 year age group comprised the majority of respondents, and based on researcher observations, the majority of females had young children and were more than likely stay-at-home mothers with partners working full-time within the community. Anecdotally, the researchers noted a significant lack of males shopping during the day.

Seventy percent of respondents indicated that they had not left Churchill within the last 30 days. This value is particularly noteworthy as the survey was conducted in August and the underlying belief was that many would travel south in preparation for the coming winter and/or school year. However, given the seasonal nature of much of the employment in Churchill many people may not travel outside of the community during the employment season knowing they are returning south in a short period of time. Moreover, whereas the most used and affordable mode of transportation out of Churchill is the train, some respondents mentioned that the long train journey and costs discouraged frequent travel. Respondents indicated that their main motivation for travelling outside of the community was for personal reasons. Some respondents suggested that they specifically leave town to shop and others stated that they left Churchill to visit family and friends. In casual conversation after the survey, several respondents mentioned that the most coveted employment is with local airlines. They suggested that these jobs come with great benefits to immediate family members such as reduced airfares and free shipping rates. Respondents with family members working in these positions indicated they would often order goods from other communities and especially those available in Thompson (Figure 1) where easy access to rail and/or airplane for shipping items via these familial relationships is easy and readily accessible. While this last point is anecdotal, it does suggest an underlying issue with affordability in living in Churchill.

Researchers found that many residents utilized the same website (www.Well.ca) to satisfy their shopping needs because it offered a range of goods including personal hygiene products, food items, and minor home furnishings. Most importantly, it offered free shipping on products that were not readily available in Churchill. In this way, residents were providing for themselves those items that could not be reasonably bought in Churchill. Residents indicated reasons for online shopping included greater selection of goods, cheaper prices, and incentives such as free shipping.

As expected, the survey found that produce was the most common item purchased locally. This can be explained by the

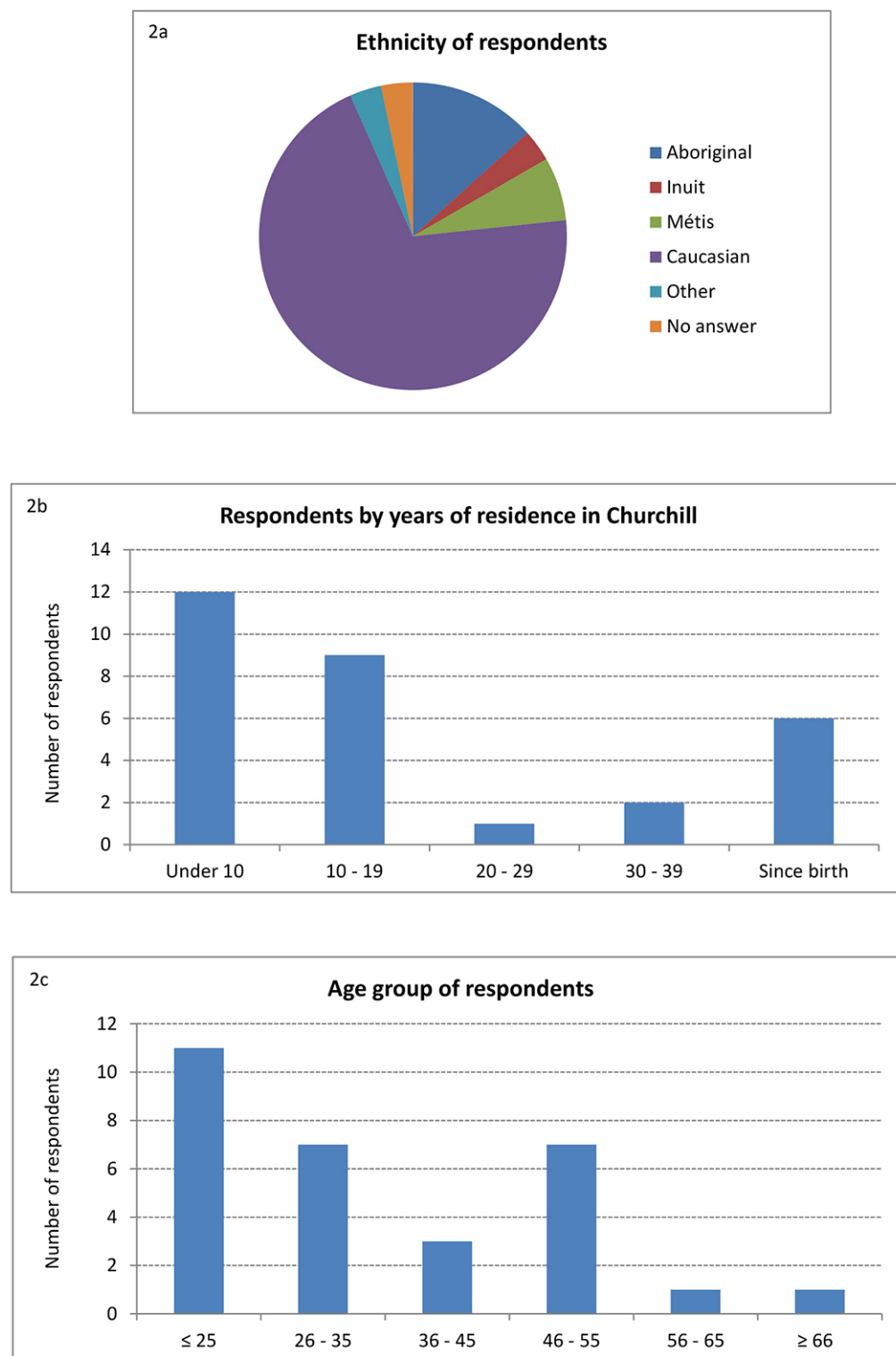


Figure 2
Ethnic group membership, residency, and age group of survey respondents

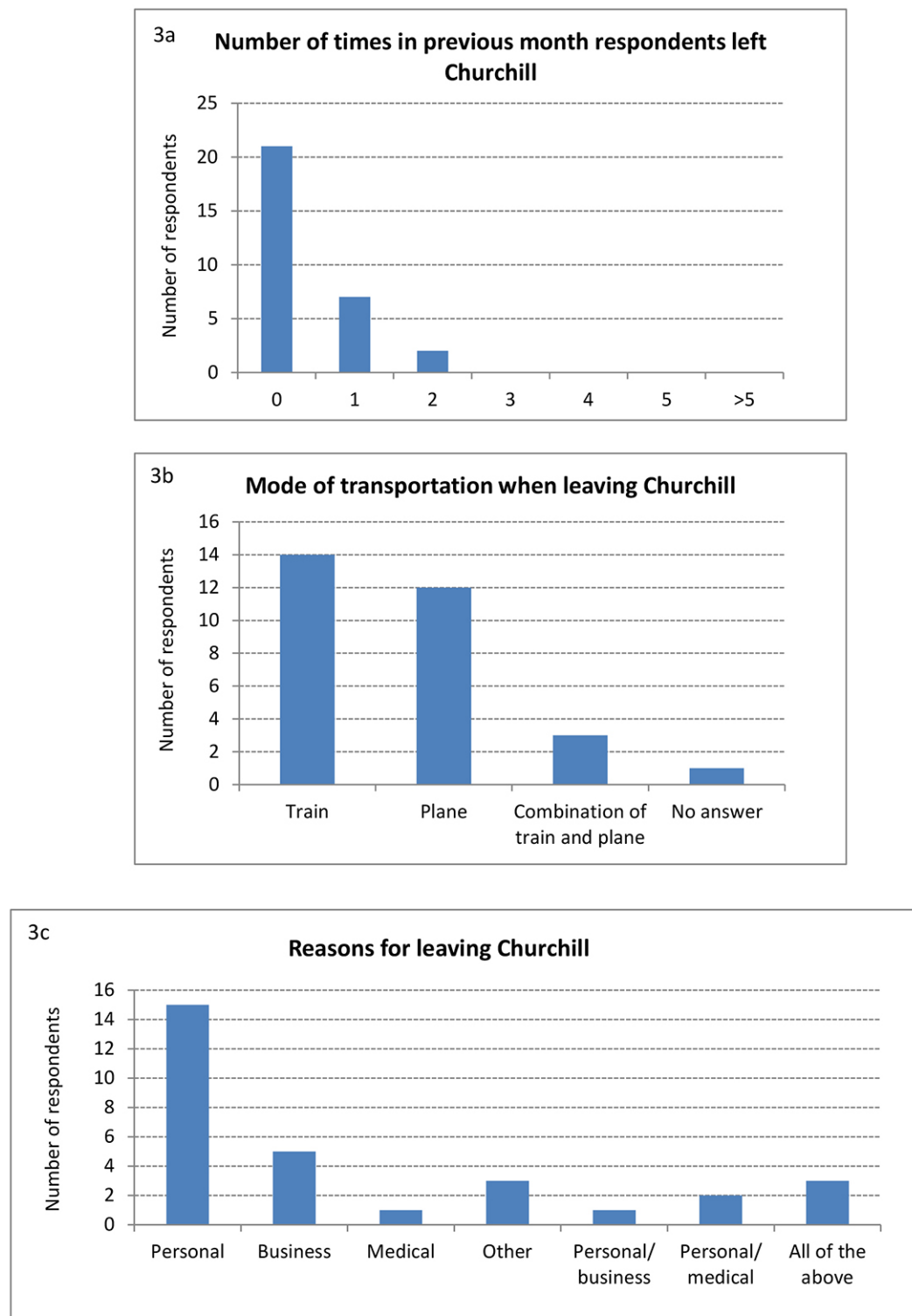


Figure 3
Travel characteristics of survey respondents

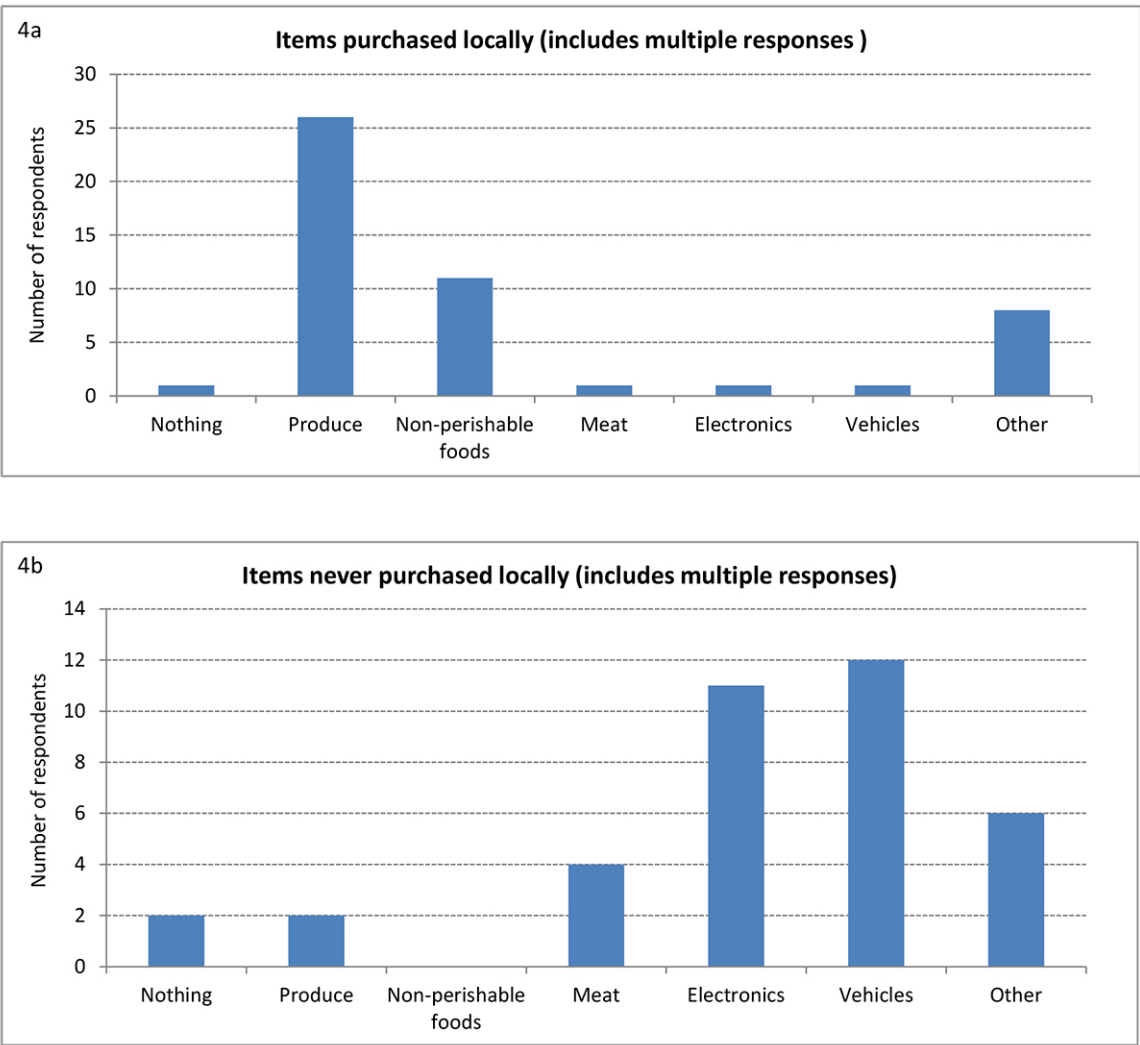


Figure 4
Local purchasing habits of survey respondents

fragility of produce in transport and the need for fresh perishables. It could also be explained by most residents not having left Churchill within the last 30 days. Many respondents noted that they were unhappy with the quality, price and selection of the produce available to them. Although produce was the most frequently purchased item in the community, this was of necessity rather than strict choice. The other locally purchased item was alcohol. Alcohol is one of the few items available in Churchill for which prices are the same as in southern communities because of government regulation. In contrast, goods that respondents did not purchase in Churchill included vehicles and electrical goods. These items are either unavailable or the price is extremely inflated to combat transportation costs. Other category responses for goods purchased out of town were baby and personal hygiene products.

Access to country foods decreases dependence on southern market food (Lawn et al. 2003). The current study shows that most respondents knew someone who sourced food through hunting. Nevertheless, this knowledge did not transfer to their

personal consumption. Only 57 percent of respondents reported consuming country foods in their diet to a very limited degree. As cultural foods are generally associated with the local Aboriginal community, the dominance of Caucasians in the respondent sample may have skewed this number significantly. Also, given the seasonality of employment, many individuals may have known of people who hunt and/or fish but did not use those sources as a food supplement because they were short-term residents within the community and the investment in acquiring and storing these foods was too great. Lastly, many of these seasonal employees may have had some type of food allocation through their employer thereby offsetting the higher costs of locally purchased meat.

Conclusion

While this study did not examine food security directly, it did examine the retail/consumer conditions present in Churchill that

may create a food insecure situation for an individual or family. The survey suggests that fresh produce is the most available local consumer product but respondents indicated that price and selection were major issues. Other items such as electronics and vehicles were so expensive that they are sourced from outside the community. Additionally, because of internet retailing many residents are able to source products from websites thereby successfully insulating/protecting themselves from the higher costs associated with local purchasing. Since Churchill has regular rail and airplane access, many websites offer free or low-cost shipping, a benefit that is not associated with more northerly communities.

With regard to food security, this study confirms that many of the underlying factors identified in the literature also exist in Churchill. It can be postulated that, if residents did not have ready access to the reasonably priced products in southern communities and were forced to purchase the majority of their consumer goods in Churchill, a much more desperate situation could exist. It appears that residents are able to trade off high food costs locally with savings on other products purchased online or outside of Churchill.

Finally, Churchill presents a unique situation for research into food security as it is isolated from the south but has daily, year-round transportation access that ensures a high degree of regular connectivity compared to even communities that are slightly more northern where access is restricted to plane or cargo barge. While conducting this study, researchers routinely entered several of the local businesses to seek respondents. In two cases, fresh and or other foods were available for sale outside of the lone grocery store. In the case of the fresh produce, the store owner indicated that the produce available at the grocery store was too expensive and given the nature of their business they are able to bring in fresher and a more seasonal selection of produce alongside the normal goods they import from the south. This “community first” attitude suggests there may be other ways community members combat food security situations that were not revealed in the survey. Given this observation, the authors recommend that future studies on food security in northern communities employ an open-ended interview or focus group approach as the nature of these data collection techniques better allows researchers to delve into specific community situations that may help to combat specific food security issues.

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Esterhazy field trip guide

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This field guide provides an overview of the geomorphic patterns of the Saskatchewan Plain and the Qu'Appelle Valley south of Esterhazy. The guide was first drafted to accompany a field trip conducted in conjunction with the 37th annual meeting of the Prairie Division of the Canadian Association of Geographers (PCAG). The meeting was held in Esterhazy from September 20 to 23, 2013 and was hosted by the Department of Geography and Environmental Studies, University of Regina.

After leaving Esterhazy the field trip route heads south on Highway 637 (Figure 1). The first stop is approximately 5.7 km south of Esterhazy and 650 m east of Highway 637 on a gravel road at the Kaposvar National Historic Site (Stop 1). Once back on Highway 637 the route continues south for 5 km to Stop 2 located at the northern rim of the Qu'Appelle Valley.

From the Stop 2 the route proceeds 1 km down into Qu'Appelle Valley on Highway 637 and then turns east on an unnamed road towards the community of Tantallon. After 9.6 km the route turns north on an unnamed road towards the rural municipality Hazel Cliffe. This road is followed for 5.7 km into the Kaposvar Valley before turning west on to Pioneer Road. Stop 3 is reached after traveling for 300 m on Pioneer Road. The route then continues west on Pioneer Road for 10.2 km before turning north on Highway 637 and heading back to Esterhazy.

Stop 1: Kaposvar Historic Site

The region south of Esterhazy is part of the Saskatchewan Plain (550 – 600 m ASL), a drift-mantled plain of relatively low relief

underlain by soft Cretaceous sedimentary bedrock (Figures 2 and 3) (Klassen 1972). The transition from the Manitoba Lowlands, the First Prairie Level, to the Saskatchewan Plain, the Second Prairie Level, is marked by the Manitoba Escarpment (Figure 2). The escarpment is composed mainly of Cretaceous rocks (Odanah Member of the Pierre Formation.) The Odanah shale, formerly a member of the Riding Mountain Formation, caps the Manitoba Escarpment (Young and Moore 1994).

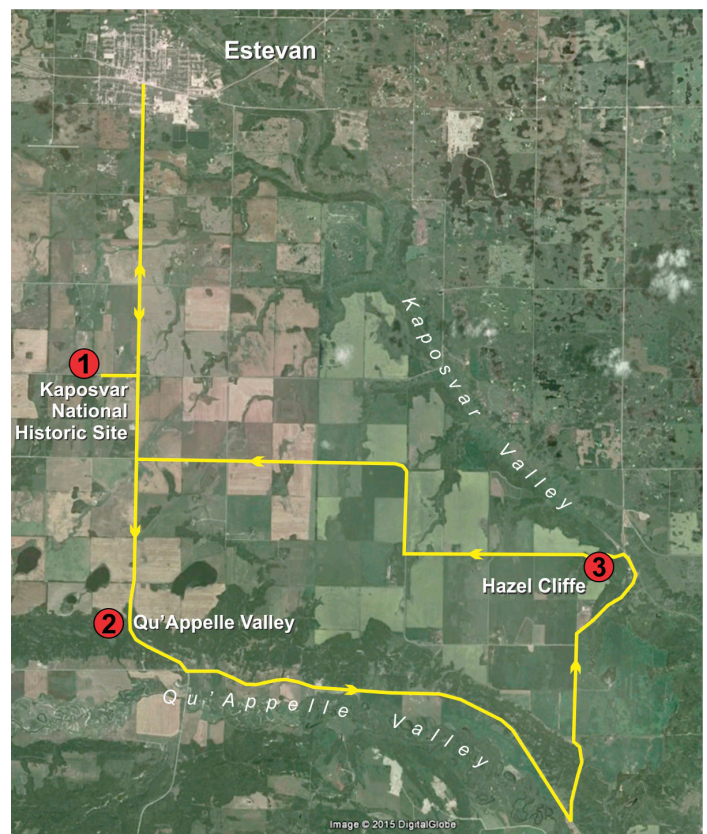


Figure 1
Field trip route map
Basemap: © Google Maps

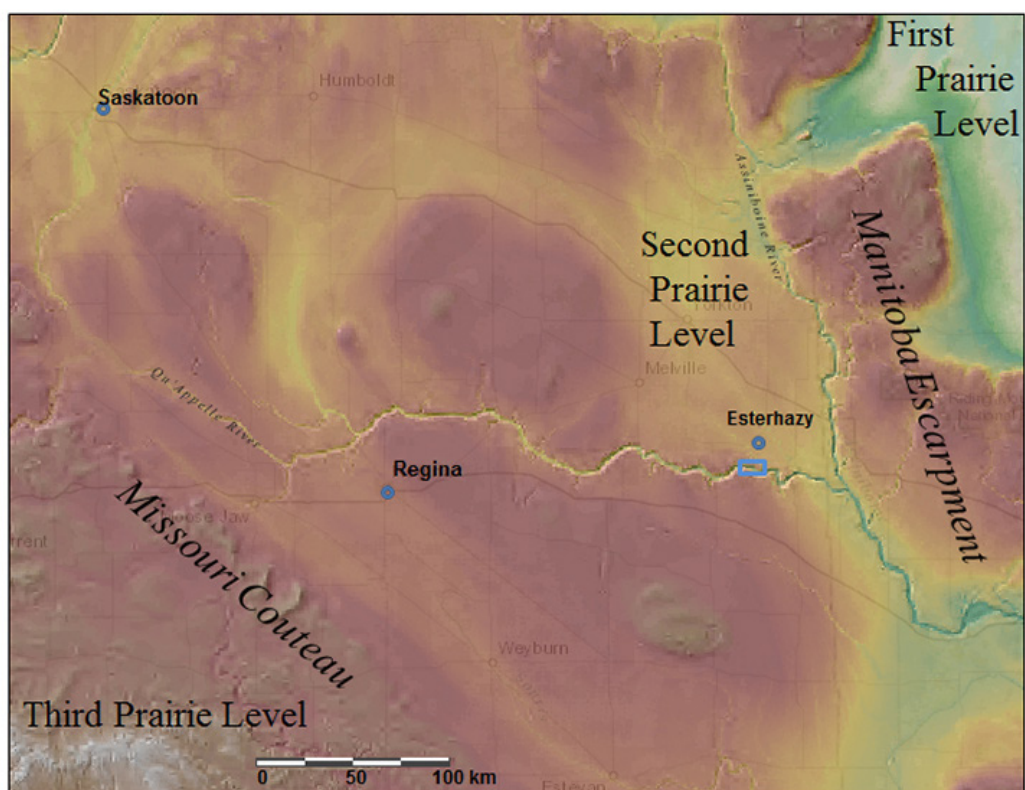


Figure 2
Terrain map of southern Saskatchewan

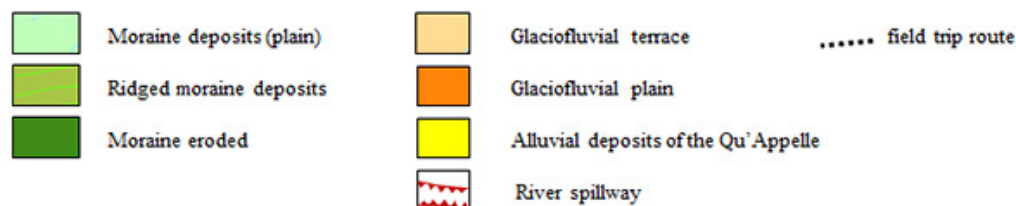
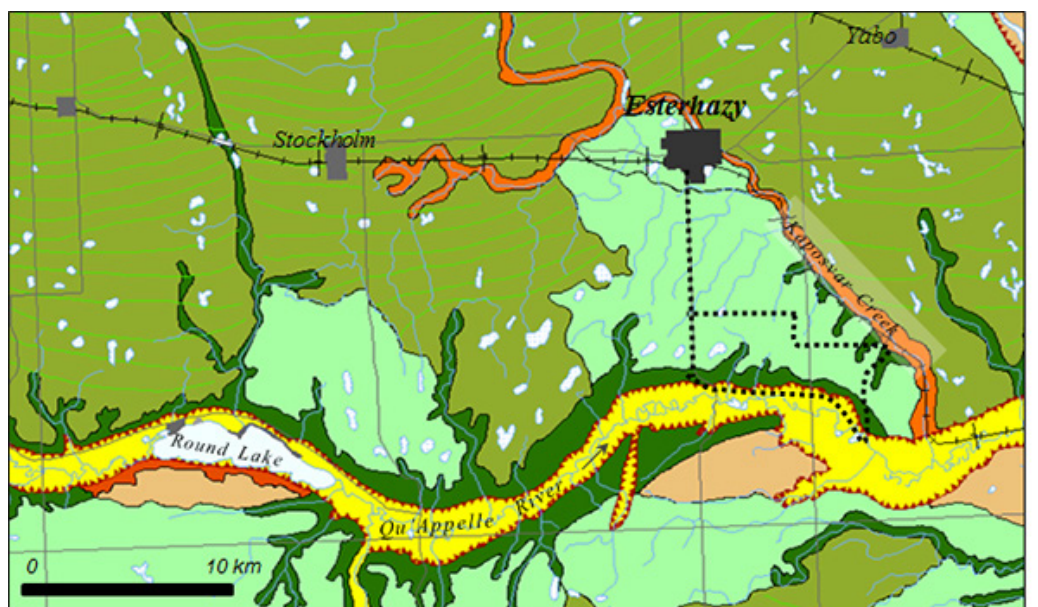


Figure 3
Surficial geology map and geomorphology (Source: http://www.infomaps.gov.sk.ca/website/SIR_Geological_Atlas/viewer.htm)

The Second Prairie Level underlain by marine shale of the Pierre Formation is mostly covered by glacial drift to a depth of 450 to 455 m. Overlying Quaternary till deposits of the Saskatoon Group are up to 60 m thick (Christiansen 1972).

The topography of the area is characterized by gentle to moderate slopes and a hummocky-ridged surface with kettles. The area around Esterhazy lies in the Qu'Appelle Valley basin, a sub-basin of the Assiniboine River Plain. Most of the area is drained by Kaposvar and Cutarm Creeks which drain to the Qu'Appelle River. The Kaposvar Creek Channel was eroded by meltwater, whereas water flowing from proglacial Saltcoats Lake eroded the Cutarm Spillway (Figures 1 and 3) (Christiansen 1979; Kehew et al. 2009).



Figure 4
Terrain map showing a series of large ridges trending from northeast to southwest south of Esterhazy



Figure 5
Ridge east of Kaposvar Historic Site (Stop 1)
Photo credit: U. Hardenbicker

South of Esterhazy and west of Kaposvar Creek a series of large ridges trending southwest to northeast are found (Figures 4 and 5). It is not clear how these ridges were formed. Sauer (1978) proposed that the ridges are formed by glacial thrusting which were smoothed by subsequent glaciers and covered by a thin drift layer.

For the majority of the Holocene this area was dominated by parkland and mixed-grass prairie vegetation, but since European colonization approximately 95% has been converted to agricultural fields and pastures (Shorthouse 2010). Thick black soils are dominant. These are found in relatively moist areas of the Black soil zone of the Aspen Parkland Ecoregion. The soils are neutral to moderately alkaline in nature. They have developed in loamy glacial till, and are associated with hummocky and undulating landscapes (Saskatchewan Soil Survey 1987, 1991).

Stop 2: The Qu'Appelle Valley south of Esterhazy

During geological and ground-water reconnaissance investigations in eastern Saskatchewan, outcrops of folded and faulted bedrock of the Odanah Member of the Pierre Formation were discovered along the sides of the Qu'Appelle Valley in the region south of Esterhazy (Christiansen 1972). The 45 m thick clay shale bedrock capped by a layer of siliceous shale was first identified as the light grey weathering Odanah shale bedrock. This unusual bedrock outcrop was later interpreted as a thrust block of clay shale bedrock attributed to ice-thrusting (Sauer 1978). Since the deformed block of bedrock (about 1000 km²) was much larger than other ice-thrust structures in southern Saskatchewan Aber et al. (1989) argued that the megablock is a result of glacial rafting (Kupsch 1962; Aber et al. 1989; McGinn 2000). After freezing to the underside of a cold-based glacier the bedrock block was entrained and transported to the current location.

Slope failures were and are common in the Qu'Appelle Valley and its tributaries, especially where stream erosion reaches the drift-shale contact (Christiansen 1960). But nowhere in the Qu'Appelle Valley have mass movements controlled slope form and valley shape more than south of Esterhazy. The reason for this lies in the unusual bedrock exposure in this region. The natural slopes across the area range from 4 to 10 degrees, whereas most of the slopes in the Qu'Appelle developed in till have a slope angle of 25 to 33 degrees (Figures 6 and 7). The distinct gentler slopes and the narrow valley floor are the result of multiple large landslides and mark the area where the Qu'Appelle Valley cuts through the shale megablock (Figure 8). Sauer (1978) reported five large landslides on municipal roads constructed in this area of disturbed clay shale bedrock (Figures 7 and 9).

The valley fill of the Qu'Appelle Valley consists mainly of alluvial clay, silt, and sand, along with some gravel. Colluvial sediments and landslide deposits of shale and till are found near the valley sides. The thickness of the fill varies from 40 to 55 m (Figure 7).



Figure 6

Aerial photo (left) and topographic map (right) of the landside area in the Qu'Appelle Valley south of Esterhazy (modified after Sauer 1978)

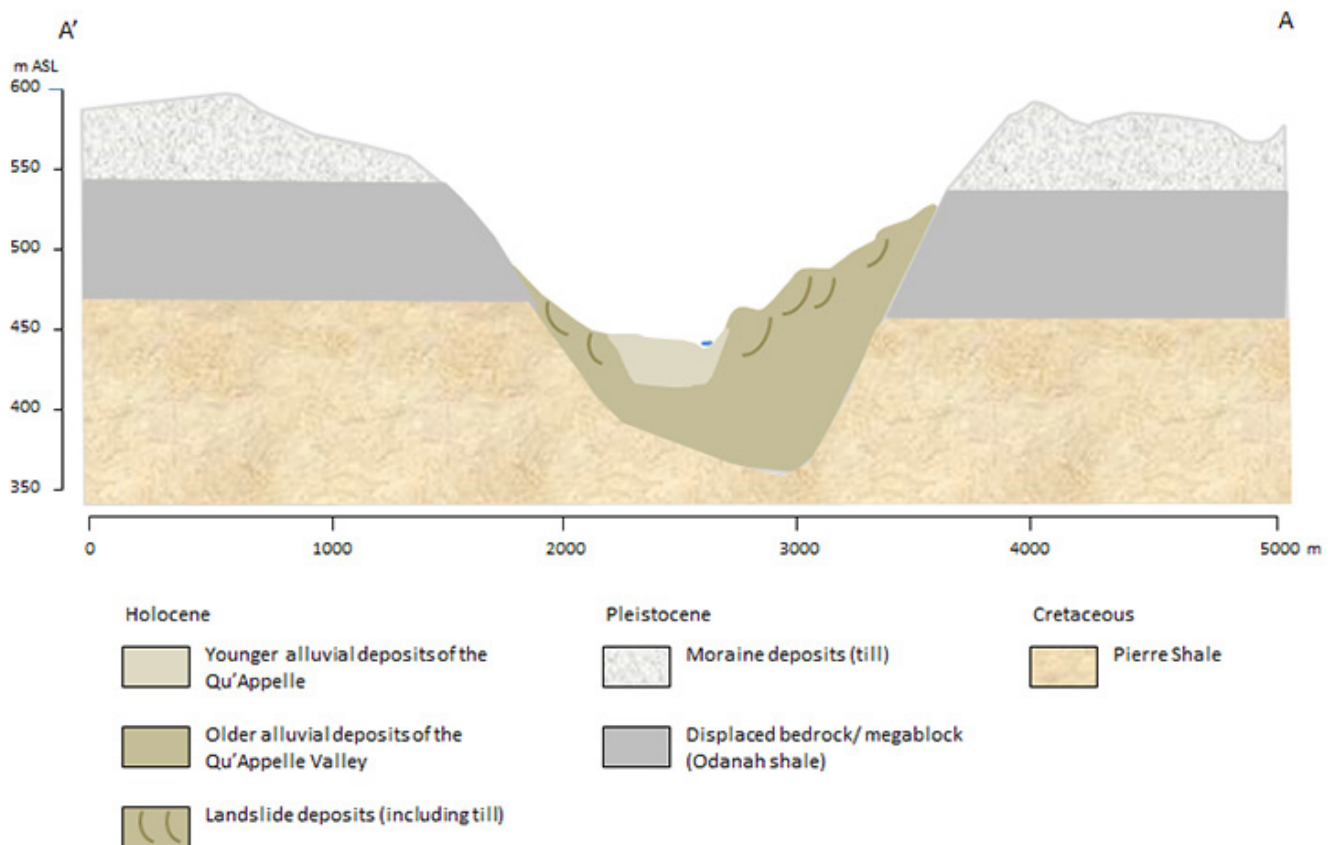


Figure 7

Cross profile of the landside area in the Qu'Appelle Valley south of Esterhazy (after Christiansen (1971) and Sauer (1978))
See Figure 6 (left) for location of profile A – A'

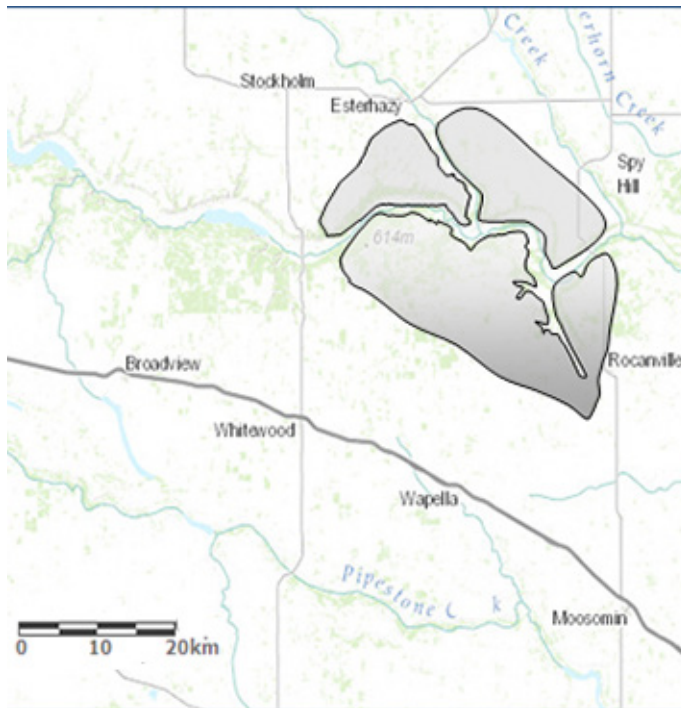


Figure 8
Location of the Esterhazy megablock (after Sauer 1978)



Figure 9
Warning sign on Highway 637 south of Esterhazy
Photo credit: U. Hardenbicker

Christiansen (1972) has identified six stages in the glacial history of the Qu'Appelle Valley south east of Esterhazy. Sequentially, deposition of the Empress Group was followed by deposition of tills and incision of the Qu'Appelle Valley to about 457 m ASL. Aggradation of gravels by glacial meltwater then formed the Tantallon terrace (c. 35 m thick), a prominent landscape feature which includes boulders from the Odanah shale (Figures 10 and 11). This depositional phase was followed by



Figure 10
Highway 637 overlooking the Qu'Appelle Valley south of Esterhazy. Level parts of the middle slope section of the north facing slope marking the Tantallon terrace level (Stop 2)
Photo credit: U. Hardenbicker



Figure 11
Outcrop of the Tantallon terrace south of Highway 637
Photo credit: U. Hardenbicker

further incision of the valley to about 380 m ASL and recent deposition of alluvium (c. 40 to 45 m thick).

Deposition of alluvium started more than 12,000 years ago. The initial rate of deposition was rapid and has continued at a decreasing rate to the present time (Christiansen 1972; Klassen 1972). The material in the Qu'Appelle Alluvium was brought to the valley in three ways.

First, sediment was deposited when the Qu'Appelle spillway was still functioning as a meltwater spillway. Second, sediments were deposited as a result of post-glacial down-valley transport mainly by overbank and channel deposition. Third, sediments were deposited from erosion (sheetwash and slumping) of the valley walls and adjacent uplands forming thick accumulations of colluvium and alluvial fans along the walls.

**Figure 12**

Road cut west of Hazel Cliffe showing weathered shale of the Odanah Member of the Pierre Shale Formation (Stop 3)
Photo credit: U. Hardenbicker

**Figure 13**

Weathered shale, Odanah Member of the Pierre Shale Formation
Photo credit: U. Hardenbicker

Stop 3: Hazel Cliffe

The Esterhazy megablock is more or less horizontal, slightly deformed, and mostly buried under till. This deformation is confined to bedrock above about 460 to 490 m ASL (Christiansen 1972). The 490 m contour line was used as a minimum outline for the megablock. Neither the direction of emplacement nor the source of the mega raft is known (Aber et al. 1989) (Figures 7 and 8).

The Qu'Appelle Valley cuts through the middle of the megablock (Figure 8). But the best exposure of the highly folded and faulted displaced bedrock block of Odanah shale is found in road cuts west of Hazel Cliffe (Figures 1, 12 and 13). The brittle dry shale is grey or slightly greenish grey and breaks with a sub-conchoidal fracture (Mugridge and Young 1983). The joints and bedding planes within the shale are stained brown or reddish to purplish brown from iron and manganese weathering products. Exposed bedrock disintegrates and weathers very quickly and shows typical signs of deformation and faulting as a result of ice pushing (Figure 14).

**Figure 14**

Road cut south of Hazel Cliffe showing weathered and glacially disturbed outcrop of the megablock
Photo credit: U. Hardenbicker

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